NERC Guidance on the Safe Use of Lithium Batteries

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1. Scope

Lithium batteries may be of two main types. The first is of the 'primary' non-rechargeable type, the second is of the 'secondary' rechargeable type, usually lithium ion batteries. This guidance is mainly aimed at secondary, lithium ion, batteries with only brief comment on primary lithium batteries with regard to their transport and disposal, and to not try to recharge them.

2. Introduction

Lithium batteries are useful because of their high charge density which gives them a power advantage over other types of battery.

Lithium batteries are used in a wide variety of both scientific equipment and personal electrical equipment. There are two main types of lithium batteries – primary (non-rechargeable) and secondary (non-rechargeable) but they are all high energy power sources and so are potentially hazardous, especially if damaged, exposed to fire or short circuited when they may, in extreme circumstances, cause fires or explode.

Lithium is an alkali metal that in its elemental state can react violently with water and burst into flame, particularly when finely divided or has a large surface area/volume ratio (such as foil). In batteries it is used with non-water based electrolytes. Primary lithium batteries have lithium anodes, i.e. elemental metal, but lithium ion rechargeable batteries will have the lithium incorporated in a compound or 'intercalated' with another material. Types of lithium based batteries are described in Appendix 1, and the results of malfunction or abuse will depend on the type of battery - all are potentially dangerous.

3. Consequences of lithium battery abuse

Type of abuse	*Possible consequences*
Over charging	Venting, fire, explosion
Charging primary cells	Venting, fire, explosion
Forced discharge	Venting
Short circuit	Overheating, venting, fire
Incineration/overheating	Venting, explosion (if heating is excessive)
Physical damage	Release of potentially hazardous materials & spontaneous ignition
Leaving for a long term uncharged or unmanaged	Venting

Note: venting in this case means release of gases from the battery, with some designs having pressure release devices to allow 'safe' venting in case of over-heating / decomposition. Other designs do not have pressure release devices in which case they may explode if they become over-pressurised due to release of gases.

4. Safe use of lithium batteries

The lithium batteries used in proprietary consumer goods are usually matched to the use and are safe by design, especially if used with the manufacturer's charging devices, although numerous product recalls and incidents show that safety cannot be taken for granted. If used correctly there is only a small risk of serious malfunction, and it is therefore important to follow the manufacturer's recommendations when using electrical equipment containing lithium batteries.

Follow the disposal advice of the manufacturer and any internal waste management guidance. Primary battery cells that are disposed of should be protected against short circuit in the waste stream and exposed terminals should be covered with insulating tape before disposal.

5. Safe use of lithium ion batteries

These are the most common type of secondary lithium battery and are widely used in all sorts of portable electronic equipment including laptops, mobile phones and many other devices. Lithium polymer (LiPo batteries) are a type of lithium ion battery that is usually not enclosed in an outer rigid containment case but rather in a flexible plastic skin. LiPo batteries pose similar risks to other lithium ion batteries but also have some additional ones. They are very useful because they are light, normally do not have a rigid outer case, which together with their high charge density makes them an ideal battery to use in remote/radio controlled unmanned devices such as Unmanned Aerial Vehicles (UAVs - also known as 'drones' and 'copters'), unmanned ground vehicles (UGVs) and submersibles. LiPo batteries are also very flexible in their design and configuration and can be made very thin. The risks between rigid lithium ion batteries and LiPo are very similar in principle except that LiPo batteries are more susceptible to damage in use if they have a non-rigid case to protect against damage caused by penetration by sharp objects / improper mounting / impact leading to internal damage and short circuiting within the battery. Some new forms of LiPo battery used in UAVs have rigid cases and built-in power management to record charge cycles and automatically discharge batteries.

<u>Standard precautions</u>

- Only use a charger that is designed for the equipment being charged that incorporates the necessary safety / protective features and is a lithium ion charger.
- **<u>Do not use</u>** a NiCad or NiMH charger with lithium ion batteries or damage / failure may occur.
- **<u>Do not</u>** crush, break open or physically abuse the batteries or the equipment that contains them.

- Take precautions to avoid short circuiting.
- Store lithium batteries at room temperature – if in cold conditions take care as removal to a warm moist area may cause internal condensation of moisture leading to a short circuit.

Specialist equipment precautions

Additional control measures over and above those for standard consumer equipment such as laptops and mobile phones must be applied when using specialist equipment. This is especially the case for equipment designed / constructed / specified or modified and serviced in house. The risks associated with lithium batteries must be included in the risk assessment for the work. Where the total weight of lithium batteries exceeds 1kg in one area then a specific risk assessment is needed. The written risk assessment must address the risks, define the control measures needed to eliminate or reduce the risk of fire or explosion, and specify the transport measures and eventual disposal procedures.

General precautions

- When charging batteries do not leave them on charge unattended / in an unoccupied area in case they burst into flame during the process - there needs to be someone present who knows how to deal with an emergency. The only exception is a proprietary device such as a laptop or mobile phone charged using its supplier's charger. Do not leave lithium ion / LiPo batteries to charge overnight when no-one is present.
- Consider creation of dedicated and segregated charging stations / areas.
- Charge batteries on a non-combustible surface, preferably in an isolated area on a concrete or ceramic surface but if necessary a metallic one although steps to avoid short circuits by contact with terminals must be in place in such cases. Ensure there are no other flammable materials close to the charging operation.
- Special protective, non-combustible battery charging cases are available that can be used for charging small batteries.
- After charging has ceased and the charger disconnected, delayed chemical reactions and failures may still occur so they should remain observed or retained in an occupied area for a period of an hour or more after charging has ceased.
- Regularly observe the LiPo batteries during charging and for 15 minutes afterwards to check there are no signs of swelling, puffiness, distortion or failure.
- Have suitable firefighting and emergency equipment available. Strictly for a lithium metal fire a Type D, special metal fire-fighting extinguisher must be used (usually graphite is specified for lithium). It is open to debate whether a lithium ion battery fire involves elemental lithium metal so a more general extinguisher may be suitable such as dry powder, copious water or a bucket of dry sand may be suitable.
- Do not expose lithium ion batteries to extreme heat (above 50ºC) or extreme cold (below -10ºC). Storage in vehicles in direct sunlight that may become very hot should be avoided.

Charging conditions

- Batteries must be cool and at ambient temperatures before charging.
- Do not overcharge or discharge too low – check the manufacturer's specification for the exact battery type used and in some case it may be within the range 3.2V to 2.7V.
- Do not store batteries fully charged for extended periods of more than 24hrs – discharge to about 50-60% capacity for storage for long periods.
- Do not use excessive charge rate currents – keep below 1x the capacity of the battery pack (1C).
- Use protected connectors / terminals that cannot be short-circuited when being handled (e.g. cover with insulating plastic tubing when not in use)
- Use a balanced battery charger as it is important that all the cells in a battery pack are maintained at the same voltage. If the voltages vary by too much (5mV ~ 10Mv), the battery may become unstable.
- Never overcharge a LiPo battery and do not 'trickle' charge one.
- The lifetime of a LiPo battery is between 300 – 500 cycles. Leaving them fully charged, depleted /dead or exposing them to high temperatures will considerably shorten this useful lifetime.

Power rating

The accepted method for expressing the power of a lithium-ion battery is now 'watt-hours' (Wh). When applied to a lithium-ion battery, watt-hour rating is a measurement of how much energy (in watts) the battery will expend over one hour.

The Wh rating may affect transport requirements for the battery and should be marked on newer batteries or be found in the battery specification. If it cannot be found the following formula will allow its calculation: **Wh = Ah × V**, where Ah is the capacity in ampere-hours and V is the voltage. If the capacity of your battery is expressed in milliampere hours (mAh), divide by 1,000 to get the value in Ah.

Other tips

- Observe the battery polarity.
- Ensure that any power pack is marked "Lithium Battery".
- Report any incident involving lithium batteries to the local safety adviser.
- Do not try to charge a primary (non-rechargeable) cell.
- Before disposal, cells and batteries should be fully discharged using a circuit that incorporates a suitable load to prevent a short circuit.

Equipment design tips

- Do include protective devices such as diodes, limiting resistors and fuses into the circuits.
- Do not allow the failure of one component to create a dangerous situation. In particular the blocking diode for backup primary cells should be made of at

least two individual diodes in series.

- Take extreme care when joining cells either in series or parallel without first consulting experts such as the manufacturer.
- Do not encapsulate lithium batteries without first consulting the manufacturer's advice.
- Do not use more than one lithium battery in the same piece of equipment without first consulting the manufacturer's advice.
- Do not install lithium batteries next to a source of heat.

6. Emergency procedures for lithium batteries of all types

a. Clear everyone from the area.
b. If you are trained to do so and can do it safely with the correct equipment, deal with the emergency using an extinguisher, fire blanket, bucket of sand etc.
c. In the event of a fire the material inside the battery may be released; this may be toxic and corrosive. One recommendation is to fight small lithium fires with a Type D special metal fire powder extinguisher but these are very special, need specialist application techniques and may not be available.
d. First Aid information on specific chemicals contained in the cell can be found in the manufacturer's safety data sheet.
e. If a Type D extinguisher is not available, use copious amounts of fresh water as a fine spray to swamp the fire. This will not extinguish the fire immediately and will result in the lithium generating hydrogen; this may fuel a fire or explosion if it is not managed. Continue to use plenty of water until the fire is extinguished and the batteries are cooled. **Be aware of the possible risk of explosion.**
f. If it is not possible to safely transfer the battery / equipment to a safe place in the open air, ventilate the area with fresh air.
g. Use suitable Personal Protective Equipment such as eye protection and gloves while clearing up.
h. Disconnect the cell or battery if practicable in a way that prevents sparks and avoids contact with internal components.
i. Leave the cell or battery in a remote, well ventilated area.
j. Dilute any spillages / residues with **plenty** of water and wash away spilt liquid that may be corrosive.
k. Report the incident to the local safety adviser.

7. Transport of lithium batteries

The rules governing the carriage of lithium cells and batteries are complex, and subject to frequent change. If you anticipate transporting equipment that contains lithium batteries, lithium batteries packed with equipment in the same box, or lithium batteries on their own, you are advised to seek early advice from the local safety adviser.

Lithium batteries of any type are designated as dangerous goods for all modes of transport and are classified in Class 9 – Miscellaneous dangerous goods and articles as:

- UN 3090 **Lithium metal batteries** (including lithium alloy batteries), and
- UN 3480 **Lithium ion batteries** (including lithium ion polymer batteries)

or, if contained in equipment or packed with equipment, as

- UN 3091 **Lithium metal batteries contained in equipment** (including lithium alloy batteries), or
- UN 3091 **Lithium metal batteries packed with equipment** (including lithium alloy batteries), and
- UN 3481 **Lithium ion batteries contained in equipment** (including lithium ion polymer batteries), or
- UN 3481 **Lithium ion batteries packed with equipment** (including lithium ion polymer batteries).

The restrictions on taking lithium batteries on aircraft change at very regular intervals so it is difficult to give specific advice that will remain valid for any period of time. Personal proprietary portable electronic consumer goods such as mobile phones, cameras, laptops, notebooks, tablets etc. containing lithium batteries are usually allowed in carry-on baggage on passenger aircraft, but this situation can change rapidly as several events in 2016 demonstrated. You should check with your airline before travelling. At the time of writing guidance on what you may carry in baggage on aircraft that includes sections on spare batteries and items containing batteries may be found on the CAA website, but this is liable to change.

A new Class 9 hazard label for all types of lithium batteries, and a new lithium battery handling mark for packages containing any type of lithium battery came into force on 1 January 2017 for all transport modes. These are shown below. The former hazard label and handling mark may continue to be used until 31 December 2018.

Reminder: new 30% state of charge for shipping Li ion batteries as cargo on aircraft
Reminder: new training requirements for people preparing Li batteries for air cargo

APPENDIX 1: MAIN TYPES OF LITHIUM BATTERIES

Lithium-Thionyl Chloride (Li-$SOCl_2$)

These are non-rechargeable and can be high capacity. The main risk is shorting the terminals together. Many types have fuses built in but some do not. They can have very low internal resistances so that, if shorted, very high currents can flow which can result in rapid heating and risk of explosion. If charging is attempted, there is also a risk of explosion. The other main risk is corrosion by salt water due to the fact that they are often used in marine applications.

Lithium Manganese Dioxide (Li-MnO_2)

Rechargeable versions are available but most are non-rechargeable. They are the type often used in watches and memory backups in computers etc.
The danger from these is in reverse charging when overheating will cause failure and possible fire or explosion.

Lithium ion (Li-ion)

A recent technology and now very prevalent in the consumer portable electronics market. These are rechargeable and represent the most dangerous risk of any rechargeable battery if charging is not carried out using the correct charging method. They cannot tolerate overcharging and cannot be trickle charged continuously because of this. Overcharging can result in the deposition of lithium metal on one of the electrodes which then becomes a fire hazard. They must be charged using a charger that obeys a rigid charging regime and has over heat protection and timeout protection.

Lithium Iron Phosphate ($LiFePO_4$)

These have a lower energy density so are more stable and are supposedly safer than most other lithium ion batteries and last longer (1400 or more charge cycles). They can be configured as much lighter replacements for 12v lead acid batteries (e.g. Tracer batteries) so may have applications for field work where formerly car batteries were used with consequent benefits for manual handling.

Effects of salt water

Salt water on any of these batteries can be a major hazard. Prolonged exposure can result in corrosion of the casing, exposing the battery components to the air. Lithium-thionyl chloride batteries are often used in marine applications but if salt water ingress into a battery chamber occurs (due to a failed pressure seal, for example), the batteries inside can become corroded resulting in extremely hazardous hydrogen chloride and sulphur dioxide vapours being produced. This can also happen if the internal electrolyte is exposed to air due to the water vapour in air. Both hydrogen chloride and sulphur dioxide are corrosive and toxic, and intensely irritating to the respiratory tract even when present in low concentrations.

Salt water immersion is sometimes recommended as a means of rendering damaged lithium ion cells safe for disposal. Care is required before following this path to make sure the battery does not still contain enough energy to short circuit or explode.