OCTOBER 2025 - V2

Update of Sept. 2023 - V1

Risk Control Services: Occupancy

Lithium-Ion Batteries Manufacturing

(incl. Gigafactory & Storage)

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SCOR

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The Art & Science of Risk

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This October 2025 V2 version is basically an update of the September 2023 V1 version, considering the latest released of the international standards (i.e., NFPA and FM data sheets) as listed in the "Technical Documents" below. Moreover, key data about processes, special hazards, and inherent safety requirements have been added for better comprehension when needed.

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 Data Sheets free viewing and download available when registered at https://www.fm.com/resources/fm-data-sheets

Note that these materials are periodically revised and updated. Please monitor the above websites for updates and/or revisions. In July 2024, FM Global decided to drop the "Global" from its brand name, becoming simply FM. As a result, in this handbook the old brand name "FM Global" and the current brand name "FM" are respectively mentioned for Data Sheets released before and after July 2024 brand name change.

Acknowledgments:

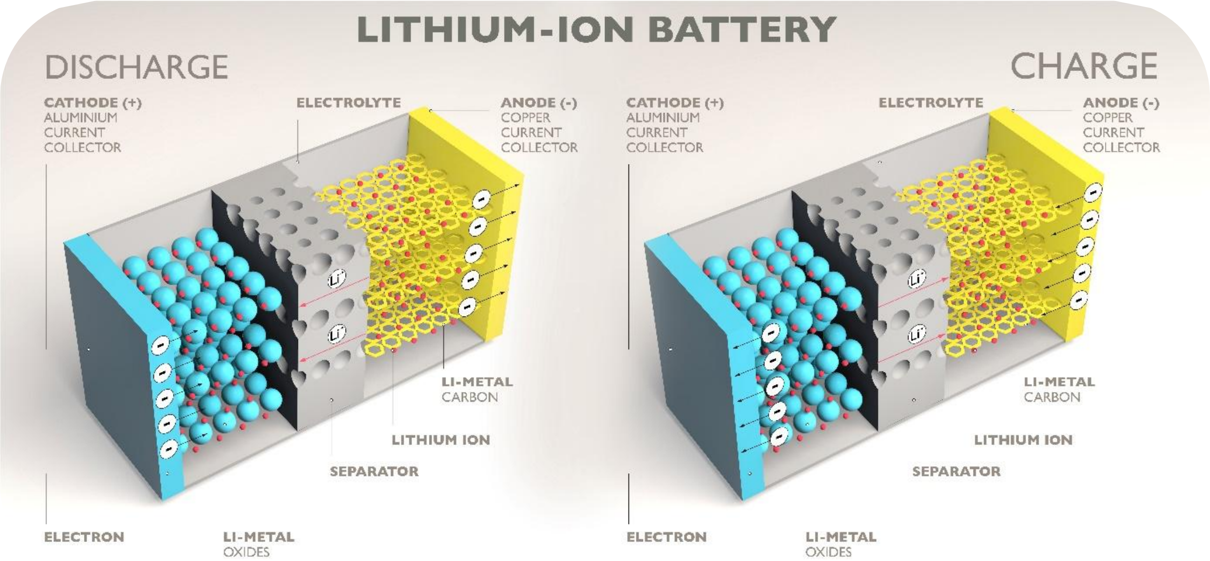
- Franck Orset (FPO) Loss Prevention Engineer

Technical Documents:

- NFPA 13 "Standard for the Installation of Sprinkler Systems" 2025, 2022, 2019 editions
- FM Data Sheet 7-112 "Lithium-Ion Battery Manufacturing and Storage" Oct 2024
- FM Data Sheet 8-1 "Commodity Classification", Jan. 2023, Oct. 2024
- FM Data Sheet 3-26 "Fire Protection for Non-Storage Occupancies" Oct. 2021, Oct. 2024
- FM Data Sheet 8-9 "Storage of Class 1, 2, 3, 4 and Plastic commodities"
- FMDS 7.7 "Semiconductor Fabrication facilities"
- 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.

A huge industrial facility that mass produces batteries for electric vehicles (EVs) is commonly called a Giga factory. Giga refers to the storage capacity in watt hours in the battery cells produced, and also to the size of the facility. Height may exceed 15 meters.


These Giga factories present a relatively high level of automation, and usually have a compact layout, high bay warehouses, Automated Guided Vehicles (AGVs) for load handling, flammable liquids, and clean rooms.

Until October 2024, there was no dedicated standard for LIB manufacturing.
Consequently, using both the NFPA standard and the FM Global Datasheet for fire protection was considered an adequate approach. This could be done in a more or less conservative way.

From October 2024 there is one dedicated standard for LIB manufacturing and storage: FM Data Sheet 7-112 “Lithium-Ion Battery Manufacturing and Storage.” (Note that this FM datasheet is for liquid electrolyte-based lithium-ion batteries - cell/module/battery – only).

As a result of the above and depending on the location and age of the facility, both the NFPA standard and the FM Datasheet for fire protection may have been considered.

Please find below some guidance for Risk Engineers and Underwriters

Table of contents

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, regarding 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.

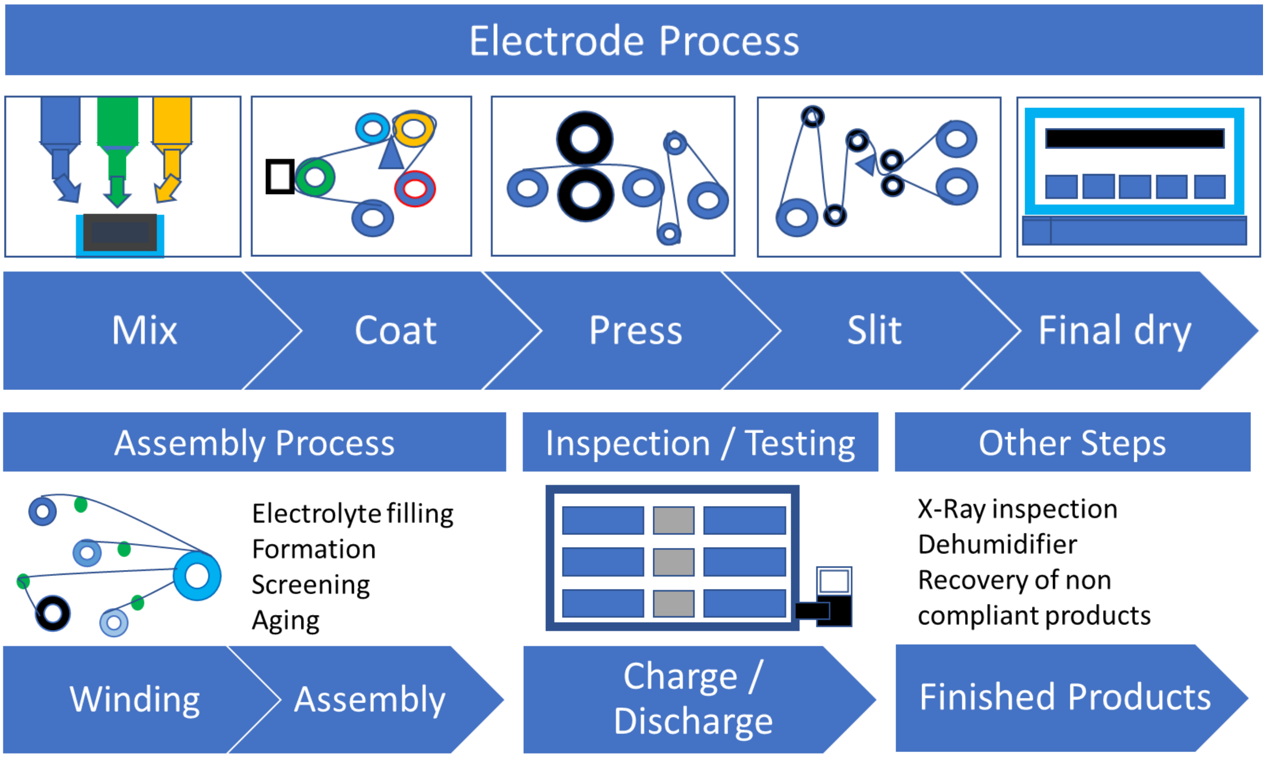
3. Process summary

- 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”.

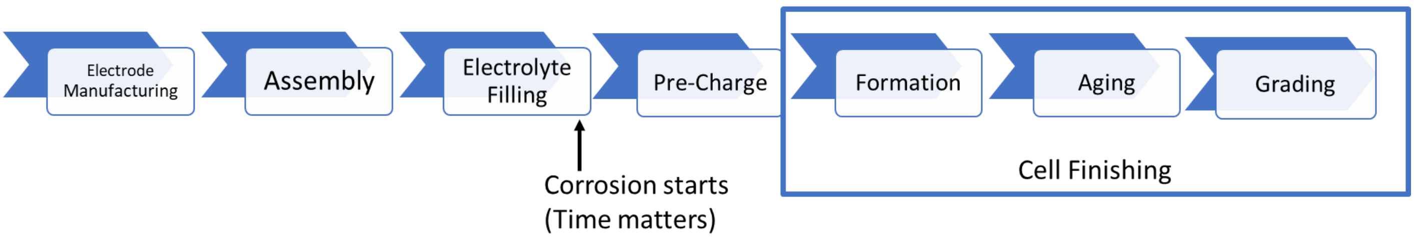
As a first approach, the simplified process may be described as follows:

- 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.



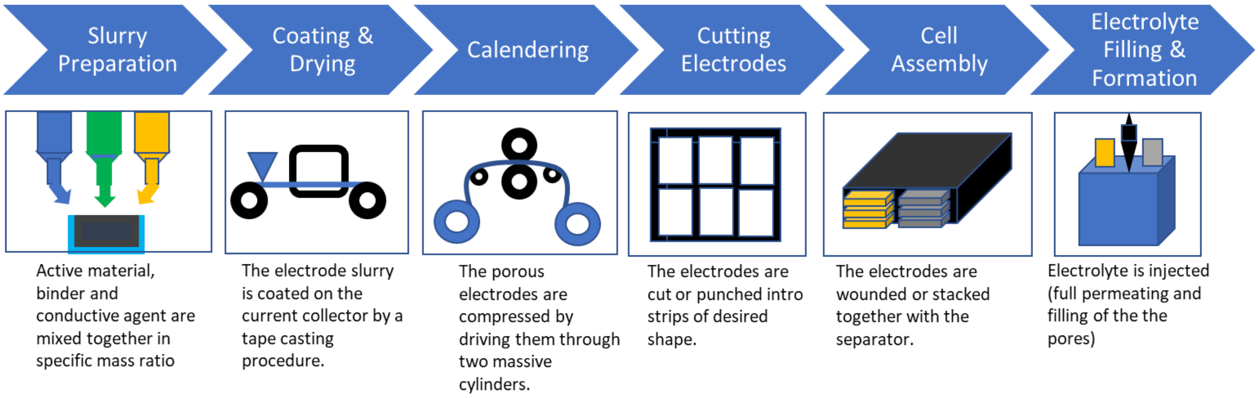
- Lithium-ion batteries in the charge/discharge phase (i.e., the so-called inspection phase) and in the aging phase do not present the same hazards:
  - At one stage of the manufacturing process, the batteries are charged and so are subject to potential Thermal Runaway. The following diagram shows that 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



An in-depth approach to the process is also provided as follows:

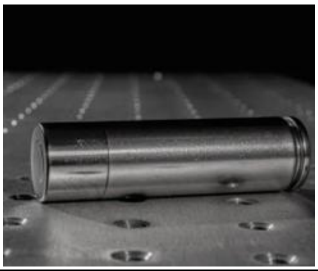
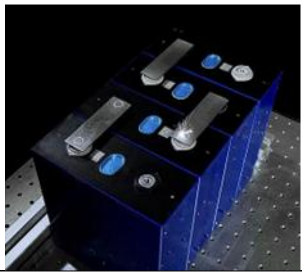
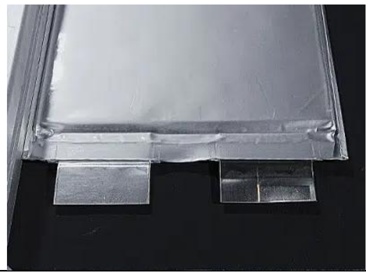
- From a plant layout standpoint, plant areas usually include: A. Electrode manufacturing, B. Cell assembly, C. Cell Finishing, D. Module assembly, E. Warehousing, and F. Offices and Utilities. Note: This is the standard layout for an integrated LIB manufacturing plant (i.e., producing. LIB for e-vehicles or LIBs for Energy Storage Systems). In some cases, third parties may be in charge of some process steps such as A. Electrode Manufacturing (e.g., a new LIB plant just starting the process from B. Cell assembly) and/or D. Module assembly.

- From a process flow standpoint, the so called "cell manufacturing process" includes the 3 first plant areas: A. Electrode manufacturing, B: Cell assembly, C: Cell Finishing.
- The "cell manufacturing process" flow chart usually includes the following steps as summarized in the following simplified block diagram:



- In more detail, the "cell manufacturing process" includes the three high-level processes and sub-processing steps mentioned above:
  - A. Electrode manufacturing: Mixing (i.e., Slurry Preparation), Coating and Drying (including solvent recovery), Calendering, Slitting, Notching, vacuum drying).
  - B: Cell assembly: separation (cutting electrodes), stacking or winding, welding conductors, electrolyte filling, enclosing.
  - C: Cell Finishing: formation, aging, testing, packaging, storage.

- The most common battery cell products are cylindrical, prismatic or pouch:

Cylindrical Cell	Prismatic Cell	Pouch Cell
		
Exemple: 4,000 to 7, 000 in an electric car	Exemple: 10,000+ in a 2MW BESS	Exemple: 4-6 modules of 36 pouches each in an electric car

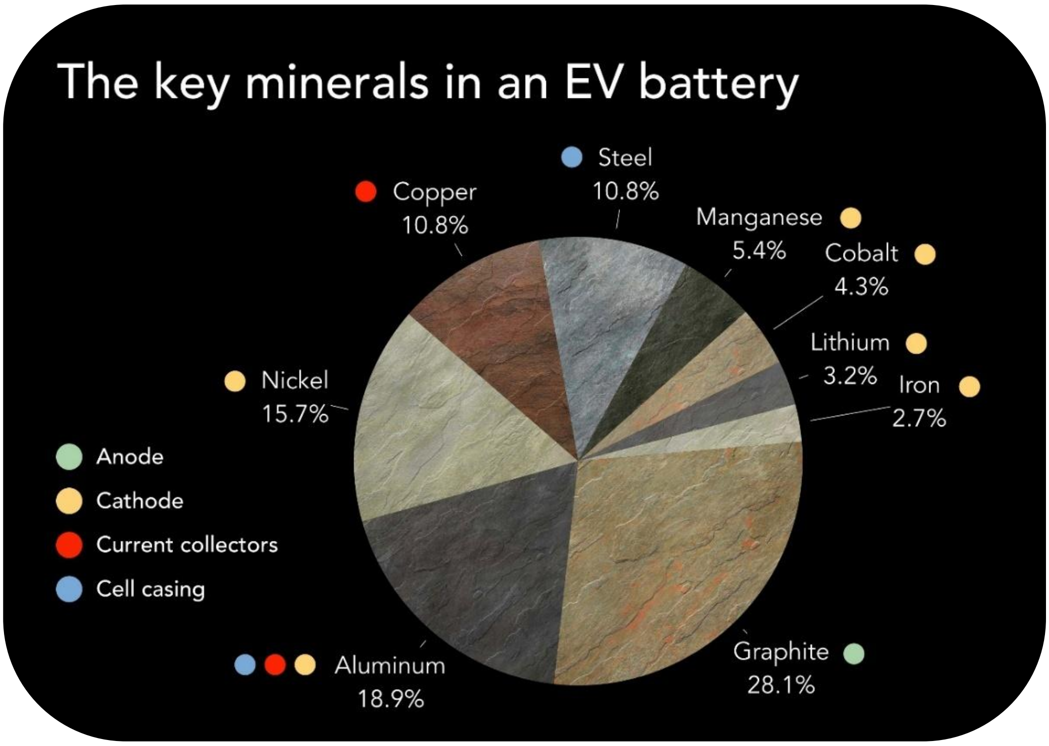
- These cell forms offer different features that are more or less adequate depending on their application, as summarized below:

Features	Cylindric Cells	Prismatic Cells	Pouch Cells
Energy density	Best	Beter	Average
Size	Best	Average	Poor
Cost	Best	Average	Average
Profile	Poor	Better	Best
Weight	Poor	Better	Best
Efficiency	Average	Best	Better
Swelling	Best	Better	Poor

Details about the sub-processing steps of the “cell manufacturing process” are given below:

A. **Electrode manufacturing**:

- Slurry preparation is commonly referred as “Mixing”. The slurries are formed by mixing active materials, carbon black, solvent, binders and additives to meet the chemistry specifications of the cathode and anode. The resulting products of the mixing are so-called “positive ink” (for positive electrode or cathode) and “negative ink” (for negative electrode or anode). The mixing process can take approximately 30 minutes to five hours. Manufacturing facilities usually run two mirror-production lines in separate clean rooms, one for the cathode and one for the anode, to avoid “cross contamination”.



- Coating and drying: the ink is coated on metal strips / foils (aluminum for the cathode and copper for the anode) 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. The drying process removes the solvent from the slurries by applying heat. The flammable solvent used in the cathode manufacturing process is typically recovered.
- Calendering: After the cathode and anode coils are cooled, they are compressed during calendering. The calendering machine gives the electrodes the required thickness and porosity.
- Cutting electrodes, commonly referred as “slitting and clipping and notching”. The wide electrode coil produced thus far, sometimes referred to as the mother coil, is divided into several smaller electrode coils or daughter coils and rewound into smaller rolls. Coated strips are cut to obtain the desired width. Clipping then gives the strip the desired length. Notching refers to a V-shaped notch and to tabs that are added to the electrode coils to form the positive and negative terminals.
- Vacuum Drying: the daughter coils are dried in a vacuum oven for 12 to 30 hours to remove residual moisture and solvents.

B. **Cell assembly**:

- Separation: The separation process is only needed for the assembly of pouch or stacked prismatic cells. This involves cutting the daughter coils into their final format using laser cutting or punching methods.

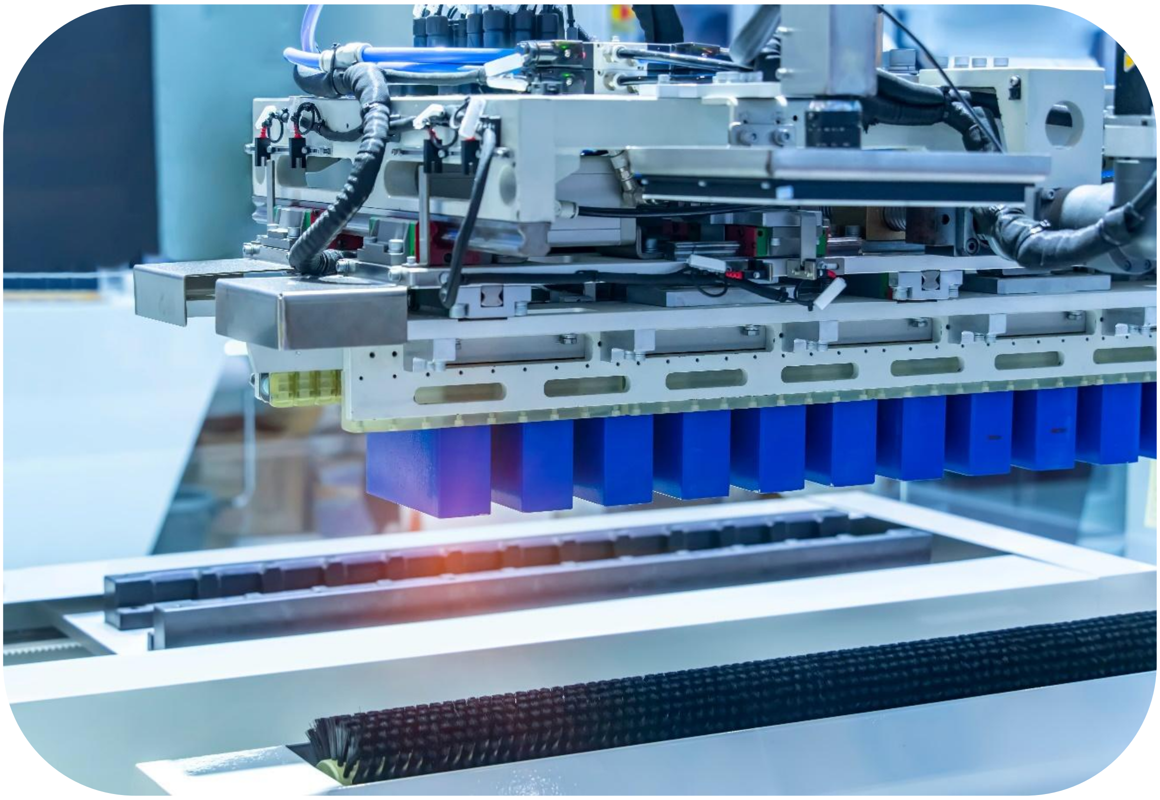
- Stacking or Winding: The winding process is used for cylindrical cells. The strips (anode and cathode) are stacked and separated by a separator, forming the electrode. The stacking process consists of placing alternating cathode sheets / foils and anode sheets / foils in a stack, with separator material between each layer, and rolling to form a jelly roll. The formed pile is then inserted into a can
- Welding: The contacts are welded to the cell stack or jelly roll and the stack or jelly roll is placed into the cell housing (pouch, can, or case) forming the cell. The cell housing is then sealed on three sides, leaving one side open to fill the cell with electrolyte in the next step.
- Filling with electrolyte: The cell is then filled with electrolyte under vacuum. Pressure with inert gas is also used to distribute the electrolyte faster
- Enclosing: the cell housing filled with electrolyte is fully sealed under vacuum. For pouch cells, another step so called "roll pressing" may then take place involving applying a defined pressure to the pouch cells in order to achieve optimum distribution and absorption of the electrolyte throughout the cell.

C. **Cell finishing**:

- Formation: The cells are placed in specially designed pallets and stored in a high-bay storage system. The cells are tested by undergoing loads, discharges, and various tests to ensure their quality. Process parameters and steps will vary from manufacturer to manufacturer and are usually proprietary (i.e., high impact on the final cell performance). Usually, the cells undergo an initial pre-charge that is followed by cycles of discharging and charging. The entire process can last up to 15 days. Electrolyte filling may be repeated at the end of the process.
- Aging: This is the final cell production step aiming to stabilize the cell properties and solid electrolyte interphase (SEI*). Aging involves monitoring each cell's parameters for quality assurance. The cells are usually charged up to 80-100% and placed in high-bay, rack storage to rest for an extended period. The duration and monitoring depend on the cell chemistry and manufacturer specifications (each cell may be monitored by the manufacturer throughout the aging process. Some other manufacturers may take the needed measurements – e.g., voltage and impedance – at the start and end of aging only). The aging process consists of multiple steps, with the cells resting at different temperatures (e.g., high temperature then ambient temperature). Note (SEI*): a polycrystalline material containing various organic and inorganic compounds, whose growth takes place at the electrode/electrolyte interface. Macroscopically, this interphase facilitates irreversible capacity loss associated with Li consumption, an increase of the cell resistance, and capacity fading. This thin, protective layer acts as a crucial barrier, regulating the flow of lithium ions.
- Testing: Process parameters and steps will vary from manufacturer to manufacturer and are usually proprietary. Testing could include pulse tests, internal resistance measurements, optical inspections, open circuit voltage tests, and leakage tests. A grade is usually assigned to the cell based on its performance data. The cell is then discharged to the shipping state of charge (SOC**), which is usually up to 30%, and sent for final packaging. Note (SOC**): The SOC is the available capacity stored in a battery, expressed as a percentage of the rated capacity. The new ICAO regulation or Technical Instruction for the Safe Transport of Dangerous Goods by Air (2015-2016 Edition) requires a controlled state of charge (SOC) at 30% or less for the shipment of Li-ion batteries by air (UN 3480). This limitation is not applicable to batteries contained in or packed with equipment (UN 3481).
- Packaging: Depending on manufacturing, the cells are either assembled into modules, packaged for shipment, or sent to the nearest user (e.g., EV manufacturer) or packaged in plastic or cardboard containers to be shipped.
- Storage: Packaged cells or modules may be stored in either palletized, solid-pile or rack storage arrangements. Automated Storage and Retrieval Systems (ASRS) may be used for highly automated manufacturing processes.

D. **Module assembly**:

- Module assembly: cells that have passed the previous tests are assembled in modules, which constitute the final product.



An example of machinery and equipment distribution for a Gigafactory with maximum production capacity is 4,000 batteries per week (40 or 50kW/h – total of 18GW).

Overview per Zones:

- Zone A (Electrode manufacturing) – 6 lines including 3 steps:
  - Mixing:
    - 16 cathode mixers using NMP solvent.
    - 12 anode mixers using purified water.
  - Coating:
    - 4 cathode coatings
    - 4 anode coatings
  - Calendering /Pressing:
    - 6 cathode presses
    - 6 anode presses

- Zones B, C, D and E (Cell manufacturing) – 7 lines (2x40kW:h and 10x50kW/h):
  - Zones B & C: Electrolyte (ELY) injection
    - Soaking 1 (8 hours)
    - Roll Press 1
    - Soaking 2 (18 hours)
    - Forming (1st charge 4 hours 60%)
    - Roll Press 2 (degassing 1 VOC using vacuum pump)
    - HTA (High Temperature 48 hours, 45°C)
    - Roll Press 3 (degassing 2 VOC)

  - Zones D & E; Forming / Aging (Charge & Discharge)
    - Forming charge / Discharge 4 hours (Enclosed Chamber Arrangements up to 12 m high)
    - Screening 1 (or Aging, 24 hours, 25°C no charge / discharge in Enclosed Chamber Arrangements up to 12 m high)
    - OCV 1 and charge & inspection (Volatile Organic Compound removal)
    - Screening 2 (or Aging, 72 hours, 25°C no charge / discharge in Enclosed Chamber Arrangements up to 12 m high)
    - OCV 2 and charge & inspection (Volatile Organic Compound removal, 2 min)
    - LPM (insulation test looking for short circuit inside cell, 10 min)
    - SOC (State of Charge - Last Charge or so called "legal charge"– 1 hour, 29%)
    - Screening 3 (or Aging, 12 hours, 25°C no charge / discharge in Enclosed Chamber Arrangements up to 12 m high)
    - Inspection (automated and cell trimming and sealing)

- Zone F (Module or stacks manufacturing) – 12 lines (assembly)
  - Assembly of 36 cells (Pouch) in one module (robot in an open roof booth)

Details for Zone A (Anode manufacturing) process – Raw Material handling:

- The raw materials arrive in big bags from the Raw Material Warehouse. In Zone A, the powders are lifted from the ground floor to the 2nd floor by autoloaders (elevators). They are then emptied into glove boxes (ATEX zone 0 around the unloading area above the glove boxes).
- The powders arrive by gravity on the 1st floor in the weighing area. Then they are transferred to the mixing area on the ground floor. There is a mixing zone for each type of electrode (anode: carbon black + deionized water + plasticizer and cathode: NMC (powder) + NMP (liquid)).
- The mixing is composed of 12 tanks of 2000 L each for the anodes for a used volume of 1200L each, and 16 tanks of 2000 L each for the cathodes for a used volume of 1200 L each.
- Each mixing tank is equipped with a planetary agitator and dispersers.
- The viscosity of the mixtures varies.
- Each batch lasts six hours.
- The ceramic-based insulating inks are four tanks of 2x200 and 2x300L
- The mixture is transferred to stainless steel tanks to be used for coating. During this phase, the coils are coated on one side, passed through the furnace (temperature by steam exchanger at 170°C), then the second side is coated and returned to the furnace. There is one furnace for the anode and one furnace for the cathode.
- The vapors of the various plasticizers and NMPs in the furnaces are treated by a RECOVERY VOC treatment plant.
- On the first floor between the mixing and the RECOVERY are the technical areas with AHU (air handling unit), dehumidifiers, chilled water and compressed air. The latter two utilities come from the U building.
- At the end of zone A, the coils pass through the calendaring in order to roll the faces of the coils. The cathode calendaring room is anhydrous.
- The electrode strips are rewound and are put on AGVs.

4. Special hazards and inherent safety requirements

From a risk control standpoint, the assessment of hazard for the Lithium-Ion Battery manufacturing process is similar to other manufacturing processes for industrial/commercial goods. The manufacturing process for lithium-ion batteries may present some unique aspects depending on cell type and manufacturer.

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-Methyl pyrrolidone—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 cleaning is carried out with the NMP recovered, then a second cleaning 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 (N-Methyl-2-Pyrrolidone. Fp: 91-93°C (196-199°F) see below for details) to be sent by pumping to the mixers (each with a volume of 8-10 m³ or more).
    - A series of agitated tanks for the storage of ink and gels prepared before transferring to the coating lines (e.g., 1,500-1,800 l each).
    - Cleaning system for 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 (86°F) 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 transferring 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:
    - NMP (N-Methyl-2-Pyrrolidone. Fp: 91-93°C (196-199°F)) The main supply should be preferably located in a detached building (i.e., utility building rooms, housing well separated rooms — at least 2hrs fire partitions — for fresh NMP tanks, pump rooms (100% redundancy recommended), used/wasted NMP tanks. NMP leak detection should be provided (e.g., ground of utility building and in process areas). The rooms should be provided with retention and drainage to an underground emergency storage tank.
    - NMP (N-Methyl-2-Pyrrolidone. Fp: 91-93°C (196-199°F)) Transfer to process area (i.e. electrode manufacturing: cathode-mixing area) should be preferably done through coaxial (i.e., double containment) piping provided with sensors detecting leakage for liquid (fresh or waste) systems that are pumped (pressurized — usually using nitrogen 3.5 bars maximum) to and from process areas. Provide pump interlock in order to stop upon leak detection and upon fire detection in the mixing area.
    - Contingency planning should be provided in case of loss of the NMP storage and pumps (e.g., direct supply from road tankers / trailers)
    - 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.

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 Nm3/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 (NMP: N-Methyl-2-Pyrrolidone. Fp: 91-93°C (196-199°F)). 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.
    - Provide fire protection for the exhaust duct (considering combustible solvent deposits in the duct).

4.3 Calendering/Slitting

- 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 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.
  - Flammable dusts and vapors can be produced during the slitting process.
- 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.
  - Vapor exhaust system should be provided.
  - ATEX in the event that the maximum heating temperature is above the HTF flash point.
  - Explosion isolation design to be considered for the machine.
  - Safety requirements for dust / vapor collectors.

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 (ELY) 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.
- Example of ELY: Lithium Hexafluorophosphate (1-) Carbonic Acid Ethyl Methyl Esther. Oxidizer class 8, Flammable 3. Fp: 29°C. Note that the ELY may contain about 60% of DEC (Diethyl carbonate. Fp. 31°C).
- ELY may be preheated (19°C) though exchangers with circulating DEC (used in the heat exchanger instead of water reacting with ELY and generating HF).

Process:

- 500-800 g of electrolyte ($LiPF_6$ + 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.

Inherent safety requirements:

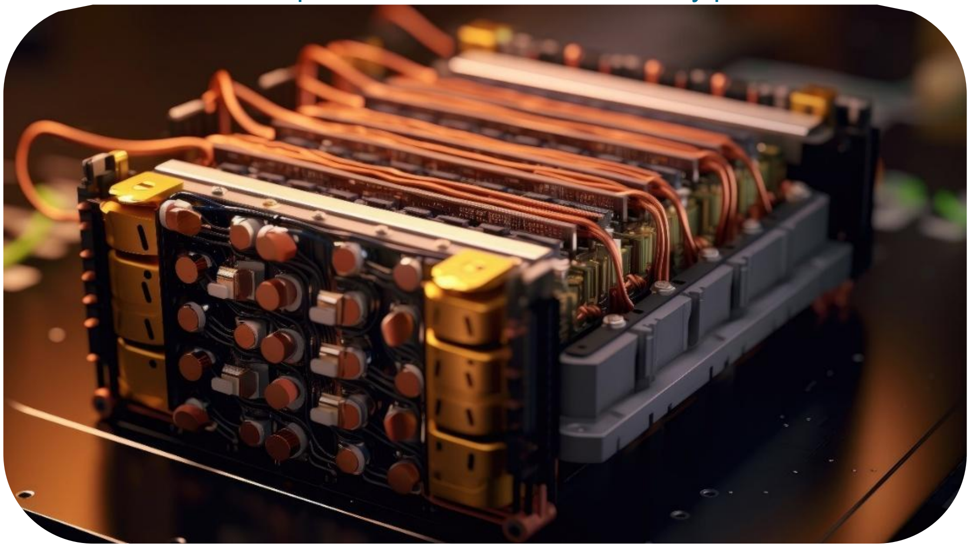
- The test chamber(s) should be 2-hour fire rated.
- Test chambers should be provided with gas detection, fire detection and thermal sensors.
- When safe (subject to risk analysis) provide interlock consisting of shutting down the charging process upon gas/fire/thermal detection.

- Flammable gases released during a thermal runaway should be collected by the emergency extraction activated in the event of fire detection. The ductwork of this emergency extraction system should be the shortest route to outdoors (away from critical processes) and should be designed according to FM Data Sheet 7-78, “Industrial Exhaust System.”

4.7 Module assembly

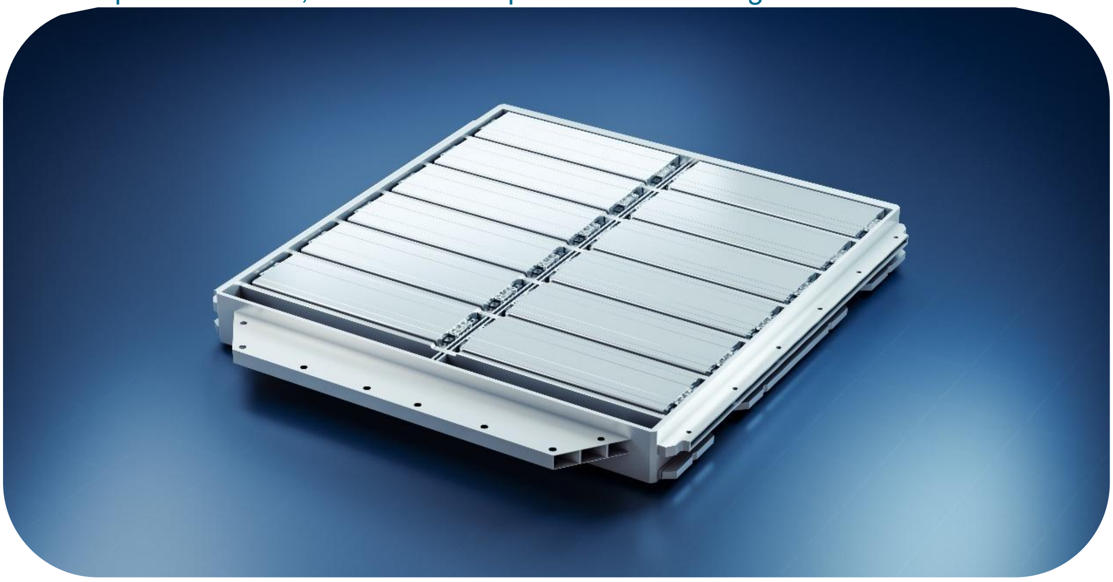
- More than one module assembly line may be installed in either the same room or a different room.
- In the first section, the battery cells are tested and prepared for assembly.
- In the second section, a so-called raw module is produced by using multiple battery cells. The cells are combined into a 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



4.8 Rejected cells

- Hazard:
  - Non-compliant cells for scrapping may represent up to 80% of production at the early stage of production for a new plant, and be gradually reduced to less than 30% after fine-tuning.
  - These non-compliant cells need to be to be sent to recycling facilities. However, the state of charge (SOC) is usually less than 30% (e.g., reportedly 29%) and would be accepted by some recycling facility only if totally de-energized.
  - When there is no de-energization facility on site, several tons of non-compliant cells for scrapping may be “temporary” stored on pallets in a process or storage building which is not dedicated for such hazard.
  - Potential fire involving one cell and thermal runaway involving several tons of non-compliant cell resulting in large loss (fire and smoke contamination).

Inherent safety requirements:

- Provide dedicated storage, adequately separated and protected, not exposing any other facilities. See storage section for rejected cells.

5. Foreseeable Loss 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_5 H_9 N O, Liquid, Flash Point: 91 °C/195.8 °F, Autoignition Temperature: 346 °C/654.8 °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 calendaring 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 Fp. 31°C), 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. Rejected Lithium-Ion batteries may be also charged at less than 30% (i.e., 29%)

  Note that lithium-Ion batteries have a propensity for thermal runaway, regardless of the State of Charge (SOC). The cells contained by the lithium-Ion batteries are potentially electrochemically active due to the electrochemical potential of lithium (tendency of metal to lose electron — first cell developed by Alessandro Volta 200 years ago — lithium having the highest potential).

  State of charge (SOC) quantifies the remaining capacity available in a battery at a given time. It is usually expressed as percentage (0% = empty, 100% = full).

Different State of Charge (SOC) for lithium-Ion batteries - main definitions and use:

SOC (SOC%)	Definitions & Uses
Less than 30% (1)	"Commercial charge" or "legal charge": less than 30% (usually 29%). Typically, the charge of rejected lithium-Ion batteries from manufacturing facilities, which should be stored in a dedicated area and de-energized prior to be sent to recycling facilities.
No more than	"Reduced state of charge" as per NFPA855: state of charge at less than or equal to 30%. "Shipping state of charge" or "Controlled state of charge: usually no more than 30% for the Safe Transport of Dangerous Goods by Air.
Between 30% and 60%	Different transport authorities legislate on the state of charge (SOC) for shipping and storage, which is typically a charge between 30% and 60%.
Above 60% (2)	States of charge above 60% are generally intended for immediate use rather than indefinite storage.

Note: the list above is not exhaustive and different authorities and legislation may have different definitions

(1) Fire tests have been conducted at these levels of charge. It has been shown that cells with a SOC below 30% have a very low propensity for thermal runaway. Thermal runaway is however still, possible.

(2) The higher the state of charge, the more reactive a battery is in a fire scenario. At a minimum, the fire severity and duration could be increased. The impact of SOC also varies for different cell chemistries and can even vary for different cells of the same chemistry.

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 protected as per NFPA standards and/or FM data sheets.
- However, until October 2024, there were no specific NFPA standards 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. There was no dedicated standard for LIB manufacturing. Using both the NFPA standard and the FM Global Datasheet for fire protection was therefore considered an adequate approach. This could be done in a more or less conservative way.
- The October 2021 interim revision of FM Data Sheet 3-26 "Fire Protection for non-storage occupancies" gave the first guidance for Lithium-Ion Battery protection and clarified that battery manufacturing includes Lithium-Ion Batteries.
- The January 2023 interim revision of FM Data Sheet 8-1 "Commodity Classification" gave the first "clarified and expanded" guidance for Lithium-Ion Battery storage protection.

Reference to FM Data Sheet 8-9 “Storage of Class 1, 2, 3, 4 and Plastic commodities” was made based upon the storage configuration (open-frame rack, solid-pile or palletized) and the protection option was based on the ceiling height.

- As of October 2024, there has been one dedicated standard for LIB manufacturing and storage: FM Data Sheet 7-112 “Lithium-Ion Battery Manufacturing and Storage”. As a result of this, the guidance for Li-ion batteries was removed from the October 2024 interim revision of the FM Data Sheet 8-1 “Commodity Classification”.

- Note that within FM Data Sheet 7-112 “Lithium-Ion Battery Manufacturing and Storage,” reference to FM Data Sheet 8-9 “Storage of Class 1, 2, 3, 4 and Plastic commodities” is also made based upon the storage configuration (open-frame rack, solid-pile or palletized), and the protection option is based on the ceiling height).

- As of mid-2025, an NFPA Technical Committee has been in charge of developing the NFPA 800 Battery Safety Code.
- As a result of the above, and depending on location and age of the facility, the following standards for fire protection may have been considered: NFPA 13 Editions 2019, 2022, 2025, FM Data sheets pre-October 2024, and FM Data Sheet 7-112 “Lithium-Ion Battery Manufacturing and storage”. Design data is given in this document for information so that Risk Engineers can identify such systems, compare with the latest standards, and give economically justified recommendations when needed.

Considering the above, fire protection should be defined according to occupancy, commodity storage and special hazards. So, mentioning NFPA standards or even FM Data Sheets 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 Miscellaneous storage and low pile storage - i.e., limited to 3.7 m (12 ft) in height – should be protected as per NFPA 13 edition 2025, Table 4.3.1.7.1, and weighed as a minimum requirement, with unusual or abnormal fuel loadings or combustible characteristics and susceptibility noted:

6.2 Storage & Supply of Electrolyte and Solvent

- This should be protected by a deluge system as per NFPA30 "Flammable and Combustible Liquids Code" (section 16.5 Fire Protection System Design Criteria) and NFPA 15 "Water Spray Fixed Systems". Foam-water sprinkler systems shall be installed in accordance with NFPA 11 Standard for Low, Medium, and High Expansion Foam. The fire protection system design depends on the class of liquid, type of storage, and arrangement (rack, pallets, bulk containers).

- Main Hazardous liquids (examples below):
  - NMP: N-Methyl-2-Pyrrolidone. Flash Point: 91-93°C (196-199°F), Boiling Point: 202°C (395.6°F), Autoignition Temperature 346°C (654.8°F), Class IIIB Liquid as per NFPA30.
  - ELY: Lithium Hexafluorophosphate (1-) Carbonic Acid Ethyl Methyl Esther. Oxidizer class 8, Flammable 3. Fp: 29°C (may contain up to 60% DEC), Class IC Liquid as per NFPA30.
  - DEC: Diethyl carbonate. Fp. 31°C (87.8°F), Boiling Point: 126°C (258.8°F), Autoignition Temperature 445°C (833°F) Class IC Liquid as per NFPA30.
  - Note for the electrolyte ELY:
    - Non-ionized $LiPF_6$ dissociates to PF_5 and LiF in organic solvents and PF_5 reacts with water. A solvent with a high dielectric constant increases the ionization of $LiPF_6$ thereby suppressing the reaction with water.
    - As the Material Safety Data Sheet (MSDS), there is no special restriction for extinguishing media for Lithium Hexafluorophosphate ($LiPF_6$) (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 foam first.
    - Note that NFPA 16 "Standard for the Installation of Foam-Water Sprinkler and Foam-Water Spray Systems" requires a discharge duration of 10 minutes. NFPA 30 requires a discharge duration of 15 minutes. Many "Authorities Having Jurisdiction" may require a discharge duration of 20 minutes.
    - Note also that if the fire is not extinguished before the foam is exhausted, water will drain out of the foam blanket, breaking down the foam.
    - The advantage of using foam is therefore deemed questionable in such cases (i.e., tridimensional fire involving tanks, pumps and piping).

6.3 The manufacturing process

Current standard

At the present time:

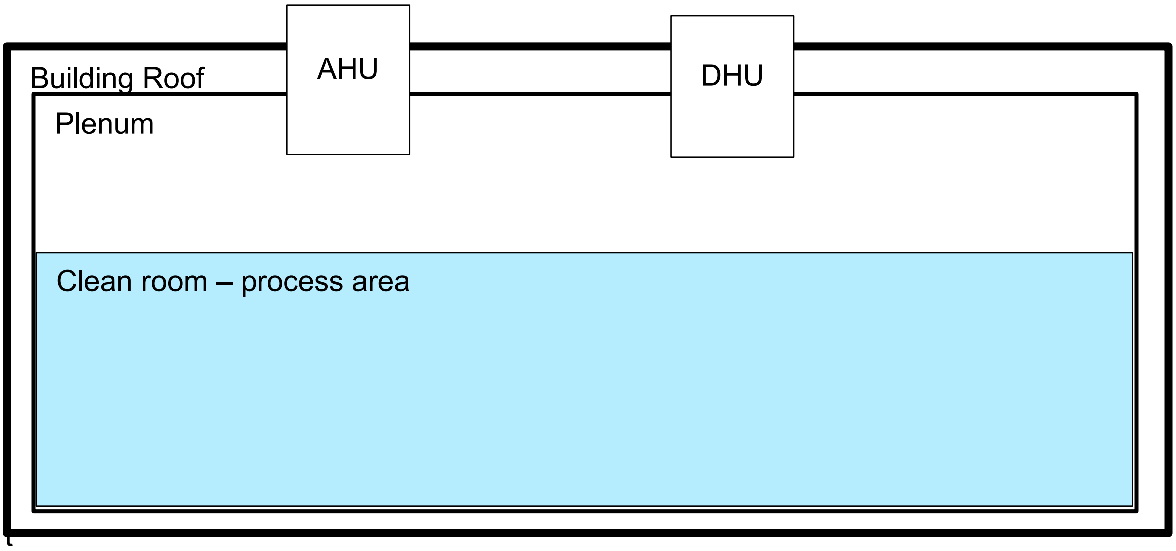
- Lithium-Ion Battery fires can exceed the common water durations for non-storage occupancies.
- Limited publicly available fire test data exists that confirms the effectiveness of any active fire protection for lithium-ion batteries.

Based on the above:

- Passive fire protection in non-storage occupancies is designed to maintain a reasonable "incidental storage" (see section above), by limiting the footprint and height of the allowable storage, and to provide adequate segregation from surrounding combustibles. This protection therefore consists of limiting and maintaining the minimum combustible load and the continuity of combustibles as a result of the activity (i.e. Work In Progress material – WIP – Finished Cells / Modules / Batteries)
- Automatic sprinkler protection is recommended to limit fire spread to the surrounding structure, equipment and building contents.

As a reminder, the manufacturing process consists of the following main steps: A. Electrode manufacturing, B. Cell assembly, C. Cell Finishing (including Formation and aging), and D. Module assembly

- All operations related to A. Electrode manufacturing and B. Cell assembly may take place in one single Manufacturing Building that may house five to ten clean room areas (i.e., Cathode Mixer; Cathode Coater; Cathode Roll Press; Anode Mixer; Anode Coater; Anode Roll Press).
- Typical section view of clean room area:



DHU: dehumidified air handling system (desiccant dehumidifier especially designed to meet the requirements of air cleanliness, temperature, and humidity)
AHU: air handling unit (used to regulate and circulate air as part of heating, ventilating, and air-conditioning)
Fire dampers should be provided in ventilation ducts.
Depending on combustible load the plenum may be sprinkler-protected
The AHU and DHU may be sprinkler-protected (subject to OEM clearance)

Ventilation ducts handling flammable vapors should be sprinkler-protected
The clean room process area is sprinkler-protected (including under obstructions).

Note on A. Electrode manufacturing - Mixing:

- 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 decompose 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 B. Cell assembly - electrolyte filling process step:

- Non-ionized $LiPF_6$ dissociates to PF_5 and LiF in organic solvents and PF_5 reacts with water. A solvent with a high dielectric constant increases the ionization of $LiPF_6$ thereby suppressing the reaction with water.
- As the Material Safety Data Sheet (MSDS), there is no special restriction for extinguishing media for Lithium Hexafluorophosphate ($LiPF_6$) (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).

As a result of the above, sprinkler systems need to be designed to protect the following process areas as per FM Data sheets pre-October 2024, FM Data Sheet 7-112 "Lithium-Ion Battery Manufacturing and storage" as summarized below:

Process areas	**Main Hazards**	**FM Data Sheet 7-112 "Lithium-Ion Battery Manufacturing Oct. 2024 and other related Data Sheets**
A. Electrode manufacturing	Chemicals and process equipment such as heaters and flammable solvent vapor in the ducts.	Ceiling sprinkler: HC-3 (*) design in accordance with Data Sheet 3-26 "Fire Protection for Non-Storage Occupancies" Table 2.3.1.10 (see below) Sprinkler Design Demands for Hazards Categories. And FM Data Sheet 7-112 "Lithium-Ion Battery Manufacturing and storage" and Table 2.1.3 (see below) for other key applicable Data Sheets for special hazards and specific process step (e.g., FMDS 7-14 "Fire protection for Chemical plant" for Mixing area)
B. Cell assembly	Use of an ignitable liquid electrolyte. The cell is potentially electrochemically active.	

Process areas	Main Hazards	FM Data Sheet 7-112 "Lithium-Ion Battery Manufacturing Oct. 2024 and other related Data Sheets
		Hose Allowance 1,900 L/min (500 gpm), 120 min duration (based on FMDS-7-14 "Fire protection for Chemical plant")
C. Cell finishing	Fire hazard due to chemical energy stored in the cell.	Ceiling sprinklers: designed to protect the surrounding occupancy Data Sheet 3-26 "Fire Protection for Non-Storage Occupancies" / Data Sheet 8-1, Commodity Classification (assuming same as for as for A. Electrode manufacturing and B. Cell assembly: Ceiling sprinkler HC-3 design in accordance with Data Sheet 3-26 "Fire Protection for Non-Storage Occupancies" Table 2.3.1.10 (see below) Sprinkler Design Demands for Hazards Categories. And FM Data Sheet 7-112 "Lithium-Ion Battery Manufacturing Table 2.1.3 (see below) for other key applicable Data Sheets for special hazards and specific process steps. No need to hydraulically balance the ceiling sprinkler system with the in-rack or bin-box protection system. Formation and Aging In-Rack sprinklers (**): **Open-Frame Rack** Arrangements: as per FM Data Sheet 7-112 "Lithium-Ion Battery Manufacturing" Figures 2.4.2.2.1-1 (see below) for Single Row Rack and 2.4.2.2.1-2.for Double Row Rack Design: minimum flow of 60 gpm (227 L/min) 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. Minimum discharge pressure for K-factor: ≥ K160 (11.2): 0.7 bar (10 psi) < K160 (11.2): 0.5 bar (7 psi) Ceiling Sprinkler demand not included In Rack Sprinkler hydraulic calculation. **Bin-box or Enclosed Chamber Arrangements** (shelving arrangements or charging chambers with four- or five-sided holding areas i.e., bin-box storage array or fully enclosed chamber) Design: at least 60 gpm (230 L/min) for the six (6) most remote sprinklers.
	Electrochemical hazards are present throughout the cell finishing steps, and the greatest fire hazard exists within the formation and aging process steps due to the large quantity of cells stored near each other for long durations. Formation and aging areas are expected to experience a higher-than-normal number of thermal runaway events. This is where the cells first undergo charging and discharging and stabilization of the cell properties, and where the solid electrolyte interphase (SEI) film occurs. A cell does not need oxygen to burn.	

Process areas	Main Hazards	FM Data Sheet 7-112 "Lithium-Ion Battery Manufacturing Oct. 2024 and other related Data Sheets
		Quick response, ordinary temperature, K115 (K8.0) or larger in-rack sprinklers **Hose Allowance** 1,900 L/min (500 gpm), 120 min duration.
D. Module assembly		No specifically indicated. Assuming same as for A. Electrode manufacturing and B. Cell assembly: Ceiling sprinkler HC-3 design in accordance with Data Sheet 3-26 "Fire Protection for Non-Storage Occupancies" Table 2.3.1.10 Sprinkler Design Demands for Hazards Categories. **Hose Allowance** 1,900 L/min (500 gpm), 120 min duration.

(*) HC-3 is defined as per Data Sheet 3-26 "Fire Protection for Non-storage Occupancies" as predominant occupancy involving areas with generally continuous heavier combustible loading, with limited quantities of ignitable liquids and/or heavier amounts of plastic. (e.g., plastic manufacturing, vehicle manufacturing and assembly, and printing plants).

Moreover, automatic sprinklers or FM-Approved water-mist shall be installed in the following areas:

- Under obstructions or mezzanines exceed 0.9 m (3 ft) in width or diameter or 0.9 m^2 (10 t^2) in area
- Inside enclosed equipment such as ovens, hoods or test enclosures made of combustible material, or within obstructed areas containing combustibles
- Inside enclosures around production equipment if the ceiling protection is not designed for HC-3 occupancies or if higher-hazard processes take place inside such as electrolyte filling, cell charging/discharging etc.

(**) Formation and aging: the higher the level of protection, the lower the number of cells that will be involved, the less flammable/corrosive gas that will be generated, and the less water that will need to be discharged into the area. This approach should limit the extent of non-thermal damage to the other cells in the area.

SCOR consideration:

Occupancy class: for reactive metal chemistry or reactive ion chemistry with flammable liquid electrolyte battery manufacturing, where thermal runaway is the prevailing hazard, FM Global DS 7-112 gives guidance on sprinkler system design.
For reactive metal chemistry or reactive ion chemistry battery manufacturing, the various "operations" may take place in one single manufacturing building that may house five to ten clean room areas (e.g., cathode mixing, cathode coating, cathode roll press, anode mixing, anode coating, anode roll press, etc.). In such cases of multiple clean rooms when thermal runaway is not the prevailing hazard, NFPA 318, "Standard for the Protection of Semiconductor Fabrication Facilities" and FMDS 7.7 "Semiconductor Fabrication facilities" can provide useful guidance on sprinkler system design.

Wet pipe vs. Dry pipe: note that **SCOR's preference is for wet-pipe sprinklers.** This is the traditional type of fire sprinkler where the sprinkler pipes are filled with pressurized water that will immediately discharge when a fire occurs. The biggest advantages that wet-pipe sprinkler systems offer are simplicity and reliability. Wet-pipe fire sprinkler systems contain the least number of components, reducing the risk of malfunction when the system lies dormant for long periods of time. The maintenance required to keep the system in good working condition is less than for some more complicated types of fire suppression systems. Due to the simplicity of these systems, they can be installed quickly and require less service time.

Should plant Management have serious concerns about water contamination due to sprinkler malfunction or pipe breakage during EQ or freezing conditions, dry-pipe systems may be considered. The decision to use a dry-pipe system rather than a wet-pipe system should be based on loss expectancy due to water contamination from accidental sprinkler water discharge, versus smoke contamination and fire damage due to late actuation of the dry-pipe system compared to wet-pipe sprinklers.

Since piping is dry, there can be delay of up to 60 seconds while water travels between the valve and the sprinkler head. A disadvantage of dry-pipe systems is that fire can spread for a slightly longer time before the affected zone is showered with water. Dry-pipe fire suppression systems also require more testing and maintenance than traditional wet-pipe systems. Dry systems require auxiliary drains and drum drips to be exercised regularly and full or partial trip testing. System reliability and longevity should also be considered when comparing dry-pipe systems with wet-pipe systems. Oxygen is the primary cause of corrosion and leaks in fire sprinkler systems.

Dry-pipe systems include:

- "Standard" dry-pipe system: The pipe is not constantly filled with water. Instead, the water is held behind a dry-pipe valve, usually some distance away from where the sprinklers are located. Like a wet-pipe system, when the temperature at the ceiling becomes hot enough, the glass bulb or fusible link of the sprinkler breaks. However, in this case, water isn't immediately available because the pipe is not filled with water. Instead, air is released from the now open sprinkler head. This creates a drop in pressure, causing the dry-pipe valve to open and water to fill the system. Water will then flow from the open sprinkler head.
- Preaction with single interlock: The operation of single interlock systems are similar to dry systems except that these systems require a "preceding" fire detection event, typically the activation of a heat or smoke detector, which takes place prior to the "action" of water introduction into the system's piping by the opening the pre-action valve, which is a mechanically latched valve (i.e., similar to a deluge valve)
- Preaction with double interlock: these systems are designed for water-sensitive areas that require the maximum protection from inadvertent water flow into the sprinkler system piping (e.g., refrigerated). Two events must take place for water to flow into the system. A fire detection device must operate, and the low air pressure switch must be triggered by the loss of system air pressure (sprinkler operation). These two signals must coexist at the releasing control panel, which only then will energize the normally closed solenoid valve, causing water to flow into the system.

Tables:

Data Sheet 3-26 "Fire Protection for Non-Storage Occupancies" Table 2.3.1.10 Sprinkler Design Demands for Hazards Categories

Table 2.3.1.10 Sprinkler Design Demands for Hazard Categories

Hazard Category	*Ceiling Height up to 30 ft (9 m)*		*Ceiling Height 30-45 ft (9-13.5 m)*		*Ceiling Height 45-60 ft (13.5-18 m)*		*Ceiling Height 60-100 ft (18-30 m)*	
	(gpm/ft²)/ft² [(mm/min)/m²]							
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
HC-1	0.1/1500 (4/140) Note 1	0.1/1500 (4/140)	0.2/2500 (8/230)	0.2/3500 (8/330)	0.2/2500 (8/230)	0.2/3500 (8/330)	0.6/1200 (24/110)	Design guidance currently unavailable.
HC-2	0.2/2500 (8/230) Note 2	0.2/3500 (8/330)	0.2/2500 (8/230)	0.2/3500 (8/330)	0.2/2500 (8/230)	0.2/3500 (8/330)	0.6/1200 (24/110)	
HC-3	0.3/2500 (12/230) Note 2	0.3/3500 (12/330)	0.3/3600 (12/340)	0.3/4600 (12/430)	0.5/3000 (20/280)	0.5/4000 (20/370)	0.6/1200 (24/110)	

Note 1. The demand area for dormitories, residential, and dwelling type areas may be based on the largest room area, but not less than four sprinklers provided fire compartmentation with a minimum one hour fire rating is present. Treat corridors as rooms in making this determination.

Note 2. For HC-2 and HC-3 occupancies with ceiling heights not in excess of 30 ft (9.1 m) and protected by wet sprinkler systems, the designs for these occupancies can be reduced to the following when 160ºF (70ºC) K11.2EC (K160EC) upright or 160ºF (70ºC) K14.0EC (K200EC) upright sprinklers are being installed:

- K11.2EC: 0.30 gpm/ft² over 1500 ft² (12 mm/min over 140 m²). Ensure a minimum of 6 sprinklers in the design
- K14.0EC: 0.30 gpm/ft² over 1000 ft² (12 mm/min over 90 m²). Ensure a minimum of 4 sprinklers in the design

FM Data Sheet 7-112 "Lithium-Ion Battery Manufacturing Table 2.1.3 for other key applicable Data Sheets for special hazards and specific process steps.

Table 2.1.3. Manufacturing Hazards and Applicable Data Sheets

Process Step	*Hazards*	*Other Key Applicable Data Sheets*
Raw Material/Electrode Coating Manufacturing		
Production of Cathode Active Material	Chemical reactions	Data Sheet 7-14, *Fire Protection for Chemical Plants* Data Sheet 7-43, *Process Safety* Data Sheet 7-45, *Safety Controls, Alarms, and Interlocks* Data Sheet 7-46, *Chemical Reactors and Reactions*
Electrode Manufacturing		
Mixing Coating Drying Solvent Recovert Calendering Slitting Notching Vacuum Drying	Ignitable liquids use, mixing Heat transfer system Ovens Concealed combustibles Thermal rolls Solvent recovery/ destruction Clean rooms Incidental storage	Data Sheet 1-56, *Cleanrooms* Data Sheet 3-26, *Fire Protection for Nonstorage Occupancies* Data Sheet 6-9, *Industrial Ovens and Dryers* Data Sheet 7-2, *Waste Solvent Recovery* Data Sheet 7-9, *Dip Tanks, Flow Coaters and Roll Coaters* Data Sheet 7-29, *Ignitable Liquid Storage in Portable Containers* Data Sheet 7-32, *Ignitable Liquid Operations* Data Sheet 7-76, *Combustible Dusts* Data Sheet 7-78, *Industrial Exhaust Systems* Data Sheet 7-88, *Outdoor Ignitable Liquid Storage Tanks* Data Sheet 7-98, *Hydraulic Fluids* Data Sheet 7-99, *Heat Transfer Fluid Systems*
Cell Assembly		
Separation Stacking or Winding Welding or Sealing Electrolyte Filling Enclosing	Ignitable liquid use and dispensing Welding Dust collectors Incidental storage	Data Sheet 3-26, *Fire Protection for Nonstorage Occupancies* Data Sheet 7-14, *Fire Protection for Chemical Plants* Data Sheet 7-29, *Ignitable Liquid Storage in Portable Containers* Data Sheet 7-32, *Ignitable Liquid Operations* Data Sheet 7-76, *Combustible Dusts* Data Sheet 7-88, *Outdoor Ignitable Liquid Storage Tanks*
Cell Finishing		
Formation Degassing Aging Testing Packaging	Pre-charging Thermal runaway Quantity of cells Non-thermal damage	Data Sheet 8-1, *Commodity Classification*

Figures:

FM Data Sheet 7-112 "Lithium-Ion Battery Manufacturing - Figures for Open Frame Rack Arrangements

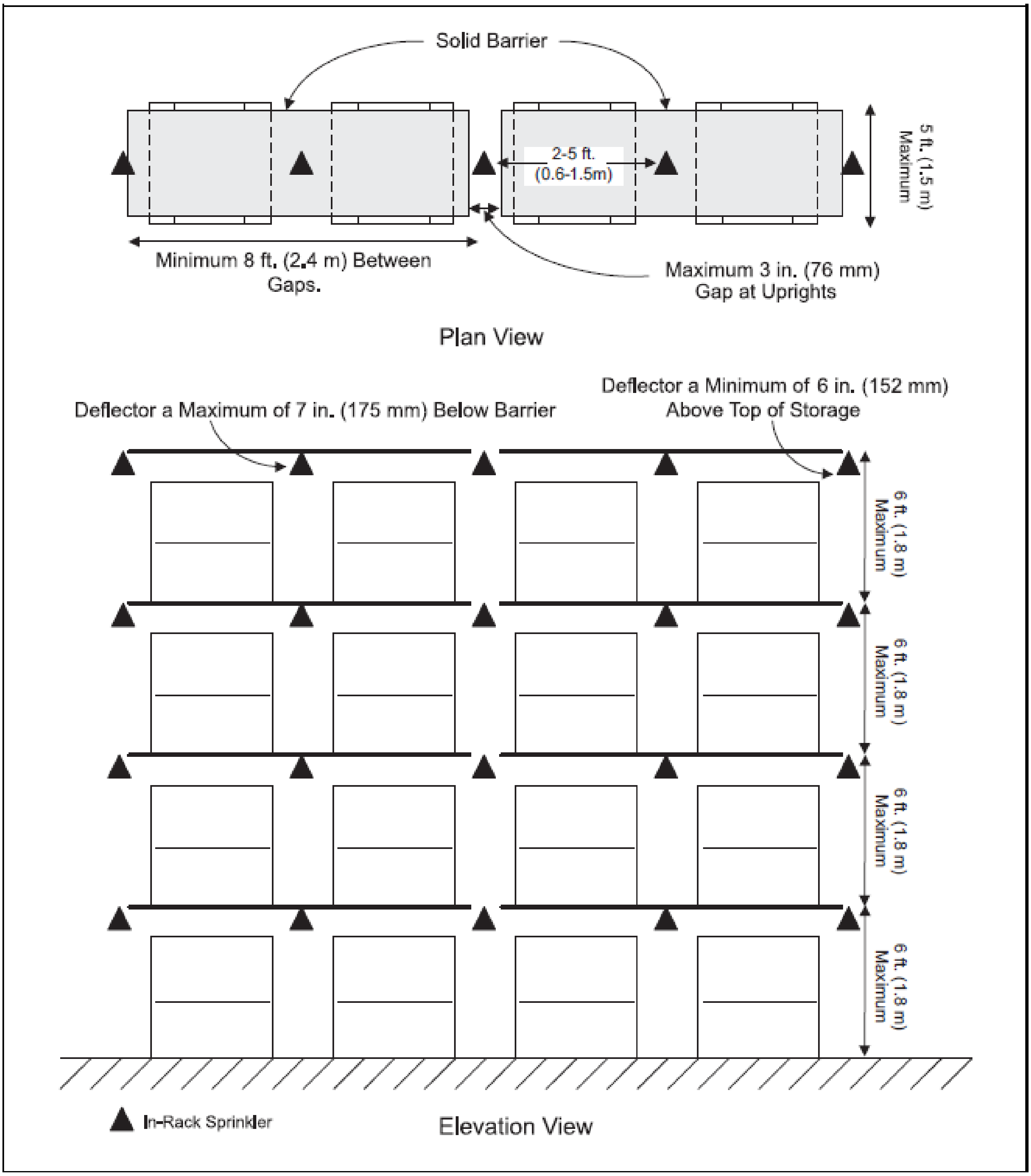


Fig. 2.4.2.2.1-1. Single-row rack in-rack sprinkler layout for li-ion cells/modules/batteries

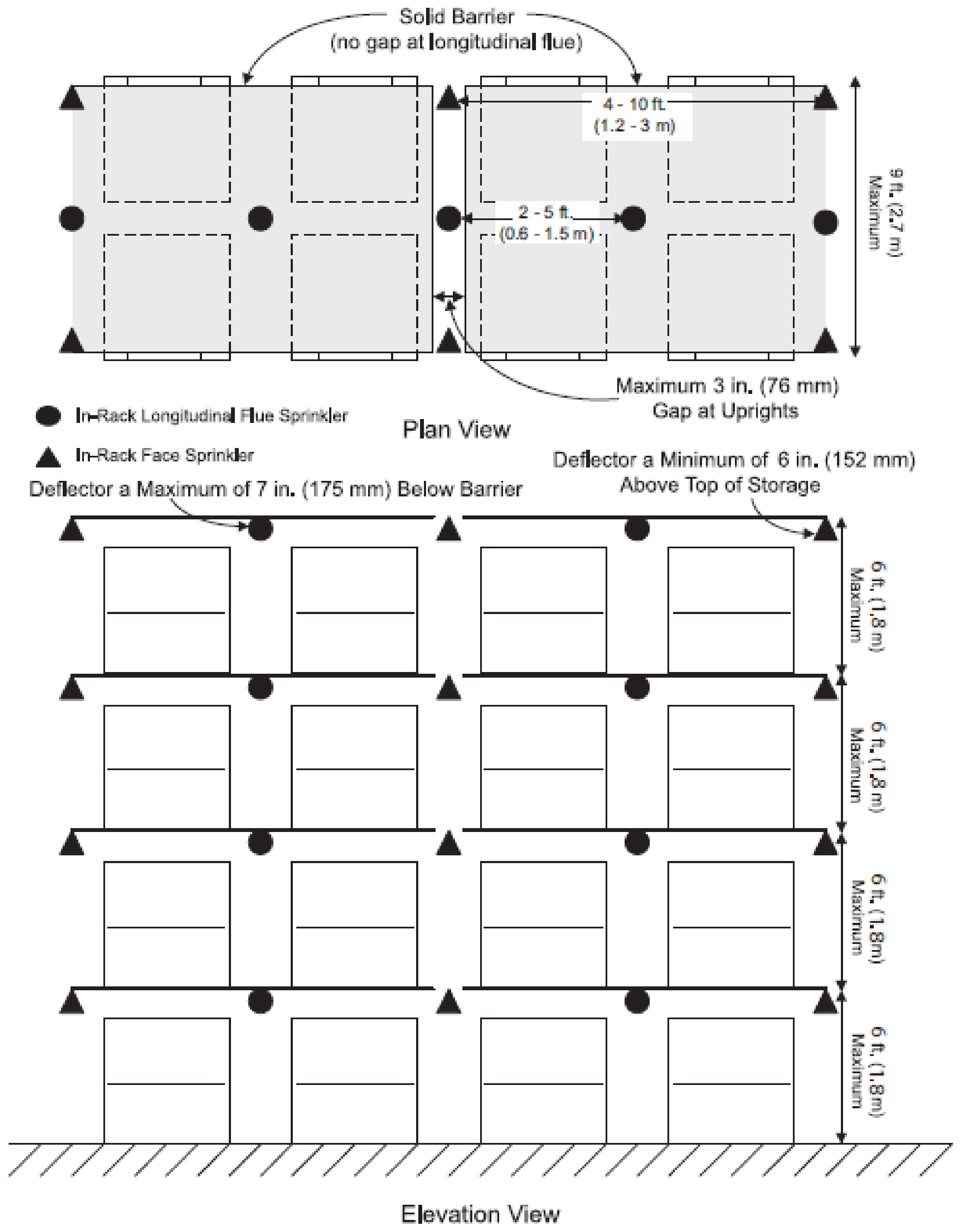


Fig. 2.4.2.2.1-2. Double-row rack in-rack sprinkler layout for li-ion cells/modules/batteries

Previous standard

For information, depending on the age and location of facilities, the following potential sprinkler design may be found for facilities protected as per NFPA 13 Editions 2019, 2022, 2025, and as per FM Data sheet pre-October 2024 re-October 2024 FM Data Sheet 7-112 “Lithium-Ion Battery Manufacturing and storage”:

Note that these designs are NOT dedicated to Lithium-Ion Battery Manufacturing and storage.

SCOR consideration:

When these designs are less conservative than those required as per Oct. 2024 FM Data Sheet 7-112 “Lithium-Ion Battery Manufacturing and storage,” the fixed fire protection of such facilities is therefore deemed NOT Adequate under current dedicated international standards.

For example: for A. Electrode manufacturing, B. Cell assembly, C. Cell Finishing (including Formation and aging), and D. Module assembly, the current standard FM Data Sheet 7-112 “Lithium-Ion Battery Manufacturing and storage” requires the following,for wet-pipe sprinklers:

- HC-3:12L/min/m² over 230m² (0.3gpm over 2500ft² up to 9m (30ft) high
- HC-3:12L/min/m² over 340m² (0.3gpm over 3600ft² between 9-13m (30-45ft) high
- Hose Allowance & Fire Water Supply Duration 1,900 L/min (500 gpm) for 120min duration.

Versus:

NFPA 318 “Standard for the production of Semiconductor Fabrication facilities” and FMDS 7.7 (2.3.4.1) Semiconductor Fabrication facilities:

- 8.15 L/min/m² (0.20 gpm/ft²) over a design area of 280m² (3000 ft²).
- Hose Allowance & Fire Water Supply Duration 946 L/min (250GPM) for 90 minutes’ duration.

As a reminder, the manufacturing process consists of the following main steps: A. Electrode manufacturing, B. Cell assembly, C. Cell Finishing (including Formation and aging), and D. Module assembly.

For manufacturing process A. Electrode manufacturing and B. Cell assembly of lithium-Ion batteries:

- All operations related to A. Electrode manufacturing and B. Cell assembly may take place in one single Manufacturing Building housing for example five to ten clean room areas (i.e., Cathode Mixer; Cathode Coater; Cathode Roll Press; Anode Mixer; Anode Coater; Anode Roll Press).
- As a result, the manufacturing process A. Electrode manufacturing and B. Cell assembly of lithium-Ion batteries including clean rooms could have been assimilated to semiconductor facilities from the hazards standpoint. Which leads to the following fire protection designs:
    - As per NFPA 13 editions 2029, 2022, 2025:
        - NFPA13 section 27 Special Occupancy Requirements / 26.23 for edition 2019 and 27.28 for editions 2022, 2025: NFPA 318 “Standard for the Protection of Semiconductor Fabrication Facilities” section 11.1.4 Building Automatic Sprinkler Systems and section 11.2.2 Exhaust Ducts.
        - Wet-pipe automatic sprinkler protection shall be provided throughout facilities containing clean rooms and clean zones as follows:

- Clean rooms or clean zones: hydraulically designed for a density of 8.15 L/min/m² (0.20 gpm/ft²) over a design area of 280 m² (3000 ft²).
- Plenum and interstitial space above clean rooms: designed for a density of 8.15 L/min·m² (0.20 gpm/ft²) over a design area of 280 m² (3000 ft²).

- Approved quick-response sprinklers shall be utilized for sprinkler installations within down-flow airstreams in clean rooms and clean zones.
- Moreover, automatic sprinklers ("interior") shall be provided in exhaust ducts conveying vapors, fumes, or mists generated by hazardous chemicals as follows:

    - In metallic and noncombustible, nonmetallic exhaust ducts where the largest interior cross-sectional area is equal to or greater than 0.048 m^2 (75 $in.^2$) and in ducts that are conveying flammable vapors or fumes at concentrations greater than 25 percent of the lower flammable limit (LFL).
    - In combustible nonmetallic exhaust ducts where the largest interior cross-sectional area is equal to or greater than 0.048 m^2 (75 $in.^2$).
    - Sprinklers installed in duct systems shall be hydraulically designed to provide 1.9 L/min (0.5 gpm) over an area derived by multiplying the distance between the sprinklers in a horizontal duct by the width of the duct.

- As per FMDS 7.7 (2.3.4.1) Semiconductor Fabrication facilities:
    - 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/m² (0.2 gpm/ft²) over the hydraulically most remote 280 m² (3,000 ft²), 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/m² (0.19 gpm/ft²) over the hydraulically most remote 280 m² (3,000 ft²), with an additional allowance of 946LPM (250GPM) for hose streams for a duration of 90 minutes.

- Note that so called non-clean room areas, including process buildings housing the clean room and plenum, may have been protected considering NFPA occupancy classes (i.e. OH1, EOH2, EH1 and EH2) as follows:
    - NFPA13 edition 2019 Building ceiling sprinkler - regardless of ceiling heights (i.e., 10-14 m high): wet-pipe sprinkler OH2 (7.5 lpm/m² over 232 m² / 0.18 gpm/sq² over 2,500 ft²) or EH1 (12.2 lpm/m² over 232 m²; 0.3 gpm/sq² over 2,500 ft²) (*)
      Vs.
    - FM global Data sheet 7-112 ("Lithium-Ion Battery Manufacturing and storage") dated October 2024 recommends using HC-3 densities related to commodity and depending on ceiling height for wet-pipe systems as follows:
        - ✓ - 12.2lpm/m² over 340 m²; 0.3 gpm/sq² over 3,600 ft² under the ceiling between 9 and 13.5 m height.

- ✓ - 20 lpm/m^2 over 280 m^2; 0.5 gpm/sq^2 over 3,000 ft^2 under the ceiling between 13.5 and 18 m height.

Vs.

- As per NFPA13 edition 2025 High Ceilings (Non-Storage): NFPA 13 historically did not give a maximum effective height for spray sprinklers or any special considerations for "high" ceilings when protecting non-storage occupancies. In the 2025 edition of NFPA 13, a key change includes limiting the sprinkler type and orientation, with minimum K-factors based upon occupancy classification, and minimum density requirements and design area as follows:

  - ✓ Sprinkler Types for Ceiling Heights over 30 ft (19.2.3.2.5):
    - OH-1 and higher – sidewall sprinklers not permitted
    - OH-2 and higher – minimum K-factor 11.2
    - OH-2 and higher – no extended coverage sprinkler with a K-factor of 22.4 or less
    - OH2 with ceiling height over 40 ft – no standard response sprinkler

  - ✓ Sprinkler Density/Areas for Ceiling Heights over 30 ft (19.2.3.5.2): New design areas and density requirements for ceilings over 30 ft are summarized in the table below:

Occupancy Hazard	Ceiling Height	Sprinkler Orientation	Sprinkler Coverage	K-factor	Minimum Density	Increase of Design Area
OH-1	> 30 ft	Upright or Pendent	Standard or Extended	5.6 or greater	Per table 19.2.3.1.1	30%
OH-2	> 30 ft but </= 40 ft	Upright or Pendent	Standard or Extended	11.2 or greater	0.37	None
OH-2	>40 ft	Upright or Pendent	Standard	11.2 or greater	0.45	30%
OH-2	>40 ft	Upright or Pendent	Extended	25.2	0.45	None
EH-1 & EH-2	>30 ft	Upright or Pendent	Standard	11.2 or greater	0.45	None
EH-1 & EH-2	>30 ft	Upright or Pendent	Extended	Greater than 22.4	0.45	None

Courtesy of FPO - Franck Orset

Note: There are 2 approaches for the determination of area/density requirements.

- Single point sprinkler design criteria vs. sprinkler system design curves
  - NFPA 13 used to provide curves that gave several options with multi-point design criteria. This enabled users to cost effectively match water supplies to the building occupancy hazard. This is referred to as design curve design criteria.
  - For "simplification purpose" since the 2022 Edition, NFPA 13 now proposes single point options (two per occupancy) for new systems in addition to the curves:
    - Over 140 m^2 (1500 ft^2) and over 280 m^2 (3000 ft^2) for light hazard, ordinary hazard group 1 and ordinary hazard group 2
    - Over 232 m^2 (2500 ft^2) and over 280 m^2 (3000 ft^2) for extra hazard group 1 and extra hazard group 2

    - Over 186 m² (2000 ft²) for commodity class I to IV storage or over 232 m² (2500 ft²) for Group A plastics.

  The densities are the ones taken from the original curves (with possible adjustment based on height of storage, for example).

  Only the first demand is to be applied (e.g., upper space in buildings housing clean rooms including plenum and non-clean room areas within a gigafactory).

  The second demand, over 280 m² (3000 ft²) only applies for certain conditions relating to buildings with unsprinklered combustible concealed spaces (e.g., upper space in building housing clean rooms including plenum and non-clean room areas within a gigafactory: The space above the plenum housing combustible equipment, such as a high density of cable trays, Reinforced Fiber Plastics, combustible ducts, etc.).

  - Curves are no longer proposed since the 2025 Edition of NFPA 13 2025 Edition.
  - Other standards, such as FM Global data sheet or European Standards, have chosen single point design criteria, which ensure better sprinkler performance by limiting design to higher densities, and simplify the design and review process. The single point criteria are generally presented in tabular format, versus the traditional graphical presentation

Note on clean room classification: FED STD 209E vs. ISO 14644-1

Gigafactories, large-scale facilities producing batteries for electric vehicles, utilize cleanrooms to maintain a highly controlled environment for manufacturing sensitive components like lithium-ion batteries.

Clean rooms are classified by the numbers of particles in a given volume of air. The FED STD 209E counts the number of particles per cubic foot. The ISO 146444-1 counts the number of particles per cubic meter.

Before global clean room classifications and standards were adopted by the International Standards Organization (ISO), the U.S. General Service Administration's standards (known as FS209E - Airborne Particulate Cleanliness Classes in Cleanrooms and Cleanzones) were applied virtually worldwide.

However, as the need for international standards grew, the ISO established a technical committee and several working groups to delineate its own set of standards.

FS209E contains six classes, while the ISO 14644-1 classification system adds two cleaner standards and one dirtier standard. The "cleanest" clean room in FS209E is referred to as class 1; the "dirtiest" clean room is a class 100,000.

ISO clean room classifications are rated according to the amount of particulate of specific sizes that exist per cubic meter. The "cleanest" clean room is a class 1 and the "dirtiest" a class 9. ISO class 3 is approximately equal to FS209E class 1, while ISO class 8 approximately equals FS209E class 100,000.

By law, Federal Standard 209E can be superseded by new international standards. It is expected that 209E will be used in some industries over the next few years, but that eventually it will be replaced internationally by ISO 14644-1.

Common classifications for gigafactory clean rooms include ISO 7 and ISO 6, with some operations requiring even cleaner environments like ISO 5 or specialized dry rooms with extremely low humidity.

For manufacturing process C. Cell finishing of lithium-Ion batteries – Formation process step:

- Lithium batteries in charge treated the same way as BESS: automatic sprinklers designed to deliver a minimum density of 12.2 mm/min/m² (0.3 gpm/ft²) over the entire area of the room or 232 m² (2,500 ft²), (i.e., EH1 occupancy), whichever is smaller", and 1900LPM/500 gpm for 120 min (90 min minimum). 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 were 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/m² (0.3 gpm/ft²) over the entire area of the room or 232 m²/2,500 ft²) or even for EH2 occupancy (i.e., 15.5 mm/min/m²/0.38GPM/ft²) over 280 m² (3,000 ft²) and 1900LPM/500 gpm for 90-120 min.
- Other protection design for formation and aging / Enclosed Chamber Arrangements (five-sided holding areas in metal up to 10m high) may consist of control mode sprinkler protection:
  - Ceiling sprinklers as per NFPA for so-called non-clean room areas as described above
  - One sprinkler provided in each bin-box (reportedly 125 LPM each) holding area for eight holding areas.

  Note;

  - FM global Data sheet 7-112 ("Lithium-Ion Battery Manufacturing and storage") dated October 2024 recommend designing the bin or chamber sprinkler system to supply at least 60 gpm (230 L/min) for the six (6) most remote sprinklers. Use quick response, ordinary temperature, K8.0 (K115) or larger in-rack sprinklers.
  - Based on the above, wet-pipe ceiling level protection below 30 ft (designed as per NFPA from EH1) should provide adequate fire protection similar to FM HC-3, in addition to the sprinklers provided in each bin-box

6.2 Incidental / low-piled storage in manufacturing process areas

- "Incidental" and "low-piled" storage consists basically of Work In Progress material (WIP: i.e., Finished Cells / Modules / Batteries) at various States of Charge (SOC), which is located within a manufacturing facility and results from that facility's activities. The arrangement may be solid-pile, palletized, rack, shelf, or bin-box storage that is normal for an occupancy (e.g., small amounts of packaging, raw materials, or the products being made). This is likely to be at the start or end of a production line, but is not limited to these areas (i.e., buffer storage of WIP material on the process line aiming to prevent any disruption of the supply chain).

- State of charge (SOC) quantifies the remaining capacity available in a battery at a given time and in relation to a given state of ageing. It is usually expressed as percentage (0% = empty; 100% = full).

As per FM Data Sheet 7-112 “Lithium-Ion Battery Manufacturing and storage,” the packaging and storage arrangement should meet the following criteria in order to be considered incidental storage or low-pile storage:

<table>
<tr><th>1. Cells / Modules /Batteries stored in metal or cardboard boxes</th><th>1. Cells / Modules /Batteries stored in unexpanded plastic containers</th></tr>
<tr><td colspan="2">2. Storage piles are limited to 18.6 m² (200 ft²)
3. Storage height limited to 1.8 m (6 feet)
4. Piles are separated by a minimum 3 m (10 ft) aisle
5. Battery state of Charge (SOC) cannot exceed 60%</td></tr>
<tr><td>The automatic sprinkler design criteria are based on the surrounding occupancy (i.e., the environment the incidental storage is in). See “The manufacturing process” section (current standard):
- Ceiling sprinkler: HC-3 (*) design in accordance with Data Sheet 3-26 “Fire Protection for Non-Storage Occupancies” Table 2.3.1.10 Sprinkler Design Demands for Hazards Categories.
And
- FM Data Sheet 7-112 “Lithium-Ion Battery Manufacturing and storage” and Table 2.1.3 for other key applicable Data Sheets for special hazards and specific process step</td><td>Protect storage of lithium-ion batteries as low-piled storage of Uncartoned Unexpanded Plastic (UUP) per Table 2.4.3.2 – See below</td></tr>
<tr><td colspan="2">When these Cells / Modules /Batteries are stored in racks, please consider the same protection – with rack automatic sprinklers – as for C. Cell Finishing / Formation and aging / In-Rack sprinklers – see section 6.3: “The manufacturing process”).</td></tr>
</table>

Table 2.4.3.2. Sprinkler Protection for Low-Piled Storage of Lithium-ion Batteries in Plastic Containers

Commodity	Max Ceiling Height, ft (m)	Quick-Response						Standard-Response				
		K11.2 (K160)	K14.0 (K200)	K16.8 (K240)	K22.4 (K320)	K25.2 (K360)	K25.2EC (K360EC)	K11.2 (K160)	K14.0 (K200)	K19.6 (K280)	K25.2 (K360)	K25.2EC (K360EC)
Wet System, Pendent Sprinklers, 160ºF (70ºC), Number of AS @ psi (bar)												
UUP	30 (9)	25 @ 50(3.4)	10 @ 62(4.3)	10 @ 43(3)	14 @ 24(1.7)	14 @ 19(1.3)	12 @ 38(2.6)	25 @ 50(3.4)	25 @ 32(2.2)	25 @ 16(1.1)	25 @ 10(0.7)	25 @ 50(3.4)
	45 (14)		10 @ 62(4.3)11	10 @ 43(3)	14 @ 24(1.7)	14 @ 19(1.3)						
	60 (18)				10 @ 50(3.4)	10 @ 40(2.8)						
Wet System, Upright Sprinklers, 160ºF (70ºC), Number of AS @ psi (bar)												
UUP	30 (9)	25 @ 50(3.4)	10 @ 62(4.3)	10 @ 43(3)			12 @ 38(2.6)	25 @ 50(3.4)	25 @ 22(1.5)		25 @ 10(0.7)	
	45 (14)		10 @ 62(4.3)	10 @ 43(3)								

6.4 Storage of New & Refurbished lithium-ion batteries

Note that this section addresses only the storage of cells/modules/batteries excluding so-called finished products containing a Lithium-Ion Battery, such as personal electronic devices (laptop computers, tablets, cell phones, etc.), mobile mobility devices (e-bikes, scooters, e-mopeds, etc.), power tools and household items (vacuums, toys, etc.).

Current Standard

- This section addresses new (finished product) or refurbished cell / module / battery storage.
- In term of fire protection, the requirement included in Oct. 2024 FM Data Sheet 7-112 “Lithium-Ion Battery Manufacturing and storage” should apply as follows:
    - **Solid-pile or palletized storage arrangements** per Table 2.4.5.1-1. below, applying for Lithium-Ion Cell/module with State of Charge (SoC) of 60% maximum for a storage height up to 4.5 m (15 ft) with a maximum ceiling height of 12 m (40 ft):

Table 2.4.5.1-1. Protection Guidelines for Lithium-Ion Cells/Modules/Batteries in Solid-Piled or Palletized Storage Arrangements

Maximum Lithium-ion Cell/Module State of Charge	*Maximum Ceiling Height*	*Storage Height*	*Packaging*	*Protection (QR Sprinklers only)*
60%	40 ft (12 m)	15 ft (4.5 m)	Wood crate, metal encased or corrugated carton with cellulosic and/or unexpanded plastic internal packaging only	CUP per Data Sheet 8-9 (Note 1)
			Corrugated carton with expanded plastic internal packaging	CEP per Data Sheet 8-9 (Note 1)
			Unexpanded Plastic external packaging	UUP per Data Sheet 8-9 (Note 1)
			Unexpanded Plastic external packaging with > 40% expanded plastic (by volume) inside	UEP per Data Sheet 8-9 (Note 1)

Note 1. Use the Data Sheet 8-9 protection table based upon the storage configuration (solid-pile or palletized) and the protection option based on the ceiling height.

CUP: Cartoned Unexpended Plastic; CEP: Cartoned Expended Plastic; UUP: Uncartoned Unexpanded Plastic; UEP: Uncartoned Expanded Plastic;

Notes:

- Storage above the batteries for ceiling-only protection is not allowed.
- A minimum of 3 m (10 ft) space separation between storage of lithium-ion cells/modules/
- batteries and other combustibles.
- A minimum of 3 m (10 ft) wide aisle spaces within solid-pile and palletized storage should be provided such that the maximum contiguous width of abutted storage does not exceed 4.5 m (15 ft).
- Hose Allowance & Fire Water Supply Duration demand and duration to be defined in accordance with Data sheet 8-9 mentioned in the Table 2.4.5.1-1 (i.e. FMDS 8-9 see above) for ceiling design (no In-Rack).

SCOR analysis and notes:

The above FM Table 2.4.5.1-1. for solid piled or palletized storage arrangement is basically established upon the following key criteria:

- State Of Charge with a maximum of 60%
- Packaging type
- Ceiling sprinkler protection: Quick Response (QR) only.
- Ceiling sprinkler protection design referring to FM Data Sheet 8-9 “Storage of Class 1, 2, 3, 4 and Plastic commodities” mostly for storage not exceeding 4.5 m (15 ft) in height (for information “miscellaneous storage” as per NFPA is defined as storage height that cannot exceed 3.7 m (12 ft) in height).
- Maximum ceiling height 12 m (40 ft)

Quick Response (QR) Sprinkler vs. Standard Response Sprinkler:

- Sprinkler Response Type: Sprinkler response types are determined by their Response Time Index (RTI). This is a method of measuring thermal sensitivity under standardized test conditions. In addition to sprinkler response time, sprinklers can also have different thermal elements that are designed to activate at varying temperatures.
- Standard Response Sprinkler: Sprinklers defined as standard response have a thermal element with an RTI of 80 (meters-seconds)$^{1/2}$ or more.
- Quick Response (QR) Sprinkler: A type of spray sprinkler that has a thermal element with an RTI of 50 (meter-seconds)$^{1/2}$ or less and is listed as a quick-response sprinkler for its intended use. A quick response sprinkler is similar to a standard response sprinkler, except that it possesses a fast-response operating element, so when exposed to the same temperature change, a quick response sprinkler will operate faster than a standard response sprinkler. Where glass bulbs are used for standard spray sprinklers, the diameter of the bulb of a QR sprinkler is typically less than that of a standard response sprinkler. Where a metallic alloy is used, the operating heat responsive element of a standard response sprinkler has more mass than the element used in a QR sprinkler.

Comparison with NFPA 13, 2019, 2022, 2025 editions.

Similar solutions — as per FM Table 2.4.5.1-1. above — for lithium-Ion batteries may be found as per the following sections for the fire protection of plastic commodities in solid piled or palletized storage:

- Chapter 21 CMDA
- Chapter 22 CMSA
- Chapter 23 ESFR
- Chapter 24 Alternative for the above

NFPA acronyms:

CMDA : Control Mode Density Area; CMSA: Control Mode Specific Application;

Example of Solid-pile or palletized storage arrangements below:

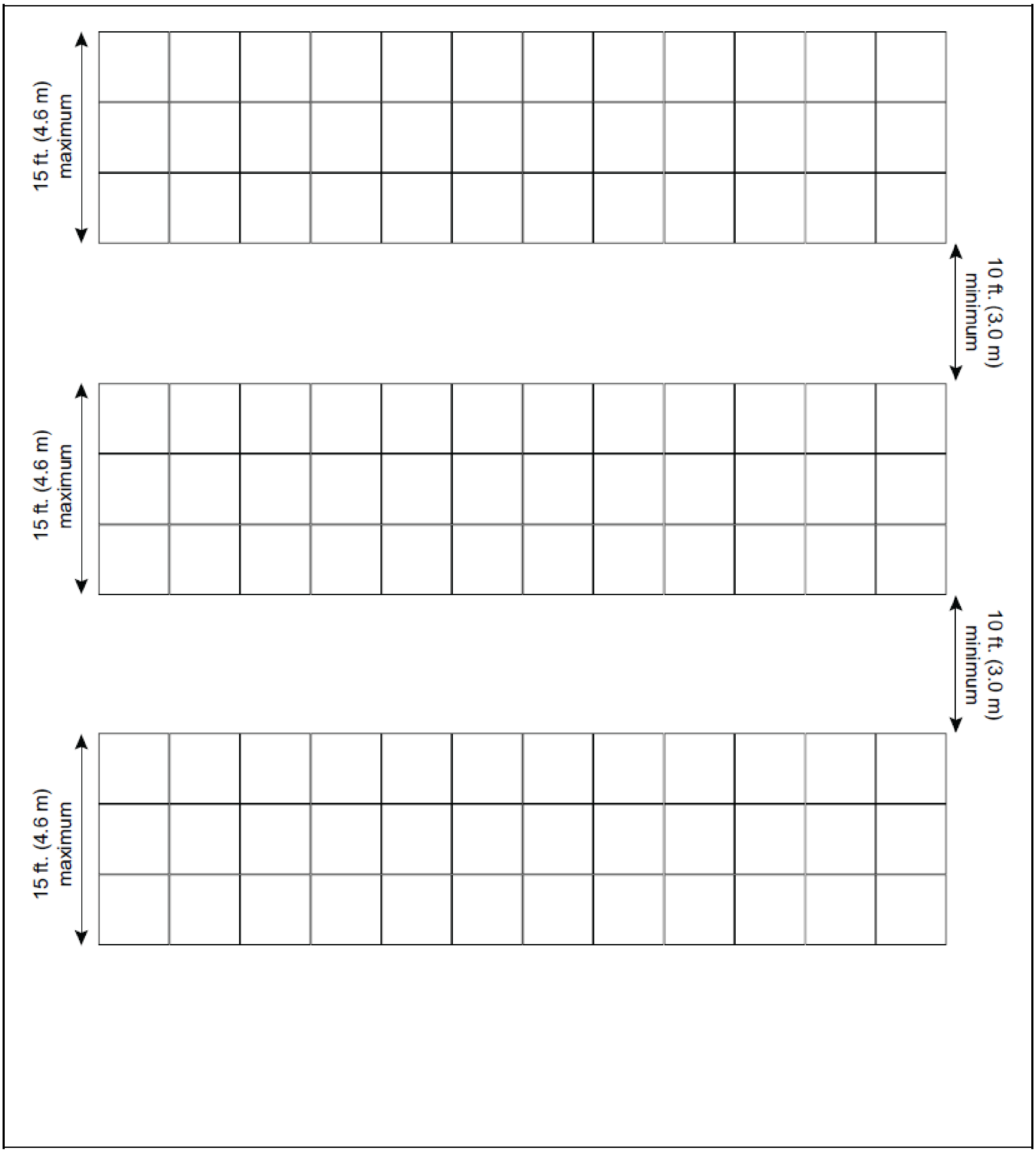


Fig. 2.4.5.4. Example of solid-pile and palletized storage arrangement

- **Open-frame rack storage arrangements** per Table 2.4.5.1-2. below:

Table 2.4.5.1-2. Protection Guidelines for Lithium-Ion Cells/Modules/Batteries in Open-Frame Rack Storage Arrangements

Lithium-ion Cell/Module State of Charge	*Maximum Ceiling Height*	*Maximum Storage Height*	*Packaging*	*Ceiling Protection (QR sprinklers only)*	*In-Rack Protection*
≤ 60%	40 ft (12 m)	15 ft (4.5 m) (Maximum of 3 tiers)	Wood crate, metal encased or corrugated carton with cellulosic and/or unexpanded plastic internal packaging only	CUP per Data Sheet 8-9 (Note 1)	NA
			Corrugated carton with expanded plastic internal packaging	CEP per Data Sheet 8-9 (Note 1)	NA
			Unexpanded plastic external packaging with ≤ 40% expanded plastic (by volume) inside	UUP per Data Sheet 8-9 (Note 1)	NA
			Unexpanded plastic external packaging with > 40% expanded plastic (by volume) inside; or expanded plastic external packaging	UEP per Data Sheet 8-9 (Note 1)	NA
			Uncartoned	Per surrounding occupancy	See Section 2.4.2.2, 2.4.5.5, and 2.4.5.6.
	> 40 ft (12 m)	NA	Cartoned or uncartoned	Per surrounding occupancy	See Section 2.4.2.2, 2.4.5.5, and 2.4.5.6
> 60%	NA		Cartoned or uncartoned	Per surrounding occupancy	See Section 2.4.2.2, 2.4.5.5, and 2.4.5.6

Note 1. 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.

FM data sheet acronyms:
CUP: Cartoned Unexpanded Plastic; CEP: Cartoned Expanded Plastic; UUP: Uncartoned Unexpanded Plastic; UEP: Uncartoned Expanded Plastic
(QR) Quick Response

Notes:

- For open-frame single and double-row rack storage of cells/modules/batteries that require in-rack sprinkler protection as per Table 2.4.5.1-2 (above) using Figures 2.4.2.2-1 and 2.4.2.2-2 (see section 6.3: “The manufacturing process” – Current standard / C. Cell finishing / Formation and aging / open- frame rack arrangements):
  - Design: minimum flow of 60 gpm (227 L/min) 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.
  - Minimum discharge pressure for K-factor:
    - ≥ K160 (11.2): 0.7 bar (10 psi)
    - < K160 (11.2): 0.5 bar (7 psi)
  - **And the following changes**:

        - Install in-rack sprinklers at a maximum vertical distance of 3.7 m (12 ft) between each level (instead of 1.8 m (6 ft)).
    - Ceiling Sprinkler demand not included In Rack Sprinkler hydraulic calculation.

- For multi-row rack storage of cells/modules/batteries that require in-rack sprinkler protection per Table 2.4.5.1-2 (above):
    - Use Figure 2.4.5.6. (below)
    - Design: minimum flow of 60 gpm (227 L/min) 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.
    - Minimum discharge pressure for K-factor:
        - ≥ K160 (11.2): 0.7 bar (10 psi)
        - < K160 (11.2): 0.5 bar (7 psi)
    - **And the following changes** (compared to section 6.3: "The manufacturing process" – Current standard / C. Cell finishing / Formation and aging / open-frame rack arrangements):
        - Install in-rack sprinklers at a maximum vertical distance of 3.7 m (12 ft) between each level (instead of 1.8 m (6 ft)).
        - Install vertical barriers constructed of plywood (minimum of 10 mm [3/8 in.]) or sheet metal (minimum of 0.7 mm [22 ga.]) at vertical uprights, approximately 6.1 m (20 ft) apart for limiting horizontal fire spread.
    - Ceiling Sprinkler demand not included In Rack Sprinkler hydraulic calculation

- Hose Allowance & Fire Water Supply Duration 1,900 L/min (500 gpm), 120 min duration.

SCOR analysis and notes:

The above FM Table 2.4.5.1-2. for open-frame rack storage is based on the following key criteria:

- State Of Charge with a threshold of 60%
- Packaging type
- Ceiling sprinkler protection: Quick Response (QR) only.
- Ceiling sprinkler protection design referring to FM Data Sheet 8-9 "Storage of Class 1, 2, 3, 4 and Plastic commodities" mostly for storage (except uncartoned category) not exceeding 4.5 m (15 ft) in height (for information "miscellaneous storage" as per NFPA is defined as storage height that cannot exceed 3.7 m (12 ft)).

Quick Response (QR) Sprinkler vs. Standard Response Sprinkler:

- Sprinkler Response Type: Sprinkler response types are determined by their Response Time Index (RTI). This is a method of measuring thermal sensitivity under standardized test conditions. In addition to sprinkler response time, sprinklers can also have different thermal elements that are designed to activate at varying temperatures.
- Standard Response Sprinkler: Sprinklers defined as standard response have a thermal element with an RTI of 80 (meters-seconds)$^{1/2}$ or more.
- Quick Response (QR) Sprinkler: A type of spray sprinkler that has a thermal element with an RTI of 50 (meter-seconds)$^{1/2}$ or less and is listed as a quick-response sprinkler for its intended use. A quick-response sprinkler is similar to a standard response sprinkler, except that it possesses a fast-response operating element, so when exposed to the same temperature change, a quick response sprinkler will operate faster than a standard response sprinkler. Where glass bulbs are used for standard spray sprinklers, the diameter of the bulb of a QR sprinkler is typically less than that of a standard-response

sprinkler. Where a metallic alloy is used, the operating heat responsive element of a standard-response sprinkler has more mass than the element used in a QR sprinkler.

Comparison with NFPA 13, 2019, 2022, 2025 editions.

Neither dedicated solutions nor similar solutions — as per FM Table 2.4.5.1-2. above — for lithium-Ion batteries as per the following sections for the fire protection of commodities in SRR, DRR, MRR:

- Chapter 21 CMDA
- Chapter 22 CMSA
- Chapter 23 ESFR
- Chapter 24 Alternative for the above

NFPA acronyms:

CMDA: Control Mode Density Area; CMSA: Control Mode Specific Application
SRR: Single Row Rack; DRR: Double Row Rack; MRR: Multiple Row Rack

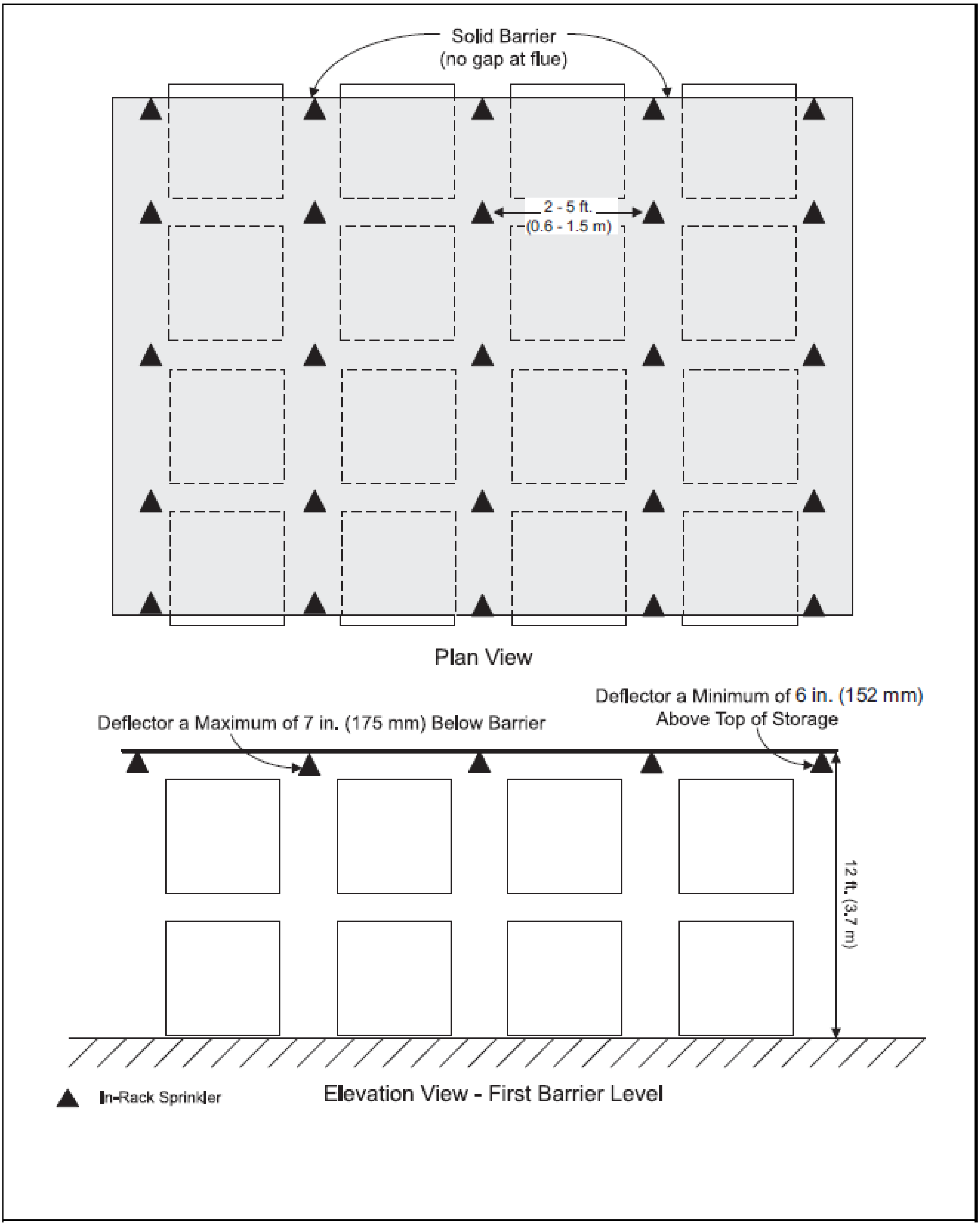


Fig. 2.4.5.6. Multi-row rack in-rack sprinkler layout for li-ion cells/modules/batteries

Previous Standards

For information, depending on the age and location of facilities, the following potential sprinkler design may be found for storage protected as per the Jan. 2023 edition of 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," before the October 2024 re-October 2024 FM Data Sheet 7-112 "Lithium-Ion Battery Manufacturing and storage" was released:

Previous standards were designed for storage before or after the inspection phase and after assembly, including Work In Progress, Finished Products and Rejected.

In October 2024, the FM Global Data Sheet 8-1 "Commodity Classification" was revised. The guidance for Li-ion batteries, Section 2.4.2, has been relocated to FM Loss Prevention Data Sheet 7-112, "Li-Ion Battery Manufacturing and Storage."

SCOR consideration:

When these designs are less conservative than those required as per the fixed fire protection of such facilities, they are deemed NOT Adequate as per current dedicated international standards.

Example:

Jan 2023 FM Global Data Sheet 8-1 "Commodity Classification"

- Table 2.4.2.1. Protection of Lithium-Ion Cells and Modules / Storage Arrangement **Open-frame rack, solid piled or palletized**:
- Plastic external packaging treated as UUP Uncartoned Unexpanded Plastic
- Hose Allowance & Fire Water Supply Duration: 946 L/min. (250 gal./min.) hose stream demand for at least 120 minutes:

Oct. 2024 FM Data Sheet 7-112 "Lithium-Ion Battery Manufacturing and storage"

- Table 2.4.5.1-1. Protection Guidelines for Lithium-Ion Cells/Modules/Batteries in **Solid-Piled or Palletized** Storage
  - Arrangements containing Unexpanded Plastic external packaging with >40% expanded plastic (by volume) inside are treated as UEP - Uncartoned Expanded Plastic
  - Hose Allowance & Fire Water Supply Duration to be defined as per FMDS 8-9 "Commodity Classification)
- Table 2.4.5.1-2. Protection Guidelines for Lithium-Ion Cells/Modules/Batteries in **Open-Frame - Rack** Storage Arrangements differentiate between Unexpanded plastic external packaging:
  - with ≤ 40% expanded plastic (by volume) inside is treated as UUP - Uncartoned Unexpanded Plastic
  - with >40% expanded plastic by volume is treated as UEP - Uncartoned Expanded Plastic
  - Hose Allowance & Fire Water Supply Duration 1,900 L/min (500 gpm), 120 min duration

As per edition Jan. 2023 of 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:

- 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

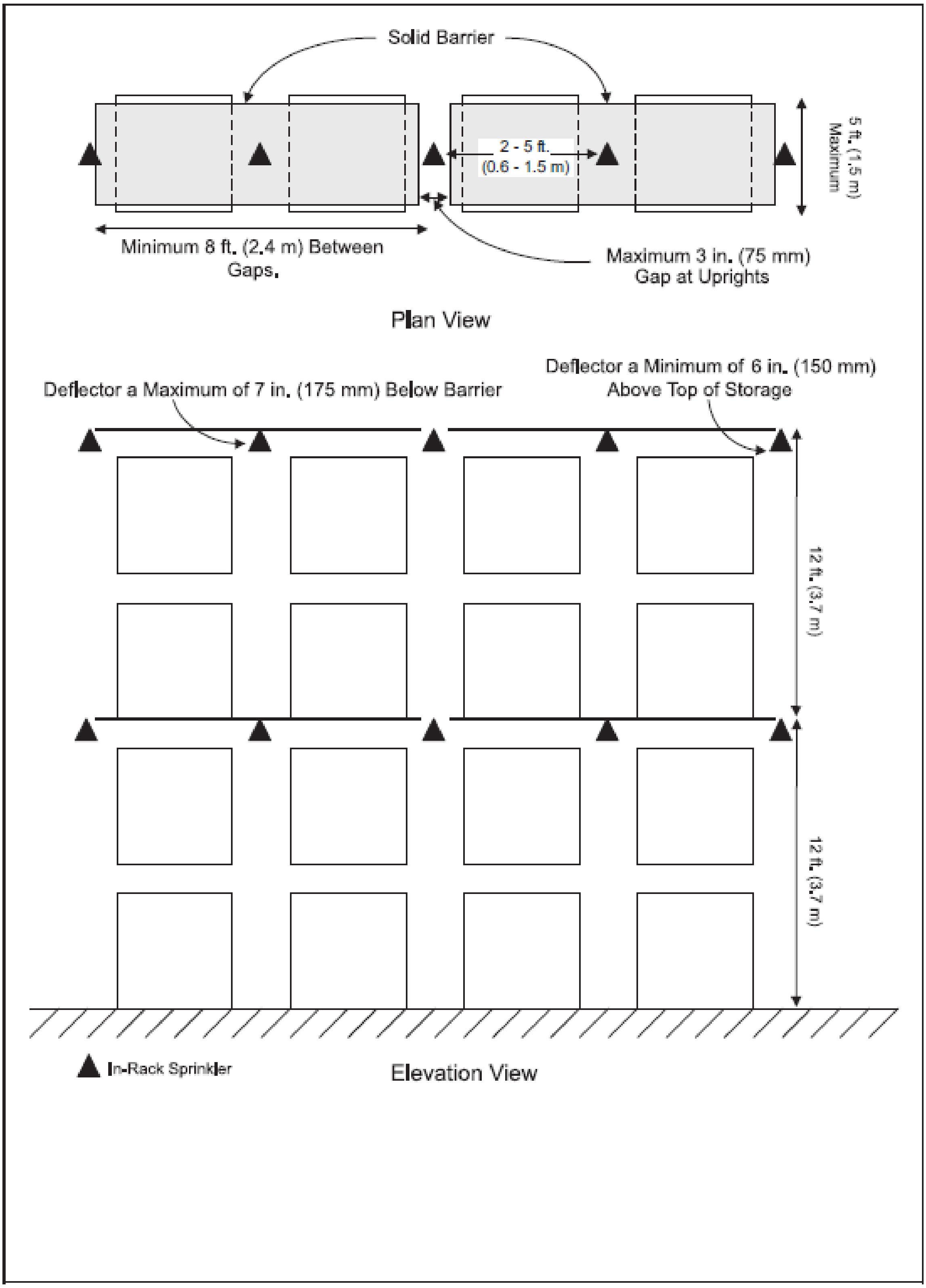
Li-ion Cell/ Module State of Charge	*Ceiling Height*	*Storage Height*	*Storage Arrangement*	*Packaging*	*Ceiling Protection (QR sprinklers only)*	*In-Rack Protection*
≤ 60%	≤ 40 ft (12 m)	Maximum 3 levels of storage up to a total height of 15 ft (4.5 m)	Open-frame rack, solid-pile or palletized	Wood 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
		NA	Open-frame rack	Uncartoned	Per surrounding occupancy.	See Section 2.4.2.2
	> 40 ft (12 m)			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.

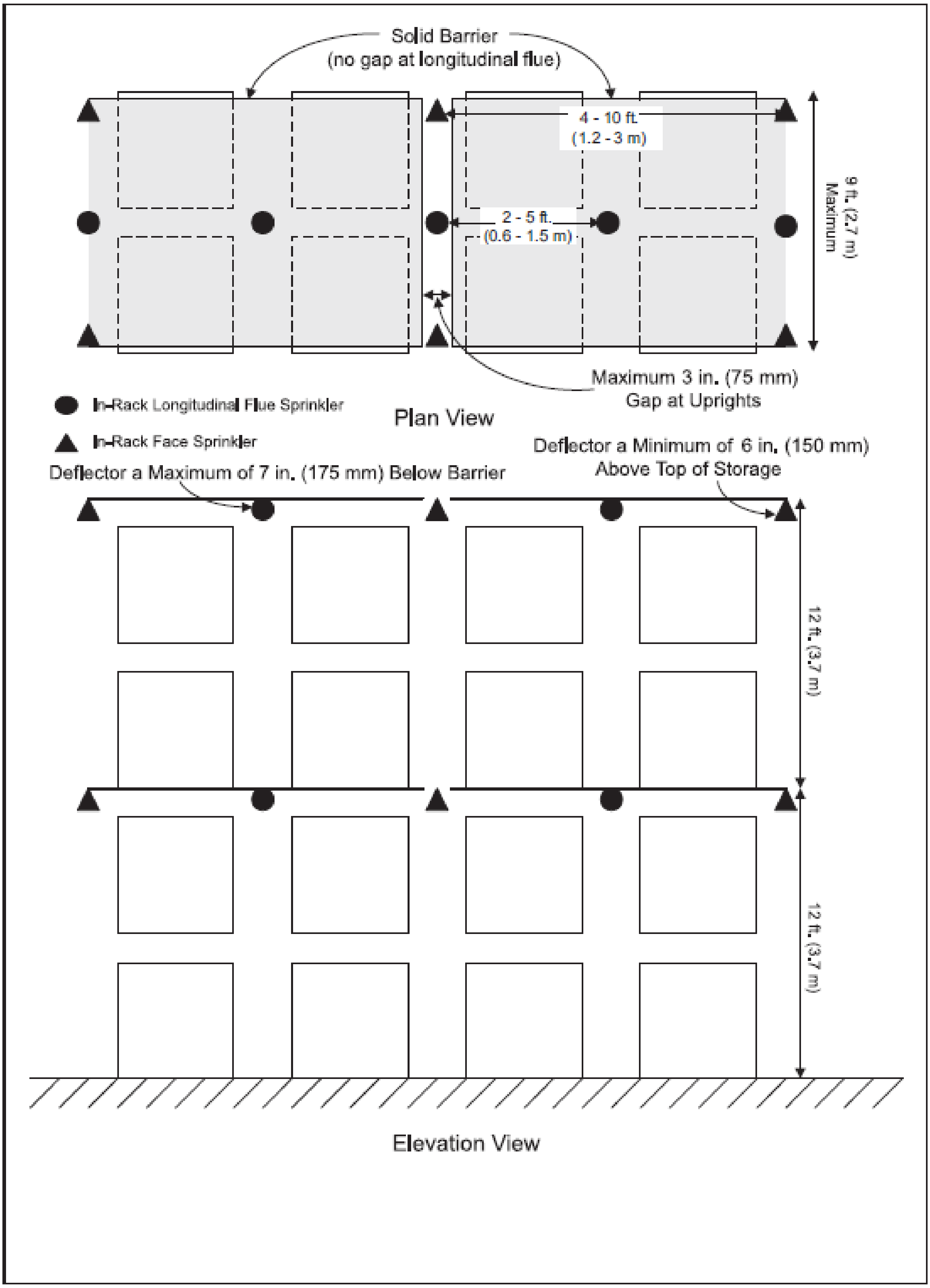
CEP: Cartoned Expanded Plastic; UUP: Uncartoned Unexpanded Plastic

- 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



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



- 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.
- Hose Allowance & Fire Water Supply Duration: 946 L/min. (250 gal./min.) hose stream demand for at least 120 minutes.

6.5 Storage of Rejected lithium-ion batteries

- The rejected cells/modules/batteries should be removed from process and storage areas or other important areas and should be relocated in a cut-off room or detached building / structure as follows:
- Outdoor storage (i.e., light structures such as a container or canopy):
    - At least 3 m (10 ft) separating distance between outdoor storage areas and noncombustible building walls and 6.1 m (20 ft) of space to combustible walls or walls with windows.
    - Should be limited to two (2) pallets high and storage footprints no larger than 84m² (900 ft²).
    - Individual storage piles should be separated by at least 3.0 m (10 ft).
    - Outdoor storage should be accessible by the fire service, with direct access to fire hydrants.
- Cut-off room as follows:
    - Indoor storage height to one (1) pallet high. Where greater heights are needed, the storage should use an open-frame rack arrangement.
    - For **storage in open-frame racks,** protect the racks with in-rack sprinklers in accordance with Section 2.4.2.2. of FM Data Sheet 7-112 "Lithium-Ion Battery Manufacturing and storage," as summarized below:
        - Ceiling sprinklers: designed to protect the surrounding occupancy Data Sheet 3-26 "Fire Protection for Non-Storage Occupancies" / Data Sheet 8-1, "Commodity Classification" (assuming same as for as for A. Electrode manufacturing and B. Cell assembly: Ceiling sprinkler HC-3 design in accordance with Data Sheet 3-26 "Fire Protection for Non-Storage Occupancies" Table 2.3.1.10 (see below) Sprinkler Design Demands for Hazards Categories.
          And
        - FM Data Sheet 7-112 "Lithium-Ion Battery Manufacturing Table 2.1.3 (see section 6.3: "The manufacturing process" above) for other key applicable Data Sheets for special hazards and specific process steps.
        - No need to hydraulically balance ceiling sprinkler system with the in-racks.
        - In-Rack sprinklers (same as for Formation and Aging):
            - Open-Frame Rack Arrangements: as per FM Data Sheet 7-112 "Lithium-Ion Battery Manufacturing" Figures 2.4.2.2.1-1 (see section 6.3: "The manufacturing process" above) for Single Row Rack and 2.4.2.2.1-2.for Double Row Rack.
            - Design: minimum flow of 60 gpm (227 L/min) 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.

        - Minimum discharge pressure for K-factor:
            - ✓ ≥ K160 (11.2): 0.7 bar (10 psi)
            - ✓ < K160 (11.2): 0.5 bar (7 psi)
        - Ceiling Sprinkler demand not included In Rack Sprinkler hydraulic calculation
    - If storage is in open-frame racks, protect the racks with in-rack sprinklers in accordance with Section 2.4.2.2. of FM Data Sheet 7-112 "Lithium-Ion Battery Manufacturing and storage" as summarized
- For **on-floor or palletized storage**:
    - Ceiling sprinkler design: 12 L/min/m² (0.3 gpm/ft²) over-the-room footprint.
    - Direct outside access to cut-off rooms.
    - Hose stream allowance of 500 gpm (1,900 L/min) and Fire Water Supply duration of minimum 120 min.

6.6 Storage of Cells/Modules/Batteries in Finished Products

Finished products include, but are not limited to, personal electronic devices (laptop computers, tablets, cell phones, etc.), lawn equipment (lawn mowers, leaf blowers, etc.), power tools and household items (vacuums, toys, etc.), micro-mobility (skateboard, hoverboard, scooters, e-bikes, etc.), drones, etc.

Note that finished electric vehicle (cars, trucks, lift trucks) modules or packs are not considered finished products;

As per 2024 FM Data Sheet 7-112 "Lithium-Ion Battery Manufacturing and storage."

SOC (%	Finished Products protection
Up to 60%.	As per Data Sheet 8-9, Storage of Class 1, 2, 3, 4 and Plastic Commodities, using the product's commodity classification, excluding the battery hazard (*)
Above 60%	A per Data Sheet 8-9 using the product's commodity classification, excluding the battery hazard, and **a protection design that includes both ceiling and in-rack sprinklers**. (*) Note: In-rack protection schemes that do not require balancing the ceiling and in-rack sprinkler demand are acceptable. (*)

(*) Hose stream demand and water supply duration in accordance with Data Sheet 8-9.

SCOR analysis and notes:

The above protection for storage of Cells/Modules/Batteries in Finished Products is basically established upon the following key criteria:

- State Of Charge with a threshold of 60%
- Packaging type
- Ceiling sprinkler protection design referring to FM Data Sheet 8-9 "Storage of Class 1, 2, 3, 4 and Plastic commodities".

- No given restriction for maximum storage height or maximum ceiling height 12 m (40 ft)
- No guidance for sprinkler type

Comparison with NFPA 13, 2019, 2022, 2025 editions.

Similar solutions for the storage of Cells/Modules/Batteries in Finished Products may be found as per the following sections for the fire protection of commodities in solid piled or palletized storage or rack storage:

- Chapter 21 CMDA
- Chapter 22 CMSA
- Chapter 23 ESFR
- Chapter 24 Alternative for the above

NFPA acronyms:

CMDA: Control Mode Density Area; CMSA: Control Mode Specific Application;

SRR: Single Row Rack; DRR: Double Row Rack; MRR; Multiple Row Rack

7. Pre/post-incident Planning

- A pre-incident plan with the fire service and Emergency Response Planning should be developed including:
    - Employees and emergency responders should have a clear understanding of the hazards related to Lithium-Ion Batteries and the limits of fixed fire protection:
        - Fire and thermal runaway: this is when the Lithium-Ion Battery begins to vent flammable gas that can be ignited due to sparking from the cell, open flames, or exposure to nearby electrical equipment. To date there is no test showing that active fire protection can stop this process. Thus, especially when the cells are enclosed. Automatic sprinklers can provide cooling to surrounding structures and adjacent modules/packs, in order to limit the fire spread.
        - So-called reignition: there is no reignition as such. Reignition means that during the initial fire and thermal runaway, the battery was not fully consumed and electrochemical potential is still there (SOC is equal to zero, or in other words the battery is not fully discharged).
        - Explosion: if the battery begins to vent during thermal runaway without immediate gas ignition, these gases can accumulate in a closed space (e.g., the module enclosure itself) before igniting and resulting in an explosion).
        - Unpredictable nature of fire and explosion.
    - Manual fire protection methods to be employed:
        - Within the different areas of the plant (i.e., process areas, storage areas, utilities).
        - Considering both inherent and special hazards (i.e., chemicals in mixing areas, flammable solvent and electrolyte, lithium batteries electrochemistry)
        - Note that, to date, even with automatic fixed fire protection in process areas (i.e., control mode), final extinguishment is expected to be performed manually. However, safe and efficient manual firefighting in such congested areas (with racks and automated storage and retrieval systems) is virtually impossible.
    - 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.

Note: in some lithium-ion battery plants the storage of battery pack may be not far from the battery charge/discharge section, a process (as previously mentioned) which is one of the most hazardous in terms of fire risk. The picking robots may be equipped with thermal detectors designed to have the robot automatically retrieve the affected individual pack from the rack and immersed it in a brine (*) filled steel vat located away from the rack. This vat is then removed outdoors. The same “automated immersion strategy” may be found by some EV manufacturers on the assembly line where the LIBs are handled and installed. This method developed “in-house” is so far neither formalized nor detailed in any norm and standard.
(*) the purpose of the brine is to increase the conductivity of the liquid for easing the de-energization of the lithium-Ion battery. Some first responders also propose to use copper dust mixed with the liquid.

Other publications in this series:

- RISK CONTROL PRACTICE: SPECIAL HAZARD Belt Conveyors & Related Equipment

- RISK CONTROL SERVICES: OCCUPANCY
  - Waste & Recycling Facilities

- RISK CONTROL SERVICES: FIRE PREVENTION
  - Oxygen Reduction Atmosphere Systems
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