Storage Sprinkler Portfolio from Viking Solves Problems Resulting from the Storage of Lithium-Ion Cells and Modules

Introduction

Factory Mutual Data Sheet 8-1 *Commodity Classification* provides guidance on classifying stored commodities by providing examples of Class 1, 2, 3, unexpanded plastic, and expanded plastic storage commodities. This guidance is intended to be used in conjunction with the protection recommendations contained in Data Sheet 8-9, *Storage of Class 1, 2, 3, 4 and Plastic Commodities*.

In January 2023 Factory Mutual published a revision FMDS 8-1 to include guidance on categorizing lithium-ion batteries. The change also included lithium-ion battery storage protection guidance. Now that there are protection provisions in both data sheets the intent of this paper is to outline how these two data sheets now work together to provide protection guidance for lithium-ion cells, modules, and products with lithium-ion batteries.

FMDS 8-1 – *Commodity Classification*

To understand the protection requirements for lithium-ion cells, modules, and products with lithium-ion batteries it is necessary to determine how these items are classified as a commodity. A commodity is classified based on an evaluation of the stored materials, internal packaging, external packaging, and material handling products. All these components must be included to provide an accurate classification.

Commodities are classified as follows:

- Noncombustible (*least hazardous*)
- Class 1
- Class 2
- Class 3
- Class 4/Cartoned unexpanded plastic (CUP)
- Cartoned expanded plastic (CEP)
- Uncartoned unexpanded plastic (UUP)
- Uncartoned expanded plastic (UEP) (*most hazardous*)

As a commodity to be classified the primary hazard in a lithium-ion battery is the combustible electrolyte contained within the cell that may become pressurized if the cell is damaged or subjected to abuse.

A lithium-ion battery fire can be started due to (1) thermal abuse resulting from poor cooling or external fire, (2) electrical abuse from overcharging or an external short circuit, (3) mechanical

abuse, by penetration or crash, or (4) internal short circuit which could be due to manufacturing flaws or aging.[1]

Thermal runaway is a term used for the rapid uncontrolled release of heat energy from a battery cell; it is a condition when a battery creates more heat than it can effectively dissipate. Thermal runaway in a single cell can result in a chain reaction that heats up neighboring cells. As this process continues it can result in a battery fire or explosion. This can often be the ignition source for larger battery fires.[2]

The primary hazard results in a differentiation between wet or dry cell batteries and Lithium-ion batteries. Table 2.3 *Examples of Material Classification* of FMDS 8-1 establishes four design approaches under the category of Batteries and differentiates between wet cell, dry cell, and Lithium-ion cells. Below is an extract from the table showing the different design approaches. Note that Items 1-6 will refers to FMDS 8-9 for sprinkler protection design requirements while requirements for Lithium-ion cells, modules and products (Item 7) remain within FMDS 8-1.

Item	Material	Class
	Batteries	
1	Dry cell (Excluding lithium metal and lithium-ion batteries) Uncartoned	Class 1
2	Wet cell (non-ignitable electrolyte) (e.g. automobile, boats) Uncartoned	Class 1
3	Dry cell (Excluding lithium metal and lithium-ion batteries) Cartoned	Class 2
4	Wet cell (non-ignitable electrolyte) (e.g. automobile, boats) Cartoned	Class 2
5	Batteries with plastic casing, empty	UP
6	Wet cell (non-ignitable electrolyte) large vehicles (e.g. trucks)	UP
7	Li-ion cells, modules, and products with li-ion batteries	See Section 2.4.2

Extracted from FMDS 8-1 Table 2.3

Large-scale tests have shown sprinklers can control fire spread and reduce the hazard of Energy Storage Systems (ESS) fires. For these tests the overall hazard of an ESS fire in a commercial occupancy was assessed by the reduction of fire intensity, potential for fire damage to the surroundings, and containment of the fire the origin rack.[4]

In FMDS 8-1 the protection requirements for Lithium-ion batteries are located in Section 2.4.2 and first divided into whether the batteries are new or refurbished. Storage of new batteries may require in-rack sprinklers in accordance with Section 2.4.2.2 depending on storage height. Storage of used or refurbished batteries will require in-rack sprinklers regardless of storage height.

Determining the appropriate protection for new batteries requires working through five variables, State of Charge, Ceiling Height, Storage Height, Storage Arrangement, and Packaging. FMDS 8-1 defines State of Charge as "the real amount of energy stored in the system, compared to its rated capacity, and is stated as a percentage (0%-fully discharged to 100%-full charged)." The lower the State of Charge, the lower the hazard. Most finished products in storage have a State of Charge between 40 percent and 60 percent. Furthermore, the United States Department of Transportation limits the State of Charge when shipping to 30 percent.[3] However, when batteries are in use or charging their State of Charge will be well beyond 60 percent and may be beyond 100 percent, or in a supercharged state.

As previously stated, Section 2.4.2 contains five variables for determining the protection of Lithium-ion cells and modules. These are set in Table 2.4.2.1

First is *State of Charge* which is divided into two categories: 60 percent or less, and greater than 60 percent.

The second variable is *Ceiling Height* and that is divided into 40 feet or less, and greater than 40 feet.

The third variable is *Storage Height*. Regardless of the height of the ceiling the storage height is limited to 3 levels of storage up to 15 feet in height.

Storage Arrangement is the fourth variable and covers open-frame rack, solid-pile or palletized. Finally, the fifth variable is *Packaging* which contains various combinations of wood crate, metal encased, corrugated cartons and plastic external packaging. It also requires identification of internal packaging as cellulosic, unexpanded, or expanded plastic.

Once the decision path is completed through these variables the ceiling sprinkler protection and/or the need for In-Rack sprinkler protection is selected. On the next page is a reproduction of Table 2.4.2.1 showing six design scenarios based on the categories described.

FMDS 8-1-Table 2.4.2.1 Protection of Lithium-ion Cells and Modules

State of Charge	Ceiling Height	Storage Height	Storage Arrangement	Packaging	Ceiling Protection (*QR sprinklers only*)	In-Rack Protection
≤60%	≤40ft	Maximum 3 levels of storage up to a total height of 15 ft	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 12@35psi	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
	>40ft			Cartoned or Uncartoned	Per surrounding occupancy	See Section 2.4.2.2
>60%	NA					

While open-frame rack and solid-pile or palletized storage were combined in FMDS 8-1 for the purposes of protecting Lithium-ion cells and modules, once FMDS 8-9 is applied the design requirements are separated by storage arrangement and the appropriate table must be selected as follows.

Commodity	Piled Arrangement	Open-Rack Arrangement
CEP	Table 4	Table 9
UUP	Table 5	Table 10

Protection Scenarios

Table 2.4.2.1 provides guidance for six protection scenarios. Scenarios 1 through 3 start with a State of Charge of ≤60 percent and a ceiling height ≤40ft and continue with a maximum storage height of 3 levels up to a total of 15ft and a storage arrangement of open-frame, solid-pile or palletized.

Scenario 1

State of Charge	Ceiling Height	Storage Height	Storage Arrangement	Packaging	Ceiling Protection (QR sprinklers only)	In-Rack Protection
≤60%	≤40ft	Maximum 3 levels of storage up to a total height of 15 ft	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 12 @ 35psi	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
	>40ft			Cartoned or Uncartoned	Per surrounding occupancy	See Section 2.4.2.2
>60%	NA					

In Scenario 1 the packaging is limited to wood crate, metal encased, or corrugated carton with cellulosic and/or unexpanded plastic internal packaging. For this scenario the ceiling protection requirements are limited to K22.4 and K25.2 quick response storage sprinklers with a 12-sprinkler design at 35psi. This would result in a theoretical system demand of either 1590 gpm for the K22.4 or 1789gpm for the K25.2.

Scenarios 2 and 3 change the packaging variables to corrugated carton with cellulosic or expanded plastic **internal** packaging in Scenario 2 or using plastic **external** packaging in Scenario 3. These scenarios reference FMDS 8-9 for ceiling protection design as either Cartoned Expanded Plastics (CEP) or Uncartoned Unexpanded Plastics (UUP).

Scenario 2

Table 2.4.2.1 Protection of Lithium-ion Cells and Modules

State of Charge	Ceiling Height	Storage Height	Storage Arrangement	Packaging	Ceiling Protection (QR sprinklers only)	In-Rack Protection
≤60%	≤40ft	Maximum 3 levels of storage up to a total height of 15 ft	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 12 @ 35psi	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
	>40ft			Cartoned or Uncartoned	Per surrounding occupancy	See Section 2.4.2.2
>60%	NA					

The sprinkler demands for Scenario 2 are found in Tables 4 and 9 in FMDS 8-9 resulting in the following theoretical flows based on ceiling height, sprinkler K-factor.
The following table shows the various Viking product solutions and system demands for Cartoned Expanded Plastics (CEP).

CEP Piled Storage								
			Pendent			Upright		
Max. Ceiling Height	K-Factor	SIN	Design	Flow		SIN	Design	Flow
30 ft	11.2	VK377	25 @ 50	1979		VK531	25 @ 50	1979
	14.0	VK500	12 @ 50	1187				
	16.8	VK503	12 @ 35	1192				
	22.4	VK506	12 @ 25	1344				
	25.2	VK510	12 @ 20	1352				
35 ft	22.4	VK506	12 @ 63	2133				
	25.2	VK510	12 @ 50	2138				
40ft	22.4	VK506	12 @ 75	2327				
	25.2	VK510	12 @ 60	2342				

CEP Open-Rack Storage								
			Pendent			Upright		
Max. Ceiling Height	K-Factor	SIN	Design	Flow		SIN	Design	Flow
20 ft	11.2	VK377	18 @ 28	1066		VK531	15 @ 50	1187
	14.0	VK500	12 @ 18	712				
	16.8	VK503	12 @ 13	726				
	22.4	VK506	9 @ 20	901				
	25.2	VK510	9 @ 20	1014				
25ft	14.0	VK500	12 @ 35	993				
	16.8	VK503	12 @ 24	987				
	22.4	VK506	10 @ 20	1001				
	25.2	VK510	9 @ 20	1014				
	25.2EC	xx	8 @ 60	1561				
30 ft	14.0	VK500	12 @ 50	1187				
	16.8	VK503	12 @ 35	1192				
	22.4	VK506	12 @ 25	1344				
	25.2	VK510	12 @ 20	1352				
40ft	22.4	VK506	12 @ 75	2327				
	25.2	VK510	12 @ 60	2342				

Scenario 3

Table 2.4.2.1 Protection of Lithium-ion Cells and Modules

State of Charge	Ceiling Height	Storage Height	Storage Arrangement	Packaging	Ceiling Protection (QR sprinklers only)	In-Rack Protection
≤60%	≤40ft	Maximum 3 levels of storage up to a total height of 15 ft	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 12 @ 35psi	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
	>40ft			Cartoned or Uncartoned	Per surrounding occupancy	See Section 2.4.2.2
>60%	NA					

The sprinkler demands for Scenario 3 are found in Tables 5 and 10 in FMDS 8-9 resulting in the following flows based on ceiling height, sprinkler K-factor.

The following table shows the various Viking product solutions and system demands for Uncartoned Unexpanded Plastics (UUP).

UUP Piled Storage								
			Pendent			Upright		
Max. Ceiling Height	K-Factor	SIN	Design	Flow		SIN	Design	Flow
30 ft	11.2	VK377	25 @ 50	1979		VK531	25 @ 50	1979
	14.0	VK500	9 @ 100	1260				
	16.8	VK503	9 @ 70	1265				
	22.4	VK506	9 @ 50	1425				
	25.2	VK510	9 @ 40	1434				
35 ft	22.4	VK506	12 @ 63	2133				
	25.2	VK510	12 @ 50	2138				
40ft	22.4	VK506	12 @ 75	2327				
	25.2	VK510	12 @ 60	2342				

			Pendent	
Max. Ceiling Height	K-Factor	SIN	Design	Flow
20 ft	11.2	VK377	15 @ 50	1187
	14.0	VK500	12 @ 32	950
	16.8	VK503	12 @ 22	945
	22.4	VK506	9 @ 25	1008
	25.2	VK510	9 @ 20	1014
25ft	14.0	VK500	9 @ 50	891
	16.8	VK503	9 @ 35	894
	22.4	VK506	9 @ 25	1008
	25.2	VK510	9 @ 20	1134
30 ft	14.0	VK500	15 @ 50	1484
	16.8	VK503	15 @ 35	1490
	22.4	VK506	10 @ 50	1583
	25.2	VK510	10 @ 40	1593
40ft	22.4	VK506	12 @ 75	2327
	25.2	VK510	12 @ 60	2342

Note. no upright protection schemes over 15’-0” ceilings.

Like Scenarios 1 through 3, Scenario 4 has a State of Charge of 60 percent or less and a maximum ceiling height of 40 feet or less. The difference in this scenario is that there is no limit on the storage height, but the storage arrangement is limited to open racks and the packaging is uncartoned.

Scenario 4

Table 2.4.2.1 Protection of Lithium-ion Cells and Modules

State of Charge	Ceiling Height	Storage Height	Storage Arrangement	Packaging	Ceiling Protection (QR sprinklers only)	In-Rack Protection
≤60%	≤40ft	Maximum 3 levels of storage up to a total height of 15 ft	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 12 @ 35psi	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
	>40ft			Cartoned or Uncartoned	Per surrounding occupancy	See Section 2.4.2.2
>60%	NA					

In Scenario 5 the State of Charge is 60 percent or less but now the ceiling height is greater than 40 feet. The height of the storage is again unlimited, and the storage arrangement must be open-frame rack and the packaging is cartoned or uncartoned.

Scenario 5

Table 2.4.2.1 Protection of Lithium-ion Cells and Modules

State of Charge	Ceiling Height	Storage Height	Storage Arrangement	Packaging	Ceiling Protection (QR sprinklers only)	In-Rack Protection
≤60%	≤40ft	Maximum 3 levels of storage up to a total height of 15 ft	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 12 @ 35psi	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
	>40ft			Cartoned or Uncartoned	Per surrounding occupancy	See Section 2.4.2.2
>60%	NA					

In Scenario 6 the State of Charge is greater than 60 percent. In this case neither the ceiling height or the storage height is applicable, the storage arrangement must be open-frame rack and the packaging is cartoned or uncartoned.

Scenario 6

Table 2.4.2.1 Protection of Lithium-ion Cells and Modules

State of Charge	Ceiling Height	Storage Height	Storage Arrangement	Packaging	Ceiling Protection (QR sprinklers only)	In-Rack Protection
≤60%	≤40ft	Maximum 3 levels of storage up to a total height of 15 ft	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 12 @ 35psi	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
	>40ft			Cartoned or Uncartoned	Per surrounding occupancy	See Section 2.4.2.2
>60%	NA					

Ceiling Protection

It is important to note that Scenarios 1 through 3 are utilizing ceiling-only sprinklers and there is additional guidance in FMDS 8-1 based on storage arrangement. First, if the storage is in open-frame racks then no storage is permitted above the batteries. Second, if the storage is piled or palletized then a 10-foot separation must be provided between the lithium-ion storage area and all other combustibles.

Scenarios 4 through 6 require ceiling protection “per surrounding occupancy”. This provision directs the user to FMDS 2-0, FMDS 8-9, or an occupancy-specific data sheet for guidance on protection the facility surrounding the lithium-ion storage area.

In-Rack Sprinklers

As previously noted, there are three protection scenarios that require the use of In-Rack sprinklers.

1. When the storage is over 40 feet in height
2. When the State of Charge is over 60%
3. Protecting used or refurbished cells or modules.

When in-rack sprinklers are required, horizontal barriers of plywood or sheet metal must be provided and the approved in-rack sprinklers must be either K8.0 or K11.2, 165°F rated, quick-response in-rack sprinklers.

It is important to note that there is no special test or approval or listing for fire sprinklers protecting lithium-ion cells or modules. Any claims of a special listing for a sprinkler to protect lithium-ion batteries are completely false and misleading. Ceiling sprinklers are already FM Approved sprinklers as are In-Rack sprinklers. There is however an approved design using In-Rack sprinklers established in Section 2.4.2.2.

Below is a list of approved In-Rack sprinklers that would meet the requirements of Section 2.4.2.2. Viking has several approved In-Rack sprinklers that are K5.6 but the pressures necessary to achieve the required design flows are prohibitive and they are not permitted to be used in this design.

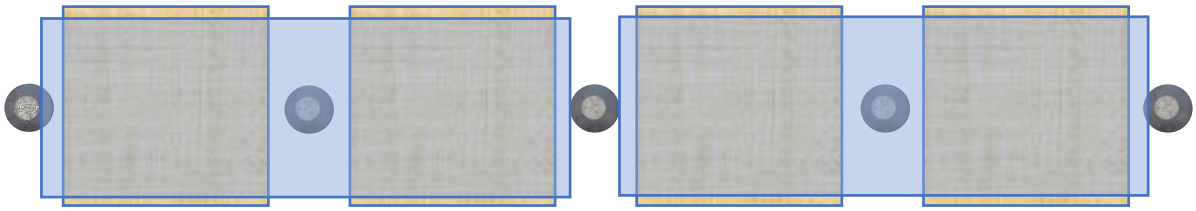
K-Factor	FM Approved Viking In-Rack Sprinklers
8.0	VK352, VK353, VK566, VK567
11.2	VK377

Section 2.4.2.2 states that in-rack sprinklers must provide a minimum flow of 60 gpm out of the hydraulically most remote six (6) sprinklers if a single barrier is installed or the most remote eight (8) sprinklers if there are two barriers used. Examples of this are provided on the following pages. This results in a required minimum pressure of 56psi for K8.0 and 28psi for K11.2 sprinklers. The design choice is at the discretion of the designer.

The sprinklers used for the six-sprinkler calculation are the most remote three face sprinklers and three flue sprinklers in a double-row rack if one barrier is provided, and two face sprinklers and two flue sprinklers on two levels in a double-row rack if two or more barrier levels are provided.

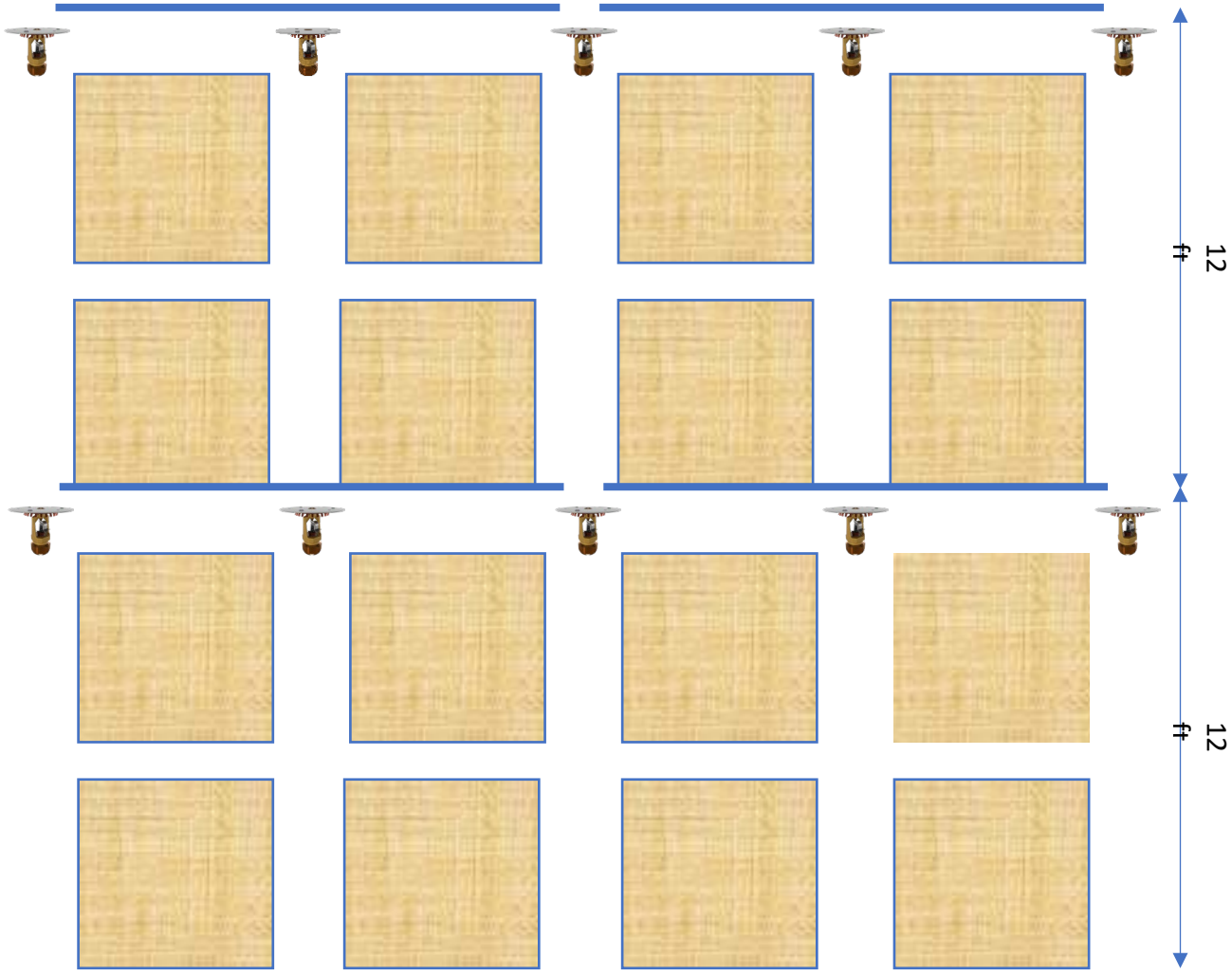
The ceiling sprinklers are designed to protect the surrounding occupancy and the demand is not included in the hydraulic calculations for in-rack sprinklers.

Solid Barrier
Minimum 8ft. between gaps
Maximum 3in. gaps at Uprights
2 to 5ft. sprinkler spacing.



Plan View

7-inch maximum deflector distance below barrier
6-inch minimum deflector distance above top of storage

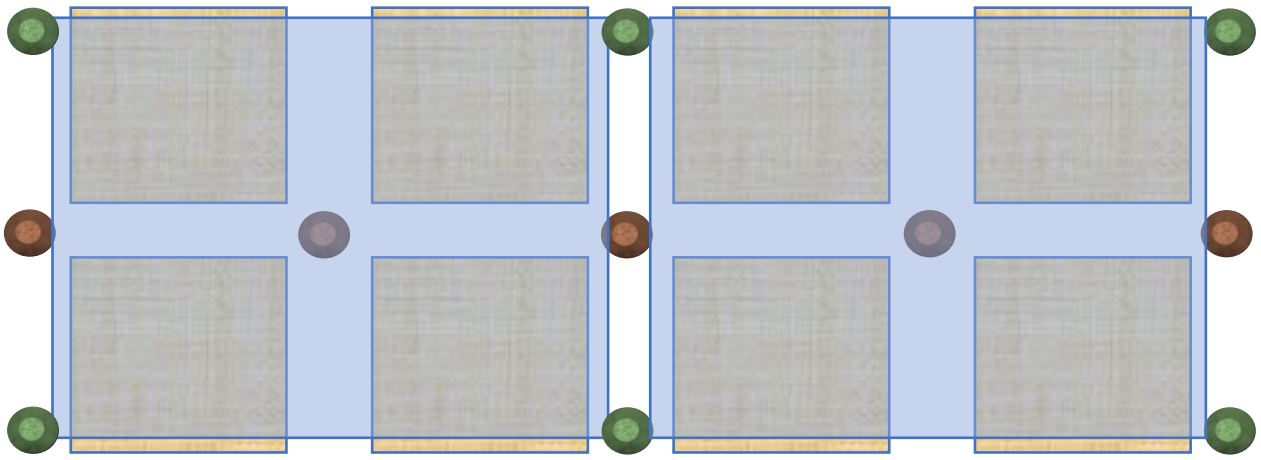


Elevation View

Figure 2.4.2.2-1

Solid Barrier – No gap at longitudinal flue
Solid Barrier – Maximum 9ft width
Solid Barrier – Maximum 3in. gaps at Uprights

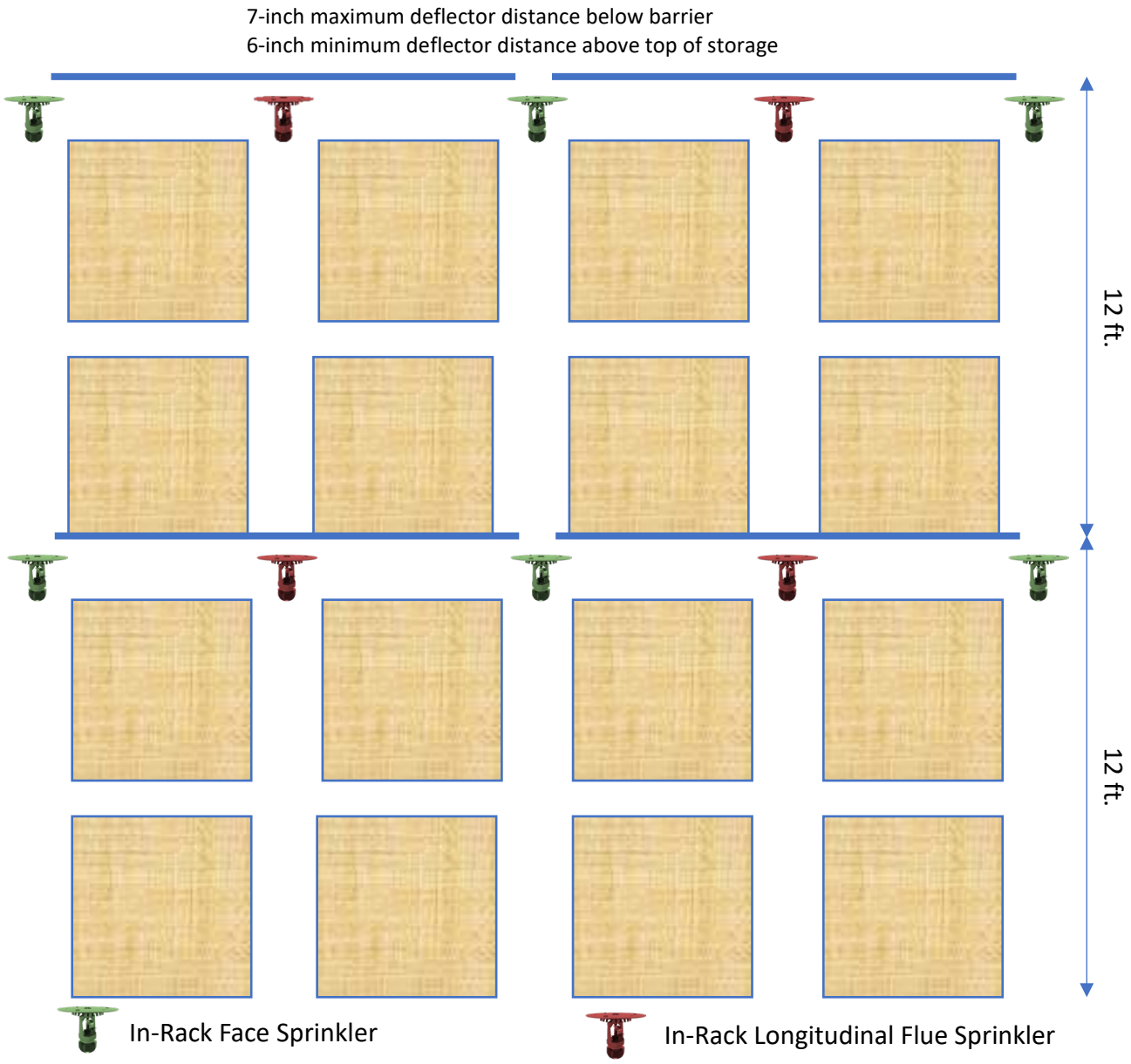
4-10ft. between face sprinklers
2-5ft. between longitudinal flue sprinklers



Plan View

In-Rack Longitudinal Flue Sprinkler

In-Rack Face Sprinkler



Elevation View

Figure 2.4.2.2-2

Conclusions

Tests have been conducted at the module level to evaluate the performance of different fire suppressants such as water, wet chemical, and dry chemical. The tests concluded that water was the most effective fire suppressant.[5]

Factory Mutual does not have any special tests or approvals for sprinklers protecting Lithium-ion cells or modules but does contain specific guidance on how systems are designed and supplied.

Viking has FM Approved sprinklers that can meet all design requirements in FMDS 8-1 and 8-9 – from which the direction provided offers us all some more answers than our previous outstanding questions!

— Jim Lake, Vice President – Training, Viking Group, Inc.

References

FMDS 2-0 – *Installation Guidelines for Automatic Sprinklers*
FMDS 8-1 – *Commodity Classification*
FMDS 8-9 – *Storage of Class 1,2,3,4 and Plastic Commodities*

Footnotes

1. Bisschop, Roeland; Willstrand, Ola; Rosengren, Max - “Handling Lithium-Ion Batteries in Electric Vehicles: Preventing and Recovering from Hazardous Events”. Fire Technology / 1 November 2020.
2. Energy Storage Systems Safety Fact Sheet, National Fire Protection Association / June 2020
3. Lithium Guide for Shippers, US Dept. of Transportation / September 2021
4. Long, R. Thomas, Jr; Misera, Amy – Sprinkler Protection Guidance for Lithium-Ion Based Energy Storage Systems, Fire Protection Research Foundation / June 2019
5. DNV-GL, “Considerations for ESS Fire Safety,” Consolidated Edison New York, NY, Final Report 0APUS301WIKO(PP151895), Rev.#, 2017