Lithium Battery Safety Procedure

Approval:

Signature on file	*2/23/2011*
Environmental, Health & Safety Director	Date
Signature on file	*2/23/2011*
Institution Safety Committee Chair	Date

TABLE OF CONTENTS

1.0 PURPOSE

This Procedure describes the safety requirements for lithium (primary) and lithium-ion (secondary) batteries that are used in battery packs. This Procedure covers normal and emergency conditions and applies to all WHOI personnel that design, use, store, and dispose lithium battery packs.

2.0 DEFINITIONS

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.

Primary or non-rechargeable lithium cells: These cells have lithium metal or lithium compounds as the anode and are non-rechargeable. Many different primary cell chemistries are available. Lithium metal is water reactive and forms hydrogen and lithium hydroxide in aqueous solution. The lithium in primary cells is hermetically sealed to avoid this exothermic reaction. Lithium's melting point is 357°F.

Secondary or rechargeable lithium-ion cells: These cells do not contain metallic lithium and are rechargeable. Secondary cells contain lithium intercalation anode materials, where the lithium ion moves from the anode to the cathode during discharge and from the cathode to the anode when charging.

3.0 RESPONSIBILITIES

3.1 Engineers/Designers

- Implementation of all applicable provisions of this Procedure.
- 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 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 and system reliability during the battery pack's entire life cycle.
- Ensure that written standard operating procedures (SOPs) for lithium and lithium-ion powered research devices are developed and include methods to safely 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 Procedure.
- Assist in the investigation of incidents involving batteries subject to this Procedure.
- Assist in training and communicating safety requirements to WHOI personnel.
- Waste management (universal waste and hazardous waste).

3.3 Distribution Department

- Provides assistance with transportation of lithium batteries, including proper packaging and documentation.

3.4 Research Vessel (R/V) Science Parties

- Implementation of all applicable provisions of this Procedure.
- If the batteries and/or equipment containing batteries require special handling procedures, notifies Marine Operations Coordinator in advance of cruise.
- Include 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 (WHOI vessels).
- 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 that is transmitted to the ship.
- Review SOPs prepared under 3.1.

3.6 Chief Mate (Vessel Safety Coordinator)

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

4.0 CELL HANDLING PROCEDURES

Battery manufacturers report that inadvertent short circuits caused by abuse during handling are the largest single source of field failures for both lithium and lithium-ion cells, especially during receipt, inspection, and storage of cells. Problems associated with shorting as well as other hazardous conditions can be reduced by observing the following guidelines:

- Cells should be transported in non-conductive carrying trays. This will reduce the chances of cells being dropped, causing shorting or other physical damage.
- 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.
- Written work instructions or checklists should be generated for assembly and testing procedures. After a cell has been inspected it should be returned to its original container. All inspection tools (including calipers, rulers, etc.) should be made from, or covered with, a non-conductive material, when possible.
- Wear safety glasses whenever handling batteries. Remove jewelry items such as rings, wristwatches, pendants, etc., that could come in contact with the battery terminals. Jewelry has been accidently welded to lithium battery cells, causing serious burn injuries.
- All dented cells should be disposed. 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 cells.
- 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.
- 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.
- Cells should not be forced into battery holders or other types of housings. Check for proper fit before inserting the cells into any type of housing. 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. Excessive force should not be used to free a cell or battery lodged inside the housing.
- Primary 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

Minimize the inventory of lithium batteries in storage by implementing a just-in-time inventory system in both storage and use areas.

<u>5.1 Primary Lithium Batteries</u>

- NEVER leave packages or pallets of batteries unattended where they can be damaged by personnel or vehicles.
- Primary lithium batteries shall be stored inside a flammables storage cabinet. The cells should be safely contained inside the original manufacturer' packaging and adequately protected with electrical insulating material.
    - The cabinet shall conform to NFPA 30 or equivalent: 18 gauge sheet steel, double wall, locked, and labeled with contents. At least 2" clearance shall be maintained around the cabinet for ventilation and fire control.
    - The cabinet's location must be protected from forklifts, hand trucks, overhead loads, and other conditions that could result in cell damage and abuse leading to an inadvertent short circuit while in storage.
    - The cabinet's location should be under overhead sprinkler coverage and isolated from flammable liquids and hazardous waste. No other hazardous or combustible material should be stored in or on the cabinet. Store cells within the manufacturers approved temperature range.
    - Unless approved by EH&S and the Facilities Department, avoid more than one flammables storage cabinet per fire space for storing primary lithium batteries.

- The laboratory working inventory (outside of storage) is limited to the number of primary lithium batteries needed for the current work day or shift.
- All storage areas should be visually inspected at least weekly. Documentation of inspections does not need to be maintained. Separate fresh and depleted cells.
- Lithium batteries shall not be stored in non-laboratory areas such as offices.
- The presence of primary lithium batteries in storage cabinets shall be documented on the applicable Space Hazard Placard.
- Storage areas with more than 5 pounds of metallic lithium must be placarded with a NFPA 704 diamond that is at least 18” on each side with applicable information (e.g., Health 3, Flammability 2, Reactivity 2, and Special Hazard ~~W~~).

5.2 Secondary (lithium-ion) Batteries

- All applicable storage requirements for primary cells shall be followed, except secondary cells do not need to be stored in a flammables storage cabinet. Minimize the inventory in storage.

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 and type (same chemistry) of 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 Hazard Analysis

Battery pack designers and engineers are responsible for performing a hazard analysis (system safety analysis) to identify the various failure modes and hazards associated with the proposed configuration, type(s), and quantity of batteries used. This can be critical for battery pack designs, where a single cell failure could cause a fire involving multiple cells or the entire battery pack. Based on this analysis, safety-related design and testing criteria must be incorporated into battery pack designs. As necessary, battery pack engineers and designers must develop standard operating procedures that include methods to identify and mitigate possible battery cell and pack failures that may occur during assembly, deployment, data acquisition/retrieval, transportation, storage, and disassembly/disposal.

It is generally most cost-efficient to conduct the hazard analysis process during the design phase. There are numerous hazard analysis methods that may be used, from simple/preliminary to more complex. The hazard analysis method should be appropriate for the system design. Some examples of these methods include: Energy Trace and Barrier Analysis, Failure Mode and Effect Analysis, Fault Hazard Analysis, Fault Tree Analysis, Hazard and Operability Study, Preliminary Hazard Analysis, and What-If Analysis.

6.3 Designing Safer Battery Packs

The design of a battery pack can adversely impact the safety characteristics of individual cells. 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. Battery packs should be designed to avoid conditions leading to short-circuiting, forced over discharging, charging, or excessive heating. This can be accomplished through proper design and use of protective devices such as fuses, thermal switches, heat sinks, and diodes.

Based on the hazard analysis, feasible controls must be identified and incorporated into the battery pack design. The design objective is to increase the likelihood that the battery packs will perform reliably and safely during their entire life-cycle. Some basic hazard controls and design recommendations that should be considered during the design phase are listed below.

- Always use the same size cells in series or parallel connections. Don't mix cell chemistries and different cell sizes. Follow manufacturer's instructions and review Material Safety Data Sheets (MSDSs) for the battery cells being used.
- Primary lithium cells should not be connected to a power source or otherwise charged. When possible, use series diodes to block any possible charging current from entering through the discharge terminal.
- Cells fabricated into a battery pack should be of the same age (lot code) and history. Discharged cells should not be mixed in a pack or stored with new cells.
- Thermal cutoff (TCO) or resettable 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 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 output 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 connections to cells within the string, other than for cell voltage monitoring. This will reduce 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. 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.
- 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.

6.4 Battery Pack Fabrication

After the battery pack design is complete, the next step is fabrication of the battery packs. During fabrication, it is important to follow the design drawings and associated procedures. In accordance with quality control procedures, the battery packs should be inspected at various stages of production and the proper design verified. During and after fabrication, battery cells and packs will need to be safely stored. Some basic safety precautions that should be followed during battery pack fabrication and storage are listed below.

- Store cells in original manufacturer's container until they are ready to be assembled into battery packs. Store primary lithium cells in cool, dry and well ventilated location.
- Don't allow positive and negative leads to contact. Loose wires should not be stripped until it is time to install a connector, or the connector harnesses should be assembled prior to attaching them to the cell terminals. If no connector is used, wire ends should be insulated. When cutting wires, only cut one wire at a time.
- If available, use non-conductive tools and avoid placing battery cells and packs on electrically conductive surfaces.
- Don't solder directly to cell case and never touch a cell case directly with a hot soldering iron. Only solder to the free end of solder tabs that are welded to the case.
- 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.
- All battery packs should be appropriately labeled with key information, such as type of battery, its voltage, temperature limit, manufacturer name, date, etc.

7.0 SHIPMENT

Only trained and authorized personnel may prepare, package, and ship lithium batteries. Contact the Distribution Department for assistance.

- Lithium batteries must be prepared and packaged in a manner that prevents a short circuit and other abusive conditions that could lead to a failure during transportation.
- Lithium batteries must be prepared, packaged, and shipped in accordance with all applicable requirements, including Department of Transportation (DOT), International Air Transport Association (IATA), and International Maritime Organization (IMO). Fines and penalties for non-compliance can be substantial.

8.0 EMERGENCY PROCEDURES

Only trained and properly equipped emergency response personnel should respond to lithium battery emergencies, including: leaking cell, vented cell, hot cell, and fires. If WHOI emergency responders cannot safely respond to an emergency involving lithium batteries, Falmouth Fire Rescue or other qualified emergency services must be summoned.

Emergency procedures are described below and in WHOI's Comprehensive Emergency Management Plan: http://ehs.whoi.edu/ehs/DesktopDefault.aspx?tabindex=0&tabid=1&itemID=16.

8.1 Hot Cells

A hot cell is a condition that arises due to an internal or external short circuit of the cell or battery. It the cell temperature continues to rise above the critical temperature, the hot cell could vent or explode.

- As soon as it has been determined that a hot cell situation exists, evacuate all personnel from the area. The area should be secured to ensure that no unnecessary persons enter.
- From a shore-side facility, dial x2911 from a safe location to report the emergency. On an R/V, notify the Bridge and initiate the vessel emergency response procedures.
- If the situation allows, prior to evacuating, determine if an external short circuit is present. If safe to perform, quickly remove the short-circuit. The area should remain evacuated until the cell has cooled to room temperature.

  Response Procedure for Emergency Responders:

  - Ensure unauthorized personnel have evacuated the hot cell area.
  - Monitor the temperature with a remote device (non-contact thermometer is available at EH&S office).
  - If remote temperature monitoring device is not available, keep area evacuated/secured and do not handle battery for at least 24-hours.
  - When the cell cools and is safe to handle, remove it from the area and dispose as universal waste.

8.2 Vented and Leaking Cells

Major manufacturers of primary lithium batteries report that it is unlikely that a cell will explode and that this rare event is usually the result of a condition that raises the cell temperature above its critical point. Depending upon the cell chemistry of the primary lithium batteries, an exploded or vented cell could fill a space with dense white smoke that can cause severe irritation to the respiratory track, eyes and skin. Depending upon the cell chemistry, the following chemical compounds could be released from an exploded or vented cell: hydrogen chloride, sulfur dioxide, bromine, and chlorine. Avoid exposure to these airborne contaminants.

- If a cell has vented, leaked or exploded, evacuate all personnel from the area. The area should be secured to ensure that no unnecessary persons enter.
- From a shore-side facility, dial x2911 from a safe location to report the emergency. On R/V, notify the Bridge and initiate the vessel emergency response procedures.

  Response Procedure for Emergency Responders:

  - Ensure unauthorized personnel have evacuated the vented or exploded cell area.
  - If necessary, ventilate the space where the cell vented or exploded until the smoke has cleared and the odor is gone.
  - Monitor the temperature with a remote device (non-contact thermometer or thermal imager). When the cell cools and is safe to handle it can be neutralized with baking soda inside a sealed bag and disposed as universal waste. Contact EH&S for disposal instructions, x3347.
  - If remote temperature monitoring device is not available, keep area evacuated/secured and do not handle battery for at least 24-hours.
  - Electrolyte spill areas and cell explosion debris should be neutralized with baking soda. Contact EH&S (x3347) for disposal requirements.

8.3 Electrolyte Exposures and First Aid

While the electrolyte composition will vary depending on the type of primary lithium battery cell, the general first aid procedures are the same for an exposure to the electrolyte. Electrolyte that is exposed to air at normal temperature and pressure can react with moisture to generate sulfur dioxide, hydrogen chloride, and chlorine. Refer to the specific material safety data sheet (MSDS) for detailed, cell-specific information. General first aid procedures are listed below.

- From a shore-side facility, dial x2911 from a safe location to report the emergency. On R/V, notify the Bridge and initiate the vessel emergency response procedures.
- EYES: Flush with water for at least 15 minutes and hold eyelids open to rinse thoroughly. Remove contaminated garments.
- SKIN: Flush with water for at least 15 minutes and remove contaminated garments.
- INHALATION: Move to fresh air. Monitor airway breathing and circulation. If necessary, implement appropriate first aid and/or CPR procedures.
- For significant exposures to electrolyte, get immediate medical attention. The applicable MSDS should be sent with the patient to the hospital.

8.4 Primary Lithium Battery Fires

Only trained and properly equipped emergency responders should attempt to fight a primary lithium battery fire. Cells exposed to excessive heat beyond their recommended temperature range can explode. A cell fire within a battery pack can lead to the chain reaction that involves multiple cells. Note: metallic lithium melts at about 180°C (356°F). Depending on the cell chemistry, the thermal decomposition byproducts may include chlorine, hydrogen chloride, sulfur dioxide, and other compounds. A major battery manufacturer reports that portable fire extinguishers should be considered a last resort for fighting a primary lithium battery fire, as they require emergency responders to be in close proximity to the fire. Therefore, Class D (yellow) portable fire extinguishers are not recommended for use in any primary lithium battery storage or use areas.

During a lithium battery fire there are two main objectives: 1) life safety, and 2) preventing the spread of fire to other cells, preventing cell venting, and protecting the building/property. The most effective way to achieve these goals is through the use of large amounts of water. Lithium metal is contained in primary cells and is water reactive; however a major battery manufacturer reports that the relatively small amount of lithium in a cell would be rapidly consumed and thus minimizing the risk of a lithium-water reaction. Flooding the fire area with water will cool the surrounding cells and reduce the likelihood of additional cells venting. Flooding water also helps to extinguish secondary fires that could lead to a building structural fire.

The general fire procedures for primary lithium batteries are listed below.

- From a shore-side facility: 1) pull fire alarm, 2) call x2911 from a safe location to report the emergency, and 3) evacuate the area.
- On R/V, notify the Bridge and initiate the vessel emergency response procedures.

8.5 Secondary Lithium-ion Battery Fire

Secondary lithium batteries contain an ionic form of lithium and do not contain metallic lithium. Therefore, the above precautions for primary lithium batteries do not apply to lithium-ion battery fires. The general fire procedures for secondary lithium batteries are listed below.

- From a shore-side facility: 1) pull fire alarm, 2) call x2911 from a safe location to report the emergency, and 3) evacuate the area.
- On R/V, notify the Bridge and initiate the vessel emergency response procedures.

- Fight the fire if it is small (incipient stage), safe to do so, and you are adequately trained. Lithium-ion battery fires are considered an ordinary combustible fire; therefore a portable ABC fire extinguisher can be used. Additional emergency procedures, including fire procedures are available on the EH&S website and should be reviewed: http://ehs.whoi.edu/ehs/DesktopDefault.aspx?tabindex=0&tabid=1&itemID=16.

9.0 WASTE MANAGEMENT

All waste management steps (collection, temporary storage, recycling, disposal, etc) for spent or waste lithium and lithium-ion batteries must conform to the Universal Waste Management Guideline, which is available on the EH&S web site: http://ehs.whoi.edu/ehs/. The basic waste management procedures are described below.

- Isolate/secure all battery cell and pack leads and terminals to prevent short circuiting.
- Ensure the type of batteries is clearly written on the cell or pack.
- Gently place the spent cells and packs in the appropriate universal waste collection container. DO NOT throw the batteries into the collection container, as this can cause a short circuit. Spent lithium and lithium-ion batteries should go into the same universal waste container that is labeled 'lithium batteries.' Do not mix lithium batteries with other types of batteries, such as alkaline.
- Single cells of lithium-ion (secondary) batteries can go into the regular trash. However, spent lithium-ion battery packs must go into the lithium battery drum.
- Large quantities of spent lithium batteries (e.g., pallets) should be collected near the point of generation and do not need to be deposited in or near the universal waste drums. Contact EH&S for assistance: wastepickup@whoi.edu or x3347.