

SAFETY AND HANDLING GUIDELINES FOR ELECTROCHEM LITHIUM BATTERIES



Electrochem Battery Division of Wilson Greatbatch, Ltd.

10,000 Wehrle Drive, Clarence, NY 14031
Tel: 716-759-5395 Fax: 716-759-2562

100 Energy Drive, Canton, MA 02021
Tel: 781-575-0800 Fax: 781-575-1545

web page: www.greatbatch.com
e-mail: electrochem@greatbatch.com

Thomas Klementowski
Manager, Engineering
Electrochem Battery Division

Paul Krehl
Safety and Regulatory Manager
Wilson Greatbatch, Ltd.

x Thomas Klementowski

Date: 7 NOV 2000

x Paul W. Krehl

Date: 7 NOV 2000

Revision Original
November, 2000

Index

<u>Section</u>	<u>Title</u>	<u>Page</u>
1.0	INTRODUCTION	3
2.0	SAFE HANDLING GUIDELINES	5
2.1	RECEIVING INSPECTION AND STORAGE OF CELLS	5
2.2	CELL STORAGE	7
2.3	HANDLING PROCEDURES DURING PRODUCT ASSEMBLY	7
2.4	PACKAGING FOR SHIPMENT	9
3.0	BATTERY PACK ASSEMBLY	12
3.1	CELL SELECTION	12
3.2	BATTERY PACK DESIGN	13
3.3	BATTERY FABRICATION	17
4.0	HANDLING UNDER ADVERSE CONDITIONS	18
4.1	PROCEDURES FOR HANDLING A HOT CELL	18
4.1.1	Minimum Equipment Required	19
4.1.2	Procedure	19
4.2	PROCEDURE FOR HANDLING CELLS THAT HAVE VENTED	20
4.2.1	Minimum Equipment Required	21
4.2.2	Procedure	21
4.2.3	First Aid Procedures in Case of Contact with Electrolyte	22
4.3	PROCEDURE FOR CELLS THAT HAVE EXPLODED	22
4.3.1	Minimum Equipment Required	22
4.3.2	Procedure	23
4.3.3	First Aid Procedures in Case of Contact with electrolyte	24
4.4	FIRES INVOLVING LITHIUM BATTERIES	24
4.4.1	Minimum Equipment Required	25
4.4.2	Procedure	25
4.4.2.1	Initial Response	25
4.4.2.2	Clean-up	26
4.4.2.3	First Aid Procedures in Case of Contact with Electrolyte	27

SAFETY AND HANDLING GUIDELINES FOR
ELECTROCHEM LITHIUM BATTERIES

1.0 INTRODUCTION

The Electrochem Battery Division of Wilson Greatbatch Ltd. Manufactures a wide variety of lithium batteries for use in military, oil exploration, oceanographic and other demanding commercial applications. The specific cell chemistries manufactured by the Electrochem are summarized in Table I.

TABLE I

<u>Product Designation</u>	<u>Chemistry</u>	<u>Open-circuit Voltage (V)</u>	<u>Operating Temp Range (°C)</u>
QTC85/QTCII85	SOCl ₂	3.6	-40 to 85
BE100	SOCl ₂	3.6	-40 to 85
BCX72/BCXII72	SOCl ₂ /BrCl	3.9	-55 to 72
CSC93	SO ₂ Cl ₂ /Cl ₂	3.9	-32 to 93
PMX150/165	SO ₂ Cl ₂ /Cl ₂	3.9	-40 to 150/165
BE150/165	SOCl ₂	3.6	-40 to 150/165
MWD150	SOCl ₂	3.6	0 to 150
BE180	SOCl ₂	3.6	+50 to 85
VHT200/BE200	SOCl ₂	3.6	+70 to 85

The success of these systems is partially due to the fact that they contain more energy per unit weight than conventional batteries. However, the same properties which result in a high energy density also contribute to potential hazards if the energy is released at a fast, uncontrolled rate. With proper use and handling, these cells have demonstrated an excellent safety record. The cells produced by E•I are being used successfully by NASA and in other applications where safety and reliability is of utmost importance.

Because of the recognition of hazards associated with high energy density systems, safety has been incorporated into the design and manufacture of Electrochem lithium cells and batteries. For example, all commercial cells

utilizing spirally wound electrodes are internally fused to protect the user against the hazards associated with short circuits. While we have designed our cells and battery packs to be tolerant to adverse conditions, these very active chemical systems have limitations. Certain hazards are associated with exposure to heat and its subsequent effects on sealed cells. These hazards include possible battery venting, explosion and/or fires. The initial source of heat can be external (fire, soldering iron) or internal, such as heating caused by short circuit, forced overdischarge, charging conditions or excessive mechanical abuse.

Specifically, mechanical abuse in the form of excessive shock or vibration can result in case deformation or crushing and damage to the electrodes and/or separator material.

Most primary lithium cells have a warning printed on their label that cautions against the following conditions:

- short-circuit
- charging
- forced overdischarge
- excessive heating or incineration
- crush, puncture or disassembly

Not guarding against these conditions may result in a hot cell or battery pack that could either vent or explode. With Electrochem cells, the ensuing hazards associated with a hot cell, typically do not occur the instant the cell is abused. Rather, the cell heats up over a period of time and subsequently vents or explodes when its critical temperature is reached. The rate of heating is proportional to the extent of the abusive condition. For example, if a charging current is limited to the leakage current through a blocking diode, no heat will be generated. However, a 3A charge will cause a cell to heat to its critical temperature over a period of 8-10 minutes (depending on the size of the cell and the ambient temperature). Our cells are designed to operate over the temperature range listed in Table I. The critical temperature (as measured on the cell case) for the QTC/QTCII, BCX/BCXII, CSC and BE100 cells is in the range of 125°C to 150°C. The critical temperature for the PMX and BE150 cells is 165-180°C. The critical temperature for the BE180 cells is 190-200°C, and the critical temperature for the BE200 and VHT200 cells is 210-215°C.

One condition that could lead to a sudden explosion is severe structural deformation of the case or internal components due to excessive mechanical abuse.

2.0 SAFE HANDLING GUIDELINES

The intent of this section is to provide lithium battery users with guidelines necessary for safe handling of cells under normal manufacturing and use conditions. This document will address three principle areas:

- (1) Receiving inspection and subsequent storage of cells.
- (2) Handling procedures during product assembly.
- (3) Packaging for shipment.

2.1 RECEIVING INSPECTION AND STORAGE OF CELLS

In general, the conditions that cause damage to cells and jeopardize the safety of personnel are summarized on the label of each cell. These conditions include:

- Short circuit
- Charging
- Forced Overdischarging
- Excessive heating or incineration
- Crush, puncture or disassembly

Rough handling or excessive shock and vibration could also cause problems.

The most frequent forms of cell abuse can be easily identified and controlled in the workplace. It is our experience that inadvertent short circuits are the largest single cause of field failures. In addition, random short circuiting is a common problem in receiving inspection, since cells are handled frequently at this stage.

All Electrochem cells are internally protected against the hazards associated with short circuits. This is accomplished by incorporating a fast acting fuse under the terminal cap. While the fused cells will neither heat, vent, nor explode under a direct short circuit condition, they will be

rendered useless (zero volts). However, cells subjected to an intermediate short (a current limited to just below the fuse value) could overheat resulting in a venting situation. This is especially true if the cells are in an insulating environment. Therefore, shorting cells should be avoided.

Problems associated with shorting as well as other hazardous conditions can be greatly reduced by observing the following guidelines:

- Cover all metal work surfaces with an insulating material.
- The work area should be clean and free of sharp objects that could puncture the insulating sleeve on each cell.
- Never remove the terminal cap, shrink wrap or protective potting from a cell or battery pack.
- All personnel handling cells should remove jewelry items such as rings, wristwatches, pendants, etc., that could come in contact with the battery terminals.
- If cells are removed from their original packages for inspection, they should be neatly arranged to preclude shorting. Do not stack or scatter the cells. They should be placed in plastic carrying trays with individual compartments for each cell.
- Cells should be transported in plastic trays set on push carts. This will reduce the chances of cells being dropped on the floor causing shorting or other physical damage.
- All inspection tools (including calipers, rulers, etc.) should be made from, or covered with, a non conductive material such as plastic or kapton.
- Cells should be inspected for physical damage, possibly caused by dropping the cell. Cells with dented cases or terminal caps should be inspected for electrolyte leakage. If any is noted, the cell should be disposed of in the proper manner. (See Section 4.0 for handling procedures of leaking or vented cells.)
- Measure the open-circuit-voltage (OCV) of the cell. The nominal OCV for each cell chemistry is printed on each cell label. Note: An open circuit voltage of 0.0 volts is indicative of a blown fuse. This cell

should also be removed from inventory and returned to the factory for rework.

- 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.
- The cells must never be disassembled. In addition, never attempt to repair a blown fuse. This must only be replaced at the factory.

2.2 **CELL STORAGE**

Storage of hazardous materials is generally regulated by Federal, State and local codes. These codes may regulate the location and amount of material that may be stored in a designated area. In addition these general guidelines should be followed:

- 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.
- Store the cells in an isolated area, away from combustible materials. Store depleted cells in an area separate from fresh cells.
- Any lithium battery storage area should have immediate access to a class D fire extinguisher and respirators.
- Never stack heavy objects on top of boxes containing lithium batteries to preclude crushing or puncturing the cell case. Such 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.

2.3 **HANDLING PROCEDURES DURING PRODUCT ASSEMBLY**

Since isolated incidents involving lithium cells are possible, we recommend that safety glasses be worn by all production personnel. The above guidelines concerning the reduction of short circuit incidents should be incorporated in all areas of the facility. Additional precautionary measures should be observed in production areas to avoid more serious problems associated with heat, especially around soldering equipment or during routine performance testing at elevated temperatures.

One way to limit the potential for incidents that could occur in a manufacturing area is to reduce exposure to the cells. This can be accomplished by utilizing "just in time" concepts when delivering cells to the production area. Deliver only the required amount of cells (on a daily basis) to production. Keep additional cells in the stock area.

- Written work instructions should be generated for each manufacturing procedure.
- Transport cells in plastic trays set on push carts. This will reduce the chances of cells being dropped on the floor causing shorting or other damage.
- Heat sensitive sheets can be placed over the plastic trays. Hot cells, indicative of a potential problem, are easily identified using this technique.
- 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.
- Many Electrochem cells (spiral wound construction) incorporate a fuse under the terminal cap. A wave soldering operation will blow the fuse rendering the cell useless. Hand solder all spirally wound cells.
- 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.

- For the same reasons stated above, excessive force should never be used to free a cell or battery lodged inside a housing.
- Cells and/or batteries, should not be exposed to high voltage AC sources or other DC power supplies. This could result in subjecting the cells to charging or forced-discharging currents.
- All ovens or environmental chambers used for testing cells or batteries should be equipped with an over temperature controller to protect against excessive heat.

2.4 **PACKAGING FOR SHIPMENT**

U. S. domestic transportation is regulated by the Department of Transportation (DOT) through Title 49 Code of Regulation (49 CFR), HM-181 part 173.185. Internationally, air transportation is regulated by the International Air Transport Association (IATA). Pursuant to 49 CFR 173.185, all shipments of hazardous materials must comply with packaging regulations based on recommendations made by the United Nations. The new regulations require "performance oriented" packaging that must pass the following tests designed to demonstrate package integrity:

- Drop test
- Leak proof test (where applicable)
- Internal pressure (hydraulic) test (where applicable)
- Stacking test

These tests are usually performed by authorized independent testing organizations. Once certified the package is assigned a UN code identifying it as such.

While the U.S. Department of Transportation recognizes three classifications for lithium batteries, less of a distinction is made between solid cathode and liquid cathode cells in the most recent 49 CFR. Furthermore, cells shipped in equipment are addressed separately in the regulations. Certain lithium cells/batteries are considered non-dangerous and are not restricted if they meet the following requirements:

- Each liquid cathode cell must contain 0.5 g or less of lithium.
- Each solid cathode cell must contain 1.0 g or less of lithium.
- Each cell must be hermetically sealed.
- Each battery with a liquid cathode must contain an aggregate quantity of one gram or less of lithium.
- Each battery with a solid cathode must contain an aggregate quantity of two grams or less of lithium.
- Batteries must be separated to prevent short circuits.
- If a liquid cathode battery contains more than 0.5 grams of lithium, or if a solid cathode battery contains more than 1.0 grams of lithium, it must not contain a liquid or gas which is considered dangerous unless the liquid or gas, if free, would be completely absorbed or neutralized by other materials in the battery.
- Proper packaging and labeling guidelines must be followed.

Cells or batteries that exceed the above lithium content limitations may also be non-restricted if they meet the following requirements: (It should be noted that no distinction is made between solid or liquid cathode cells at this point)

- Each cell must contain 5.0 g or less of lithium (or lithium alloy).
- Each battery must contain 25.0 gms or less of lithium (or lithium alloy).
- Each cell or battery is of the type proven to be non-dangerous by testing in accordance with tests in the UN Recommendations on the Transport of Dangerous Goods, Tests and Criteria. These are tests T-1 through T-6.
- Cells and batteries must be separated to prevent short circuits.

It should be noted that cells and batteries, and equipment containing cells and batteries which were first transported prior to January 1, 1995 may continue to be transported in accordance with the applicable requirements in effect on October 1, 1993, until January, 2003.

Value added distributors must also test their battery packs to the above requirements even though similar designs may have been tested and shipped by Wilson Greatbatch Ltd.

If cells or batteries exceed the above lithium content limitations then they may be transported as items of Class 9 **if they meet the requirements in paragraphs (e)(1) through (e)(9) of 49 CFR, §173.185.**

- Cells must not contain more than 12 grams of lithium (or lithium alloy) and are permissible on cargo aircraft only. Cells containing up to 3 grams of lithium may be shipped on passenger aircraft.
- Batteries must be packed in UN packaging with not more than 500 g of lithium per packaging for cargo aircraft and 125 g of lithium for passenger aircraft.
- Maximum allowable gross weight per package is not to exceed 35 kg for cargo aircraft or 5 kg for passenger aircraft.
- Cells must be packed in such a manner as to prevent movement or short circuiting.
- Each cell or battery is of the type proven to be non-dangerous by testing in accordance with tests in the UN Recommendations on the Transport of Dangerous Goods, Tests and Criteria.
- Labels required: "miscellaneous" and "cargo aircraft only" ("cargo aircraft only" label used only when applicable).
- Packaging required: UN approved.
- Shipper's Declaration of Dangerous Goods must be completed.
- This regulation does not apply to depleted cells with open circuit voltage of less than two volts or 2/3 voltage of the undischarged cell.
- Markings "lithium batteries - UN3090" must appear on box.

Lithium batteries, contained in equipment - UN3091

- The quantity of lithium metal contained in any piece of equipment must not exceed 3 g per cell and 125 g per battery for shipment aboard passenger aircraft or 12 g per cell and 500 g per battery for shipment aboard cargo aircraft.
- Not more than 5 kg of lithium batteries may be contained in any piece of equipment.
- Labels required: "miscellaneous" and "cargo aircraft only" ("cargo aircraft only" label required when cells contain over three grams of lithium).
- Equipment containing lithium batteries must be contained in strong outer packaging which is waterproof.
- Requirements of 5.0 in the IATA book must be met.
- Requirements in IATA packaging Instruction 912 must be met in addition to the general packaging requirements in Instruction 903.
- Cells must not be capable of being discharged during transport to the extent that the open circuit voltage is less than the lower of two volts or 2/3 of the voltage of the undischarged cell.
- Markings "Lithium Batteries contained in equipment UN3091" must appear on box.

As of January 1, 1991 the DOT requires shippers of hazardous materials, such as manufacturers and distributors, to be in compliance with the Emergency Response Communication Standard per Title 49, Part 171 et. al. This regulation requires that the shipper of hazardous materials use the proper shipping name, have a 24-hour emergency response information system and provide emergency response mitigation information with each shipment.

Lithium batteries, for disposal, may be transported to a permitted storage facility and/or disposal site by motor vehicle only. They must be packaged in a strong outer box and isolated with an effective means to prevent external short circuits.

3.0 BATTERY PACK ASSEMBLY

While Electrochem cells possess a high power and energy density, many applications require even greater voltage, current or capacity than a single cell can provide. The solution can be a battery pack of series and/or parallel configuration. The purpose of this document is to provide a qualified user with guidelines for the selection, design and fabrication of lithium cells into battery packs.

The design of a battery can either enhance or denigrate the safety characteristics of individual cells. For example, a series configuration may increase the potential for subjecting cells to forced overdischarge conditions. Parallel strings can lead to charging currents. Battery packs should be designed to avoid conditions leading to short circuiting, forced overdischarging, charging, or overheating. This can be accomplished through proper design and use of protective devices such as fuses, thermal switches, heat sinks and diodes as required.

3.1 CELL SELECTION

The manufacturer of lithium cells should provide sufficient information to enable them to be used safely. It is then up to the user to take note of this information when designing battery packs. It is important to know the working limits of the cells selected so that the battery packs will meet the customer's performance requirements without undesirable reactions.

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

- Always use the same cell chemistry in a battery pack. Do not mix Li/SO₂, Li/SOCl₂, SO₂Cl₂, Li/MnO₂ or any other type of cell in a pack design.
- Always use the same size cells in series or parallel connections.
- Cells fabricated into batteries 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.

3.2 **BATTERY PACK DESIGN**

It is strongly recommended that batteries be built by the cell manufacturer or an authorized value-added-reseller. If this is not practical, the manufacturer should be consulted such that the most appropriate 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 not only have a high resistance to leakage current, but must also be a good dielectric. The insulation resistance is usually expressed in M and the dielectric strength is measured in terms of volts/mil thickness of material. It should be noted that the insulation resistance of materials decreases rapidly with increased temperature. Also, absorbed moisture reduces the insulation resistance, and moisture and humidity could have a large effect on the surface leakage of a battery.

The materials used to protect individual cells were chosen because of their high dielectric strength and temperature tolerance. The dielectric strength of the shrink wrap used on the cells is as follows:

<u>Materials</u>	<u>Nominal thickness</u>	<u>Dielectric strength</u>
PVC	4-6 mils	1083 volts/mil
Kynar	8-10 mils	800-1000 volts / mil
FEP	8-10 mils	2000 volts / mil

Materials with similar properties should be used in the construction of battery packs.

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 termination's must be isolated from traces on the underside of the board. Solder points can have sharp protrusions that can puncture thin materials such as Kapton tape. Thick, puncture resistant insulation must be used in these areas. Designers should consider surface mount technology to eliminate traces and through holes on the underside of the boards.

Following are the minimum requirements for protecting battery packs from specific abusive conditions:

- In the fabrication of battery packs where cells or batteries are connected in parallel, diode protection is required to eliminate the exposure of cells to charging currents. Figure 1 shows the proper placement of diodes in a battery pack to eliminate charging currents from adjacent battery strings.

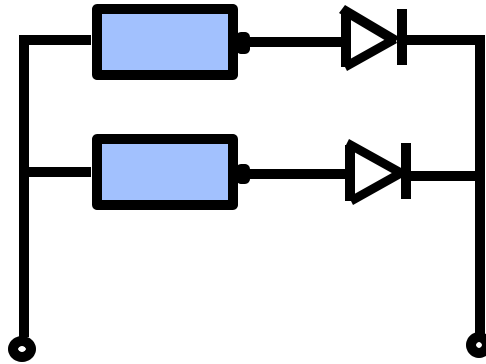


Figure 1
Charge Protection

There are four factors one must consider when selecting a diode:

- Forward Current (I_F) - This is the maximum rated current which the diode can pass. The I_F must be greater than the expected current of the battery.
- Reverse Current (I_R) - This is the amount of current the diode will pass in the reverse direction. The diode selected should have an I_R less than 0.1mA. This will alleviate the effects charging currents have on both cell safety and performance.
- Reverse Voltage or Breakdown Voltage (V_R) - This is the amount of reverse voltage which can be applied to the diode before breakdown occurs. V_R should be selected to be greater than the OCV of any one of the battery strings.
- Forward Voltage Drop (V_F) - This is the amount of voltage lost due to the use of a diode. If a diode is placed in series with a 3.0V cell the usable voltage will be $3.0 - V_F$. Two types of diodes are available. Silicon diodes have a V_F of 0.7 volts. If the particular application requires that a high voltage be maintained then the performance of the cell may be slightly enhanced by using a germanium or schottkey diode with a V_F of 0.3 volts.

It is particularly important to use diodes in this configuration where there is another power source (e.g. where the cell or pack is used as a back-up to

main power). Precautions must be taken to avoid charging of the battery from the external source.

Diodes can also be used to protect cells in a series string from forced overdischarge conditions. Figure 2 shows the proper placement of a diode to eliminate forced overdischarge conditions.

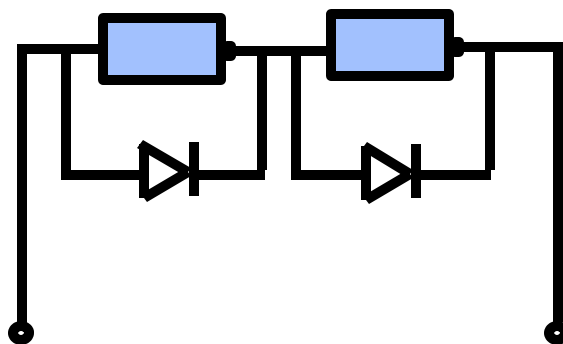


Figure 2
Reversal Protection

Each cell in a series string should be equipped with a diode connected in parallel. Under normal operation, the current will flow through the cell because the diode is reversed biased. If a given cell in the series string is prematurely depleted, its shunt diode will become forward biased and the current will pass through it. This is a simple yet effective way to minimize hazards associated with forced overdischarge conditions. It is important to pick diodes with a low I_R for this type of use. Otherwise, the cells will be prematurely discharged through the diode. Additional protective measures that should be considered are:

- In-line fuses should be fitted external to the battery such that they may be replaced after the short circuit is cleared.
- A limiting resistor could also be placed in series with the diode. This should limit the current to the lowest practical value consistent with the application.

- Thermal cutoff (TCO) or resettable polymeric, positive temperature coefficient (PTC) resistors can be used to keep the pack from exceeding the safe temperature limits of the cells.
- Both the surrounding thermal environment and the heat output of a battery pack during operation should be evaluated. The heat generation of the cells should be calculated.
- 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.
- The bottom of most high temperature cells will swell as a normal result of high temperature discharge. The cell compartment must be designed with adequate inter-cell spacing to accommodate this expansion.
- 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. A vent mechanism should also be incorporated in rigid housings to avoid rupture of the outer battery case.
- Shock and vibration requirements must be considered in the design of any battery pack. All cells must be protected from excessive shock and vibration.
- It is unlawful to ship more than 500g of lithium in any one container. Therefore, large packs may have to be designed in a modular fashion and assembled in the field.

3.3 BATTERY FABRICATION

It is essential that engineering drawings and work instructions are completed prior to the initial pack construction. The general handling procedures outlined in this document should also be observed. Also, safety procedures should be in place to cover any hazards that may arise while assembling and handling battery packs.

Personnel assembling battery packs should comply with the following recommendations:

- Safety glasses must be worn at all times. All jewelry should be removed so that the cell could not be inadvertently shorted.
- 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.
- Avoid cutting or piercing the insulating shrink wrap on the cells.
- 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 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.
- Under no circumstances should the terminal cap and fuse assembly be removed from a cell.

4.0 **HANDLING UNDER ADVERSE CONDITIONS**

Abusive conditions discussed in previous sections must be avoided to ensure safe handling of our cells. However, if mistakes are made in battery pack design or in cell handling that result in a cell venting or exploding, the user should be equipped to cope with such emergencies. Our intent is to provide any handler with knowledge which is needed for safe handling of cells that have been subjected to these extreme conditions. This document will address four principle areas:

- (1) Hot cells
- (2) Cells that have leaked or vented
- (3) Cells that have exploded
- (4) Fires involving lithium batteries

4.1 **PROCEDURES FOR HANDLING A HOT CELL**

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

If the situation allows before leaving, the person who first noticed the hot cell should quickly determine if an external short-circuit is present and remove it as quickly as possible. After the short has been removed, the cell should start to cool. However the area should remain evacuated until the cell has cooled to room temperature and has been removed from the area. The temperature of the cell should be monitored periodically with a remote sensing device such as an infrared temperature sensor.

If the hot cell situation persists, then the following course of action can be considered.

4.1.1 **Minimum Equipment Required**

- Infrared temperature probe
- Safety glasses
- Helmet with impact resistant face shield
- Non-conductive extended pliers

4.1.2 Procedure

- As soon as a hot cell is detected, completely evacuate the area of all personnel.
- Periodically monitor the temperature of the cell with the remote probe for the first two hours or until one of the three following situations occurs:
 - the cell starts to cool;
 - the cell vents; or
 - the cell explodes.
- If the cell starts to cool, monitor its temperature once an hour until it returns to ambient temperature.
- If remote temperature sensing equipment is not available, do not handle the cell for a period of 24 hours.
- Remove the cell from the work area once it has cooled and return to normal operations.
- Dispose of the cell in accordance with local, state and federal hazardous waste regulations.
- Procedures for handling cells that continue to heat and, resultantly, either vent or explode will be addressed in Sections 4.2 and 4.3.

4.2 PROCEDURE FOR HANDLING CELLS THAT HAVE VENTED

All Electrochem lithium batteries are hermetically sealed in a 304L stainless steel case. A glass-to-metal seal is used as an electrical feedthrough for the positive terminal. Under normal operating conditions, a cell will not leak or vent. However, cell leakage or venting could occur if the cell is overheated or the glass seal is compromised by excessive physical abuse.

The severity of a vent condition can range from a slight leak around the glass-to-metal seal to a violent expulsion of material through the glass seal, thereby causing the cell to become a projectile.

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 either corrosive or flammable vapors summarized in Table II.

TABLE II

<u>Cell Chemistry</u>	<u>Vent Products</u>	<u>Properties</u>
QTC/QTCII, BCX/BCXII, MWD, VHT and all BE series	SOCl ₂ Br ₂ , Cl ₂ , HCl	Non-flammable, eye irritation Corrosive, inhalation hazard, causes chemical burns to skin. Negligible fire hazard,
CSC and PMX	SO ₂ Cl ₂ Cl ₂ , HCl H ₂ SO ₃ SO ₂	Non-flammable, eye irritation corrosive, inhalation hazard, causes chemical burns to skin. Negligible fire hazard,

All precautions should be taken to limit exposure to the electrolyte vapor. Product safety data sheets are attached in appendix A for our particular cell chemistries.

4.2.1 Minimum Equipment Required

- A Class D fire extinguisher
- Eye protection or face shield
- Respirator suitable for organic vapors, chlorine, HCl and SO₂
- Neoprene rubber gloves
- Lab coat or chemically resistant apron
- Bicarbonate of soda (baking soda), calcium oxide (lime) -or- acid spill clean up kit
- Vermiculite, 3M Power Sorb (universal absorbent material), Speedy-Dry (clay absorbent)
- Individual thick plastic bags with sealing mechanism

4.2.2 Procedure

Should electrolyte leak from a cell the following actions should be taken:

- Evacuate personnel from all areas which are affected by the gas.
- Ventilation should be initiated and continued until after the cell is removed from the area and the pungent odor is no longer detectable.
- If the cell vented as a result of excessive heating, it must be allowed to cool to ambient temperature before handling. (Refer to hot cell procedure in section 4.1)
- Put on lab coat, rubber gloves, safety glasses and respirator. Remove the cell to a well ventilated area.
- Place each leaking cell in a separate, sealable plastic bag. Eliminate excess air and seal the bag.
- Place one cup of vermiculite or other absorbent material in a second bag along with the first bag. Eliminate excess air and seal.
- Place the double-bagged cell in a third bag containing approximately one cup of lime or baking soda. Seal the bag.
- Absorb and/or neutralize spilled electrolyte with an absorbent material or baking soda.
- Sweep contaminated baking soda or absorbent material into a sealable plastic bag for disposal.
- Clean the area with copious amounts of water or an ammonia-based cleaner.
- Dispose of the vented cell and contaminated absorbent material in accordance with local, state and federal hazardous waste disposal regulations.

4.2.3 First Aid Procedures in Case of Contact with Electrolyte

EYES -- Immediately flush eyes with a direct stream of water for at least 15 minutes while forcibly holding eyelids apart 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. If breathing is difficult have trained person administer oxygen. If respiration stops, give mouth-to-mouth resuscitation. GET MEDICAL ATTENTION IMMEDIATELY.

4.3 **PROCEDURE FOR CELLS THAT HAVE EXPLODED**

Electrochem cells have the highest energy density of any commercial lithium battery on the market. It is the combination of high voltage and capacity, coupled with light weight, that makes our cells attractive for many specialty applications. However, when a large amount of energy is contained in a small package, the results can be energetic if the system is abused.

It is unlikely that any lithium battery would involuntarily explode. These events are rare and are usually the result of an abusive condition that raises the cell's temperature above its critical point. However, in the event of a lithium battery explosion, a room could fill quickly with dense white smoke which could cause severe irritation to the respiratory tract, eyes and skin. All precautions must be taken to limit exposure to these fumes.

4.3.1 **Minimum Equipment Required**

- A Class D fire extinguisher
- ABC Class fire extinguisher (for possible secondary fires)
- Respirator suitable for organic vapors, chlorine, HCl and SO₂ or air pack
- Eye protection or face shield
- Rubber gloves, lab coat or chemically resistant apron
- Bicarbonate of soda or calcium oxide (lime) -or- acid spill clean up kit (J.T. Baker Co.)
- Vermiculite, 3M Power Sorb (universal absorbent material), Speedy-Dry (clay absorbent)
- Individual thick plastic bags with sealing mechanism, glass jars.

4.3.2 **Procedure**

Should a cell explode the following actions should be taken:

- Evacuate personnel from all areas which are affected by the smoke.
- Ventilation should be initiated and continued until after the cell is removed from the area and the pungent odor is no longer detectable.
- Although this scenario is unlikely, should there be a fire resulting from an explosion, methods for dealing with this contingency are addressed in Section 4.4.
- The exploded cell may be hot. It must be allowed to cool to ambient temperature before handling. (See hot cell procedures)
- Put on a lab coat, rubber gloves, safety glasses and respirator.
- If a cell explodes the surrounding area may be covered with black carbonaceous material along with metal parts from the cell. Cover the black carbonaceous material with a 50/50 mixture of baking soda (or lime) with vermiculite or other universal absorbent material.
- Sweep the contaminated baking soda/vermiculite mixture into a sealable plastic bag. Gather in such a way as to avoid excessive dust. Metal parts can also be included in this container. Note: Metal fragments should never be packaged with live cells. This could cause the cell to become shorted.
- Seal the plastic bags in a glass jar and dispose of contents in accordance with local, state and federal hazardous waste disposal regulations.
- Clean the area with copious amounts of a baking soda/water solution, or an ammonia-based cleaner. Follow with soapy water.

4.3.3 First Aid Procedures in Case of Contact with electrolyte

EYES -- Immediately flush eyes with a direct stream of water for at least 15 minutes while forcibly holding eyelids apart 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. If breathing is difficult, have trained person administer oxygen. If respiration stops, give mouth-to-mouth resuscitation. GET MEDICAL ATTENTION IMMEDIATELY.

4.4 FIRES INVOLVING LITHIUM BATTERIES

All metals will burn under proper conditions depending on such factors as physical form, oxidizing atmosphere, and severity of the ignition source. Alkali metals such as lithium will burn in a normal atmosphere. It should also be noted that lithium reacts explosively with water to form hydrogen. The presence of minute amounts of water may ignite the material and the hydrogen gas.

Once ignited, a metal fire is difficult to extinguish with ordinary means. This is due to the intense heat produced by the burning metal, the temperature of which may reach as high as 3000°F.

Specially formulated extinguishing agents are required to control or put out a lithium fire. In particular, a graphite based extinguisher (Lith-x) should be used. These agents function generally by forming a layer or crust of material over the burning metal, thereby excluding air that is required to sustain combustion. Lith-x, which is a popularly used graphite based agent, may be applied from an extinguisher or by shoveling the loose powder onto the fire.

In the event of a lithium fire, a room could become filled with dense white smoke, mostly comprised of lithium oxide and/or other metal oxides. This condition could cause severe irritation to the respiratory tract, eyes and skin. All precautions must be taken to limit exposure to these fumes.

It should also be noted that the following procedures are only applicable to fires involving a single cell. Larger fires involving multiple cells should be handled by professionally trained people.

In addition, it is Electrochem's practice to use an extinguishing agent best suited to quench the bulk of the fuel available. For example, if a single cell were to start burning during a destructive analysis a lith-x extinguisher

would 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. A BC type or CO₂ extinguisher could be used on solvent/electrical fires or a general purpose ABC type could be used on all combustible materials. It is important to address each type of fire with the appropriate extinguisher.

DO NOT USE ABC OR CO₂ TYPE EXTINGUISHERS ON LITHIUM METAL FIRES.

4.4.1 Minimum Equipment Required

- A Class D fire extinguisher (Lith-x)
- An ABC class fire extinguisher (for possible secondary fires)
- Self-contained breathing apparatus
- Full fire-fighting protective clothing
- Heat resistant gloves
- Goggles or safety glasses
- Non-conductive extended pliers
- Shovel, mineral oil

4.4.2 Procedure

4.4.2.1 Initial Response

- In order to respond adequately to any emergency situation a primary response team should be established. After training in safety and handling procedures, along with first aid and fire fighting methods, the primary response team will be able to respond to situations involving lithium batteries.
- When a fire is detected the first action is to completely evacuate all personnel from the area and sound the fire alarm immediately.
- The primary response team is paged to the area where the fire is located. The team is informed of any pertinent information regarding the situation by the person who reported the fire.
- Quarantine the area. Ventilation should be initiated and continued until the burning material is removed from the area and the pungent odor is no longer detectable.

- Two members of the team will then enter the area with the appropriate fire-fighting and safety equipment.

NOTE: Lithium melts at 180°C. It becomes highly reactive and when ignited, lithium fires can throw off molten lithium metal particles. Furthermore, cells adjacent to any burning material could overheat causing a violent explosion. Fire-fighting teams must be made aware of any hazardous materials in the vicinity of the fire.

- Completely bury the burning material with Lith-x to extinguish the fire. Never leave the fire unattended because it may reignite.
- If necessary, attend to any secondary fires with the appropriate extinguishing agent.
- After all material has apparently burned and cooled, carefully turn over the remaining residue and be prepared to extinguish, should re-ignition occur.
- Carefully place the residue in a steel drum using a long-handled shovel, and cover with excess Lith-x. The residue may contain unreacted lithium, therefore limit exposure to moisture. This can be accomplished by covering the residue with mineral oil.

4.4.2.2 **Clean-up**

- A lab coat, rubber gloves, safety glasses or goggles and respirator should be worn during cleanup.
- The surrounding area may be covered with black carbonaceous material along with metal parts from the cell. Cover the black carbonaceous material with a 50/50 mixture of baking soda (or lime) with vermiculite. A wet sweeping compound may also be used to avoid dust. Nonetheless, gather the material in such a way as to avoid excessive dust.
- Sweep the contaminated baking soda/vermiculite mixture into a sealable plastic bag. Metal parts can also be included in this container.
- Seal the plastic bags in a glass jar or other suitable container.
- Clean the area with copious amounts of a baking soda/water solution, or an ammonia-based cleaner. Follow with soapy water.

- Dispose of all materials in accordance with local, state and federal hazardous waste disposal regulations.

4.4.2.3 **First Aid Procedures in Case of Contact with Electrolyte and Molten Lithium Metal:**

EYES -- Immediately flush eyes with a direct stream of water for at least 15 minutes while forcibly holding eyelids apart 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. IF MOLTEN LITHIUM METAL IS EMBEDDED IN THE SKIN AND CANNOT BE REMOVED, COVER WITH MINERAL OIL AND GET MEDICAL ATTENTION IMMEDIATELY.

INHALATION -- Move to fresh air. If breathing is difficult have trained person administer oxygen. If respiration stops, give mouth-to-mouth resuscitation. GET MEDICAL ATTENTION IMMEDIATELY.