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Shipboard Li Battery Safety Guidelines

Table of Contents

1.0 PURPOSE

The intent of this guideline is to provide the users of lithium and lithium ion batteries with guidance to facilitate the safe handling of battery packs and cells under normal and emergency conditions.

2.0 DEFINITIONS

There are two types of lithium battery cells in common use:

Primary or non-rechargeable metallic lithium cells

These cells are constructed with metallic lithium. The metallic lithium in a non-rechargeable primary lithium battery is a combustible alkali metal that self-ignites at 352 F, and when exposed to water or seawater reacts exothermically and releases hydrogen.

Secondary or rechargeable lithium ion cells

Rechargeable secondary cells utilize lithium ions that are intercalated into graphite, lithium metal oxides and/or lithium salts. There is no metallic lithium in a lithium ion battery.

Cell: a single Primary or Secondary battery.

Battery Pack

An assembly of cells that are connected in series or parallel. Each Battery Pack typically contains only one type of cell, primary or secondary.

3.0 RESPONSIBILITIES

3.1 Engineers/Designers

- Implementation of all applicable provisions of this guideline.
- Obtain and review the battery manufacturers Material Safety Data Sheet (MSDS), Technical Specification sheet(s) and/or other available documentation prior to the design and use of battery packs. Perform hazard analysis (a.k.a. risk assessment) to understand the various failure modes and hazards associated with the proposed configuration and type(s) and number of batteries used.
- Based on a hazard analysis, incorporate appropriate safety-related design and testing criteria into battery pack and device design, with the design objective of increasing the safety margin during the battery pack life cycle. Ensure safety-related requirements are incorporated into design.
- Ensure that written standard operating procedures (SOPs) for Lithium and Lithium Ion powered devices are developed that include mechanisms to mitigate possible battery failures that can occur during: assembly, deployment, data acquisition, transportation, storage, and disassembly/disposal.

- Ensure that acceptance and quality-control procedures include verification of safety design features.

3.2 Environmental, Health & Safety (EH&S) Office

- Maintain this guideline.
- Assist in the investigation of incidents involving batteries subject to this guideline.
- Assist in training and communicating requirements to UCSD personnel.
- Waste management (Universal waste and Hazardous waste).
- Emergency Response procedures and training.

3.3 Distribution Department

- Provides guidance for the packaging of lithium-containing batteries and equipment for shipment.
- Provides guidance in the preparation of shipping papers.

3.4 Research Vessel (R/V) Science Parties

- Implementation of all applicable provisions of this guideline.
- If the batteries and/or equipment containing batteries require special handling for shipping, notifies Marine Operations Marine Technician office (x41632) in advance of cruise.
- Includes Material Safety Data Sheets and/or Technical Data Sheets in the hazardous materials inventory that is transmitted to the ship.
- Ensure that the use of lithium and/or lithium ion batteries is included in the Cruise Planning Questionnaire .
- Notify ships Master when equipment arrives on-scene.
- Review/understand SOPs prepared under 3.1.

3.5 Marine Operations Coordinators

- Include Lithium and Lithium Ion Battery information in the hazardous materials inventory form that is transmitted to the ship.
- Review SOPs prepared under 3.1.

3.6 Vessel Safety Coordinator

- Implementation of the applicable provisions of SOPs and this Guideline, including emergency procedures.
- As appropriate, include lithium and lithium ion battery emergency response procedures in drills

and training.

4.0 CELL HANDLING PROCEDURES

Inadvertent short circuits are the major cause of failures for both Lithium (Primary) and Lithium Ion (Secondary) cells. Problems associated with shorting as well as other hazardous conditions can be reduced by observing the following guidelines:

Please note that these are general recommendations, and as such, all items may not be applicable to the wide range of batteries covered by this Guideline.

- Written work instructions or checklists should be generated for assembly and testing procedures.
- Wear safety glasses whenever handling batteries
- Remove jewelry items such as rings, wristwatches, pendants, etc., that could come in contact with the battery terminals.
- All dented cells or batteries with dented cells should be disposed, regardless of electrolyte leakage. Denting of sides or ends increases the likelihood of developing an internal short circuit at a later time.
- Cover all metal work surfaces with an insulating material. Work areas should be clean and free of sharp objects that could puncture the insulating sleeve on each cell.
- If cells are removed from their original packages for inspection, they should be arranged to preclude shorting. Do not stack or scatter the cells. They should be placed in non-conductive carrying trays with individual compartments for each cell.
- Cells should be transported in non-conductive carrying trays. This will reduce the chances of cells being dropped, causing shorting or other physical damage.
- All inspection tools (including calipers, rulers, etc.) should be made from, or covered with, a non conductive material.
- Measure the open-circuit-voltage (OCV) of the cell. The nominal OCV for each cell chemistry is printed on the cell label or in the manufacturer's data sheet. An open circuit voltage of 0.0 volts may be indicative of a blown fuse. However, if no fuses are present in the circuit, 0.0 volts could be a result of complete discharge.
- After a cell has been inspected it should be returned to its original container.
- If leads or solder tabs need to be shortened, only cut one lead at a time. Cutting both leads at the same time can short the cell.
- Never touch a cell case directly with a hot soldering iron. Heat sinks should be used when

soldering to the tabs and contact with the solder tabs should be limited to a few seconds.

- Exercise caution when handling cells around solder pots. If leads need to be tinned, do only one at a time. Also, guards should be in place to prevent cells from falling into solder pots.
- Cells should not be forced into battery holders or other types of housings. This could deform the bottom of the case causing an internal short circuit. Furthermore, the terminal cap could be crushed putting pressure on the glass-to-metal seal. This could result in a cell venting. Check for proper fit before inserting the cells into any type of housing.
- Excessive force should not be used to free a cell or battery lodged inside the housing.
- Cells and/or batteries, should not be exposed to high voltage AC sources or other DC power supplies that could result in subjecting the cells to unanticipated charging or forced-discharging currents. Secondary cells should be charged only according to the cell or battery manufacturer's directions, particularly with respect to maximum applied voltage.

5.0 CELL STORAGE

- Cells should be stored in their original containers.
- Store the cells in a well ventilated, dry area. The temperature should be as cool as possible to maximize shelf-life. Observe the manufacturers minimum and maximum storage temperatures.
- Store the cells in an isolated area, away from combustible materials. Store depleted cells in an area separate from fresh cells. Allow space for complete encapsulation with Lith-X in the event of a fire.
- Any Primary Lithium battery storage area should have immediate access to both a class D and an ABC fire extinguisher.
- Never stack heavy objects on top of boxes containing lithium batteries to preclude crushing or puncturing the cell case. Severe damage can lead to internal short circuits resulting in a cell venting or explosion.
- Do not allow excessive quantities of cells to accumulate in any storage area.

6.0 BATTERY PACKS

6.1 Cell Selection

Obtain and review the battery manufacturer's design information for the cells to be used. It is important to know the working limits of the cells selected, so that the battery packs will meet performance requirements without undesirable reactions.

Designers should choose batteries with the lowest power output needed to meet the application requirements. In addition, the following basic rules must be observed:

- Always use the same size cells in series or parallel connections.
- Cells fabricated into a battery pack should be of the same age (lot code) and history.
- Primary and secondary cells should not be mixed together in a battery pack.
- Partially discharged cells should not be mixed with fresh cells in a battery pack.

6.2 Battery Pack Design

The design of a battery pack can either enhance or reduce the safety characteristics of individual cells and the pack. For example, a series configuration may increase the potential for subjecting cells to forced over-discharge conditions and parallel strings can lead to charging currents. Another hazard of series and parallel connections is that the added voltage or current during a fault can exceed the ratings of the protective devices inside the cells. For example, eight or more 18650 lithium ion cells in series can cause failure of the internal current limiter when operation is attempted, as they are only rated to sustain 30V.

Battery packs should be designed to avoid conditions leading to short circuiting, forced over-discharging, charging, overheating or other known failure conditions. This can be accomplished through proper design and use of protective devices such as fuses, thermal switches, heat sinks and diodes.

It is strongly recommended that batteries be built by the cell manufacturer or an authorized value-added- reseller. If this is not practical, the battery manufacturer should be consulted such that the most appropriate design and protective devices are chosen for each type of application.

Battery packs must be designed to avoid conditions leading to low level current leakage paths or direct short circuiting. This is accomplished by choosing the proper insulating materials for use in the pack construction.

The materials chosen must have a high resistance to leakage current. It should be noted that the insulation resistance of materials decreases rapidly with increased temperature. Also, absorbed moisture also reduces the insulation resistance, and moisture and humidity could have a large effect on the surface leakage of a battery.

In certain instances, the materials chosen must also display good abrasion or puncture resistance in addition to having good electrical properties. For example, if circuit boards are mounted directly on top of the battery, cell terminations must be isolated from traces on the underside of the board. Solder points can have sharp protrusions that can puncture thin materials. Thick, puncture resistant insulation must be used in these areas. Consider surface mount technology to eliminate traces and through holes on the underside of the boards.

Additional hazard control measures that should be considered include:

- In-line fuses should be fitted external to the battery such that they may be replaced after a short circuit is cleared.

  Thermal cutoff (TCO) or resetable polymeric, positive temperature coefficient (PTC) resistors can be used to limit cell temperature rise when that rise is caused by external current flow through the protective device.

  Both the surrounding thermal environment and the heat output of a battery pack and/or individual cells should be evaluated. If the hazard analysis (see section 6.3) determines that a remote means of monitoring cell temperature may be needed, devices such as thermocouples, and infrared temperature sensors should be considered.

  For larger packs or for batteries run at high rates, additional thermal management must be considered. For example copper or aluminum heat sinks could be incorporated into the pack design to effectively conduct excessive heat away from the cells during discharge.

  Cells connected in series should not contain a center voltage tap. This will eliminate the possibility of cells being unequally discharged.

  Batteries should not be encapsulated without first consulting the manufacturer.

  Battery pack construction should take into account the need for cell vents to function (where applicable). There should be an unrestricted escape path for the fumes such that pressure does not build up in the battery pack or housing. A vent mechanism should also be incorporated in rigid housings to avoid rupture or an explosion in the event of overpressure.

  Shock and vibration requirements must be considered in the design of any battery pack. All cells must be protected from excessive shock and vibration.

  In general, regulations specific to the mode of transportation intended to be used (air, land, water) may limit the amount of lithium in any one container. Therefore, large packs may need to be designed in a modular fashion and assembled in the field. Verify potential shipping requirements and limitations prior to the final design.

6.3 Hazard Analysis

To increase the safety margin and decrease the failure rate, the hazard analysis process should be considered during the design phase. This can be the case for battery pack designs, where there is a possibility that a component failure could give rise to an increased hazard. A number of different methods can be used, varying from simple analytical approaches to complex mathematical modeling. The hazard analysis method should be appropriate to the system design. Examples of hazard analysis methods are listed below.

Checklists: Checklists can be used as a basic method for itemizing potential hazards or undesirable outcomes that need to be considered.

Event tree analysis: This technique uses inductive reasoning to translate different initiating events into possible outcomes.

Fault modes and effects analysis (FMEA) and fault modes, effect and criticality analysis (FMECA): FMEA and FMECA are similar hazard identification and frequency analysis techniques that evaluate all possible fault modes within an item of equipment and determine their effects.

Fault tree analysis: This identifies each undesired event and determines all the ways in which it could occur.

Hazard and operability studies (HAZOP): HAZOP studies examine each part of an entire system to determine how deviations from the intended function or performance can lead to undesirable outcomes.

Preliminary analysis: This is a hazard identification and frequency analysis technique that can be used to assess potential hazards at an early design stage.

Reliability block diagram: A graphical frequency analysis technique that uses system models to investigate overall reliability.

Common mode failure analysis (CMFA): CMFA evaluates the impact of coincidental failure in different parts of a complete system.

Delphi techniques: These techniques involve processes for combining expert opinions from different sources into a model for estimating risk.

Hazard indices: These can be used to analyze different system options in order to identify that option having the lowest risk.

Monte Carlo simulation: Monte Carlo simulation uses mathematical modeling to evaluate the effect on performance of system variations and changing operating conditions.

6.4 Battery Pack Fabrication

Personnel assembling battery packs should comply with the following recommendations:

- Avoid cutting or piercing the insulating shrink wrap from the cells; all jewelry should be removed. Cells received from the factory should remain in their original containers until they are to be assembled into battery packs.

- Cells should not be placed on electrically conductive surfaces. All work surfaces should be constructed with non conductive materials.

- Do not solder directly to the cell case. Only solder to the solder tabs welded to the case.

- Solder tabs that extend from the case and terminal cap should be insulated. •
Loose wires should not be stripped until it is time to install a connector. If no connector is used, wire ends should be insulated.

- Should wire trimming be necessary, only cut one wire at a time.

- All battery packs should be labeled with the appropriate warnings as they appear on the cell label.

- Certain potting compounds are exothermic (release heat) when they set. It is important that the maximum temperature of the cell is not exceeded during the potting process.

7.0 SHIPMENT

All batteries must be made safe for handling prior to packing for shipment. The written SOP (see section 3.1) should specify steps to take in preparation for shipment or transportation. U. S. domestic transportation is regulated by the Department of Transportation (DOT). Internationally, air transportation is regulated by the International Air Transport Association (IATA). Maritime transport is controlled by International Maritime Organization (IMO) whose regulations are contained in the International Maritime Dangerous Goods (IMDG) Code. Various weight limits apply to batteries, batteries with equipment, and batteries in equipment for each of passenger and cargo aircraft. Pursuant to 49 CFR 173.185, all shipments of hazardous materials must comply with packaging regulations based on recommendations made by the United Nations. Fines and penalties for non-compliance can be substantial.

The SIO SOMTS department has personnel trained in US and International regulations who should be contacted for packaging guidance and the preparation of shipping papers (X40193).

8.0 EMERGENCY PROCEDURES

8.1 Releases from Cells (Vented, Leaked or Exploded)

The electrolyte contained within the lithium cells can cause severe irritation to the respiratory tract, eyes and skin. In addition, violent cell venting could result in a room full of hazardous air contaminants, including corrosive or flammable vapors. All precautions should be taken to limit exposure to the electrolyte vapor. Review the MSDS or product information sheet PRIOR to working with cells, so that you are familiar with the steps to take in the event of a release.

8.1.1 General

Waste lithium and lithium ion batteries are stored at universal waste accumulation areas throughout the UCSD campus and on offsite facilities and these batteries are used in various shore-side and field locations. Lithium battery releases should be cleaned up using the spill kits located at the EH&S Office or at satellite facilities. Only trained and qualified personnel (with proper personal protective equipment) should attempt to clean up a lithium battery release. Emergency procedures for handling a lithium battery release (primary, non-rechargeable cells) are described below. Additionally, emergency information is available in UCSD's Emergency Guide: http://blink.ucsd.edu/safety/emergencies/preparedness/guide.html#Chemical-or-Radiation-spill

8.1.2 Hazards

- Lithium may emit a colorless to pale yellow gas with a sharp, pungent odor.
- The electrolyte contained in lithium cells can cause severe irritation to the respiratory tract, eyes, and skin.
- Potential hazards may include the release of:
  - Thionyl chloride, bromine, chlorine dioxide, hydrochloric acid, sulfur dioxide and sulfuryl chloride gasses

- Strongly acidic wastewater and hydrogen gas from reaction with water

8.2 Handling a Hot Cell

- As soon as it has been determined that a hot cell situation exists, completely evacuate all personnel from the area. The area should be secured such that no unnecessary persons enter.

- From a shore-side facility, dial 858-534-3660 from a safe location to report the emergency.

- On R/V, notify the Bridge and initiate the vessel emergency response procedures.

- If it is safe to do so before evacuating the area, quickly determine if an external short-circuit is present and remove it as quickly as possible. Note that some cell chemistries may enter a thermal runaway reaction above a certain temperature; thus, a cell may continue to gain heat and there may be a cascade to other cells.
- The area should remain evacuated until the cell has cooled to room temperature.

- Using appropriate personal protective equipment and after the hot cell has cooled to normal temperature, the cell should be removed from the work area. All "hot" cells should be disposed as universal waste. Dispose of the cell in accordance with the UCSD universal waste program:

http://blink.ucsd.edu/safety/research-lab/hazardous-waste/electronics.html

8.3 Fires

- From a shore-side facility, dial 858-534-4357 from a safe location to report the emergency

- On R/V, notify the Bridge and initiate the vessel emergency response procedures.

- Only trained and qualified personnel should attempt to fight a lithium or lithium ion battery fire.

- Battery fires that are beyond the incipient stages may require personnel protective equipment, such as self-contained breathing apparatus and heat/fire protective bunker gear.

- In addition to the battery itself, packaging materials, plastics, electronic components and flammable solvents may be involved in a fire.

8.3.1 Lithium (Primary, Non-Rechargeable) Batteries

- Lithium will burn in a normal atmosphere and reacts explosively with water to form hydrogen. The presence of minute amounts of water may ignite the material and the hydrogen gas. Lithium fires can also throw off highly reactive molten lithium metal particles. Cells adjacent to any burning material could overheat causing a violent explosion.

- Use an extinguishing agent that is best suited to quench the bulk of the fuel that is available. For example, if a single cell were to start burning, a Lith-X Class D extinguisher should be used to quench the fire.

- If other combustibles catch fire as result of the lithium battery, then use the appropriate extinguishing agent to douse these secondary fires. It is important to address each type of fire with the appropriate extinguishing agent.

- When using Lith-X, completely bury the burning material with the Lith-X to extinguish the fire. Lith-X functions by forming a layer or crust of material over the burning metal. Lith-X may be applied from an extinguisher or by shoveling the loose powder onto the fire.

- Rechargeable, secondary cells utilize lithium ions that are intercalated into graphite, lithium metal oxides and/or lithium salts. There is no metallic lithium in a lithium ion battery. Because there is no metallic lithium in a lithium ion battery, ordinary extinguishing agents, like an ABC extinguisher, can be used on a fire involving lithium ion batteries.

Another method for fighting Li metal battery fires is to use large amounts of water. In the unlikely event that primary lithium batteries are involved in or near a fire, the principle concern is personal safety. The area should immediately be evacuated and all personnel accounted for. Emergency response organizations, either internal or external, should be immediately notified.

The secondary concern in the unlikely event of a fire involving lithium batteries is to prevent the spread of the fire and minimize cell venting. The most effective way of achieving these goals is through the use of large amounts of water. Lithium metal is a water reactive material; however in the unlikely event of a lithium fire, the lithium would be rapidly consumed thus minimizing the risk of a lithium-water reaction.

Flooding the area with water accomplishes two tasks. The water will cool surrounding cells and batteries and reduce the likelihood of additional cells venting. Flooding waters will also help to extinguish any secondary fires present in the area. In the event of a cell venting, a water fog pattern will help to reduce airborne concentrations of sulfur dioxide gas. The water will become a very weak sulfuric acid and is typically diluted by the large amounts of water used.
When attempting to fight a lithium battery fire, appropriate personal protective equipment should be worn. Respiratory protection should include self contained breathing apparatus and protective clothing should include firefighter turnout or bunker gear per local regulations. Portable fire extinguishers should be considered a last resort for fighting a lithium battery fire as they require emergency responders to be in very close proximity to the fire. There are several types of portable extinguishers available commercially.

Class D fire extinguishers (copper based) have been developed for and proven successful for extinguishing lithium and lithium alloy fires. The compound acts as a smothering agent and also acts as a heat sink. Copper-based extinguishing media is able to cling to vertical surfaces. Care should be taken to ensure that Class D fire extinguishers are of the copper-type, and not sodium chloride. The sodium chloride extinguishing agent is not intended for the high heat of a lithium fire, nor will it cling to vertical surfaces.

Graphite-based extinguishing media are effective on smaller lithium metal fires. These work by smothering the fire. This material will not cling to vertical surfaces, but has been developed for high-heat metal fires such as magnesium and lithium

9.0 FIRST AID PROCEDURES

In case of contact with electrolyte, gases, or combustion byproducts from a lithium battery or lithium ion battery release, the following first aid measures should be considered:

- EYES: Immediately flush eyes with a direct stream of water for at least 15 minutes with eyelids held open, to ensure complete irrigation of all eye and lid tissue. Get immediate medical attention.

- SKIN: Flush with cool water or get under a shower, remove contaminated garments. Continue to flush for at least 15 minutes. Get medical attention, if necessary.

- INHALATION: Move to fresh air. Monitor airway breathing and circulation. Take appropriate first aid and/or CPR actions, as necessary. Get immediate medical attention.

10. Waste Management

All waste management for spent or waste lithium and lithium ion batteries must conform to the UCSD universal waste management plan: http://blink.ucsd.edu/safety/research-lab/hazardous-waste/battery/index.html