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# Risk Control Services: Occupancy

## Lithium-Ion Batteries Manufacturing

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The Art & Science of Risk



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Standard recommendations based on recognized international standards and good practices are proposed. Moreover, very good NFPA (National Fire Protection Association) and FM Global Property Loss Prevention Data Sheets on these subjects exist. Since there is no need to reinvent the wheel, readers are referred to those references when relevant.

- NFPA free viewing at <http://www.nfpa.org/>
- FM Global Data Sheets free viewing and download available when registered at <http://www.fmglobal.com/>

Note that these materials are periodically revised and updated. Please monitor the above websites for updates and/or revisions.

### Acknowledgments:

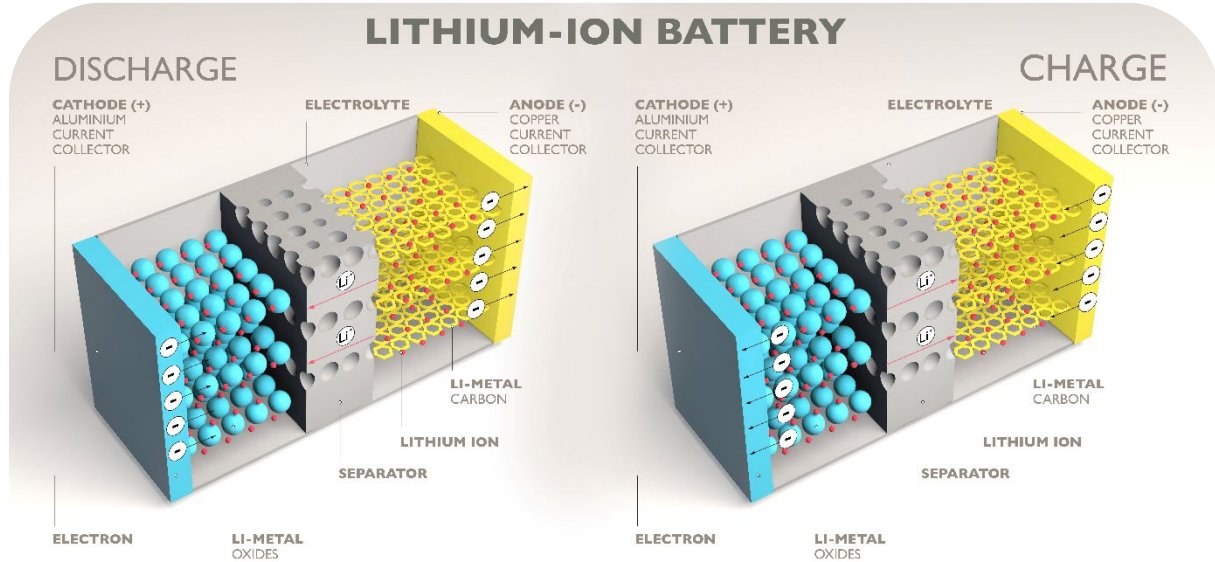
- Franck Orset (FPO) Loss Prevention Engineer

### Technical Documents:

- NFPA 13 Standard for the Installation of Sprinkler Systems
- FM Global Data Sheet 8-1 Commodity Classification (2.4.2 Lithium-Ion (Li-Ion) batteries)
- FM Global Data Sheet 8-9 Storage of Class 1, 2, 3, 4 and Plastic commodities
- SCOR Handbook “Stationary Batteries Energy Storage Systems” (ESS/BESS)
- SCOR handbook “Renewable Energy”

## SCOPE

Demand for lithium-ion batteries (Li-Ion batteries or commonly referred as LIBs) is growing. These batteries are used in electric vehicles (EVs), mobility applications (e.g., e-bikes, scooters), energy storage (ESS/BESS) for renewable energy and for other applications (e.g., drills, hammers, lighting).



As a result, more and more LIB manufacturing facilities are being built around the world. There is currently no dedicated standard for LIB manufacturing. As a result, using both the NFPA standard and the FM Global Datasheet for fire protection is an adequate approach. This can be done in a more or less conservative way.

Please find below some guidance for Risk Engineer and Underwriters

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## 1. Foreword

- Facilities under construction can be included as an extension of existing operational plant in the property policy (same Contract ID).
- For both construction and operation risks, loss scenarios related to the three classes—endogenous-inherent, exogenous-surrounding exposure and natural—apply.
- CAR/EAR loss scenarios for some industrial risks under construction are similar to loss scenarios for operating risks considering that the worst case occurs on the last day of construction and or during cold/hot testing. In such cases, the special hazards involved are the same during the construction or operation phase.
- Moreover, for risks under construction, other scenarios resulting from faulty design, faulty material and faulty workmanship should also be considered.

## 2. Building construction materials

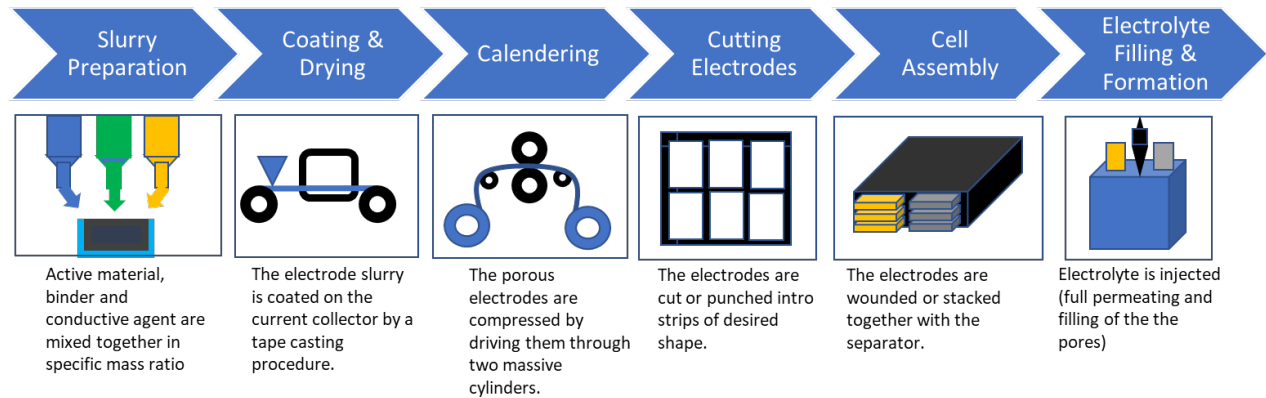
- Only non-combustible building materials should be used.



Caution: photovoltaic panels (PVs) may be installed on the roof of manufacturing buildings, and constitute an aggravating factor. This should not be permitted on a combustible roof. If PVs are installed, please refer to the SCOR handbook “Renewable Energy” (page 38 “SCOR Risk Control Standpoint for Surface-Mounted PV”) for guidance.

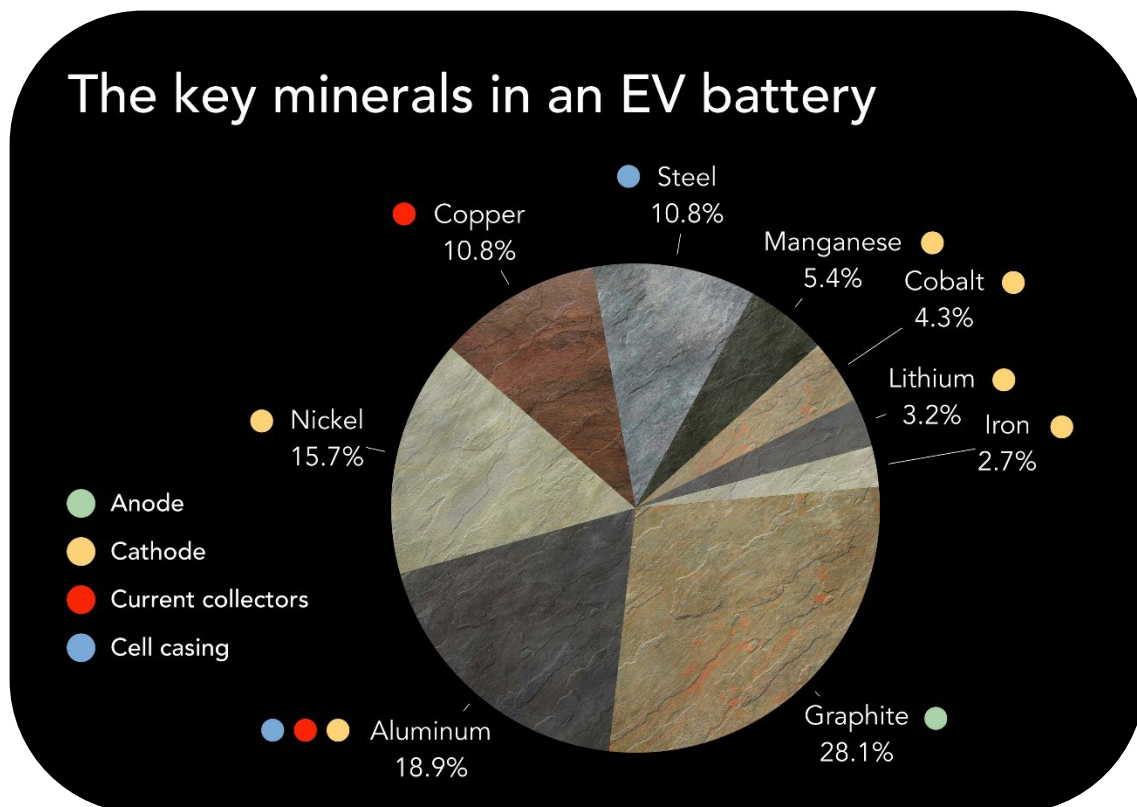
## 3. Process summary

- A LIB manufacturing facility is usually described as “Manufacturing plant for electrodes, cells and battery modules for passenger cars and light electric utility vehicles, for electric trucks and, possibly, for stationary electric storage”.
- Plant areas usually include A. Electrode manufacturing, B: Cell assembly, C: Aging, D: Module assembly, E: Warehousing, F: Offices and Utilities.
- The process flow chart usually includes the following steps as summarized in the following simplified block diagram:



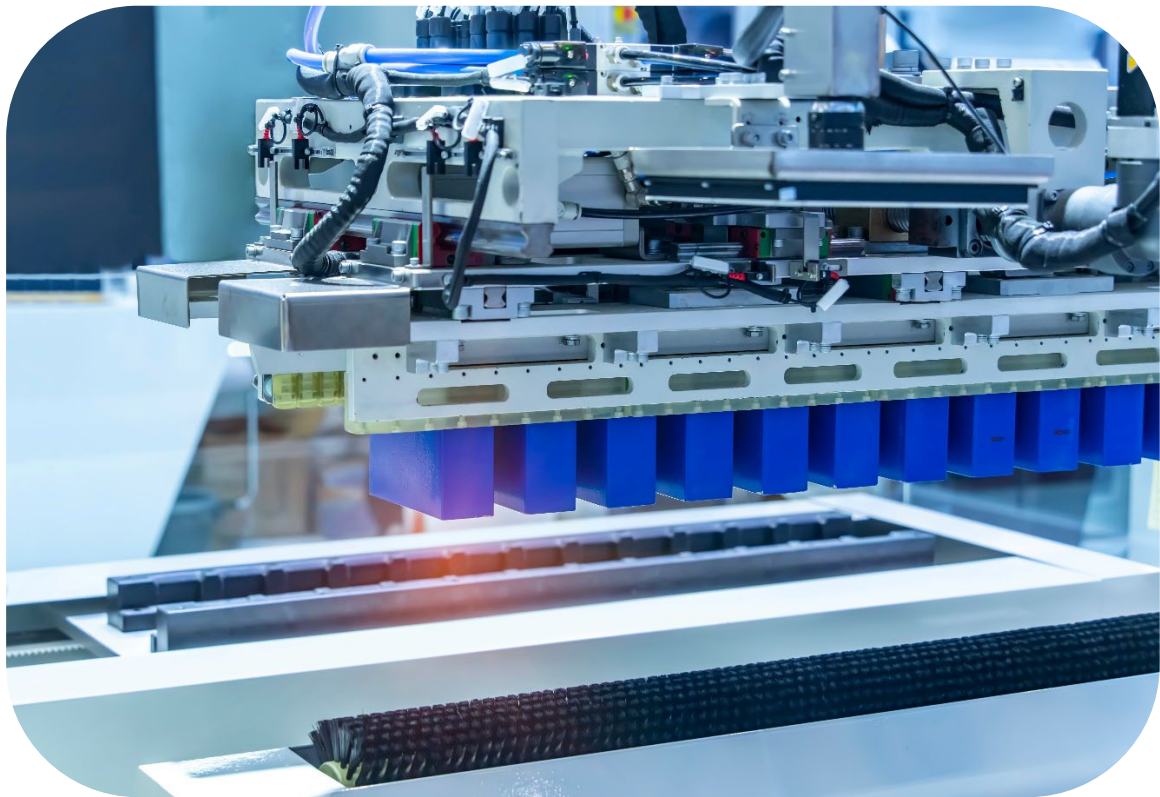
Details about the main steps of the manufacturing process:

- Slurry preparation is commonly referred as “Mixing”. The products necessary for the preparation of so-called “inks” (powders of active materials, adhesives and conductive elements) are introduced into specific mixers for “positive ink” or “negative ink”.



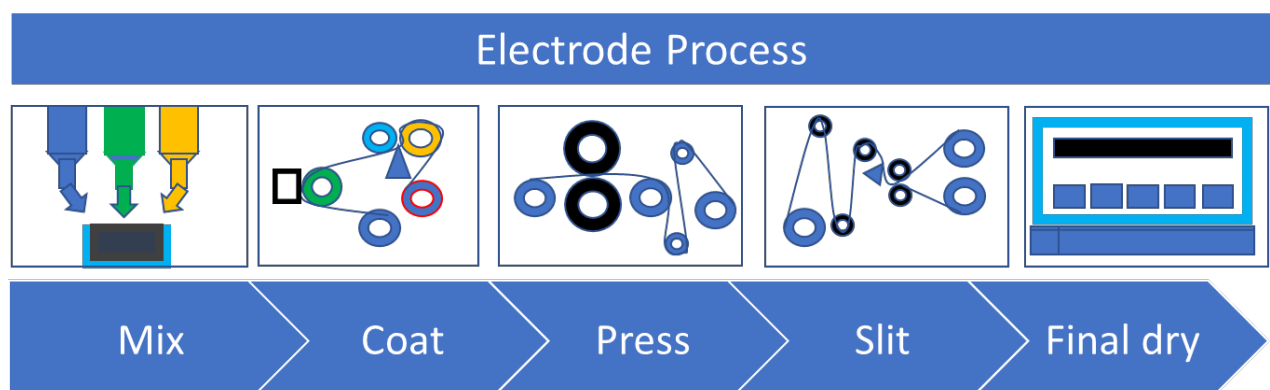
- Coating and drying: the ink is coated on metal strips and then introduced into the drying furnace to evaporate the solvents and water. These strips form the anode and the cathode of the future cells.
- Calendering: the calendering machine gives the electrodes the required thickness and porosity.
- Cutting electrodes, commonly referred as “slitting and clipping”. Coated strips are cut to obtain the desired width. Clipping then gives the strip the desired length.
- Cell assembly: the strips (anode and cathode) are stacked and separated by a separator, forming the electrode. The formed pile is then inserted into a can and welded, forming the cell.
- Filling with electrolyte: the cell is then filled with electrolyte.

- Formation: the cells are tested by undergoing loads, discharges and various tests to ensure their quality. Electrolyte filling is repeated at the end of the process.
- Module assembly: cells that have passed the previous tests are assembled in modules, which constitute the final product.

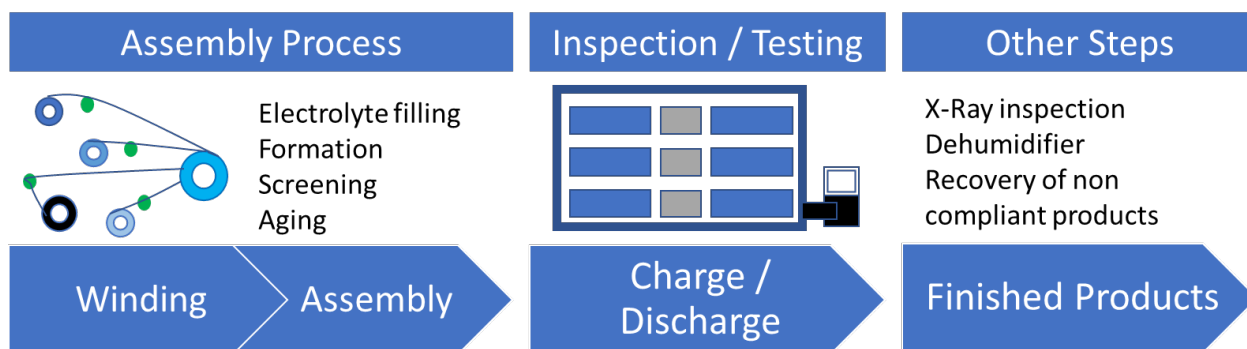


Depending on the process area, another possible simplified process is as follows:

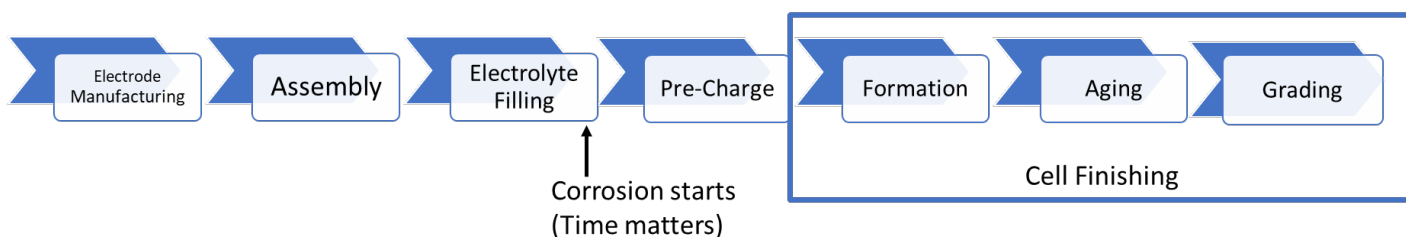
- Primary operations housed in such a plant include: Electrode Production, Assembly, Formation, Testing and Modularization.
  - All these operations may take place in one single Manufacturing Building that may house 5 to 10 clean room areas (i.e., Cathode Mixer; Cathode Coater; Cathode Roll Press; Anode Mixer; Anode Coater; Anode Roll Press).
  - Several further cell assembly operations are performed including, aging, charging, screening, electrolyte filling and formation.
  - As a result, in addition to the main Manufacturing Building, the plant may include a Utility Building, Safety Test Building, Hazardous Storage Building, Control Building, and other ancillary buildings including a yard.







- Lithium-ion batteries in the charge/discharge phase (i.e., the so-called inspection phase) and in the aging phase do not present the same hazards:
  - At one stage of the manufacturing process, the batteries are charged, and so are subject to potential Thermal Runaway. The following diagram shows that charging is done just after electrolyte filling to avoid corrosion, but at a low charge of 2V only per cell. [Pre-Charging vs. Formation in Lithium-Ion Cells | Electronic Design](#)



## 4. Special hazards and inherent safety requirements

The special hazards related to the process described above and the inherent safety requirements are summarized below:

### 4.1 Slurry Preparation

Raw material storage and handling:

- The NMP (N-Methylpyrrolidone—see below for details) is usually delivered by tanker and then deposited in storage tanks, located indoors. The room should be at least 2hrs fire rated and linked to a retention tank. The first step is to dose the NMP into the mixing vessel in duty in the Positive Mixing preparation room.
- Active powders are packaged in paper bags. Powders are then weighed and introduced through a hopper into the mixing vessel. Dust emissions should be collected and treated through ATEX (explosion proof) dust collectors. The mixer should be blanketed with nitrogen to avoid any risk of dust explosion (organic powders). After homogenization, the ink is checked before and after degassing.



#### Mixing:

- The preparation of the “positive ink” and the “gel” may include the following equipment:
  - A series of sealed mixers (with capacity ranging from 1,000 l up to 2,500 l or more). Reaction temperature is usually lower than 55 °C at relatively low pressure—less than 1 bar #14.5 psi or negative pressure around (-1) bar # (-14.5) psi. Once the tank is empty, the mixer needs to be cleaned (i.e., a first clean is carried out with the NMP recovered, then a second clean is carried out with water using a cleaning nozzle. The condensed NMP may be used for several cleans until it is considered as a waste).
  - A series of buffer tanks to dose the NMP (see below for details) to be sent by pumping to the mixers (each with a volume of 8-10 m<sup>3</sup> or more).
  - A series of agitated tanks for the storage of ink and gels prepared before transfer to the coating lines (e.g., 1,500-1,800 l each).
  - Cleaning system for the mixing plants, consisting of different condensed NMP tanks.
- The preparation of the “negative ink” is done in the aqueous phase (no use of NMP) and follows the same process as the preparation of the positive ink. The products introduced are miscellaneous powders (toxic and/or combustible) and demineralized water. For the preparation of negative inks and the gel, the equipment will be as follows:
  - a. Series of sealed mixers (with capacity ranging from 1,000 l up to 2,500 l or more). Reaction temperature usually lower than 30 °C at relatively low pressure—less than 1 bar #14.5 psi or negative pressure around (-1) bar # (-14.5) psi.
  - b. A series of agitated tanks for the storage of the prepared ink before transfer to the coating lines (e.g., 1,500-1,800 l each).
  - c. The vapors are collected and treated by scrubbers and carbon filters located outdoors.
- Work in progress materials: handling and storage:
  - After the quality of the manufactured positive ink has been validated, the contents of the tank may be transferred to mobile transfer tanks, which are routed to the coating line before being connected to it.
- Inherent safety requirements: the most important risk is the explosion of NMP vapors or dust (carbon and graphite powders) during mixing operations. The following inherent safety elements (i.e., safeguards) should be provided to prevent and mitigate this risk:

- Continuous air extraction above the powder weighting station. Handling powder in the event that extraction is not in service should be prohibited. An alarm should be provided locally and relayed to a constantly attended location in case extraction is stopped or in case the airflow is too low.
- Blanketing with inert gas (i.e., nitrogen) of the mixer containing powder and NMP.
- Immediate shutdown of the mixing process in the event of low pressure in the nitrogen supply (i.e., interlock closing the valves on the NMP supply line).
- All tanks in the mixing workshop should be provided with level indicators triggering automatic closing of the feeding valves in case of “High High” Level.
- Pressure Relief Valves should be installed on all equipment blanketed with inert gas (i.e., nitrogen) to prevent any overpressure.
- All tanks should be equipped with high-level detection with alarms, then with very high-level detection with automatic stop of their feeding, in order to control the quantity introduced into the mixer.
- All tanks should be of the double jacket type.
- The ink preparation workshop should be equipped with sprinkler systems.

## 4.2 Coating/drying

- Process:
  - The positive and negative inks prepared in the mixing building are sent on coating lines dedicated to the production of the positive electrodes and negative electrodes.
  - These inks are then introduced into the drying oven to evaporate the solvents and/or water.
  - The drying process is essentially a thermal process and does not require the addition of chemical products. The coated strips pass through drying ovens, which may be arranged on one or two levels.
  - Due to the presence of NMP in the cathode ink, the drying oven of the cathode coating line should be under vacuum in order to avoid any diffusion of NMP vapor towards the workshop.
  - The inks are introduced onto the coating lines by continuous flow pumps and by maintaining a light nitrogen overpressure, to be deposited in layers on an aluminum strip for the cathode and on a copper strip for the anode.
  - Once the coating is done, the strips pass through a two-stage drying furnace. This step does not require chemical inputs. Furnaces use steam for heating. The internal temperature of the furnace does not usually exceed 150 °C.
  - Continuous extraction takes place and the extracted air will be directed towards a treatment installation before discharge
  - The vapor resulting from the ink is continuously collected (airflow of approximately 120,000 Nm<sup>3</sup>/h) and then adsorbed through carbon filters. The purified air is released to the atmosphere.
  - The negative electrode dryer will not produce hazardous liquid effluents (only demineralized water is used for the negative ink preparation).
- Inherent safety requirements: the most important risk is the explosion of NMP vapors from the drying of the positive electrode. The following inherent safety elements (i.e., safeguards) should be provided to prevent and mitigate this risk:
  - Controls on the start-up of installations when extraction begins (automatic purging, start-up of ventilation before start-up of the line, delayed stop of ventilation after the line has been stopped).
  - High temperature sensors on the steam supply upstream of the furnace,

- Temperature sensors in the furnace with low threshold alarm and interlock in order to shut down of the coating and drying installations,
- Pressure sensors within the furnace (one per zone) and high-pressure alarm (pressure sensors should provide information on the air flow rates and on the control of the furnace vacuum),
- Pressure sensors on extraction, with low alarm and interlock in order to shut down the installation,
- Extraction flow measurement,
- Solvent concentration sensors in each zone of the furnace, equipped with two alarm thresholds:
  - 25% LFL: stop of the coating line and stop of the ink supply,
  - 50% LFL: emergency purge of the coating line atmosphere.

### 4.3 Calendering

- Process:
  - Calendering and slitting are usually done using the same machine.
  - The electrodes pass through the calendering machine, the purpose of which is to calibrate the coated part according to a certain porosity and thickness. Cylinders for calendering may be heated to approximately 80 °C with a heat transfer fluid (thermal oil).
  - The slitting process involves cutting the formed coil to obtain three coils of the desired width. The slitting of the coil strips is usually carried out using circular knives.
  - Trimming, more commonly referred to as notching, laser cuts the edges of coils that are not coated with ink. The notching is usually carried out under compressed air supply.
- Inherent safety requirements: the most important risk is a fire in the calendering machine due to an overheating of the heat transfer fluid leading to a potential pool fire. The following inherent safety elements (i.e., safeguards) should be provided to prevent and mitigate this risk:
  - Oil high temperature alarm and interlock for heater shutdown (independent of standard oil temperature regulation).
  - Safety interlocks for the immediate stop of the fluid circulation and heating in the event of loss of level or pressure within the buffer tank.
  - ATEX in the event that the maximum heating temperature is above the HTF flash point.

### 4.4 Cell assembly/Baking

- Process:
  - Stacking of the electrodes: forming a stack consisting of a positive electrode and a negative electrode isolated by a separator (two stacks are required to form a cell, also called an element).
  - The assembly of the element follows the following steps:
    - Positioning of the positive electrode,
    - Positioning of the negative electrode,
    - Hot compression,
    - X-ray control,
    - Ultrasonic welding,
    - Welding of current collectors (ultrasonic or laser),
    - Welding of current collectors on the lid,
    - Beam insulation,
    - Insertion of the element into the aluminum bucket,
    - Laser welding of the lid on the bucket,
    - Helium leak test,

- Heating and vacuum extraction.
- Baking the cells: usually carried out under vacuum in electric ovens (i.e., 70 to 80 °C) to remove the residual moisture (i.e., final drying) which can be present in the cells. This involves reaching a certain temperature at atmospheric pressure under inert gas, which will not bring back water to the process, before proceeding to the step of maintaining the temperature under vacuum.
- Cooling: carried out through a tunnel by air circulation cooled through a water/air exchanger.

#### 4.5 Electrolyte filling:

Electrolyte storage and handling:

- The Electrolyte is usually stored in tanks located in a dedicated building (“electrolyte transfer rooms”).
- The electrolyte is supplied from the electrolyte transfer rooms to the filling area by nitrogen pressure.

Process:

- 500-800 g of electrolyte (LiPF<sub>6</sub> + solvent) is introduced into each cell. This first filling corresponds to 90% +/-5% of the volume of the cell. A second (final) filling (10% +/-5%) is done during the electrical treatment.
- The cells are usually maintained under vacuum before filling and then once the filling is done the atmospheric pressure is restored in the cell by progressive injection of nitrogen.
- The dosing stations are usually equipped with specific extraction. The stations are maintained under vacuum considering the low flash point of the electrolyte (≤22 °C). The air extracted from the dosing stations is treated.

Inherent safety requirements: The most important risk regarding the electrolyte is the risk of fire and explosion and the use of flammable solvents (flash point not exceeding 38 °C/100 °F). Moreover, contact with water produces hydrogen fluoride, a highly toxic gas. The following inherent safety elements (i.e., safeguards) should be provided to prevent and mitigate this risk:

- The electrolyte transfer room should be provided with a retention and drainage to an underground emergency storage tank. The room should be fire-rated for two hours.
- Detection of electrolyte vapors at the Lower Explosive Limit with alarm:
  - within the cabinet containing the networks,
  - within the filling machine at the level of the conveyors,
  - within the air extraction of the machines,
- Fire detection (flame, smoke and temperature) with alarm:
  - within the cabinet containing the networks, within the filling machine,
  - low- and high-level detection on the buffer with alarm, and very high level with interlock in order to stop the electrolyte supply,
- Integrated retention cone with automatic lifting to the remote retention tank of the area electrolyte discharge tank,
- Level detection within the retention cone:
  - Low-level alarm and high-level interlock in order to shut down the electrolyte supply pump, very high level resulting in a safety shutdown of the unit,
  - Oxygen and HF (hydrogen fluoride) detection in the room housing the cabinets and machines (thresholds being defined with the suppliers),
  - Double walled stainless steel type and welded electrolyte supply lines from the storage. Leak detection system within the double skin sending an alarm and an interlock in order to shut down the feeding pumps.

## 4.6 Formation

Work in progress materials handling:

- This process is usually fully automated.
- Before any operation, the cells are grouped in trays (e.g., 2-3 rows of 10-12 cells) and maintained in compression in order to avoid deformation during the electrical treatment.
- Trays of cells coming from the Cell Assembly area are handled between the different stages of formation by an automatic shuttle.
- The process is designed in such a way as to avoid any human intervention in the chambers.
- The risk of fire is present during the formation process, mainly due to a thermal runaway of a cell in the event of an internal fault or impurity.

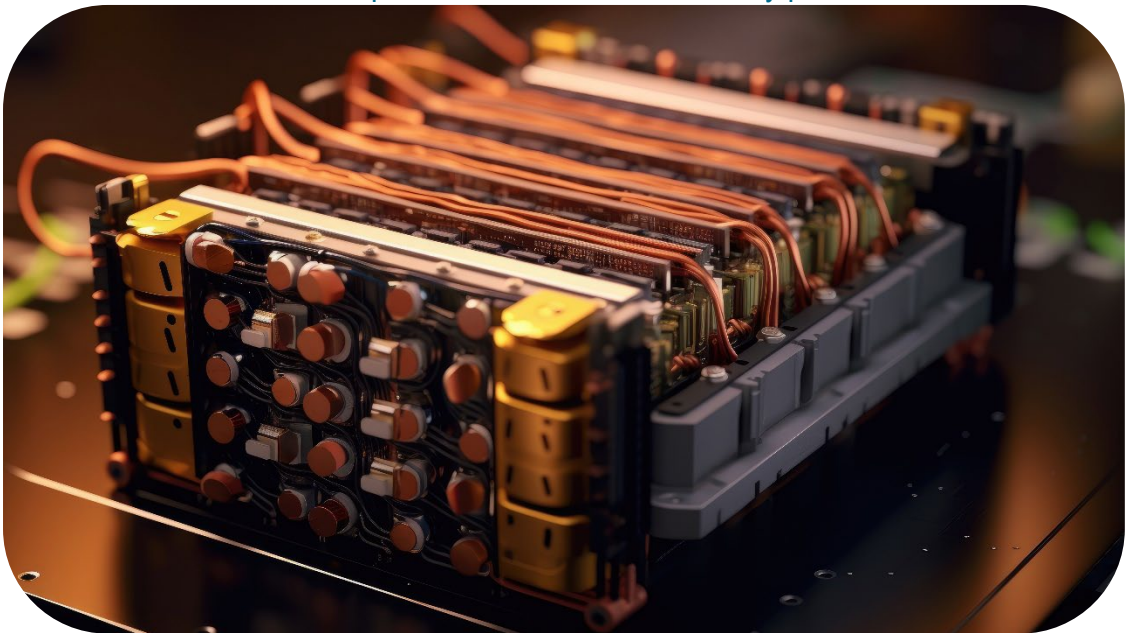
Process:

- The cells are tested by undergoing charges, discharges and various tests to ensure quality.
- After the electrical treatment, the cells are refilled with electrolyte.
- The cell formation process includes the following steps:
  - Soaking: 24-hour storage of the cell trays at 60 °C in slots. No voltage is applied at this stage. There is reportedly no fire risk at this stage, cells are not charged.
  - Formation: cells are charged for 4 hours with constant monitoring of the voltage, temperature, etc. This is the first charge of the cell. Test chambers should be 2-hour fire rated.
- Cooling storage: the elements in trays are stored in racks within slots (one slot per tray) for 4 hours to cool the elements between formation and filling, since the electrolyte has a relatively low flash point (flammable) whereas the element at the end of formation is at a temperature of about 60 °C.
- Second filling, weld and leak test: the previous electrochemical reaction consumed the electrolyte of cells, thus a second filling is required in the Cell Assembly area. The element is then welded and a leak test is performed with helium. The filling, welding and sealing test are performed continuously and under an inert atmosphere.
- High temperature storage (aging): the elements in trays are stored in racks within slots (one slot per tray) at 45 °C for 48 hours. A fire hazard is present because the elements are 100% charged in an unconfined room. A stock of 48 hours corresponds to about 4,540 elements.
- OCV/DCIR quality tests: there are several storage periods between these measures and quality tests to stabilize the cells. The following quality tests are performed in chambers:
  - OCV (Open Circuit Voltage) is carried out to measure self-discharge using a voltmeter. Two measures may be performed (called OCV1/OCV2) with a period of time between them. The difference between OCV1 and OCV2 makes it possible to determine the change in the state of charge (i.e., to measure self-discharge of the cells produced).
  - Direct current internal resistance (DCIR) of batteries is the resistance of current flowing through the battery. The DCIR value depends on multiple factors, such as battery materials, electrolyte concentration and temperature. The variation of DCIR has a great influence on battery discharge performance, especially for high-power batteries. In general, the better the battery; the lower the internal resistance. DCIR is a key indicator for evaluating battery quality.
  - The test chamber(s) should be 2-hour fire rated.
  - Test chambers should be provided with gas detection, fire detection and thermal sensors.
  - Flammable gases released during a thermal runaway should be collected by the emergency extraction activated in the event of fire detection.

## 4.7 Module assembly

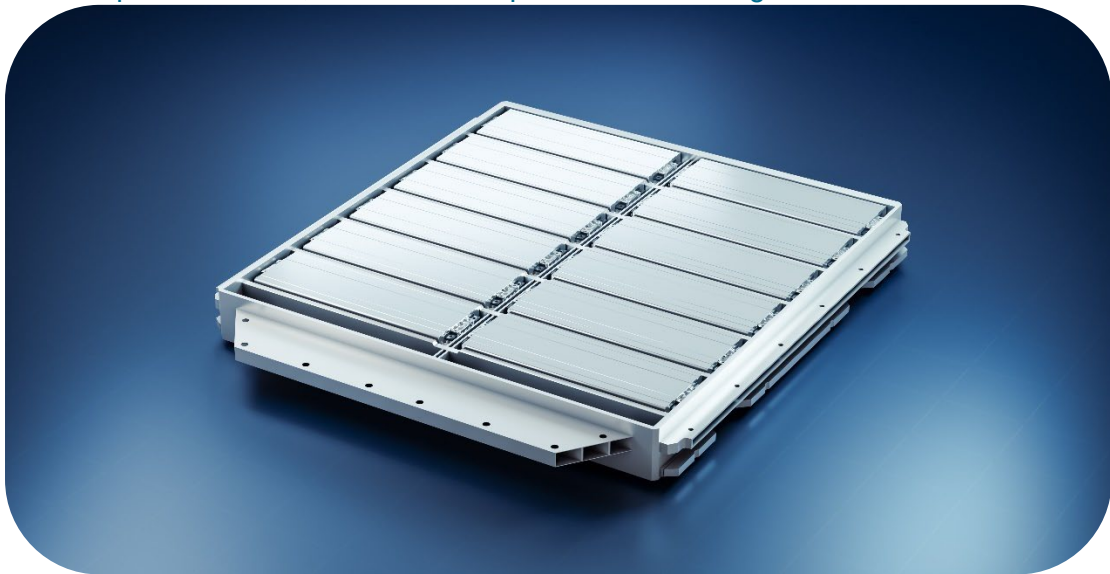
- More than one module assembly line may be installed in either the same room or a different room.
- In the first section, the battery cells are tested and prepared for assembly.
- In the second section, a so-called raw module is produced by using multiple battery cells. The cells are combined into a stack in the “merging device”. The stack is pressed together with the pressure plates, which are positioned at the ends of the stack, and the end plates, which are placed at the sides of the battery cells. The end plates are laser welded to the pressure plates of the cell stacks, thus completing the raw module. Depending on requirements, twelve to twenty-four battery cells or more are joined together to form a battery module.

Close-up of an electric vehicle's battery pack



- In the third section of the module assembly line, the battery modules are electrically connected and measured. For this purpose, the cell contacting system is put on and laser welded to the contacts of each individual battery cell.
- In the fourth and last section of the module assembly line, an automated electrical and mechanical end-of-line test of the battery modules takes place. Among other things, the insulation values are tested for voltage resistance (e.g., up to 4-5 kilovolts). This test ensures that persons and objects are protected against electrical flashovers and leakage currents. The battery housing is then covered with a heat-sealed lid to make the battery module safe to touch and protect it from dust particles.
- Once the module is assembled, it is transferred into the Finish Product storage area before shipping.

Electric vehicle lithium ion rechargeable battery module inside metal enclosure packed for car, solid li-ion cell pack manufacturing for EV automotive



## 5. Foreseen events

With regard to the special hazards described above, the following events are foreseen:

### 5.1 Fire

- Storage and handling of combustible liquid in the mixing process area for the positive electrode production: i.e., NMP: N-Methylpyrrolidone,  $C_5H_9NO$ , Liquid, Flash Point:  $91\text{ }^{\circ}C/195.8\text{ }^{\circ}F$ , Autoignition Temperature:  $346\text{ }^{\circ}C/654.8\text{ }^{\circ}F$ , Explosion Limits Upper 9.5 vol %/Lower 1.3 vol %, Flammability 2 as per NFPA, Incompatible Materials: Strong oxidizing agents, Strong acids, Strong bases, Hazardous Decomposition Products: Carbon monoxide (CO), Carbon dioxide ( $CO_2$ ), Nitrogen oxides ( $NO_x$ ), peroxides, Hazardous Polymerization: None, Hazardous Reactions: None under normal processing. Suitable extinguishing media: water spray, alcohol resistant foam, dry extinguishing powder, BC-powder, carbon dioxide ( $CO_2$ ), Unsuitable extinguishing media: water jet. Special hazards arising from the substance or mixture: Combustible. Vapors are heavier than air, spread along floors and form explosive mixtures with air.
- Thermal fluid pool fire at the calendering machine (roller heating) in the event of overheating.
- Electrical fire hazard (electrical cabinets, battery chargers, automation, distribution stations, etc.).
- Rack storage of combustible commodities.

### 5.2 Pool fire and explosion:

- Use of a flammable electrolyte ( $LiPF_6$  + solvent such as ethylene carbonate (EC) and diethyl carbonate (DEC), or EC and dimethyl carbonate (DMC), or propylene carbonate (PC) and DEC, or PC and DMC mixed by different volume ratio) that may generate a pool fire or explosion in the event of a vapor build-up. Lithium hexafluorophosphate ( $LiPF_6$ ) is currently the most widely commercialized lithium salt electrolyte.



### 5.3 Dust explosion:

- In the Mixing Area: use of carbon and graphite powders

### 5.4 Thermal runaway:

- Lithium-ion cell: during and after the formation process when the cells are partially charged.

### 5.5 Gas and mechanical explosion:

- Gas-fired boiler and/or gas explosion due to inadequate safety combustion control.
- Explosion of the steam generator (over-pressurization and rupture).

## 6. Fire protection requirement

- Several LIB manufacturing plants are usually deemed as protected as per NFPA standards. But there is no specific NFPA standard for the storage of lithium-ion batteries, nor for the manufacturing of lithium-ion batteries. The only available NFPA standard is for ESS with lithium-ion batteries (NFPA 855), which is a different occupancy.



However, fire protection should be defined according to occupancy, commodity storage and special hazards. So, mentioning NFPA is not enough. It does not mean that fire protection is adequate. Design details should be provided as summarized below:

## 6.1 Storage of raw material and packaging

This should be protected as per NFPA13 in accordance with the commodity and arrangement. Note that for exposed non-expanded plastic (such as battery casings), storage should be limited to 3.7 m (12 ft) in height based on NFPA table 4.3.1.7.1 (solid-pile, palletized, shelves, racks) and as a minimum requirement weighed, with unusual or abnormal fuel loadings or combustible characteristics and susceptibility noted:

Maximum storage Height	Maximum Ceiling Height	NFPA Classification	Design Density	Hose Allowance	Fire Water Supply Duration
1.5 m (5 ft)	-	EH1	12.2 mm/min/m <sup>2</sup> (0.3GPM/ft <sup>2</sup> ) over 280 m <sup>2</sup> (3,000 ft <sup>2</sup> )	1900LPM (500 gpm)	120 min
3 m (10 ft)	6.1 m (20 ft)	EH2	15.5 mm/min/m <sup>2</sup> (0.38GPM/ft <sup>2</sup> ) over 280 m <sup>2</sup> (3,000 ft <sup>2</sup> )		
3.7 m (12 ft)	5.2 m (20 ft)				

## 6.2 The manufacturing process

The manufacturing process includes clean rooms and is very similar to that used in semiconductor facilities from the hazards standpoint. As a result:

- For fab areas (see note on electrode manufacturing for battery cells below), apply FMDS 7.7 (2.3.4.1) Semiconductor Fabrication facilities as summarized below:
  - Provide automatic sprinkler protection at ceiling level in semiconductor fabrication areas and associated plenum spaces above clean rooms and subfabs as follows:
    - A. Design the sprinkler system to provide a minimum density of 8 mm/min/m<sup>2</sup> (0.2 gpm/ft<sup>2</sup>) over the hydraulically most remote 280 m<sup>2</sup> (3,000 ft<sup>2</sup>), with an additional allowance of 946LPM (250GPM) for hose streams.
    - B. Ensure the water supply can provide the sprinkler water and hose stream flow requirements for a duration of 90 minutes.
    - C. Use nominally rated 70 °C (160 °F) FM Approved quick-response pendent sprinklers. Sprinklers having minimum K factor of K8.0 (K115) are preferred. Sprinklers having a K factor of K5.6 (K80) can be used where the density/area recommendations are achieved with the smaller sprinkler.
  - Or at least as per NFPA13 OH2, a minimum of 7.8 mm/min/m<sup>2</sup> (0.19 gpm/ft<sup>2</sup>) over the hydraulically most remote 280 m<sup>2</sup> (3,000 ft<sup>2</sup>), with an additional allowance of 946LPM (250GPM) for hose streams for a duration of 90 minutes.
- Note on electrode manufacturing for battery cells:
  - During the manufacturing of electrodes, carrier foils made of aluminum and copper are coated with electrode material on coils known as “mother coils”.
  - Electrode material deposition: wet coating process (solvent-based or water-based) or dry coating process.
  - With metals such as lithium, ignition is very easy when metals are in finely divided forms such as powders, dusts, chips and lathe turnings. The hazards of combustible metals require special extinguishing agents. Not all agents are effective on all metals. These fires can be difficult to extinguish and mishandling

them can cause explosions and spread fire over large areas. Because most burning metals react violently with water and decomposes it into hydrogen (additional fuel and explosion hazard) and oxygen (oxidizing agent contributing to the fire), sprinkler systems are normally not recommended with metal fires. This part of the process may preferably take place within an area with inert atmosphere (i.e., argon or helium) or protected by gas (i.e., argon or helium). See “Fire protection systems for metal fires” paper.

- In the case of solvent-based wet coating, dedicated fire protection should be provided for solvent storage and dispensing facilities as per NFPA30.
- Note for the electrolyte filling process step:
  - Non-ionized  $\text{LiPF}_6$  dissociates to  $\text{PF}_5$  and  $\text{LiF}$  in organic solvents and  $\text{PF}_5$  reacts with water. A solvent with a high dielectric constant increases the ionization of  $\text{LiPF}_6$  thereby suppressing the reaction with water.
  - As the Material Safety Data Sheet (MSDS), there is no special restriction for extinguishing media for Lithium Hexafluorophosphate ( $\text{LiPF}_6$ ) (currently the most widely commercialized lithium salt electrolyte).
  - However some operators take the view that the electrolyte may produce hydrogen fluoride in contact with water so that instead of water the filling room, protection should involve an automatic gaseous extinguishing system using inert gas (i.e., argon or helium).
- Note for the formation process step:
  - Lithium batteries in charge should be treated the same way as BESS: See enclosed SCOR Stationary Battery Handbook, section “3. Focus on ESS/BESS ESS/BESS”, subsection “4. Fire Detection and Fire Protection”: “ESS/BESS rooms should preferably be protected by automatic sprinklers designed to deliver a minimum density of 12.2 mm/min/m<sup>2</sup> (0.3 gpm/ft<sup>2</sup>) over the entire area of the room or 232 m<sup>2</sup> (2,500 ft<sup>2</sup>), (i.e., EH1 occupancy), whichever is smaller”, and 1900LPM/500 gpm for 120 min (90 min minimum) See also subsection “1. Location, Arrangement & Segregation”. Note that charging operations should be performed at standard manufacturing height level. In the event that the batteries being charged are installed in high racks, there is unfortunately no reliable fire protection for such an arrangement.
  - In the case of trays of cells installed in slots during the process, each slot should be equipped with a sprinkler head (slots are separated by solid partitions, usually made of metal looking like shelves).
  - Some operators may consider an automatic gaseous extinguishing system as a first line of defense, with automatic wet pipe sprinklers as a back-up designed for EH1 occupancy above (i.e., 12.2 mm/min/m<sup>2</sup> (0.3 gpm/ft<sup>2</sup>) over the entire area of the room or 232 m<sup>2</sup>/2,500 ft<sup>2</sup>) or even for EH2 occupancy (i.e., 15.5 mm/min/m<sup>2</sup>/0.38GPM/ft<sup>2</sup>) over 280 m<sup>2</sup> (3,000 ft<sup>2</sup>) and 1900LPM/500 gpm for 90-120 min.

### **6.3 Storage of lithium-ion batteries charged/uncharged** (i.e., before or after inspection phase after assembly = Work In Progress/Finished Products).

For fire protection, consider FM Global Data Sheet 8-1 Commodity Classification 2.4.2 Lithium-ion (Li-Ion) batteries and 8-9 Storage of Class 1, 2, 3, 4 and Plastic commodities as follows:

- Protect new Li-ion cells and modules stored in open-frame racks, solid-pile or palletized storage arrangements per the guidance in Table 2.4.2.1 below (protection guidance is not differentiated on the basis of battery chemistry):

Table 2.4.2.1. Protection of Lithium-Ion Cells and Modules

Li-ion Cell/ Module State of Charge	Ceiling Height	Storage Height	Storage Arrangement	Packaging	Ceiling Protection (QR sprinklers only)	In-Rack Protection
≤ 60%	≤ 40 ft (12 m)	Maximum 3 levels of storage up to a total height of 15 ft (4.5 m)	Open-frame rack, solid-pile or palletized	Wood crate, metal encased or corrugated carton with cellulosic and/or unexpanded plastic internal packaging only	K22.4 or K25.2 (K320 or K360) 12 @ 35 psi (2.4 bar)	NA
				Corrugated carton with expanded plastic internal packaging	CEP per 8-9*	NA
				Plastic external packaging	UUP per 8-9*	NA
	> 40 ft (12 m)	NA	Open-frame rack	Uncartoned	Per surrounding occupancy.	See Section 2.4.2.2
				Cartoned or uncartoned	Per surrounding occupancy.	See Section 2.4.2.2
	> 60%	NA				

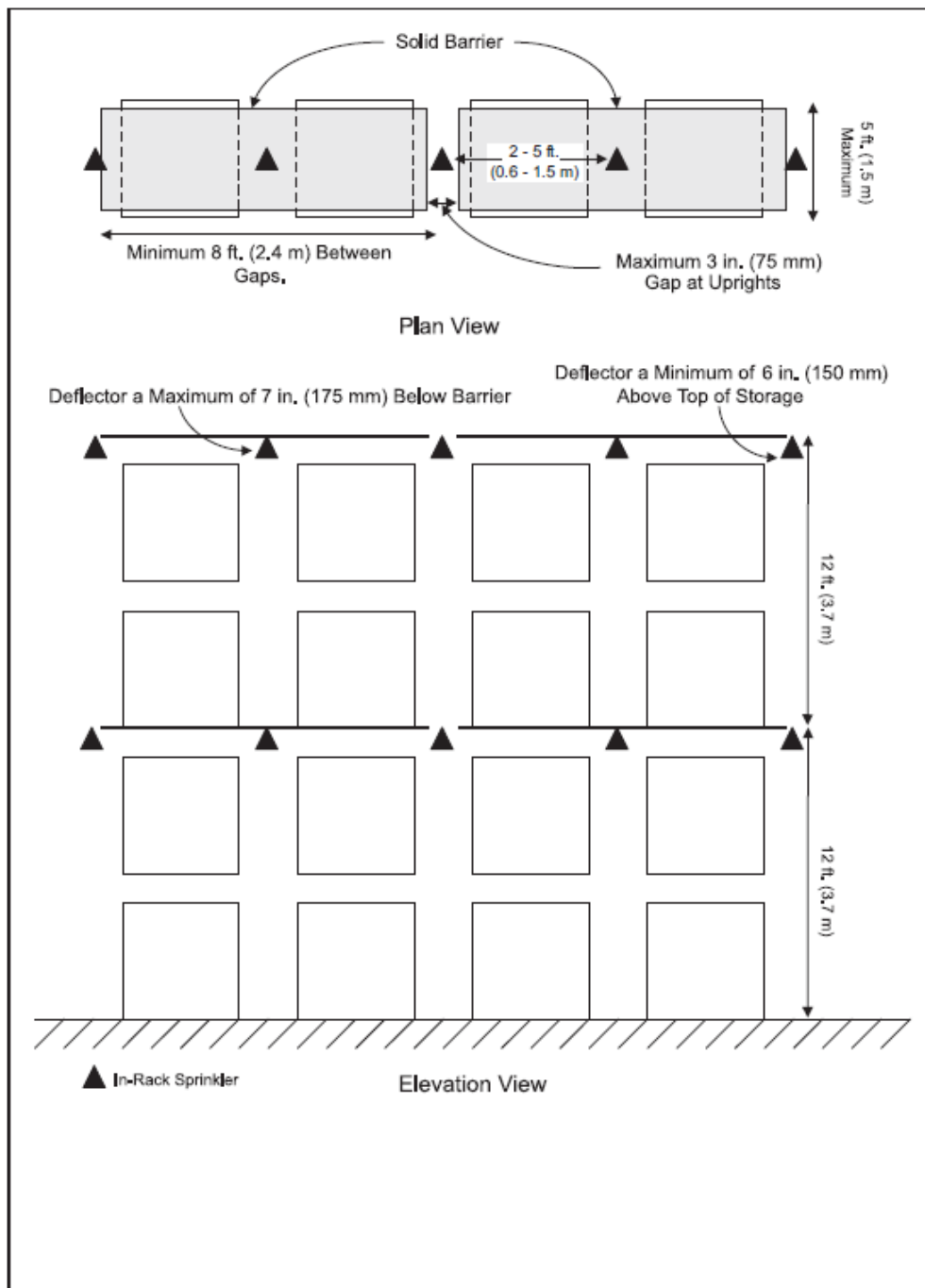
\* Use the Data Sheet 8-9 protection table based upon the storage configuration (open-frame rack, solid-pile or palletized) and the protection option based on the ceiling height.

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**CCP: Cartoned Expanded Plastic; UUP: Uncartoned Unexpanded Plastic**

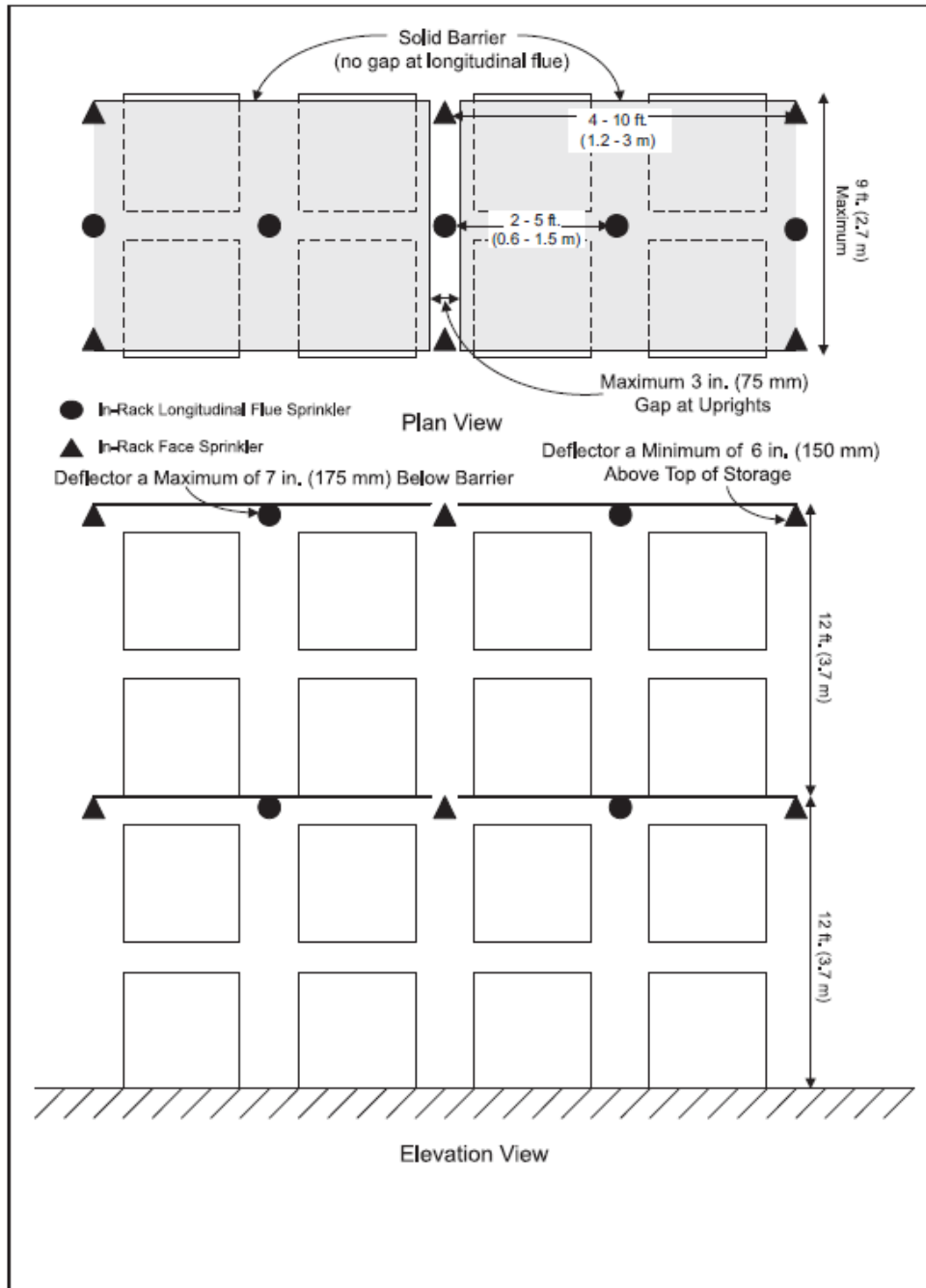
- Do not allow storage above the batteries for ceiling-only protection options.
- Provide a minimum of 3.0 m (10 ft) space separation between Li-ion cell or module storage areas and other combustibles when stored in solid-pile or palletized storage arrangements.
- Store defective or damaged cells and modules outside of the building with space separation per Data Sheet 1-42, Maximum Foreseeable Loss Limiting Factors.
- Protect used or refurbished Li-ion cells or modules with in-rack sprinkler protection as explained below.
- When in-rack sprinklers are required, provide plywood (minimum 10 mm [3/8 in.]) or sheet metal (minimum 0.7 mm [22 ga.]) horizontal barriers and in-rack sprinklers installed in accordance with Figures 2.4.2.2-1 and 2.4.2.2-2 below, depending on the rack type for storage:
  - Use a maximum vertical spacing of 3.7 m (12 ft) between barriers.
  - Li-ion cells or modules must not be stored above the top barrier level.
  - Design barriers without gaps in longitudinal flue spaces. A maximum gap of 75 mm (3 in.) between each barrier is permitted at the rack uprights (transverse flue) for single and double row racks.
  - Install K115 (K8.0) or K160 (K11.2), 74 °C (165 °F) rated, quick-response in-rack sprinklers below each barrier.

Single-row rack sprinkler layout for li-ion cells or modules



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### Double-row rack sprinkler layout for li-ion cells or modules



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- In-rack sprinkler design: minimum flow of 227LPM (60 gpm) out of the hydraulically most remote six (6) sprinklers (e.g., three face sprinklers and three flue sprinklers in a double-row rack) if one barrier is provided, or the most remote eight (8) sprinklers (e.g., two face sprinklers and two flue sprinklers on two levels in a double-row rack) if two or more barrier levels are provided.
- Face sprinkler location: within 150 mm (6 in.) of the rack face.
- Ceiling sprinkler demand shall not be included in the hydraulic calculations for in-rack sprinklers.
- Design ceiling sprinklers to protect the surrounding occupancy.

Fire Water Supply for Li-ion cell and module storage supply: must be capable of meeting the design sprinkler discharge flow rate plus a 950LPM (250GPM) hose stream demand for at least 120 minutes. For products with Li-ion batteries, the duration may be reduced to 90 minutes minimum (i.e., 90 min for OH, 120 min for EH).

## 7. Pre/post-incident Planning

- A pre-incident plan with the fire service and Emergency Response Planning should be developed including:
  - Manual fire protection methods to be employed.
  - Designated location outside of the facility to which damaged and impacted cells can be moved.
- A post-incident recovery plan that addresses the potential for reignition of Li-ion batteries should be developed as well as for the removal and disposal of any damaged or impacted cells, modules or products.
- Fire watch arrangements should be in place until all potentially damaged Li-ion cells, modules or products have been removed from the area following a fire event.

Other publications in this series:

- RISK CONTROL PRACTICE: SPECIAL HARZARD  
Belt Conveyors & Related Equipment
- RISK CONTROL SERVICES: OCCUPANCY
  - Waste & Recycling Facilities
- RISK CONTROL SERVICES: FIRE PREVENTION
  - Oxygen Reduction Atmosphere Systems
  - Fire Protection Systems for Metal Fires

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