

**Shmuel De-Leon
Energy Ltd**



Energy Storage Seminar

Battery Safety

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Why are Lithium Batteries Dangerous?

- Higher energy density than non lithium batteries contributes to potential hazards if the energy is released at a fast, uncontrolled rate.
- Primary lithium batteries contain 400-600 Wh/Kg, Rechargeable 250-275 Wh/kg, compared to 1375 Wh/Kg in TNT.
- Lithium Thionyl Chloride D-size cell has 39Wh, Rechargeable 18650 cell has 13Wh compared to an I.D.F. M26 hand grenade with 206Wh (150g TNT).

5 X



=



15 X



iPhone 6 Catch Fire in Cyclist Pocket



“I saw smoke coming out of my back pocket... I was completely bewildered about what it was. All of a sudden I felt a surging pain in my top right leg. I heard a kind of a snap and I could feel the thing melting through my shorts”.



Implantable Lithium Battery Safety Event

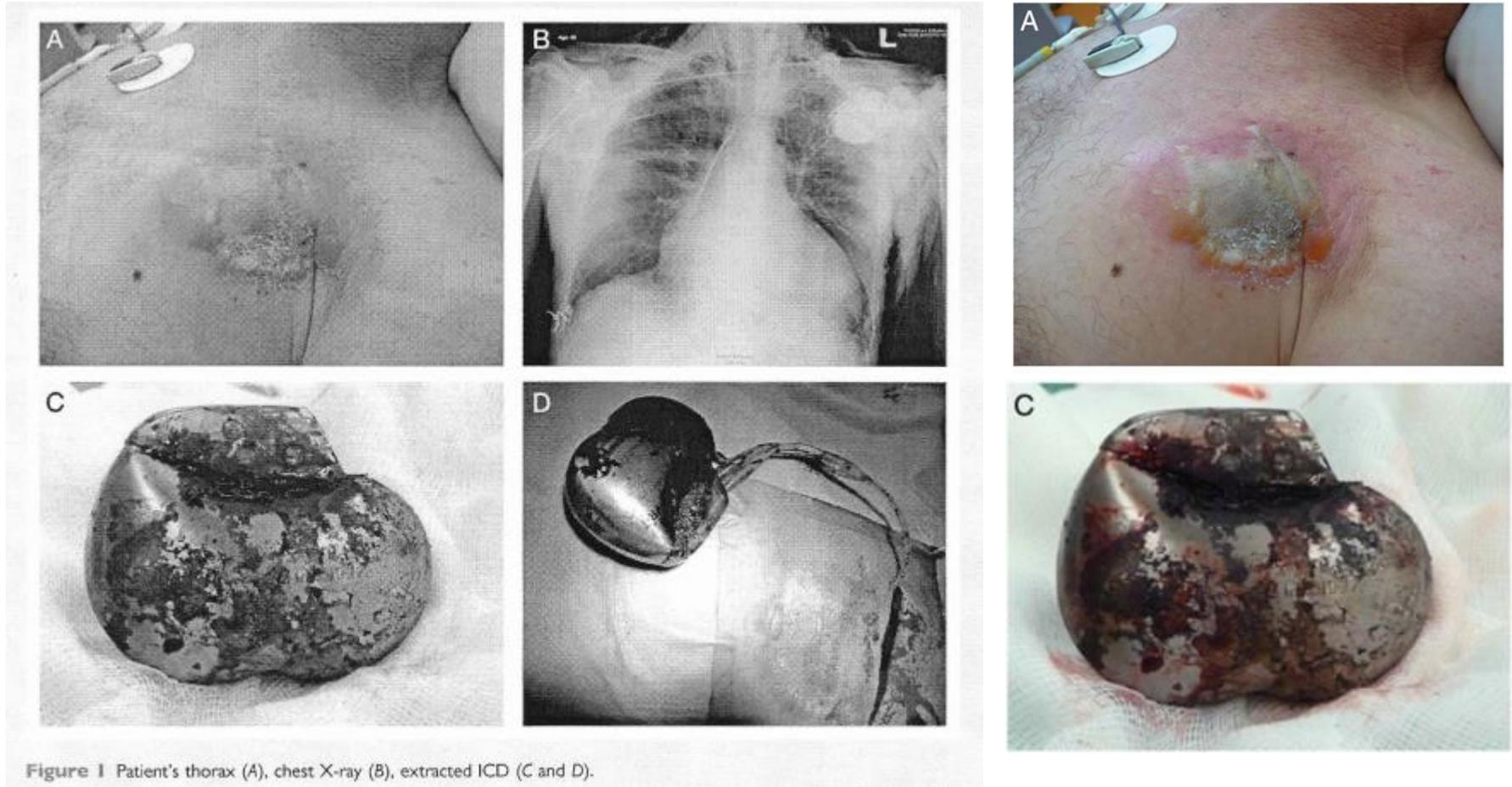


Figure 1 Patient's thorax (A), chest X-ray (B), extracted ICD (C and D).

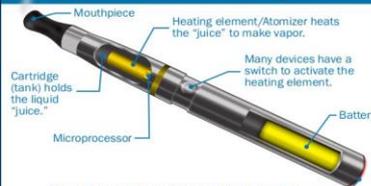
Spontaneous explosion of implantable cardioverter-defibrillator

Electronic Cigarette Battery Fire

- ❖ 2nd and 3rd degree burns to hands, face, thigh, and throat
- ❖ Hospitalized for 15 days
- ❖ Surgery and *Amputation* of right middle finger
- ❖ Phantom Pain in finger

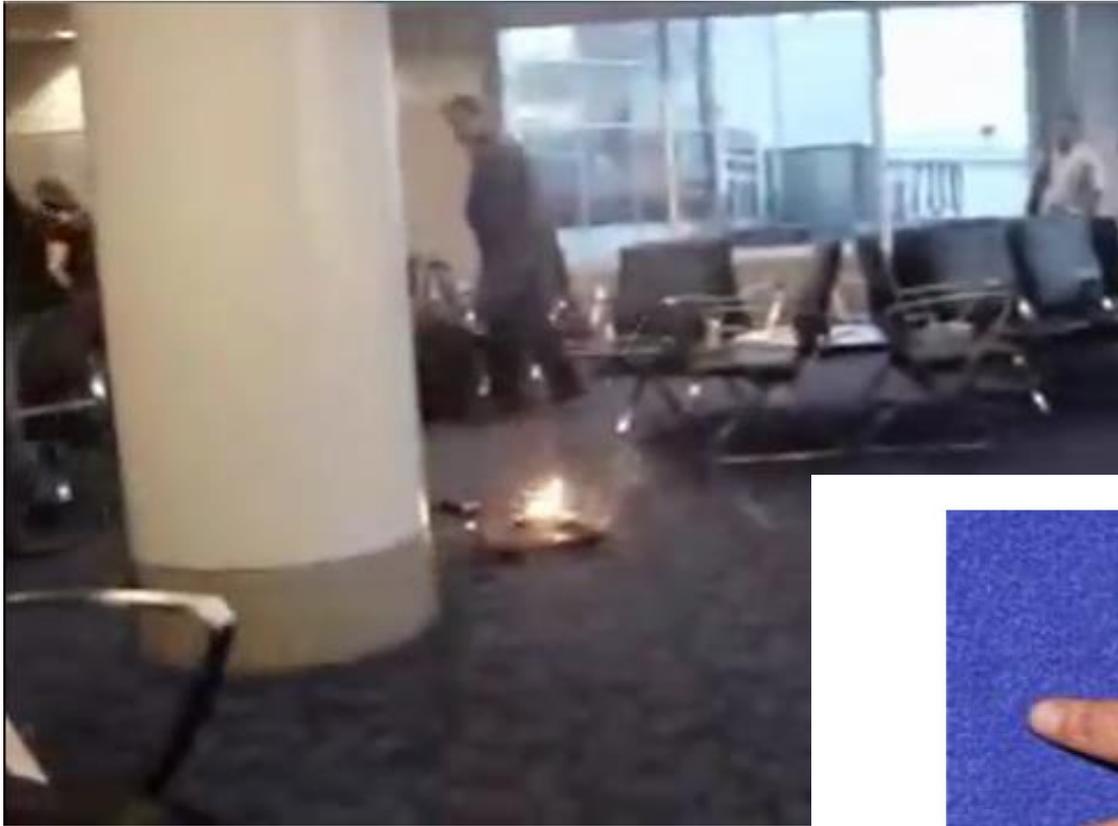


Parts of an Electronic Cigarette



Some devices have a light-emitting diode on the end to simulate the glow of a burning cigarette.

Laptop Battery Fire in an Airport Terminal



Injured hand of a 3 year child watching videos when a laptop battery explosion. The hand had healed approximately 6 months at the time of the photo.

Electric Vehicle Battery Fire



Fire of a Li-ion system in US (Flagstaff), November, 2012

1.5 MWh Li-ion storage caught fire. The fire, initially reported as transformer fire is finally identified as a fire in the storage system Li-ion. The fire crew waited until the site operator APS (Arizona Public Service Company) has cut off all power source to extinguish the fire with water within 30 minutes. The fire did not spread to the related site facilities.

Oh, here's a more recent fiery glimpse of your inevitable transition to wind and solar, this time from South Korea.



EU-VRI

Truck Fire with Used Lithium ion Batteries Novi, Michigan - September 2018



Transporting Lithium Batteries By Air

Stories from “The Front”

- Lithium Battery Thermal Runaways in Transportation are classified as Hazmat Incidents
 - The below incidents have occurred at various carriers or facilities after transport by air



Inflight – Passenger’s Baggage



Undeclared Shipment – After flying Hong Kong-Rome



Improperly declared Shipment – After flying Hong Kong- London



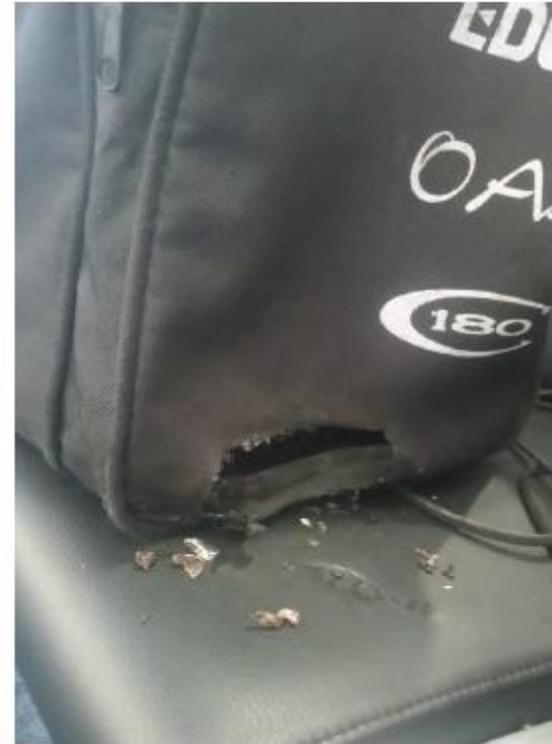
Transporting Lithium Batteries By Air

Stories from “The Front”

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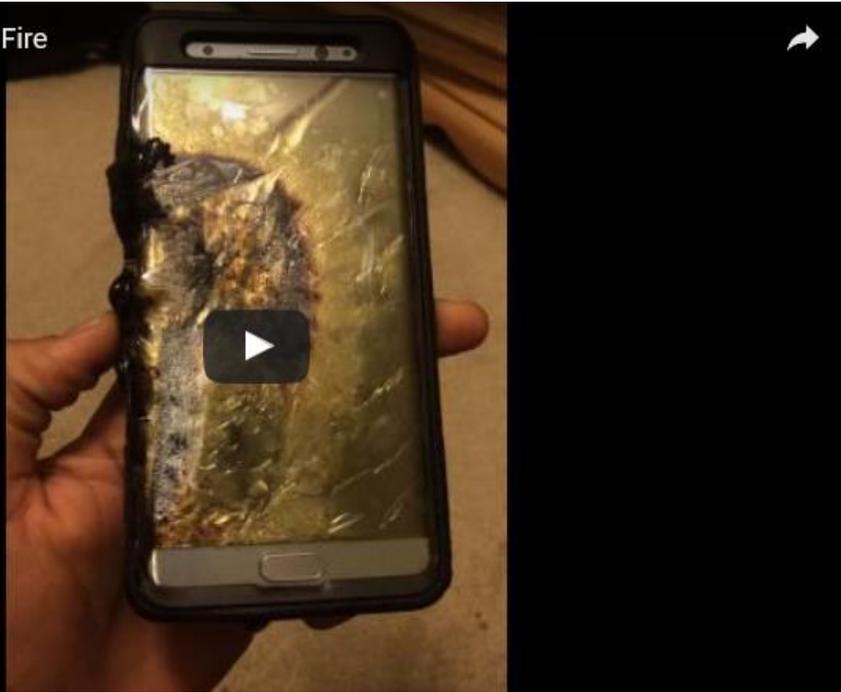


\$35 child's tablet in backpack after boarding flight



E-cigarette batteries in carry-on bag at gate prior to boarding flight

Samsung Note 7 Caught Fire



Samsung Galaxy Note 7

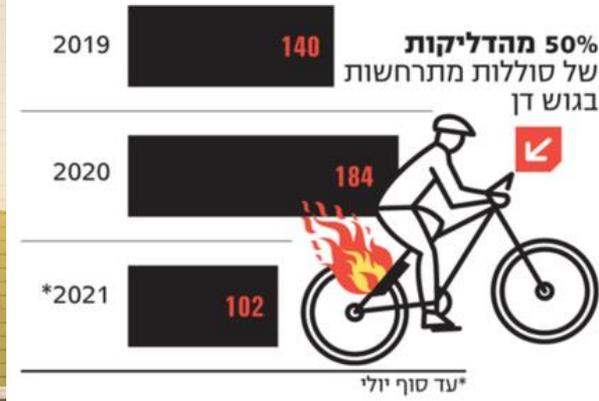


Hover boards

E-Bike Battery Fires



1. Fake batteries.
2. Battery and Charger don't fit.
3. Outdoor charging under rain.
4. Charging near combustible materials.



Battery Safety Failures Flow

Chart

External Short circuit
Internal Short circuit

- Particle
- Dendrites
- Separator failure
- Impact/puncture

Over Charge
Force Over-Discharge
External Heating
Mechanical Damage

Elevated Temperatures
Generate Heat

Heat Dissipation <
Heat Generation

Heat Dissipation >
Heat Generation

Thermal Run Away

Safe!!!

Fuse or PTC

Shut Down Separator

CID – Charge Interrupt
Device

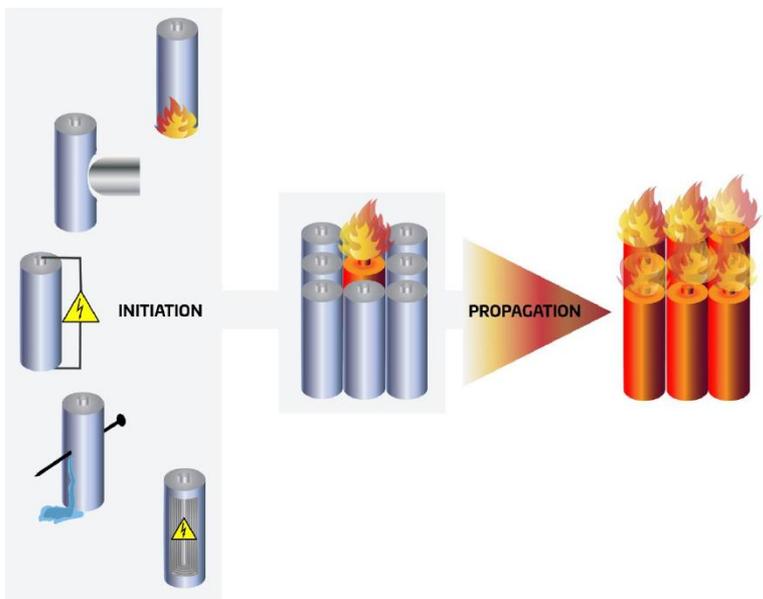
Vent, Flaming Vent

Rupture

Fire

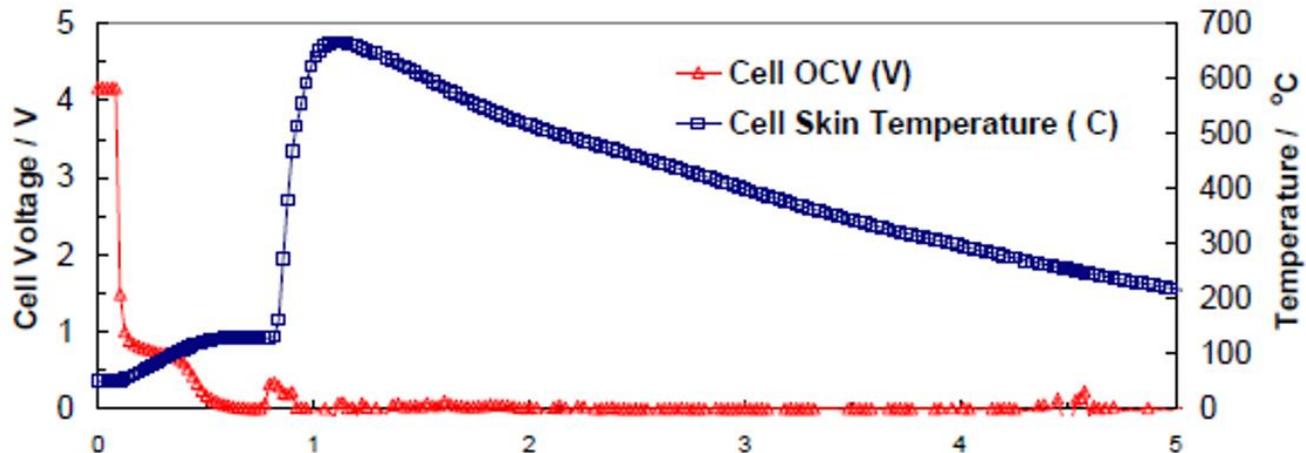
Explosion!!!

Leaking of
Noxious or acid
gasses, Strong
acids,
Flammable
gasses and
liquids



Thermal Run Away

Nail penetration with a heating blanket over 18650 cell



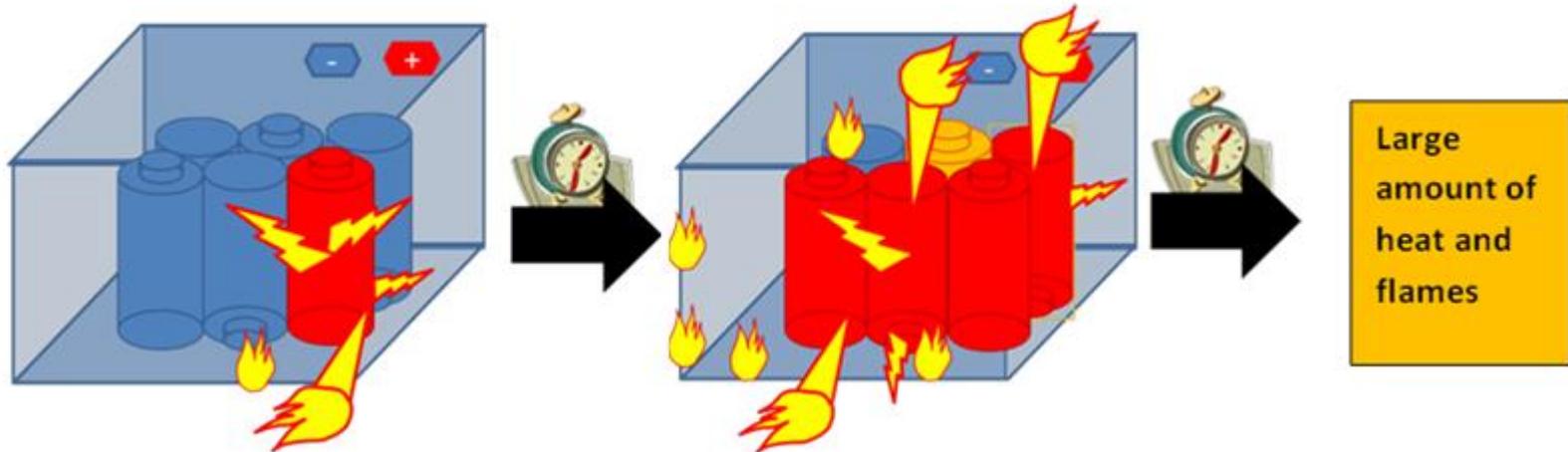
A condition whereby a battery on charge or discharge will overheat in an uncontrolled manner due to internal chemical reactions triggered upon reaching a threshold due to overcharge or over-discharge or other electrical or mechanical abuse

In case of thermal runaway the thermal energy released may be 7-11 times higher than the energy stored electrically

Worst case simulation of thermal run away is with nail penetration for a high energy cell (18650 >3Ah) – Temperatures reach 1200 Deg C due to copper melting

Chain reaction – Failure Propagation

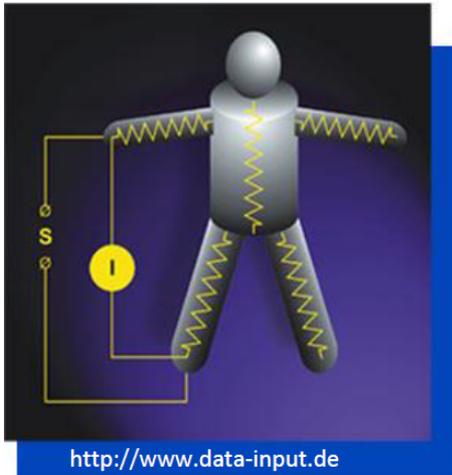
- Safety event like explosion or fire may generate high temperatures up to 600 C.
- Nearby cells in the battery may explode, vent and catch fires after because of the heat within short time.



Safety risk at battery level is much higher than to a one cell

High Voltage Hazards

Why is HV safety stressed so much?



A number of factors influence the human body resistance, but IEC has provided 1 k Ω as an average value.

12 mA @ 12 V

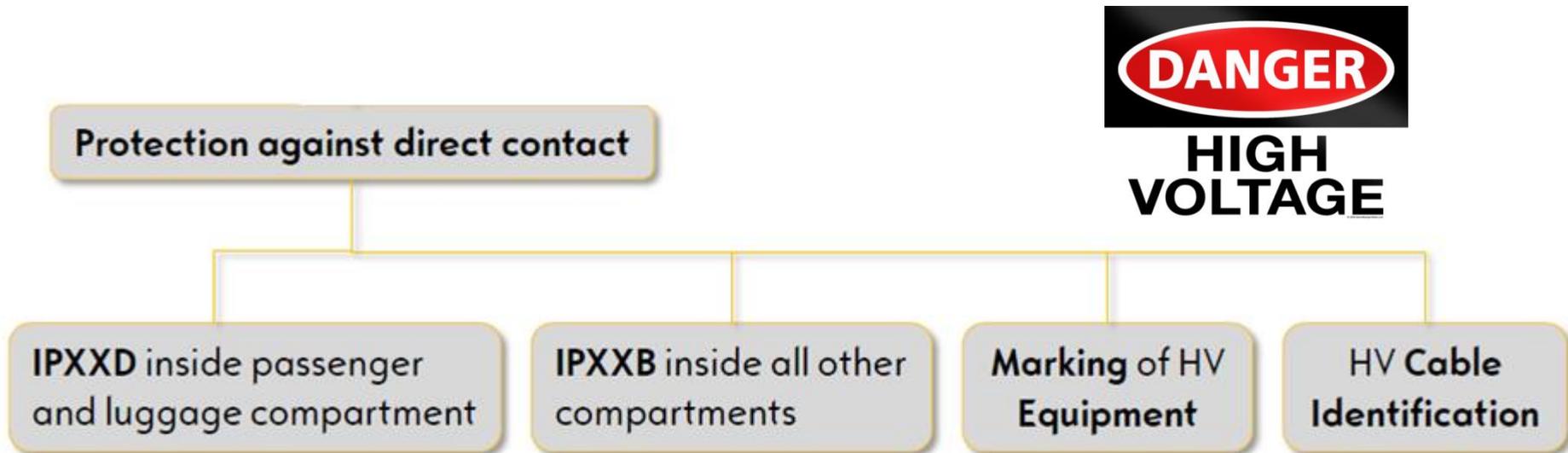
300 mA @ 300 V

Bodily Effect	dc Current [mA]
Feeling Sensation	1.0
Pain is Felt	62
“Let-Go” Threshold	76
Severe Pain; Breathing Difficulties	90
Heart Fibrillation Occurs	500

Note: @60 V, body currents are ~60 mA. Anything over 60 Vdc must be considered High Voltage.

Protection Against Direct Contact

- Live parts of the electric traction system should be protected against direct contact by persons in or outside the vehicle, through insulation or inaccessible position.
- Removal of protective devices and opening of doors, lids, and bonnets permitting access to live electrical equipment shall only be possible with tools or keys..



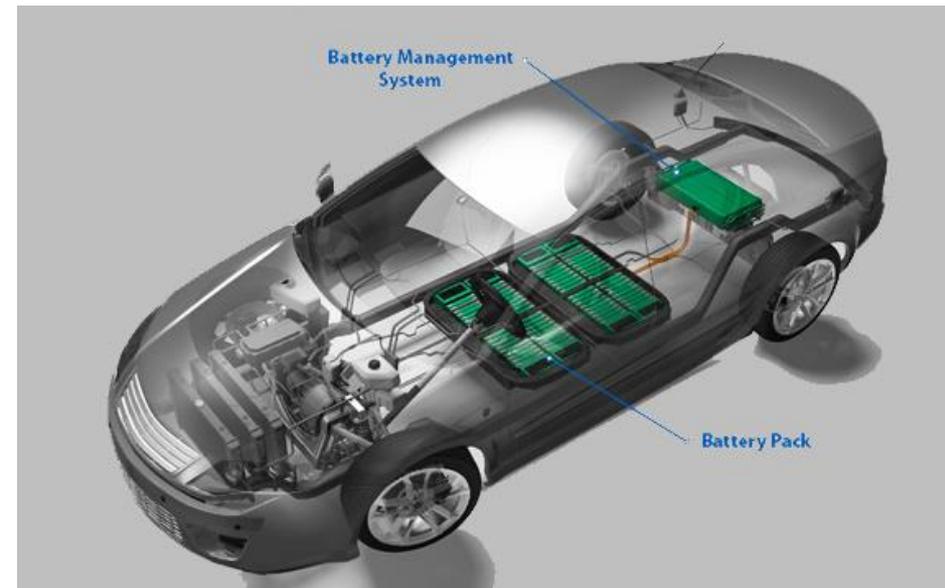
Protection Against Indirect Contact

- Any spurious connection between the traction circuit and the vehicle frame is regarded as a fault. Frame faults can lead to several hazards:
 - short circuits
 - electrocution
 - uncontrolled operation

Protection against indirect contact

Isolation Resistance

Potential Equalization



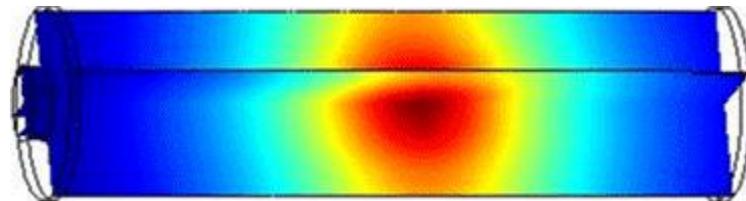
- **Following measures should be taken to avoid these hazards:**
 - **A fuse shall be built inside the battery pack, preferably in the electrical center of the battery**
 - **The vehicle frame shall be isolated from the traction circuit and shall not form any part of the power electrical circuit**
 - **All conductive parts of the vehicle, particularly accessible parts or parts adjacent to electrical equipment shall be connected with an equipotential connection**
 - **Frame fault leakage detection shall be included in routine maintenance; permanent frame fault monitoring is mandatory for certain vehicles**



Manufacturing (Field) Failures - Not Manageable - Need New Safety Technology

Field failures are not predictable.

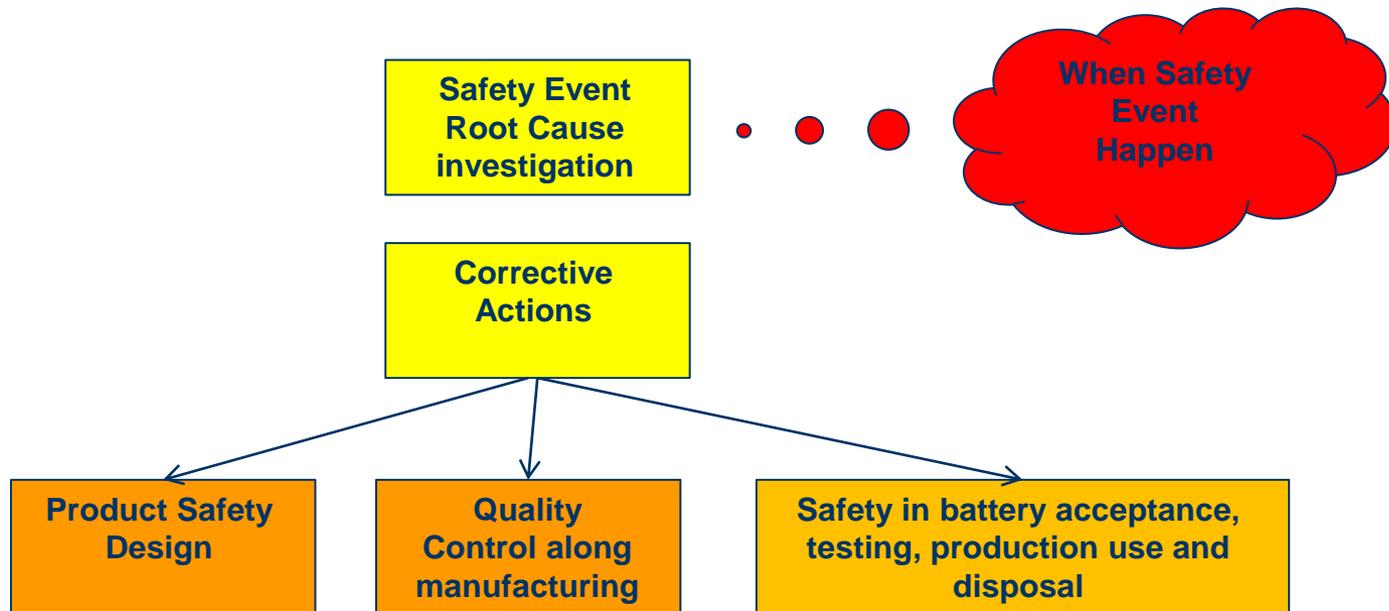
- Loose connection, separator damage, internal dendrites, internal spots that leads to an internal short circuit.
- The field failure risk is higher to aged and use cells and batteries.



Internal short circuit thermal
runaway

Investigation and Corrective Actions

- Enhanced safety is determined by implementation of several steps & methods that work synergistically to achieve a goal of:
 - Probability reduction of battery failure event.
 - Reduction of safety event results when it occurs.



Risks & Medical Damage

- **Risks**: Explosion, Leakage/Vent, Fire.
 - **Hazardous materials**: Noxious or acid gases, Strong acids, Flammable gasses and liquids.
 - **Medical risks to**: Eyes, skin, breathing, swallowing, bleeding - can lead to a death in extreme conditions.
 - **Who is at risk**: Storage, assembly, transportation, testing, disposal, waste handler personnel and users.
- * **Forced Over discharge** – Discharging a cell or battery below zero volts into voltage reversal.
- ****Over charge** – The forcing of current through a battery after all the active material has been converted to the charge state.



Safety Guidelines: Lithium Cell Acceptance Tests & Storage

1. Acceptance tests & Storage should be done by authorized employees (Get a safety training once a year).
2. Cover work or storage surfaces with an insulating material and make sure that they are clean from combustible materials and free of sharp objects.



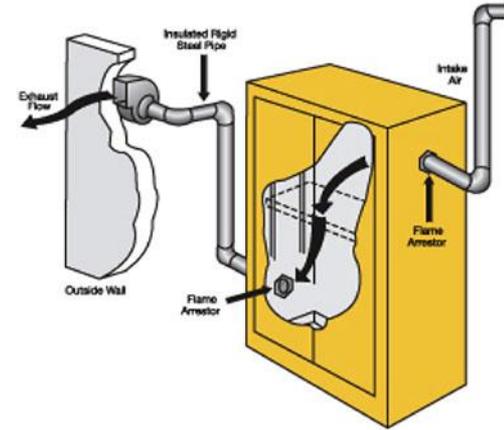
3. All personnel handling cells should remove jewelry items such as rings, wristwatches, pendants, etc., that could encounter the battery terminals.
4. All inspection tools should be made from, or covered with, a non-conductive material such as plastic or ceramic.
5. Cells should be inspected for physical damage (Corrosion, Blows, Leaks...). Cells with dented cases or terminal caps should be inspected for electrolyte leakage. If any is noted, they should be disposed of properly.



**Battery
corrosion**



6. Cells and battery testing should be done in a ventilated anti fire protective chamber or Cabinet – For large batteries, the cabinet should be filled with Argonne



Denios



7. All thermal chambers used for testing cells or batteries should be equipped with an over-temperature controller to protect against excessive heat.
8. If leads or solder tabs need to be shortened, only cut one lead at a time. Cutting both leads at the same time will short-circuit the cell.
9. Rechargeable cells forming should be done in a special room equipped with all safety equipment needed since it includes high mass of cells under tests.



Over
temperature
controller



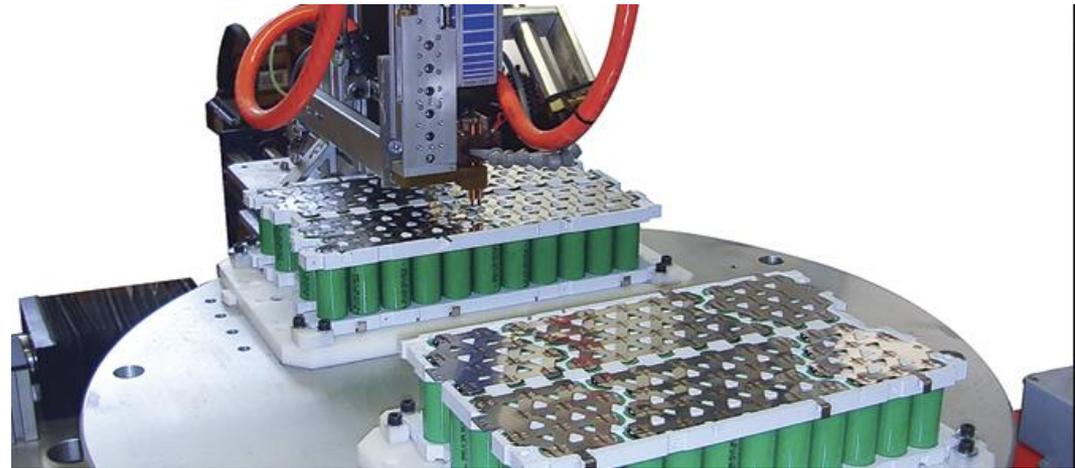
Battery
tester

10. **Ensure damaged or faulty batteries are removed immediately from storage and production areas (until they are disposed of store them at a safe distance or in a fire-rated, separate area).**
11. **Only store batteries with a UN 38.3 test certificate (prototypes should only be stored in exceptional circumstances and with a risk assessment).**

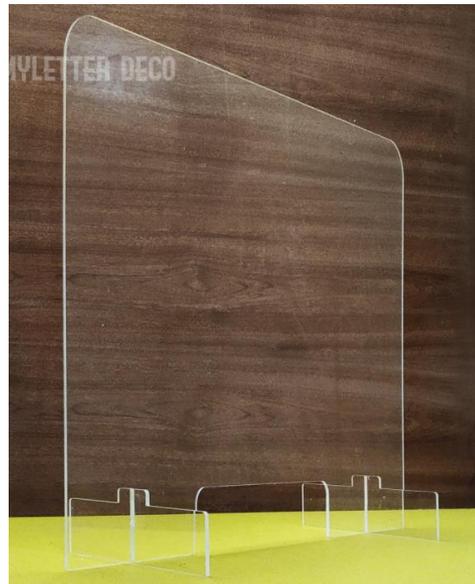


Safety Guidelines: Battery Pack Assembly & Testing

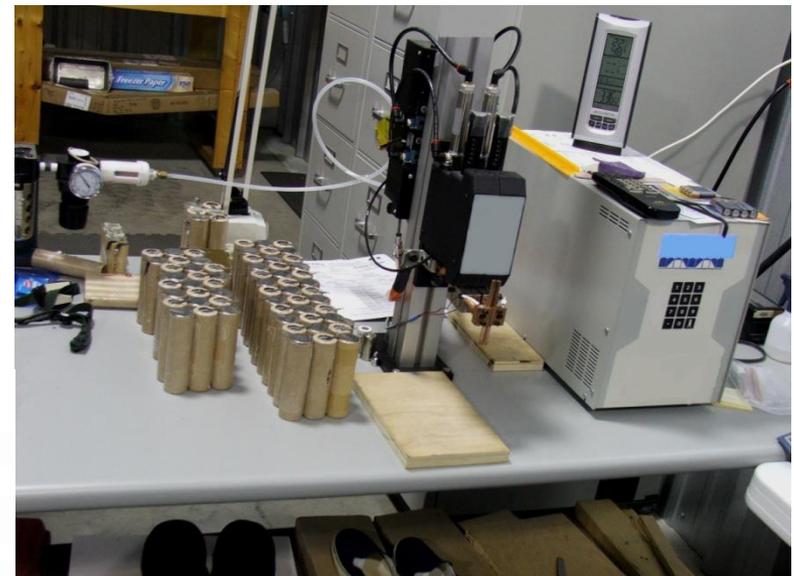
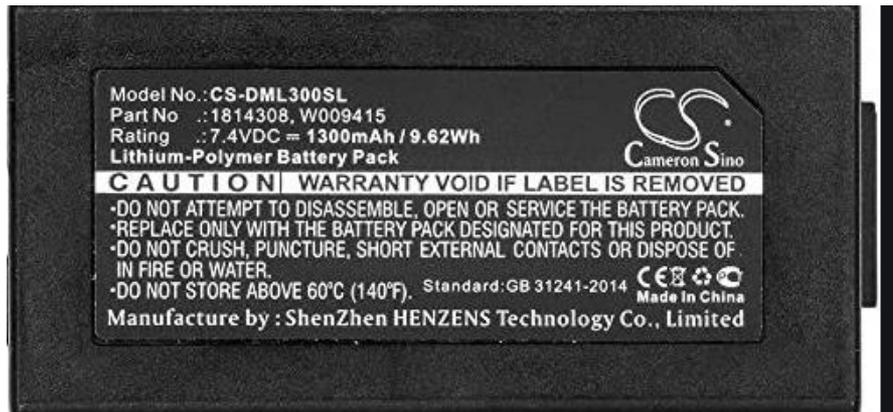
1. Battery pack assembly should be done by authorized employees in assembly area equipped with all needed safety equipment.
2. Do not assemble cells which fail acceptance tests.



3. **Safety glasses must be always worn when and work should be done behind L-Shape interference protection.**
4. **Do not solder wires or tabs directly to a cell/battery. Solder only the free end of solder tabs welded to the cell case.**
5. **Always assemble the same cell chemistry, types, State of charge, manufacturers and date codes in a battery pack.**
6. **When connecting cells in a battery, use protection circuitry according to the cell manufacturer instructions.**



7. Take care to connect the cells in the correct polarity.
8. All internal and external metal areas of a battery pack should be electrically insulated.
9. Blower temperature is limited to 150 °C. and shrinking time needs to be quick so the cells will not become too hot.
10. Solder Tabs that extend from the case and terminal cap should be insulated.
11. All packs should be labeled with the appropriate warnings, at least as those that appear on the cell.



Safety Guidelines: Lithium Battery Transportation

1. The battery shipper should be:
 - Authorized to transport lithium batteries (Get a yearly safety training).
 - Notified of the package content.
 - Trained on how to react in case of lithium battery safety problem, including first aid.
2. Cells and batteries should be packed in the inner packaging to effectively prevent internal movement which could lead to short circuits.



3. Take precautions to avoid dropping batteries during transport. When you need to transport a battery, protect the battery terminals and uninsulated connections from contact with other objects, use the original packaging or a suitable plastic container
4. The package should include relevant M.S.D.S. of the lithium battery content for the medical personnel in case of injury.
5. Have all needed safety equipment.
6. In any case of lithium battery safety problem, react according to the training instructions and immediately notify the safety personnel team.

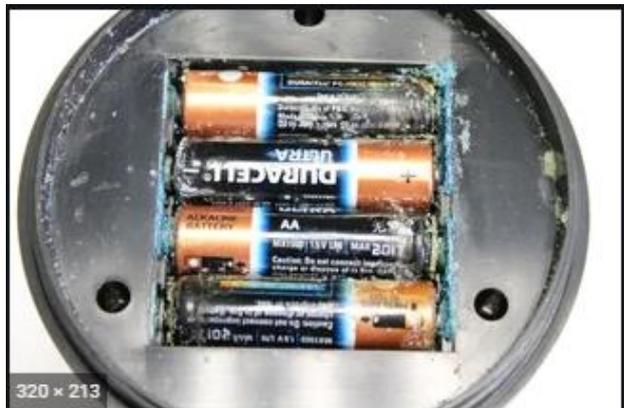


Lithium Battery Safety Guidelines: Usage

1. Do not connect cells of different chemistries, size, manufacturers, date codes, freshness or depletion in the same battery holder or device.
2. Do not short circuit a cell, battery or a charger.
3. Use cells and batteries only with the device and Charger they belong to.
4. Do not attempt to overheat or burn cells/batteries.
5. Do not expose cells/batteries to high level of impact.

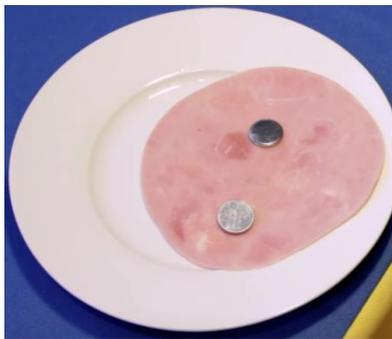


6. Do not attempt to over charge, force discharge, disassemble, crush, puncture, or incinerate a lithium cell/battery.
7. Do not use damaged/corroded cells/batteries.
8. Do not leave alkaline batteries for a long storage inside the device.
9. Turn off the device and immediately disconnect the cells/batteries if they unusual smell, become hot, change shape or there is a liquid leaking. Wait for them to cool, and do not reuse them.
10. Do not charge devices near combustible materials.



[Cell Phone Sets Girls Bed On Fire](#)

11. **Do not charge primary cells/batteries.**
12. **Don't charge non weather protected batteries outdoor under rain, snow or ice conditions.**
13. **Never leave a battery pack unobserved during charging. Always stay in or around the charging location so that you can periodically check for any signs of battery or charger distress (Alternative charge in anti fire cabinet).**
14. **Keep the cells/batteries dry – no contact with water or any liquid.**
15. **Do not put batteries in contact with conductive materials, strong oxidizers and strong acids.**
16. **Keep lithium cells/batteries far away from children.**



17. **Lithium-ion batteries assembled to offer higher voltages (over 60 V) may present electrical shock and arc hazards. Therefore, adherence to applicable electrical protection standards (terminal protection, shielding, PPE etc.) is required to avoid exposure to electrical hazards.**
18. **Do not submit to static electricity risks to avoid damages to the Protecting Circuit Board.**



Safety Guidelines for Lithium Battery Disposal

1. Sort and separate lithium & non-lithium batteries, as requested by disposal laws.
2. Insulate battery contacts - place them in a sealable plastic bag.

3. Put the plastic bags in the right battery disposal drum.

DEVICE BATTERIES



VEHICLE BATTERIES



INDUSTRIAL BATTERIES



Source: Pixabay

Separate sorting in Austria for different battery categories!



Watch for Lithium Ion or Lithium batteries that show signs of damage such as swelling, smoking, leaking or overheating.



Do NOT place damaged Lithium Ion or Lithium primary batteries in a collection box. Immediately put them in an absorbent, non-flammable material (sand or cat litter) in a cool, dry area.

- 4. Dispose of all batteries in accordance with local, state, and federal hazardous waste disposal regulations.**
- 5. Disposal personnel should have a contact phone number to call in case of safety event during transportation/disposal.**

Procedures for Handling a Hot, Leaking, Vented, Exploded Cell/Battery Pack

- 1. As soon as safety event occurs, the first action is to completely evacuate all personnel from the area.**
- 2. Injures should be provided with a first aid and then to treatment on the nearest Hospital.**
- 3. The area should remain evacuated until the cell/Battery pack has cooled to room temperature and has been removed from the area (at least 2 hours from event time).**
- 4. Ventilation should be initiated and continued until after the cell/battery pack is removed from the area and the pungent odor is no longer detectable.**



5. **Remove the cell/battery pack from the work area once it has cooled and return to a normal operation.**
6. **Dispose of the cell/battery pack.**
7. **Put on lab coat, rubber gloves, high-impact safety glasses, and respirator before handling the cell.**
8. **Place each remains materials in a separate, sealable plastic bag and seal the bag.**
9. **Place one cup of vermiculite or other absorbent material in a second bag along with the first bag and seal the bag.**

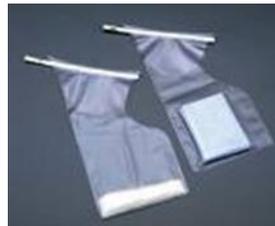


8. **Place the double-bagged cell in a third bag containing approximately one cup of lime or baking soda. Seal the bag and dispose of it.**

11. **Absorb and/or neutralize spilled electrolyte with an absorbent material or baking soda.**

12. **Sweep contaminated baking soda or absorbent material into sealable plastic bag for disposal.**

13. **Clean the area with copious amounts of water mixed with baking soda.**



Lithium Battery Fires

- 1. In the event of a lithium fire, the room could become filled with dense white smoke that could cause severe irritation to the respiratory tract, eyes, & skin.**
- 2. Lithium metal melts at 180°C and then it becomes highly reactive. When ignited, lithium fires can throw off molten lithium metal particles.**
- 3. Furthermore, cells adjacent to any burning material could overheat causing an explosion + chain reaction that cause other cell to explode.**



4. **Fire-fighting team must be made aware of any hazardous material in the vicinity of the fire.**
5. **Completely bury the burning material Class D extinguisher for Lithium Primary batteries and with Class ABC for all other batteries. Sand can also work and only with Li-Ion rechargeable batteries you can use water to cool down the fire.**
6. **After all material has burned and cooled, carefully turn over the remaining residue and be prepared to extinguish, should re-ignition occur.**



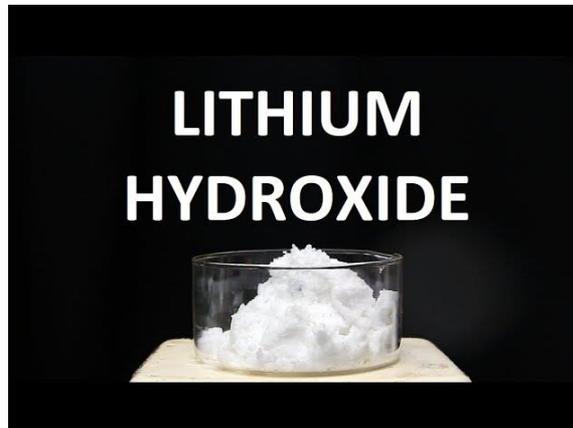
Lithium Primary Battery Fire and Water

- 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.
- 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 Class D with copper powder extinguisher should be used to quench the fire.



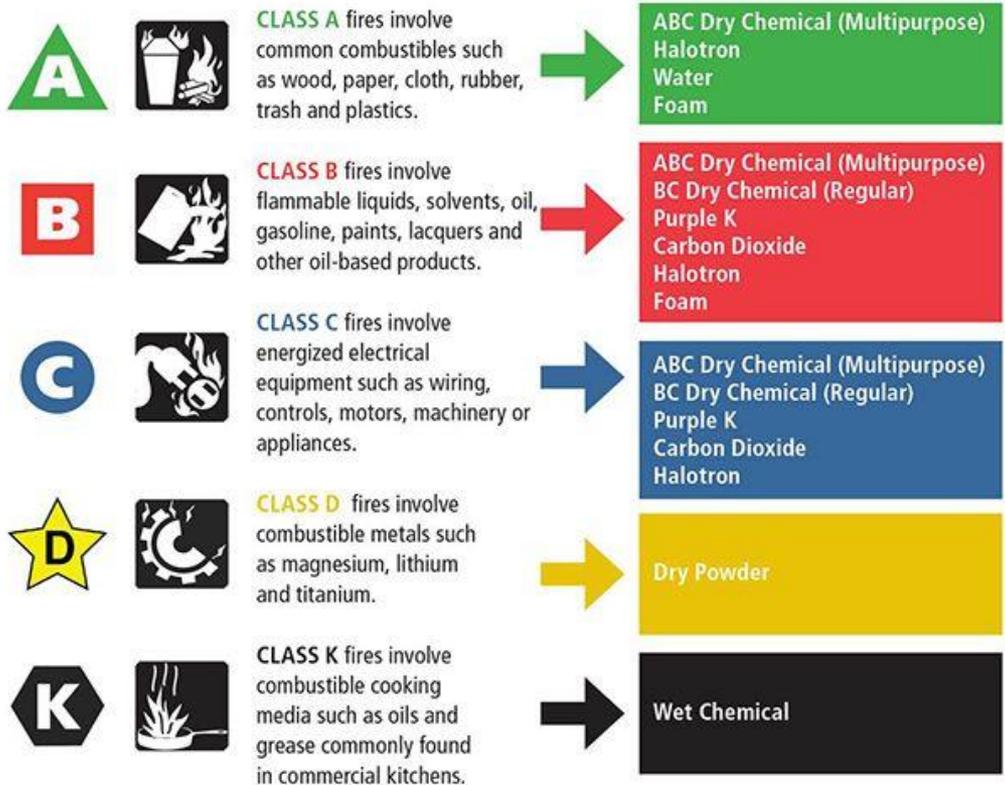
Li-Ion Rechargeable Battery Fire

- 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 (e.g., ABC extinguisher) can be used effectively on a fire involving lithium-ion batteries



Lithium Battery Extinguisher Selection Table

FIRE EXTINGUISHER SYMBOLS, CLASSIFICATIONS & AGENTS



Battery Type	Fire Involved Batteries
Lithium (primary, non-rechargeable)	Use Class D extinguishing agent with copper powder DO NOT use water
Lithium-Ion (secondary, rechargeable)	Use an ABC dry chemical fire extinguisher or water hose Fight the fire based on fueling material



First Aid: Contact With Electrolyte & Molten Lithium Metal - Eyes

- Immediately flush the eyes with a direct stream of water for at least 15 minutes while forcibly holding the eyelids open to ensure complete irrigation of all eye and lid tissue.
- Get medical attention immediately.



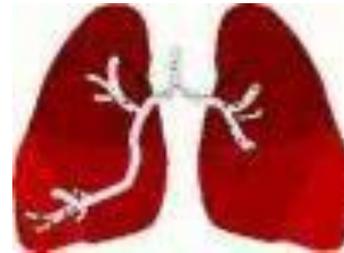
First Aid: Contact With Electrolyte & Molten Lithium Metal - Skin

- Flush with cool water or shower immediately.
- Remove contaminated clothing.
- 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.



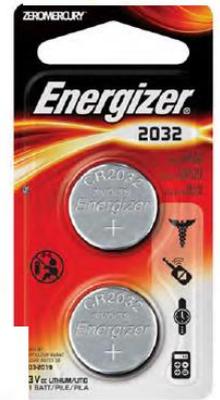
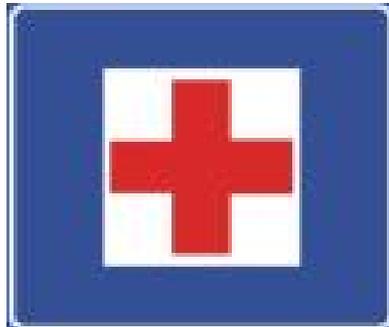
First Aid: Contact with Toxic Gases - Inhalation

- **Seek fresh air immediately.**
- **If breathing is difficult, have a trained person administer oxygen.**
- **If respiration stops, give mouth-to-mouth resuscitation.**
- **Get medical attention immediately.**



First Aid: Ingestion

- Symptoms: Cold or Flu, Difficulties to swallow food.
- Wash out the mouth thoroughly with water and give plenty of water to drink.
- Obtain medical attention immediately.



All cases should be seen by a doctor

Personal Battery Safety Equipment

1. Gas mask Chlorine, HCl, SO₂. filters
2. Full fire-fighting protective clothing.
3. Safety glasses + Protecting L-Shape interference plastic.



4. A Class D fire extinguisher for Lithium metal batteries.

- includes Sodium Chloride dry powder +
- Copper Extinguishing Agent



5. Class A+B+C extinguishers + anti-fire blanket for Li-Ion batteries.



6. Neoprene rubber, Heat resistance, High voltage rubber gloves.
7. Sealable disposable plastic bag with a zipper.
8. Plastic drum with a cover for battery disposal.



9. Baking soda or acid spill clean-up kit.



10. Eye flusher with heater + bottle eye wash.

11. Emergency Shower with heater.



12. **Self-contained oxygen breathing apparatus.**

13. **Bucket with sand.**



14. **First aid cabinet**



***** Check periodically that all the equipment is operating normally**

Can a Fire Happen in a Battery Warehouse Where Batteries are Stored Passively?

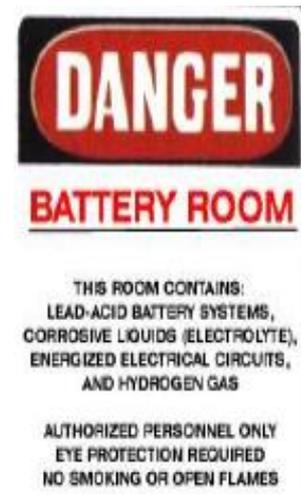
1. We know 2 events when a fire happened in a battery warehouse during night where the batteries stored passively.
2. During periodic Open Circuited Voltage tests for the cells and batteries stored in the warehouse we found cells and batteries with 0 Volt – The cells pass acceptance tests before storage.
3. **Conclusion** – Fire can happen because of late manufacturing defects short circuits.



Safety Equipment: Battery Warehouse



1. Outdoor warehouse or container used only for batteries.
2. Fire-proof building/container far away from combustible materials, including windows or door for ventilation.
3. Clear Warning labels and signs – entrance only for authorized personnel.



- 4. Fire-proof door including a window in the center and internal panic handle.**



- 5. Monitoring warehouse area with a fire alarm system connected to permanently manned location.**
- 6. Separate area for Lithium Primary Batteries and all other batteries since we use different suppression materials on each part.**
- 7. Water sprinklers or A+B+C Dry powder automatic anti-fire system for Li-Ion batteries - (Class D – Lith-X for places where primary lithium batteries are stored).**

8. Separate air conditioning system.



9. Explosion-proof lighting.



10. Hydrogen Gas Monitor (For Lead Acid battery storage).

11. Label warehouse door with contact list of employees to call in case of emergency + safety instructions + M.S.D.S.



12. Hazardous Materials Safety cabinets where outdoor storage is not possible.

13. Emergency Power shut down contactor located external to warehouse entrance next to door.



****All lithium battery safety equipment from the Personal equipment list.**

Equipment for Working With High Voltage

The following Personal Protection Equipment (PPE) should be available when around a high-voltage system:

- High-Voltage Insulated Glasses
- High-Voltage Outer Gloves
- Insulating Covers
- Insulating Bags
- Face shields
- Insulating Bags
- High-Voltage Rescue Hook (Safety Pole)

Personal Protection Equipment



Insulating Gloves

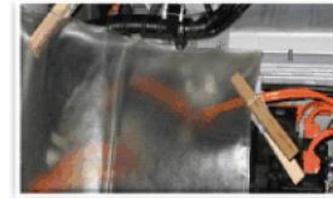


Outer Gloves (leather)



Face shield

Safety pole for electrical emergencies



Insulating covers



Insulating bags



Insulated tools

