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2022 MARCOM GOLD WINNER

Fire Protection for Lithium-Ion Battery Manufacturing Facilities

by Phil Friday, P.E., FSEPE

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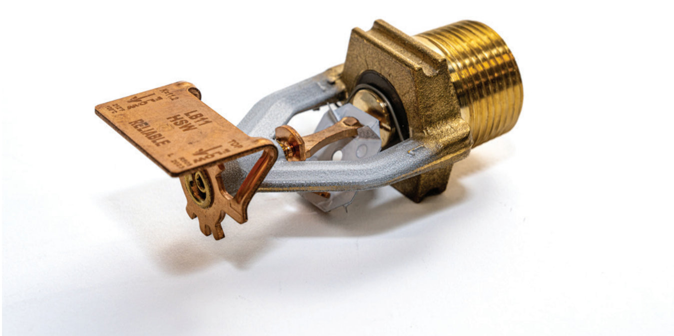
From Mike Joanis: *Phil Friday, P.E., FSFPE is the Director, Engineering Applications and Innovation, for Reliable Automatic Sprinkler Co. Inc. In Liberty, SC. Mr. Friday is a licensed professional fire protection engineer with a background in commercial and industrial building design and construction, fire protection equipment manufacturing, fire investigation, and firefighting. Mr. Friday earned a B.S. degree in Chemistry from the University of Tennessee in 1996 and a M.S. degree in Fire Protection Engineering from the University of Maryland in 2000. Mr. Friday has held numerous positions in the field of fire protection since 1991. In the 1990's he was a firefighter with the Tri-Community Volunteer Fire Department and a wildland firefighter for the United States Forest Service. He spent the last 20 years working as a fire protection engineering consultant on projects across North America. He has been an active member of the National Fire Protection Association (NFPA) and Society of Fire Protection Engineers (SFPE) for more than 20 years. In 2018 he received the designation of 'Fellow' from the SFPE.*

This article describes the development of a unique sprinkler and protection scheme for lithium-ion batteries in racking within battery manufacturing facilities.



RELIABLE LB11 SPRINKLER

Lithium-ion batteries are everywhere; from personal electronic devices (e.g., mobile phones and laptop computers) to electric vehicles (EVs) to battery energy storage systems (BESS). If it is rechargeable, chances are it contains one or more lithium-ion batteries. The manufacturing of lithium-ion batteries has largely been done outside North America; specifically in China, South Korea, Japan and other Asian countries. Recently, however, stimulated by the Inflation Reduction Act, and the push for electrification and green energy, lithium-ion battery manufacturing facilities are being built at a record pace in North America and across Europe.

[Fun Fact: The first lithium-ion battery was invented in the 1970s by researchers at ExxonMobil.[1, 2]]

Lithium-ion battery manufacturing is challenging and can be hazardous. The liquid electrolytes used in cells are highly flammable organic solvents such as ethylene carbonate and diethyl carbonate. Other constituents used to make the cells are toxic. Precision and care must be taken when assembling the cells to prevent contamination and misalignment between cathode, separator, and anode layers. Defects during cell assembly can result in thermal runaway and a fire when the cells are first charged and during formation of the solid electrolyte interphase (SEI).

Perhaps the most dangerous stages during lithium-ion cell manufacturing occur after the cells are assembled. Following assembly, cells are often placed in plastic trays (a/k/a 'formation trays') designed to accommodate many cells for handling and transport through what is known as formation, aging, and testing (FAT). During FAT, the cells are charged, conditioned, and tested. It is during FAT that small defects often manifest that can, and occasionally do, result in fires. The aging process consists of placing many 'formation trays' in tall racks. In these rooms the cells are 'aged', or conditioned, to form the SEI within the cells. Formation of the SEI is needed to allow the lithium ions to migrate efficiently back and forth between the cathode and anode during charging and discharging. The lithium-ion migration inside a cell is what allows electricity to be stored and used.

In most cases, after the cells are manufactured, they are interconnected and enclosed in a device, module, or battery pack. Battery packs range in size depending on the power and energy requirements of what they are used to power. Examples of small battery packs are those used in power tools and large packs are used to power electric vehicles.

Very few large-scale fire tests have been conducted to determine the fire protection requirements for lithium-ion cells and packs. In March 2013, FM Global published a research report titled,

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'Flammability Characterization of Li-ion Batteries in Bulk Storage'.[3] The testing and analysis focused on smaller format (i.e., 2.6 Ah) lithium-ion batteries packaged in cardboard cartons with different levels of plastic packaging and with states of charge up to 60%. One conclusion from the report is that lithium-ion batteries can be treated as cartoned, unexpanded Group A plastic (CUP) commodity if the protection system *precludes battery involvement* by early extinguishment of the carton packaging fire. Sprinklered large-scale tests that involved the batteries were not conducted as part of the project.

In October 2016, FM Global published a research report titled, 'Development of Protection Recommendations for Li-ion Battery Bulk Storage: Sprinklered Fire Test'.[4] This report describes a large-scale sprinklered test conducted with larger format (i.e., 20 Ah) 'polymer' pouch cell batteries packaged in cardboard cartons with a nominal state-of-charge (SOC) of 50% and follow-up intermediate scale (i.e., water application) testing. There was limited involvement of the batteries in the large-scale test and subsequent intermediate-scale testing suggested a higher degree of battery involvement could be protected by a scheme adequate for protection of CUP commodity for storage heights up to 15 ft. under ceiling heights up to 40 ft. The report cautioned against extending the results of the testing presented beyond the specific combination of packaging, battery, and SOC tested.

In January 2023, FM Global published protection criteria for lithium-ion batteries in general storage in FM Data Sheet 8–1. The protection recommendations in Data Sheet 8-1[5] appear to be based on FM Global's earlier work on cartoned batteries at relatively low states of charge.

Seeing a significant gap in fire protection criteria for lithium-ion batteries and the challenges and needs of the battery manufacturing industry, Reliable Automatic Sprinkler Co., Inc. decided to take the next step. There are several significant challenges associated with protecting automatic storage and retrieval system (ASRS) racking found in battery manufacturing facilities:

1. There is no protection criteria (based on large-scale testing) in NFPA 13 or FM Standards related to protection of exposed (uncartoned) lithium-ion batteries. This is due, in part, to the lack of large-scale testing that has been performed with lithium-ion batteries.
2. Installing pendent or upright in-rack sprinklers within the ASRS racking represents a significant challenge due to limited access and routing options within the unique rack configurations. The issues are compounded by the material handling equipment (e.g., robotics) present.

To start, Reliable developed the LB11 sprinkler. The LB11 is a K11.2 (K160) horizontal sidewall in-rack sprinkler with a discharge pattern specifically designed for protection of high challenge commodities. After passing the mechanical tests and required large-scale fire tests with Group A plastic commodities, the LB11 horizontal sidewall sprinkler was issued a Listing according to UL 199K, *Outline of Investigation for Fire Testing Specific Application Horizontal Sidewall Sprinklers for Installation in Racks Having Vertical and Horizontal Barriers.*

In January 2023, Reliable conducted its first large-scale test of lithium-ion batteries stored in plastic trays in racking protected with the LB11 sprinkler. The racking in the battery test was fitted with horizontal and vertical barriers like what is found in room temperature and high temperature aging rooms in battery manufacturing facilities. The test layout is shown in Figures 1 and 2 below.

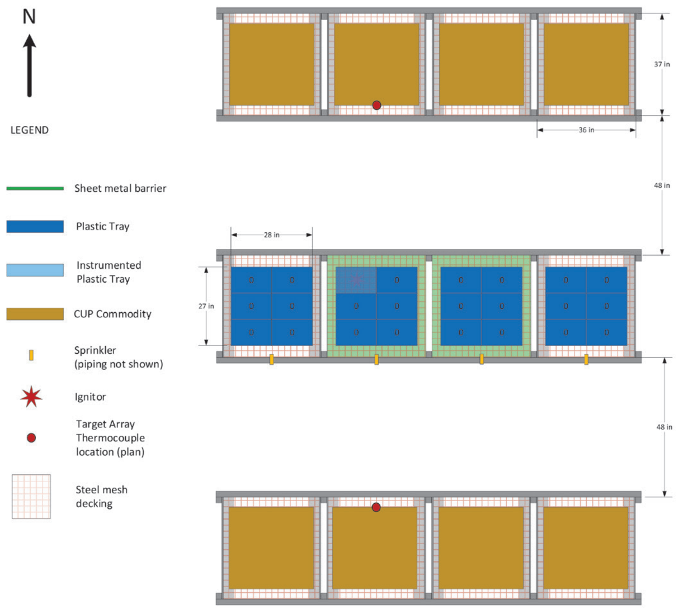

Figure 1: Test Arrangement Plan View
[courtesy of UL Solutions]

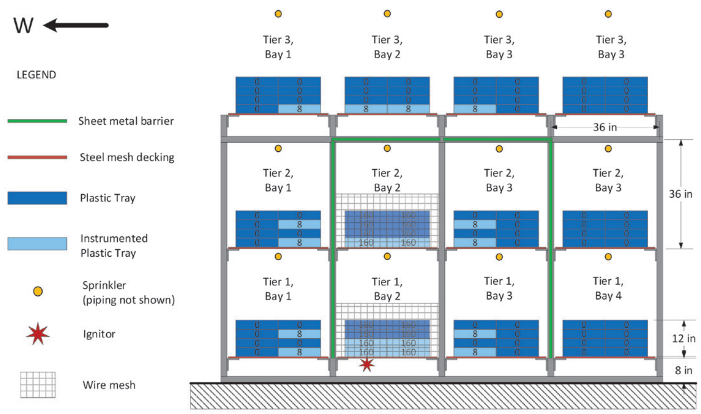

Figure 2: Main Array Elevation View (observer facing North)
[courtesy of UL Solutions]

The commodity in these tests consisted of the following:

– Cell Configuration:	18650
– Cell Quantity:	8000
– Cell State of Charge:	100%
– Cell Cathode Chemistry:	Nickel Cobalt Aluminum (NCA)
– Cell Capacity:	3500 mAh
– Plastic Trays:	Non-reinforced Polypropylene Formation Trays
– Target Commodity:	Cartoned Unexpanded Group A Plastic

Loaded trays are shown in Figure 3 below.

Figure 3: Trays Loaded with Lithium-Ion Batteries

For comparison, the number of cells included in the test is comparable to the number of cells installed in a Tesla Model S.

The test began by lighting a standard ignitor located below the stack of battery trays on the bottom level of the main array. Cell thermal runaway and cell-to-cell thermal runaway propagation occurred at 2 minutes and 6 seconds after the start of the test. The first sprinkler operated 2 minutes and 11 minutes after the start of the test. The second and last sprinkler operated at 2 minutes and 19 seconds. Within less than a minute-and-a-half of the activation of the first sprinkler, thermal runaway propagation was halted. The sprinklers were allowed to operate for 30 minutes. The test was observed for an hour after the sprinklers were shut off, and no reignition was observed. Snapshots of key moments during the test are in Figure 4 below.

Reliable has performed additional large-scale testing with the LB11 and lithium-ion batteries. The results indicate promise in protecting deeper racks with different barrier configurations.

For more information on the LB11 sprinkler, please visit the Reliable Automatic Sprinkler Co., Inc., website at **www.reliablesprinkler.com/lb11**. To discuss protection of lithium-ion batteries in battery manufacturing facilities, storage, or anywhere else, contact the author at: **pfriday@reliablesprinkler.com**.•

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[6] “UL 199K, Outline of Investigation for Fire Testing Specific Application Horizontal Sidewall Sprinklers for Installation in Racks Having Vertical and Horizontal Barrier.” Issue No. 1, UL Solutions, April 26, 2023

Figure 4. Snapshots of Key Moments in the Test.