ENVIRONMENTAL AND TRENDING ISSUES: LITHIUM-ION BATTERIES

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LEARNING OBJECTIVES

1. Evaluate the unique hazard introduced by Lithium-ion battery thermal runaway
2. Understand the process of determining proper sprinkler design criteria for Stationary Energy Storage Systems
3. Understand how to communicate with project teams on the impact the sprinkler design will have on ESS
4. Evaluate the environmental impact of a Lithium-ion battery fire and how to assist first responders in establishing emergency response plans.

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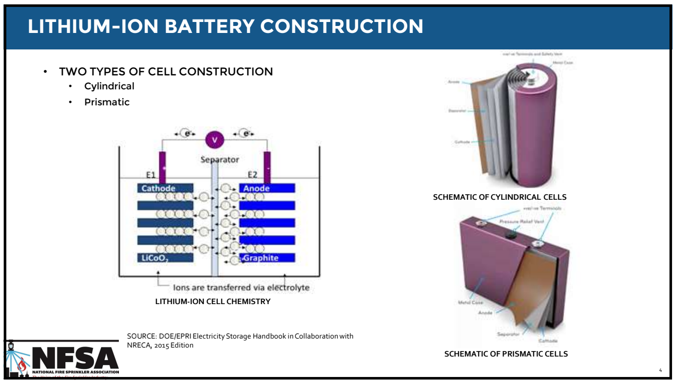
LITHIUM-ION BATTERY CONSTRUCTION
• TWO TYPES OF CELL CONSTRUCTION
• Cylindrical
• Prismatic
V
Separator
E1
E2
Cathode
Anode
LiCoO2
Graphite
Ions are transferred via electrolyte
LITHIUM-ION CELL CHEMISTRY
SCHEMATIC OF CYLINDRICAL CELLS
SCHEMATIC OF PRISMATIC CELLS
SOURCE: DOE/EPRI Electricity Storage Handbook in Collaboration with NRECA, 2015 Edition
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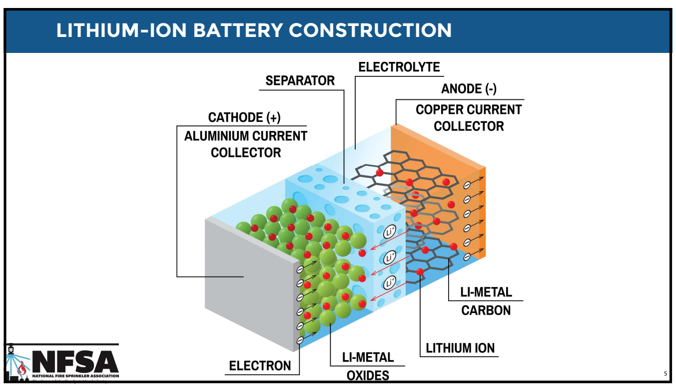
LITHIUM-ION BATTERY CONSTRUCTION
ELECTROLYTE
SEPARATOR
ANODE (-)
COPPER CURRENT COLLECTOR
CATHODE (+)
ALUMINIUM CURRENT COLLECTOR
LI-METAL CARBON
LITHIUM ION
ELECTRON
LI-METAL OXIDES
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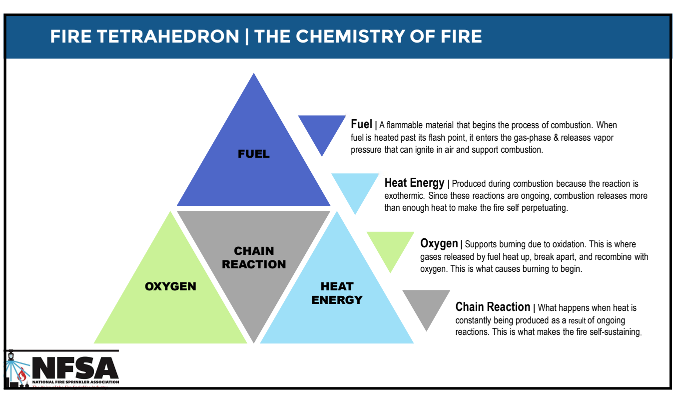
FIRE TETRAHEDRON | THE CHEMISTRY OF FIRE
FUEL
CHAIN REACTION
OXYGEN
HEAT ENERGY
Fuel | A flammable material that begins the process of combustion. When fuel is heated past its flash point, it enters the gas-phase & releases vapor pressure that can ignite in air and support combustion.
Heat Energy | Produced during combustion because the reaction is exothermic. Since these reactions are ongoing, combustion releases more than enough heat to make the fire self perpetuating.
Oxygen | Supports burning due to oxidation. This is where gases released by fuel heat up, break apart, and recombine with oxygen. This is what causes burning to begin.
Chain Reaction | What happens when heat is constantly being produced as a result of ongoing reactions. This is what makes the fire self-sustaining.
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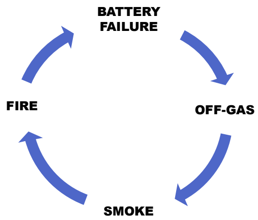
THERMAL RUNAWAY



STAGE 1: BATTERY FAILURE
Thermal, electrical, or mechanical abuse

STAGE 2: OFF-GAS GENERATION
Occurs regardless of cell form-factor

STAGE 3: SMOKE GENERATION
Catastrophic failure is imminent

STAGE 4: FIRE GENERATION
Likelihood of propagation drastically increases

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McMICKEN BESS EVENT

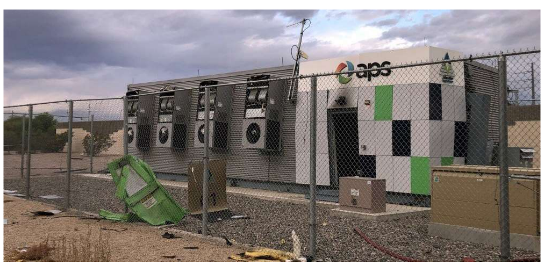

Image courtesy of DNV-GL: McMicken Battery Energy Storage System Event Technical Analysis and Recommendations

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McMICKEN BESS EVENT

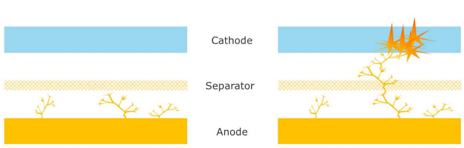

Figure 22 Li dendrites form during cycling (left), but under certain conditions may cyclically grow to penetrate the separator and short the electrodes (right), causing thermal runaway

Image courtesy of DNV-GL: McMicken Battery Energy Storage System Event Technical Analysis and Recommendations

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McMICKEN BESS EVENT

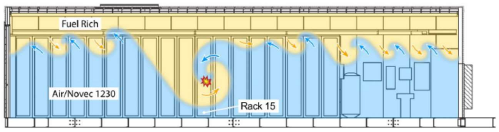

Figure 27 Colwell's simplified illustration of flammable gases near the top of the container rolling back as a reaction to the door opening, putting them in contact with residual heat or spark at Rack 15 (image credit: Colwell)

Image courtesy of DNV-GL: McMicken Battery Energy Storage System Event Technical Analysis and Recommendations

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McMICKEN BESS EVENT

Figure 8 Additional view of debris and damage to the rear door, HVAC systems, and the container

Image courtesy of DNV-GL: McMicken Battery Energy Storage System Event Technical Analysis and Recommendations

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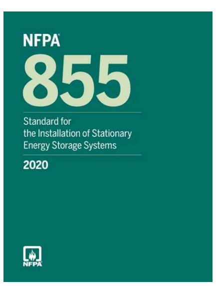
STANDARDS FOR ENERGY STORAGE SYSTEMS



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ENERGY STORAGE SYSTEMS

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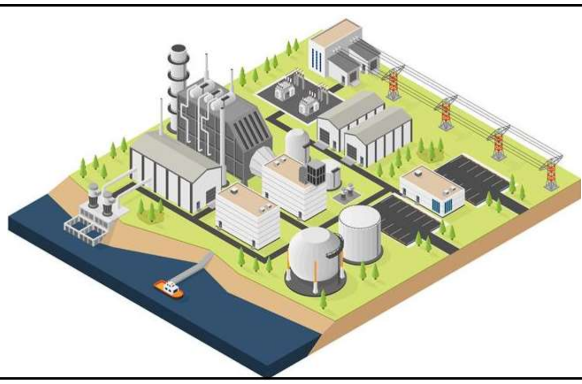

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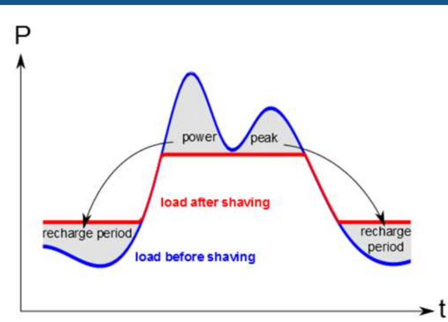
LITHIUM-ION BATTERY BULK STORAGE



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Compliance Required	Dedicated Use Buildings	Non-Dedicated-Use Buildings	Reference
Administrative	Yes	Yes	Chapter 1-3
General	Yes	Yes	Section 4.1-4.3
Size and Separation	Yes	Yes	Section 4.6
Maximum Stored Energy	No	Yes	Section 4.8
Elevation	Yes	Yes	4.3.9
Separation	N/A	Yes	4.3.6
Smoke and Fire Detection	Yes	Yes	Section 4.10
Fire Control and Suppression	Yes	Yes	Section 4.11
Water Supply	Yes	Yes	Section 4.13
Signage	Yes	Yes	4.3.5
Occupied work centers	Not Allowed	Yes	Section 4.7
Technology Specific Protection	Yes	Yes	Chapter 9-13

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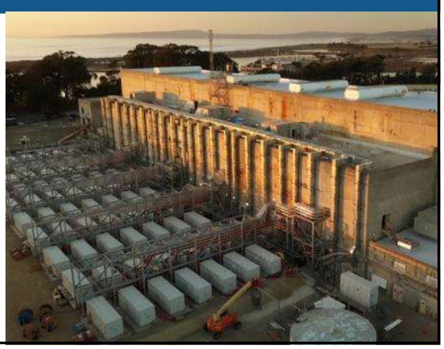
DEDICATED USE BUILDING 4.4.2.1

A. ESS Only
B. Occupants Only to Support ESS
C. No other occupancy types
D. Administrative and support personnel shall be permitted only when
   A. The areas do not occupy more than 10 percent of the building area of the story in which they are located.
   B. The areas are separated by 2-hour fire
   C. Cannot Egress through ESS



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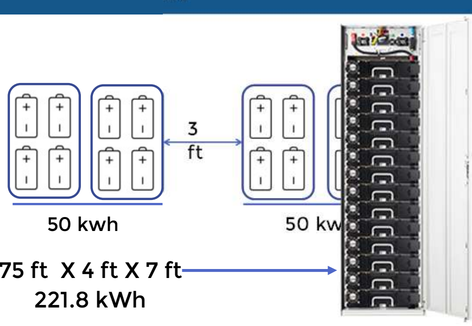
SIZE AND SEPARATION



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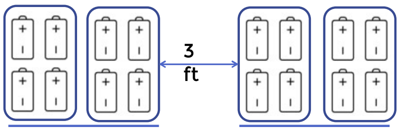
FIRE SUPPRESSION 4.11

0.3 gpm/sft over 2500 sqft



or

Large Scale Testing

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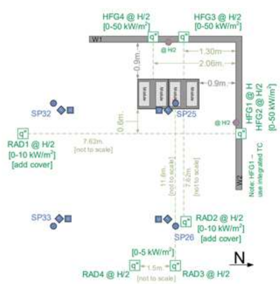
FM GLOBAL TESTING

- Testing conducted on Lithium iron phosphate (LFP), and Lithium nickel oxide (LNO) /Lithium manganese oxide (LMO) type batteries.
- The large-scale testing performed used the common criterion of an area of 3 m x 3 m (10 ft x 10 ft) and less than 16 sprinklers operating
- Every test level showed for both battery chemistries that ignition of a single module was sufficient to involve all modules within the rack tested.



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LFP RACKS

Figure 3-1: Photos of LFP rack; front (right), side (middle), and back (right).

Image courtesy of FM Global: Development of Sprinkler Protection Guidance for Lithium Ion Based Energy Storage Systems

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LFP MODULES

Figure 3-2: Photos of LFP module with front face of module shown on left side of picture.

Image courtesy of FM Global: Development of Sprinkler Protection Guidance for Lithium Ion Based Energy Storage Systems

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FM GLOBAL TESTING

- LFP posed a lower fire hazard risk
  - A Single Sprinkler was able to control the fire spread to the rack of origin.
- LNO/LMO pose a higher fire risk
  - Multiple sprinklers activated resulting in a demand area of over 2,500 ft^2 , and the fire spread from the origin rack to the target rack.
  - Module test had multiple sprinklers activate and represented a demand area of over 230 m2 (2,500 ft2). The larger demand area and observed fire spread among side-by-side racks deems it reasonable to base the sprinkler demand area on the entire room being protected.
  - For the LNO/LMO modules, the observed fire spread makes it necessary to multiply the fire duration of the first rack by the number of adjacent racks in the total configuration.

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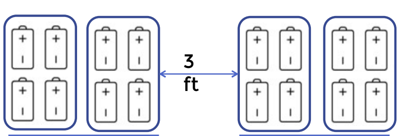
FM GLOBAL TESTS FOR LFP

0.3 gpm/sft over 2500 sqft



83.6 kwh

83.6 kwh

90 minute duration

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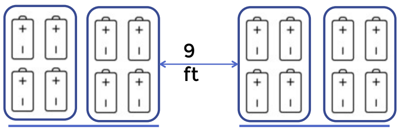
FM GLOBAL TESTS FOR NMC

0.3 gpm/sft over 2500 sqft



45 for minute duration for every adjacent rack

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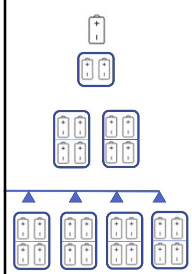
UL 9540A



Test level	Data Developed
Cell	a. Methodology required to initiate thermal runaway for testing. b. Cell surface temperature at onset of gas venting and thermal runaway. c. Gas composition, volume, and explosibility parameters.
Module	a. Number of initiating cells required for propagation of thermal runaway. b. Heat, smoke, and flammable gas release rates and total release quantity. c. Observations of external flame extension. d. Observations of deflagration and debris hazards.
Unit	a. Extent of thermal runaway propagation. b. Heat, smoke, and flammable gas release rates and total release quantity. c. Observations of external flame extension, deflagration, and debris hazards, and re-ignition hazards. d. Thermal exposure (temperature on adjacent walls, and target units; heat flux to adjacent walls, target units, and egress pathways)
Installation	a. Evaluation of fire protection method. b. Fire growth control. c. Extent of thermal runaway propagation. d. Design features related to containment of thermal runaway gases and heat that create an explosion hazard. e. Deflagration protection system. f. Egress protection. g. Thermal exposure to adjacent surfaces. h. Observations of flaming outside the installation i. Observations of reignition. j. Deflagration and debris.

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OUTDOOR OPTION

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SPRINKLER SAVE

Battery fire at Salt River Project in Arizona

Fire crews in Chandler, Arizona sent robots into a building at the Salt River Project where a 10 MW battery was smoldering.

APRIL 26, 2022 ANNE FISCHER

ENERGY STORAGE | ENERGY STORAGE | INSTALLATIONS | MARKETS & POLICY | ARIZONA

Image: Chandler, Arizona Fire Department

Article courtesy of PV Magazine

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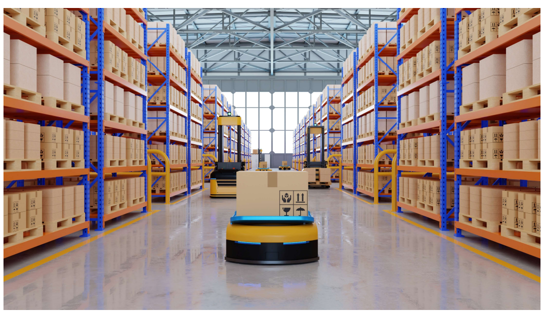
BULK STORAGE OF LI-ION BATTERIES



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FM GLOBAL TESTING OF BULK LI-ION STORAGE

Image courtesy of FM Global: Flammability Characterization of Lithium-ion Batteries in Bulk Storage

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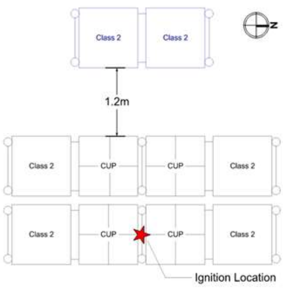
PHASE 2 FULL SCALE TEST

Test #1:
- 15 ft (3 tier) storage
- 30 foot ceilings
- Sprinklers:
  - 165°F
  - 25.2K

Test #2:
- 15 ft (3 tier) storage
- 25 foot ceilings
- Sprinklers:
  - 165°F
  - 14.0K



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OUTCOME OF TEST

Pass Criteria: Sprinklers suppress the fire within 5 minutes, suppress fire before commodity cartons are breached.

Results: In both tests, the CUP commodity cartons breached before the initial sprinkler operation. The adequacy of the ceiling-level sprinkler protection could not be established due to persistent burning of the CUP commodity beyond the predicted time of battery involvement.

NOT A TOTAL LOSS!

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FM CRITERIA

Storage Criteria
- No more than 3 tiers of rack or palletized storage
- Maximum 15 ft storage height
- Maximum 40 ft ceiling Height

Battery Criteria
- Maximum State of Charge: 60%
- Maximum weight of electrolyte: 20%
- Maximum battery capacity: 41Ah

Design Criteria
- K22.4 or K25.2 sprinklers
- 12 sprinklers flowing
- Minimum 35 psi

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WASTE MANAGEMENT FACILITIES

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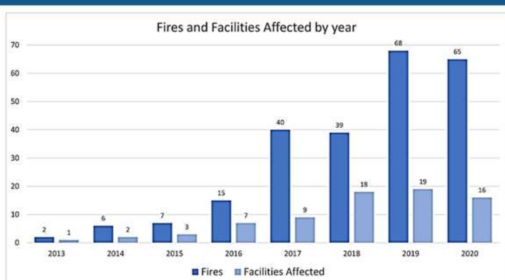
WASTE MANAGEMENT FACILITIES



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LAST SLIDE

Questions?

Complete Course Evaluation to receive certificate
Certificate on website under "My Account"

Contact: Jeff Dunkel
Jeff Dunkel

Next Tech Tuesday: June 21st, 2022
Environmental Issues With ITM

Terin Hopkins, Public Fire Protection Specialist

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Fires in Waste Management and Recycling Facilities Caused by Lithium-Ion Batteries

By Jeff Dunkel, PE, Fire Protection Engineer

In the May-June 2021 edition of ***National Fire Sprinkler Magazine***, I discussed the sprinkler application for Lithium Ion Based Energy Storage Systems. This is not the only application for this technology, and certainly not the only application in which these batteries pose a fire hazard. Li-ion batteries provide a considerable amount of power in a small light weight package at a relatively low cost. As the amount of power in these small packages (also known as energy density) increases, so does the severity of fire if a failure occurs. It is safe to say most, if not all of us use devices containing Li-Ion batteries, they can be found in electronics such as cell phones, laptops, tablets, handheld gaming devices, hearing aids, hoverboards, E-cigarettes and many other devices. Since the previous article discussed the failure mechanisms and the definition of thermal runaway, this article will focus on the impacts of those failures, especially when improperly disposed.

Identifying the problem

As mentioned, the use of Li-Ion batteries is widespread and has been for some time. These batteries do not have endless lifespans. This, of course, creates waste. In July 2021 the Environmental Protection Agency (EPA) released a study titled *An Analysis of Lithium-ion Battery Fires in Waste Management and Recycling.* This report explored the growing number of fires caused by lithium-ion batteries in the waste management process. This report details 245 fires in 64 waste facilities between 2013 and 2020 that were caused, or likely caused, by lithium metal or lithium-ion batteries. The report does not capture all fires caused by improperly discarded batteries because not all incidents are made public and not all incidents are covered by the news. Due to these limitations, they believe that the incidents they identify in the report represent the cases that were relatively easy to find and that there are likely to be a significant number of additional relevant cases. The figure labeled *Fires and Facilities Affected by year* illustrates the increase of fire incidents described in the EPA report between 2013 and 2020.

Why is this a problem?

Li-Ion Batteries are considered hazardous waste when disposed and are regulated under federal and state waste rules. Under the Resource Conservation and Recovery Act (RCRA) the disposal of Li-ion batteries must be managed to ensure they are safely disposed or recycled through the provisions of 40 CFR Part 273; however, this does not regulate household hazardous waste. Because it is incumbent on consumers to dispose of old batteries or electronics that contain batteries found in the household, it is inevitable that Li-ion batteries will be found in the municipal waste process even though retail facilities provide free battery recycling collection programs.

One mode of failure that could cause a Li-ion battery to fail is mechanical damage, which is likely to happen in the standard waste process. When this failure happens, the combustible waste surrounding this ignition source lends itself to a significant fire. While it is unknown how many waste management facilities are properly protected with fire sprinklers, it is often the case that waste facilities are exempt from local and state building code requirements. The number of losses reported are increasing, which could be a sign that the level of protection provided may not be adequate. History may have shown that the level of protection provided for these facilities in the past was adequate, but the increasing number of fires certainly suggests that a reevaluation of these facilities' suppression and detection systems is warranted. Though these facilities have strict policies not to accept Li-Ion batteries, there is currently no process to ensure they do not enter

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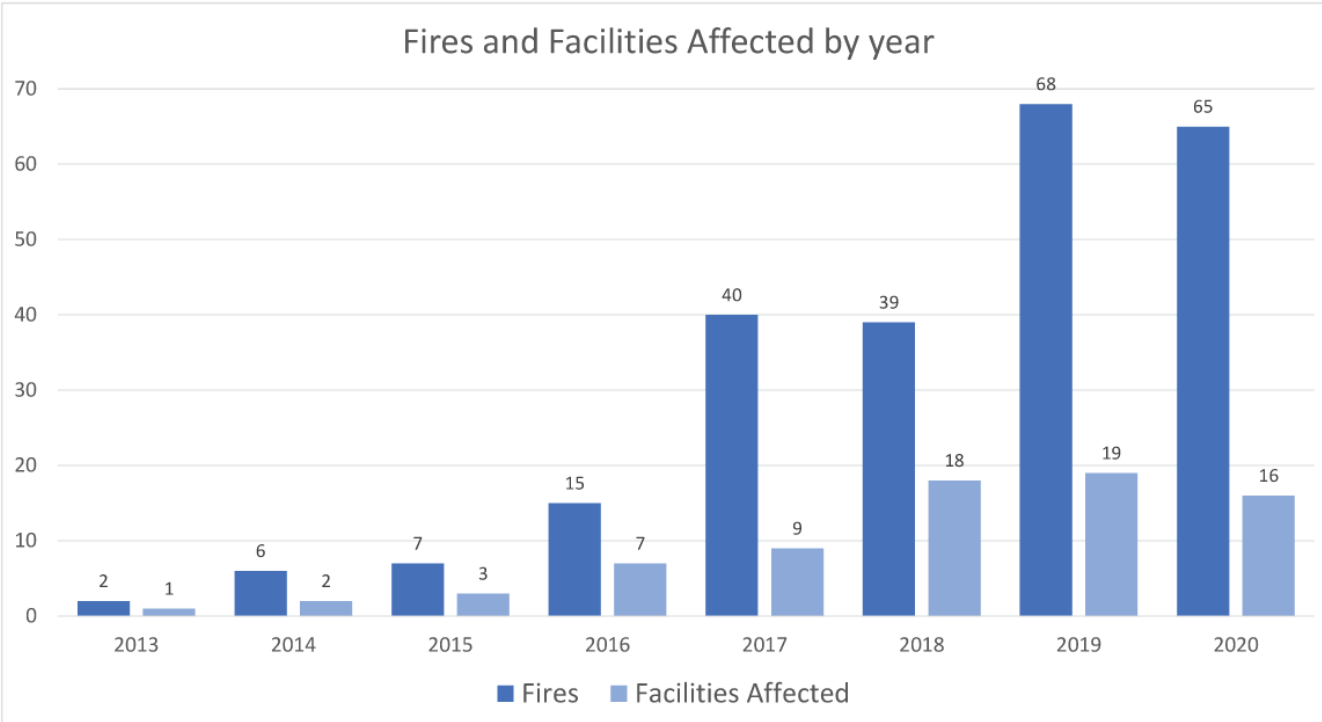

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the waste flow other than policies and operators recognizing these batteries as they enter the facility. With the increase of battery use, the likelihood and frequency they will improperly enter the common waste flow will also increase.

How should Waste Management Facilities be Protected?

Each waste management facility is different. They may receive different materials because recycling of household waste is based on their policies. They may also accept only specific materials. Along with different materials, the processes may be different from facility to facility. For this reason, it is imperative that each facility be evaluated by a competent design professional to develop a fire protection plan. This plan would include fixed suppression systems, detection systems, and portable fire extinguishers based on the materials and processes in that facility.

Based on the risk, it is likely that any hazard analysis would determine that a fire sprinkler system would be required for any indoor waste management facility. But what does the building code say? Again, while each facility is different, a waste management facility receiving typical recyclables (paper and plastics) would meet the definition of a moderate-hazard factory industrial occupancy or an F-1 Occupancy. These are defined as occupancies that include, among others, the use of a building for assembling, fabricating, finishing, manufacturing, packaging, repair or processing operations that are not classified as a Group H hazardous or Group S storage occupancy. Section 903.2.4 of the IBC requires sprinklers for Group F-1 occupancies with fire areas exceeding 12,000 square feet.

NFPA 13 does not provide specific criteria for waste management facilities. Large piles of materials make these facilities susceptible to deep-seated and shielded fires that are hard to detect and may be difficult to extinguish. It is impossible to dictate a design density for all facilities. Any analysis conducted must include a detailed review of the anticipated materials or combination of materials brought into the facility and the pile size anticipated in the specific process to evaluate the proper design criteria. Any densities lower than Ordinary Hazard Group 2 (0.2 gpm/sqft over 1,500 sqft) would most likely be inadequate. Even though the ignition source may be the Li-ion batteries, the design criteria should also be based on the bulk material of the facility and not just the batteries.

Of course, for this unique hazard, sprinklers are only part of the complete fire protection scheme. Due to the potential for deep-seated fires, hose stations would also be a prudent addition though they are not directly required by the IBC. Due to the common occurrence of fires at these facilities personnel are often trained and well versed in emergency procedures for a fire incident. With that being the case, a Class II standpipe may be a good choice. It must be communicated with the owner in advance to ensure they know the requirements for training the employees to properly fight a fire with this equipment and that the risk is acceptable.

There are additional types of suppression systems, some of which are marketed specifically for this application, such as remotely-controlled foam monitor stations coupled with video heat detection. These systems may be a good option; however, they should be used in addition to, not as a replacement of, fire sprinkler systems designed per NFPA standards.•

SOURCES:

Lett, Kathy, et al. "An Analysis of Lithium-Ion Battery Fires in Waste Management and Recycling." *EPA*, Environmental Protection Agency, 2021, https://www.epa.gov/recycle/importance-sending-consumers-used-lithium-ion-batteries-electronic-recyclers-or-hazardous.

Fire Sprinkler Application for Lithium Ion Based Energy Storage Systems

by Jeff Dunkel, PE

As a new member of Team NFSA, I would like to introduce myself. I am Jeff Dunkel, P.E. and I serve as a Fire Protection Engineer in the Contractor Services Department with Michael Joanis, P.E. My professional career started in the Oklahoma Air National Guard as an Emergency Manager. After graduating from Oklahoma State University with a B.S. Degree in Fire Protection and Safety Engineering Technology, I worked both in consulting and construction for 13 years of fire protection engineering experience. I am honored to be a part of Team NFSA and look forward to supporting the mission.

Introduction

Lithium-Ion (Li-ion) batteries are used in a wide variety of consumer products and the applications are growing every day. There is a good chance you are reading this article from a device powered by a Li-ion battery. The ability to store energy in a smaller lighter battery, also known as energy density, is what makes this technology beneficial. However, as the applications grow and as energy density increases, so does the potential for hazards. The traditional use for Li-ion batteries has been for portable devices. However, the increased energy density capabilities have made these batteries a viable technology in small- and large-scale Battery Energy Storage Systems (BESS). BESS systems can be used for residential applications, commercial/medical applications, and even grid level energy storage. Currently the largest BESS system is the Moss Landing Energy System in Monterey County California which contains 4,500 stacked battery racks each with 22 battery modules. Grid level BESS systems such as Moss Landing allow the electric utility to store surplus electricity during low demand and distribute that power during peak demand, also known as peak shaving. While there are many different types of batteries, Li-ion batteries are the most common in these applications. This is the technology we will be focusing on here.

Defining the Hazard

Since the sole function of Li-ion battery is to store electricity, one might assume a fire involving a battery of this type would be a Class C fire or electrical fire. These fires are closer to a Class B or a flammable liquid/gas fire. To understand why these fires are Class B you have to understand the construction of the batteries and the cause of these fires. Li-ion are comprised of a negatively charged anode and a positively charged cathode separated by a semi-permeable film with liquid electrolyte on both sides to allow for the transfer of ions. Another common misconception is the assumption that since these batteries contain lithium, water could create or increase a hazard since lithium metal is not compatible with water. However, with the way the lithium is incorporated into the battery in a metal oxide, water reaction is not a concern even when fully submerged.

Thermal Runaway

The primary hazard of Li-on batteries is thermal runaway. NFPA 855, Standard for the Installation of Stationary Energy Storage Systems, defines thermal runaway as: "The condition when an electrochemical cell increases its temperature through self-heating in an uncontrollable fashion and progresses when the cell's heat generation is at a higher rate than it can dissipate, potentially leading to off-gassing, fire, or explosion." While the fuel for a fire or explosion in thermal runaway is also due to gaseous electrolyte venting, the cause of this event is internal. During thermal runway, a battery rapidly releases its stored energy where the volatility of the reaction is proportional with the amount of energy stored in that cell. Active suppression systems are not effective in stopping or reversing thermal runaway. However, some systems can provide a cooling effect for the adjacent cells and potentially minimize the propagation of thermal runaway to those cells.

Thermal runaway can be caused by a few different factors outside of manufacturer defect. Thermal abuse such as loss of cooling or simply overheating or electrical abuse, by overcharging, or by physical damage to the battery cell. In general, any issue that would compromise the separation film will cause an internal short which will propagate a thermal runaway event. Once a thermal runaway event is triggered there is a high likelihood that it will propagate to adjacent cells if no thermal barrier or active cooling method is provided.

Suppression Challenges

The Fire Tetrahedron consists of four components, oxygen, heat, fuel, and a chain reaction, all of which are needed to maintain combustion. At its core, traditional fire suppression methods are basic. To properly extinguish a fire only one component of

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the Fire Tetrahedron needs to be removed. The challenge of suppressing fires involving batteries is that all the components, with the exception of oxygen, are contained or produced by the battery during a malfunction. A battery fire can be delayed with the removal of oxygen. However, it will not stop the progression of thermal runaway. In an oxygen-lean environment without flame propagation the thermal runaway process will continue to release ignitable gases. For this reason, reintroducing oxygen even hours after the initial event can cause re-ignition or explosion of released gases. Hence, any suppression system that extinguishes a fire by displacing oxygen must maintain a low oxygen level environment for a sufficient period of time, often significant, that allows operators and first responders to verify stored energy is sufficiently dissipated, flammable gases are no longer present, and the batteries are sufficiently cooled. Where typical hold times for gaseous suppression systems is minutes, a thermal runaway event could release or contain ignitable gases for hours.

A lesson was learned the hard way on April 19th, 2019 when an explosion occurred at the Arizona Public Service Company (APS) McMicken Battery Energy Storage Facility located in West Valley, Arizona. A technical analysis provided by DNV-GL of the incident concluded that a thermal runaway event occurred which caused the release of the total flooding clean agent system. However, the clean agent system was not designed or capable of preventing or stopping a cascading thermal runaway event in a BESS. Approximately three hours after the thermal runaway began, the BESS door was opened by firefighters, agitating the remaining flammable gases, and allowing the gases to make contact with a heat source which cause the explosion, injuring several firefighters.

Large Scale Testing

In June of 2019, FM Global released the first publicly available large scale fire testing for Li-ion based energy storage systems. FM Global's report documented testing for two types of Li-ion based BESS systems, each with different chemistries; iron phosphate (LFP) and Lithium nickel oxide/lithium manganese oxide (LNO/LMO), other than the battery chemistries, the equipment construction was similar. In this testing the FLP batteries exhibited a lower overall hazard where a single sprinkler operation was sufficient to control the fire to the rack of origin, with no significant involvement of the modules in the adjacent rack. The LNO/LMO test did result in the fire spreading to the adjacent rack and the number of sprinklers operating resulted in a demand area greater than 2,500 ft^2.

This report resulted in the recommended sprinkler design criteria for LFP system under a 15ft ceiling of a minimum density of 0.3 gpm/ft^2 over a 2,500 ft^2 design area using a sprinkler with a K-Factor of 5.6 or greater. The recommended fire water duration is 90 minutes. This recommended criteria applies to ESS racks limited to 83.6-kWh spaced 3ft from any non-combustibles and 5ft from combustibles.

The FM Global tests also resulted in a recommended sprinkler design criteria LFP system under a 15ft ceiling is a minimum density of 0.3 gpm/ft^2 over the entire room where the ESS is located using a sprinkler with a K-Factor of 5.6 or greater. The recommended fire water duration is 45 minutes for each rack that is located within 9ft of another BESS rack. This recommended criteria is limited to BESS racks limited to 125-KWh spaced 6ft from any non-combustibles and 9ft from combustibles.

These tests were narrow in scope and should not be used for application, they do, however, provide good insight as to what we can expect to see going forward.

Current Code Requirements

In 2016 NFPA began the development of NFPA 855, The Standard for the installation of Stationary Energy Storage Systems. The initial edition of NFPA 855 was released in 2020. The scope of NFPA 855 is not limited to Li-ion batteries or battery specific BESS, however Li-ion batteries make up the majority of BESS systems today. The scope of NFPA 855 is limited to ESS systems that exceed 20 kWh. Early in the development of this standard there was no large-scale fire testing data available for guidance. The initial direction was a "surround and drown" approach, where a single fire area would be limited to a specific energy density of 600 kWh, and the sprinkler design area would be the limits of that fire area. Since it is not possible to stop the thermal runaway process in a specific cell once it has started, the goal is to prevent the thermal runaway event from propagating to adjacent modules or racks.

NFPA 855 requires fire suppression systems for all indoor ESS installations. However, when approved by the authority having jurisdiction (AHJ), suppression systems can be omitted when the building is dedicated for the use of BESS and is located more than 100ft from buildings and lot lines. Non-dedicated use buildings are also limited to 600 kWh within a single fire area.

Outdoor walk-in enclosures also require fire suppression systems which can be omitted when agreeable to the BESS owner and approved by the AHJ. Walk-in enclosures larger than 53ft x 8.5ft x 9.5ft are considered an indoor system. BESS systems installed on rooftops or open parking garages require fire suppression and no option is given for omission. Mobile BESS systems will only require suppression systems when they are walk-in type units.

In all cases that require fire suppression, the only prescribed suppression system in NFPA 855 is a sprinkler system installed per NFPA 13. Initially the design criteria was a minimum 0.3 gpm/ft^2 over a 2,500 ft^2 design area or the entire room whichever is smaller. An addendum issued April 1st 2020 (TIA 20-1) modified this criteria to only apply to ESS units or groups with a maximum stored energy of 50 kWh. As you can see in the FM Global testing, a single battery rack or unit can easily exceed 50kWh. Additionally these groups must be separated by a minimum of 3ft. The April 2020 TIA also clarified that ESS systems that exceed the 50kWh in a single group or multiple groups spaced closer than 3ft require a large-scale fire test to determine an adequate design criteria for the specific ESS units used. The large-scale test must be in accordance with UL9540A or an equivalent standard. With the stringent energy density limits, in fire areas and groups, it is likely that the majority of sprinkler densities in any moderately sized ESS will be

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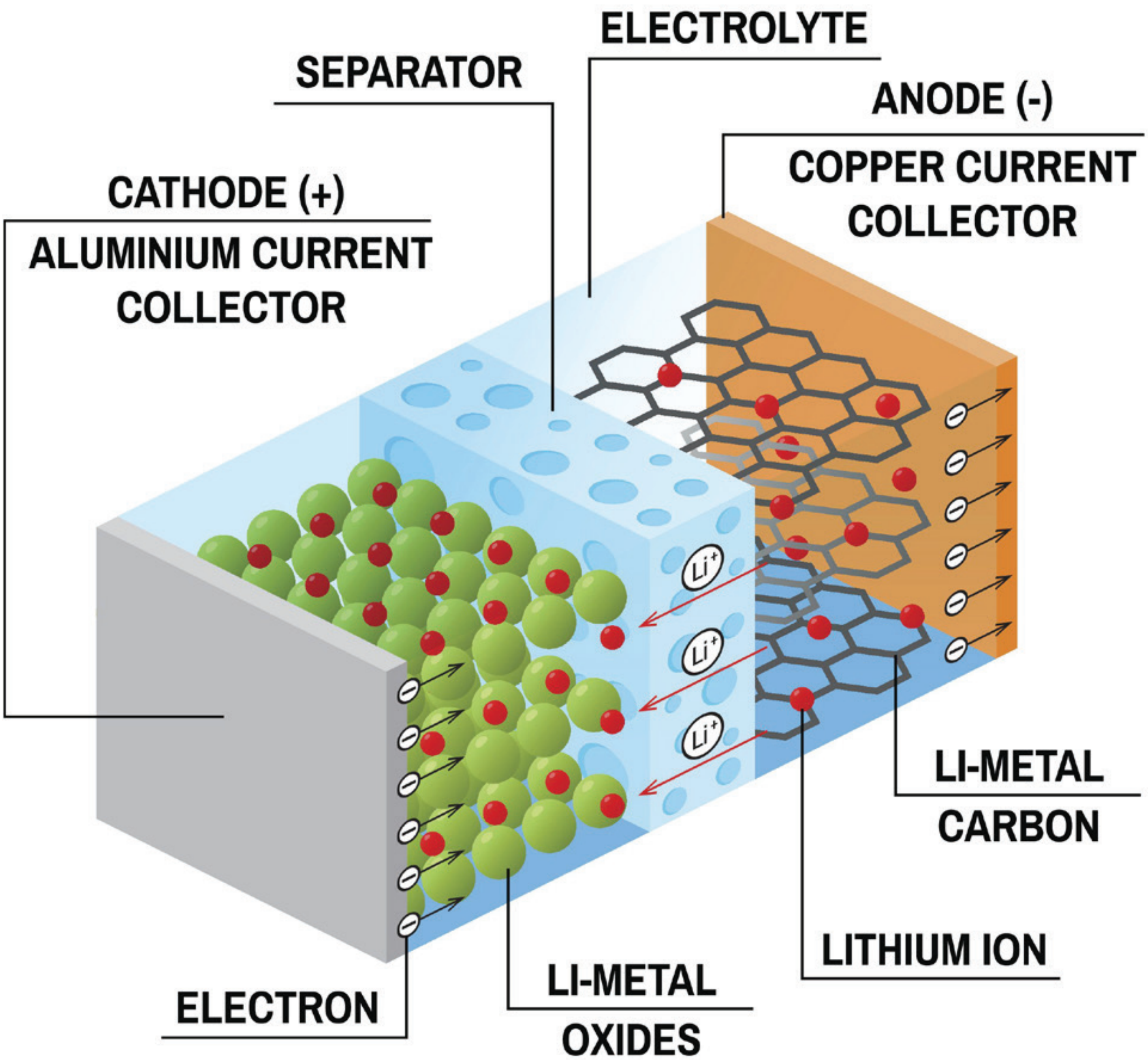

dictated by the UL9540A test. This makes the 9540A test report vital to properly design a suppression system for these facilities.

NFPA 855 does allow the use of other suppression technologies such as carbon dioxide, water spray, water mist, clean agent, and aerosol fire suppression, but only when a large scale fire test such as UL9540A has shown they are acceptable. We have learned from the FM Global testing and the APS McMicken explosion findings that a suppression system that cannot provide long term cooling or does not allow for ignitable gases to be ventilated would create design challenges. There is an industry effort to provide fire barriers and/or fire suppression systems integrated into the BESS system at the manufacturer's level. Some are water spray systems that will be connected to the building sprinkler system. More developments like this are expected as additional large scale testing is conducted.

In addition to NFPA 855, the 2018 edition of the International Fire Code has added chapter 12 for Energy Systems which in many ways mirrors the requirements of NFPA 855. The IFC Chapter 12 only applies to ESS systems in excess of 20kWh, limits groups spaced by 3ft to 50kWh, and any fire areas that exceed 600 kWh is considered a Group H-2 occupancy. The Group H-2 classification itself would require sprinklers, however the chapter specifically requires sprinklers to be installed based on criteria from NFPA 13 or large-scale fire testing.

While Li-ion battery technology may not be new, the application for large scale stationary energy systems is. We can learn from the limited publicly available large-scale testing and the incidences that we have had to date and continue to progress. The ever-changing technology for BESS and the expanding use for these technologies will ensure this topic will continue to be on the forefront of the fire protection community for some time. •

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NFSA TechNotes

Editor - Roland Asp, CET **#486** **04/26/2022**

This edition of TechNotes was written by Jeff Dunkel, P.E., Fire Protection Engineer for the NFSA.

NFSA TechNotes #486 - Fire Sprinkler Design Criteria for Bulk Storage of Lithium-Ion Batteries

NFSA has covered protection of Lithium-Ion (Li-ion) batteries in detail in recent publications. The May-June 2021 edition of the National Fire Sprinkler Magazine discussed Energy Storage Systems with Li-ion batteries. TechNotes #466 covered the same topic more specifically to the design and application of sprinkler systems in these occupancies, and the upcoming edition of the National Fire Sprinkler Magazine will contain an article on the emerging trend of waste management facility fires caused by in-properly discarded Li-ion batteries. While much has been covered, not all issues have been addressed.

Current Guidelines

There currently are many uses and applications for Li-ion batteries, and these applications are growing every day. With such widespread use, there is inevitably a need to store large quantities of these cells, or devices powered by them. Typically, the first step to determine design criteria for storage is to establish the commodity classification, herein lies the problem. NFPA 13, 2022 edition in Annex Table A.20.4 (a) lists Li-ion batteries as a commodity not addressed by NFPA 13. This section makes it clear that prescriptive criteria through NFPA 13 is not available for Li-ion batteries. The next avenue could be a performance-based design; however, without large scale testing to back up any proposed criteria it may be difficult for an AHJ to sign off.

The Research

Fortunately, while NFPA 13 does not provide guidance on commodity classification or design criteria for Li-ion batteries, The NFPA Research Foundation in conjunction with FM Global commissioned research to assist in the development of protection criteria to protect rack storage of cartoned Li-ion batteries. This project was completed in three phases, the first of which is a hazard analysis titled “Lithium-Ion Batteries Hazard and Use Assessment.” This assessment is a literature review of battery technology, failure modes and events, usage, codes, and standards, and hazard assessment during the life cycle of storage and distribution. The second phase, titled “Lithium-Ion Batteries Hazard and Use Assessment” is a comparison of the flammability characterization of common lithium-ion batteries to standard commodities in storage. Testing in phase III was conducted by FM Global who issued a report titled “Flammability Characterization of Lithium-ion Batteries in Bulk Storage,” subsequently NFPA released a report based on the findings referenced by FM Global.

Each phase building on the next, the findings in Phase III were the most consequential in regard to actual, usable fire sprinkler design criteria. While criteria was recommended, the FM Global report made it clear that the information provided by the testing does not provide the same level of information regarding protection system performance gained through Commodity Classification, meaning the report did not establish a commodity classification. This is an important distinction, since the commodity classification was not established, the only criteria that can be used without additional testing is the criteria recommended for the arrangement specifically. The storage conditions referenced in the report are:

- Rack Storage up to 15 feet
- Ceiling Heights up to 30 feet
- Bulk-packaged small-format li-ion batteries in corrugated board cartons (i.e., 18650-format cylindrical cells, power tool packs (comprised of 18650 format cells), and Polymer cells) at 50% state of charge.

Due to the cost and availability of large quantities of Li-ion batteries, Phase II established that Cartoned Unexpanded Plastics (CUP) were a suitable surrogate for Li-ion batteries, provided the protection system design suppresses the fire within 5 minutes. Essentially, if the suppression system can suppress the fire within 5 minutes this would be sufficient to prevent the battery cells, inside a plastic casing and cartoned from being damaged which could creating a thermal run-away event.

Testing

Ultimately, two tests were conducted in phase III using a three-tier-high 15-foot rack-storage array that was centered among four sprinklers, both tests utilized sprinklers rated for 165° F. The first test conducted utilized K-25.2 sprinklers under a 30-foot ceiling, the second utilized K-14.0 sprinklers under a 25-foot ceiling. In both tests the CUP commodity cartons breached before the initial sprinkler operation, and the CUP commodity itself continued to burn beyond the predicted time of battery enrollment of 5 minutes, therefore the effectiveness of the ceiling level sprinklers could not be assessed.

While not an entirely successful outcome, this research did provide valuable input and assistance for future testing regarding bulk storage of cartoned Li-ion batteries. The equivalency established in phase II will allow cartoned unexpanded plastics to be used as a surrogate commodity for future testing, which will greatly reduce the cost for much needed future testing. Also, the data gathered in phase III was sufficient for FM Global to release protection criteria.

FM Criteria

FM Data Sheet 8-1 currently is the only prescriptive criteria available for storage of Li-ion batteries and dictates no more than 3 tiers of rack or palletized storage limited to 15 ft and a maximum ceiling height of 40 ft. Sprinklers must be either K-22.4 or K-25.2 and the calculations are based on 12 sprinklers flowing at a minimum 35 psi. Other limitations to allow this criteria are, maximum battery state of charge of 60%, a maximum electrolyte weight of 20%, and a maximum battery capacity of 41 Ah. Packaging must be a carton, with cellulosic and/or unexpanded plastic internal packaging only. If the maximum battery and packaging properties are exceeded, Scheme A from FM Data Sheet 7-29 must be followed.

Future NFPA Criteria

While it is likely additional testing is needed before NFPA 13 provides criteria specific to Li-ion batteries, this research project will allow the industry to take a step forward. The need for approved prescriptive criteria is needed and may not be too far off.

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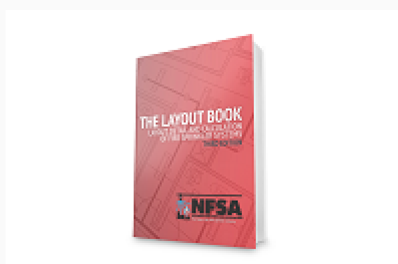

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