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ESFR SPRINKLER SYSTEMS

Fire and Security Consulting Services (FSCS) is frequently asked about ESFR sprinkler systems. It is hoped that the following will explain their development, application and limitations.

BACKGROUND

ESFR sprinkler systems were specifically developed by FMRC (FM) (Factory Mutual Research Corporation) in the 1980's to address the growing use of plastics in goods and packaging together with the increasing size and height of warehouses.

The concept of Early Suppression Fast Response (ESFR) was originally defined by FM to mean that, for the storage of a plastic commodity 7.6m high in a 9.1m warehouse, a fire would normally be suppressed with no more than the first ring of sprinklers (four to five) operating above the ignition point. This same fire scenario cannot normally be controlled using standard sprinklers installed at the ceiling level.

The storage and building heights have now been raised to 12.2m and 13.7m respectively for certain commodities by the use of larger and more advanced sprinkler design.

ESFR sprinkler systems were developed to protect warehouse occupancies with high bay racked storage of high challenge goods, and, where possible, the elimination of 'in-rack' sprinklers. Accordingly, the design contemplates fast response of the sprinklers and the application of large quantities of water.

Figures 1a and 1b below show typical 5 and 6 tier high ESFR fire tests of plastic commodities in cardboard boxes. These photographs are perhaps the only ones in the public domain and show a typical Factory Mutual ESFR testing regime where a fire is lit at the bottom tier of a double row rack. The test criteria require that not only is the fire suppressed within a specified time but that the fire does not 'jump' the aisle to the next rack.

Figure 1a - 6 Tier test

Figure 1b - 5 Tier test

FIRE CONTROL AND SUPPRESSION

The Fire Engineering Guidelines provide for the control and/or suppression of fires in compartments where sprinkler systems are installed. This is shown diagrammatically in Figure 2 below:

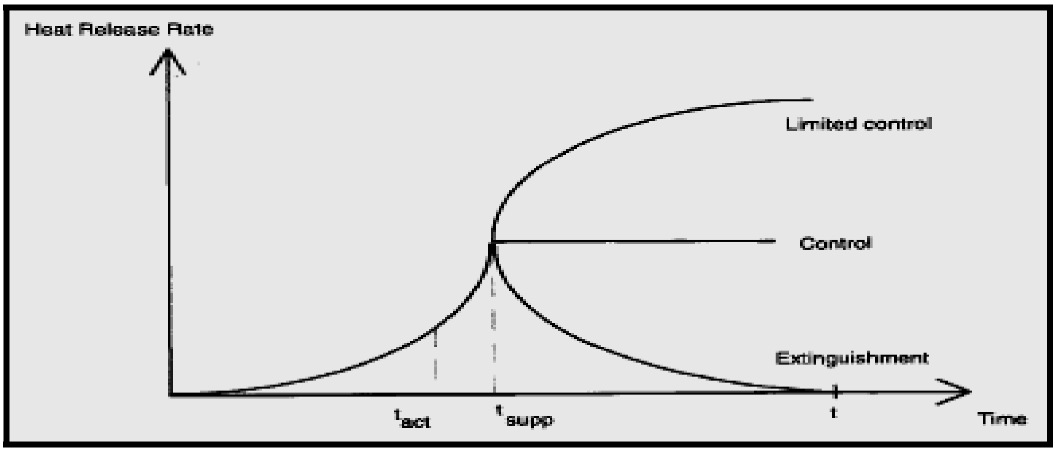

Figure 2 – Sprinkler Control and Suppression

For the Fire Engineer, the distinction between Control and Suppression may be important in the evaluation of such life safety features of large buildings including smoke control and egress.

Control Mode Sprinklers

Automatic sprinkler systems in accordance with AS 2118.1 and NFPA13 can be at least expected to control a fire at the point where 50% of the design sprinklers are operating, at which point the fire size can conservatively be assumed to maintain a constant heat release rate (HRR).

Suppression Mode Sprinklers

AS2118.1 (1999) provides for the installation of an Early Suppression Fast Response (ESFR) system. AS2118.1 references both NFPA 13 and the FM Property Loss Prevention Data Sheets 2.2, 8.1 and 8.9. Accordingly, by reference, an ESFR system is permitted under the BCA where AS2118.1 (1999) is the adopted Standard. However the 2006 edition of AS2118 which has not been adopted by the BCA has its own ESFR design data and therefore does not rely on FM.

An ESFR sprinkler system provides fire suppression by the early detection and discharge of large quantities of water early in a fire's development.

This is based upon the concept of Required Delivered Density (RDD) and Actual Delivered Density (ADD). The RDD is the amount of water that must be delivered to suppress the fire, and the ADD is the actual amount that is delivered.

If the ADD is greater than the RDD, the fire is likely to be extinguished. However, as the fire size increases the plume's upward velocities increase and the amount of water that penetrates the plume and reaches the fire decreases. This is shown diagrammatically in Figure 3 below:

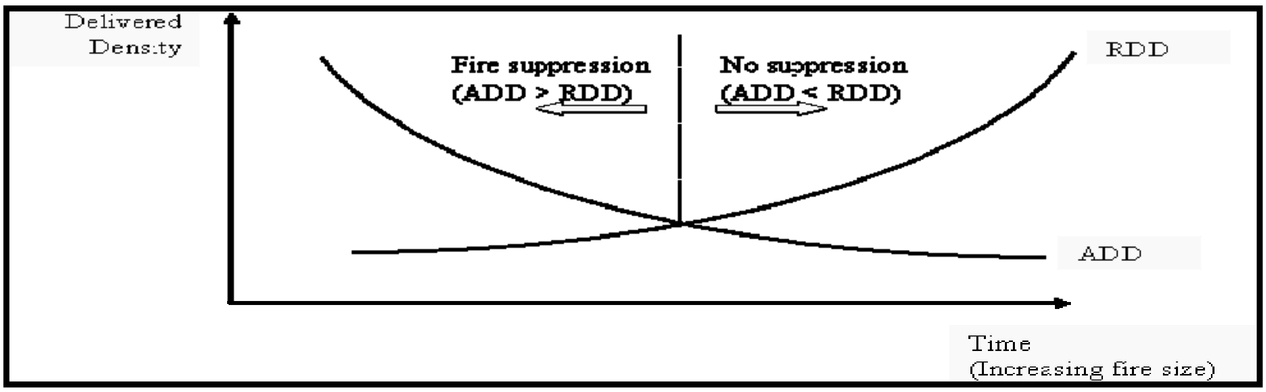

Figure 3 – Sprinkler Suppression Concept

Fire Growth

The Fire Engineer is familiar with the t^2 concept of fire growth resulting in the conventional classification of ‘slow’, ‘medium’, ‘fast’ and ‘ultra-fast’ fires. With high challenges fires of cartoned plastic commodities in high-bay racking, this concept must be ignored as the growth rates of these fires are significantly faster than conventional understanding.

The growth rates for t^2 fires and the typical high challenge fires are depicted in Figures 4 and 5 below.

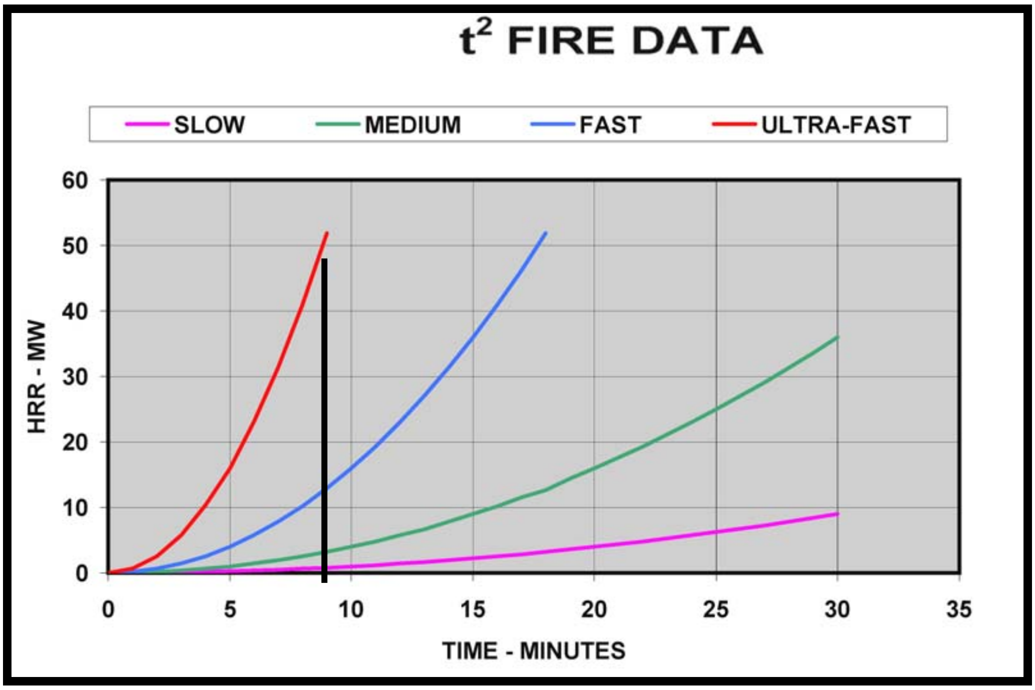

Figure 4 – t^2 Fire Growth

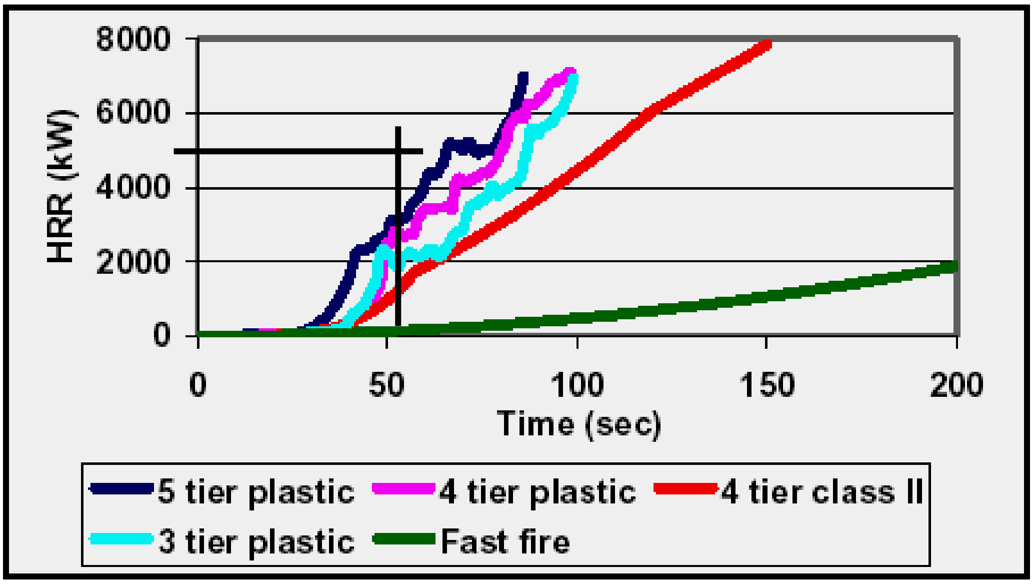

Figure 5 – ‘Plastics’ fire growth rates

From Figure 4 above, it can be seen that a conventional t2 ‘Ultra Fast’ fire growth can reach ~50MW in approximately 8.5 minutes, Figure 5 shows the fastest plastics fore reaching 50MW (5,000kW- in less than a minute!

Whilst an initial reaction might be that such fire growth rates will result in fires too large to control – let alone suppress with sprinklers; it is this fast growth that assists in the rapid detection and suppression capabilities of an ESFR sprinkler system.

When fast response sprinklers with a nominal RTI of 28 (50 Imperial) – (the “FR” part of ESFR) are used, the intense fire plume from the rapidly growing fire activates only a small number of sprinklers local to the fire.

Fire Suppression

The application of large quantities of water (the ES element of ESFR) is able to suppress the fire in the early stages. FM Global has conducted literally hundreds of live rack fire tests and typical FM Global test is shown in Figures 6 and 7 below.

Figure 6 – FM Test

Figure 7 – FM Free Burn

A typical results sheet from a series of tests is reproduced in Figure 8 below. Certain portions have been obscured to protect the confidentiality of the supplier. You will also note that the RTI has been superimposed as “50” This is because the nominal RTI for ESFR sprinkler systems is 50 (28 metric), but the actual RTI of each manufacturer is somewhat lower.

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Data Table 2 Full Scale Fire Test Summary

	TEST #1	TEST # 2	TEST # 3	TEST # 4
Date				
Commodity or Type of Fuel	Standard Plastic	Standard Plastic	Standard Plastic	Standard Plastic
Arrangement or Storage Method	Double Row Rack	Double Row Rack	Double Row Rack	Double Row Rack
Array Size (W x L)	2 x 4	2 x 7	2 x 6	2 x 6
Number of Tiers	4	5	8	7
Stack Height (ft-in.)	19-8	24-8	39-8	34-8
Ceiling Height (ft)	30	30	45	45
Clearance to Ceiling (ft-in.)	10-4	5-4	5-4	10-4
Clearance to Sprinklers (ft-in.)	8-10	3-10	3-10	8-10
Aisle Width (ft)	N/A	4	4	N/A
Ignition Centered Below (Number of Sprinklers)	1	2(1)	2	1
Sprinkler Nominal Orifice Size (gal/min/psi$^{1/2}$)	25.2	25.2	25.2	25.2
Sprinkler Temperature Rating (°F)	165	165	165	165
Sprinkler Nominal RTI ((ft-sec)$^{1/2}$)	NOMINAL 50			
Sprinkler Spacing (ft x ft)	10 x 10	10 x 10	10 x 10	10 x 10
Constant Water Pressure (psi)	20	20	50	50
Minimum Discharge Density (gal/min/ft^2)	1.13	1.13	1.78	1.78
First Sprinkler Operation (min:sec)	0:32	0:49	0:54	0:45
Last Sprinkler Operation (min:sec)	0:32	0:56	1:01	0:45
Total Number of Sprinklers Opened	1	4	6	1
Peak/Maximum One Minute Average Steel Temperature (°F)	73/72	213/212	130/125	56/56
Peak/Maximum One Minute Average Plume Velocity (ft/sec)	16.52/6.06	23.14/14.73	21.74/10.52	18.29/5.33
Peak/Maximum One Minute Average Heat Flux (Btu/sec^2)	0.11/0.00	0.99/0.56	0.21/0.07	0.06/-0.02
Time of Aisle Jump (min:sec)	N/A	N/A	N/A	N/A
Equivalent Number of Pallet Loads Consumed	less than 1	3	5	less than 1
Test Duration (min)	5	20	9	4

(1) For test #3, one of the two sprinklers closest to ignition was rendered inoperative. The inoperative sprinkler was located over the aisle space that separates the test array from the target.

Figure 8 – Typical ESFR Test Results.

There are a number of items of interest in the test results shown above and if we examine Test No.3, we can see that a total of six sprinklers operated; the first at 54 seconds and the last at 61 seconds.

From these test results it is possible to develop a fire growth and suppression curve as shown with the red graph in Figure 9. Note that as a conservative measure, the HRR is extended at 0.5MW for the duration of the fire when fire modelling is used.

These graphs have been developed by Fire and Security Consulting Services from confidential data supplied by various sprinkler manufacturers who have conducted successful ESFR testing.

The red and blue HRR graphs represent FM Global test data on rack storage of Class I through IV and plastic commodities.

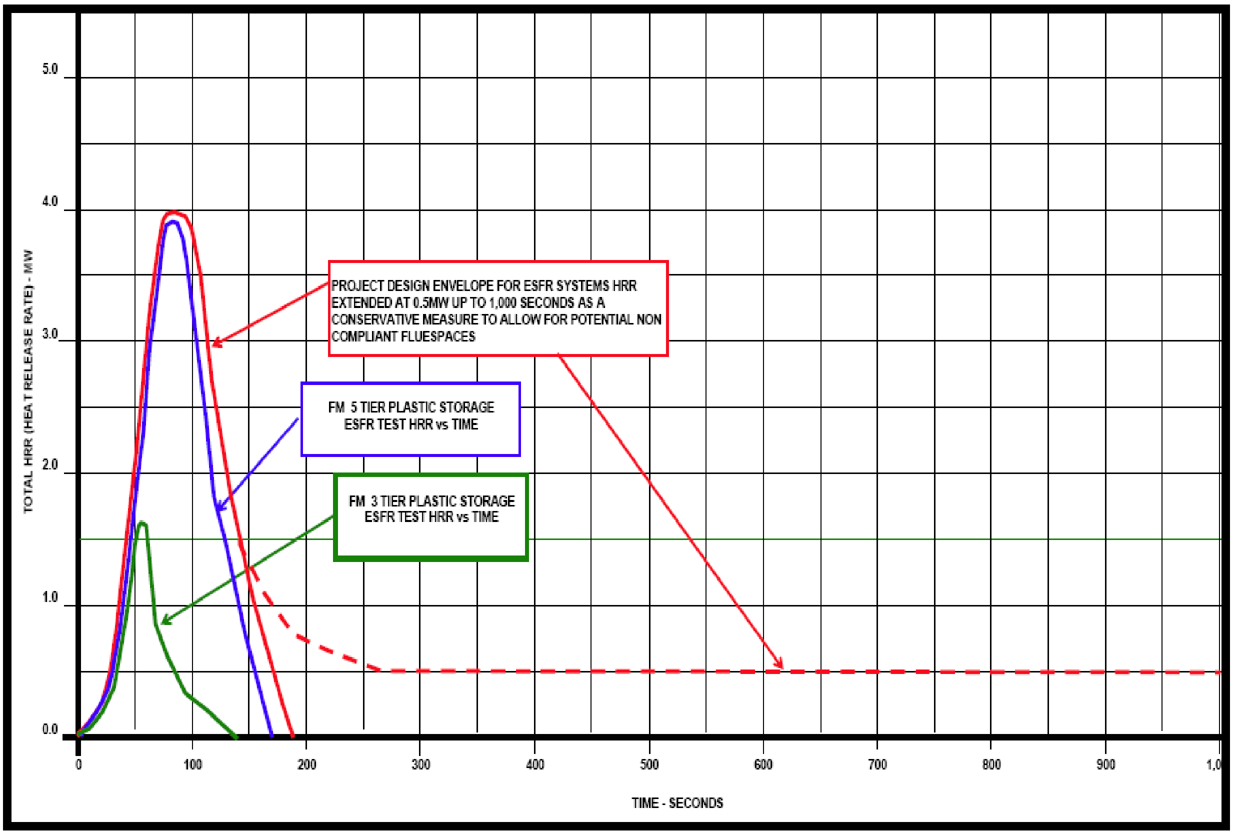

Figure 9 – ESFR Design Fire

ESFR DESIGN

There are a number of factors which determine the design of an ESFR sprinkler system, including the suitability of the building structure and configuration and the type and method of goods proposed to be stored.

Applicable Regulations

If the sprinkler system is to be installed to comply with the BCA (Building Code of Australia), it must, by definition and regulation as specified in Specification E1.5 of the BCA, comply with the adopted Australian Standard AS2118.1 (1999).

AS2118.1, under clause 2.3.3 – Special Sprinkler Systems, requires that ESFR sprinkler systems be designed in accordance with the US NFPA Code 13 and Factory Mutual Data Sheets 2-2 and 8-9.

Accordingly the following Design Codes are legally applicable to the design and implementation of an ESFR sprinkler system in Australian buildings.

NFPA 13 – Standard for the Installation of Sprinkler Systems.

- FM Global Data Sheet 2.2 (ESFR Installation Rules)
- FM Global Data Sheet 8.9 (Storage of Class 1, 2, 3, 4 and Plastic Commodities).
- The FM Property Loss Prevention Data Sheets referenced provide design guidelines for:-

  Data Sheet 2-2 'Installation Rules for Suppression Mode Sprinklers'

  Data Sheet 8-1'Commodity Classification'; and

  Data Sheet 8-9 'Storage of Class 1, 2, 3, 4 and Plastic Commodities.

As discussed earlier, the 2006 edition of AS2118 which has not been adopted by the BCA has its own ESFR design data and therefore does not rely on FM. Accordingly an ESFR sprinkler system not designed to FM with its generally onerous requirements for special pumps etc., can be designed to the 2006 edition of AS2118.1 under a Performance based Alternative Solution by a qualified Fire Engineer.

Building Design

The building structure and the installed sprinkler system and rack heights must be within the design constraints as set out in NFPA 13 and FM Global Data Sheets 2-2 and 8-9.

In very general terms, these constraints are depicted in Figure 10 below.

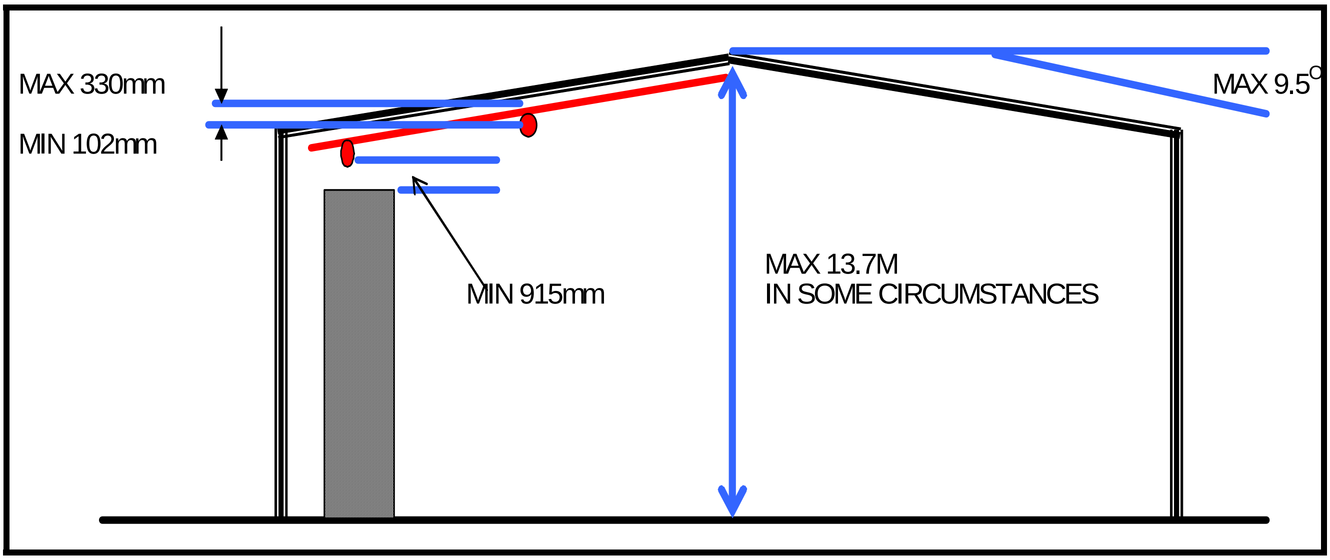

Figure 10 – Basic ESFR dimension constraints

Commodity Classification

As will be demonstrated later, the design and application of ESFR sprinkler systems is very much influenced by the classification of the commodities being stored.

Figure 11 shows the various classifications of commodities, and importantly, the percentage by weight or volume where there are mixtures of commodities.

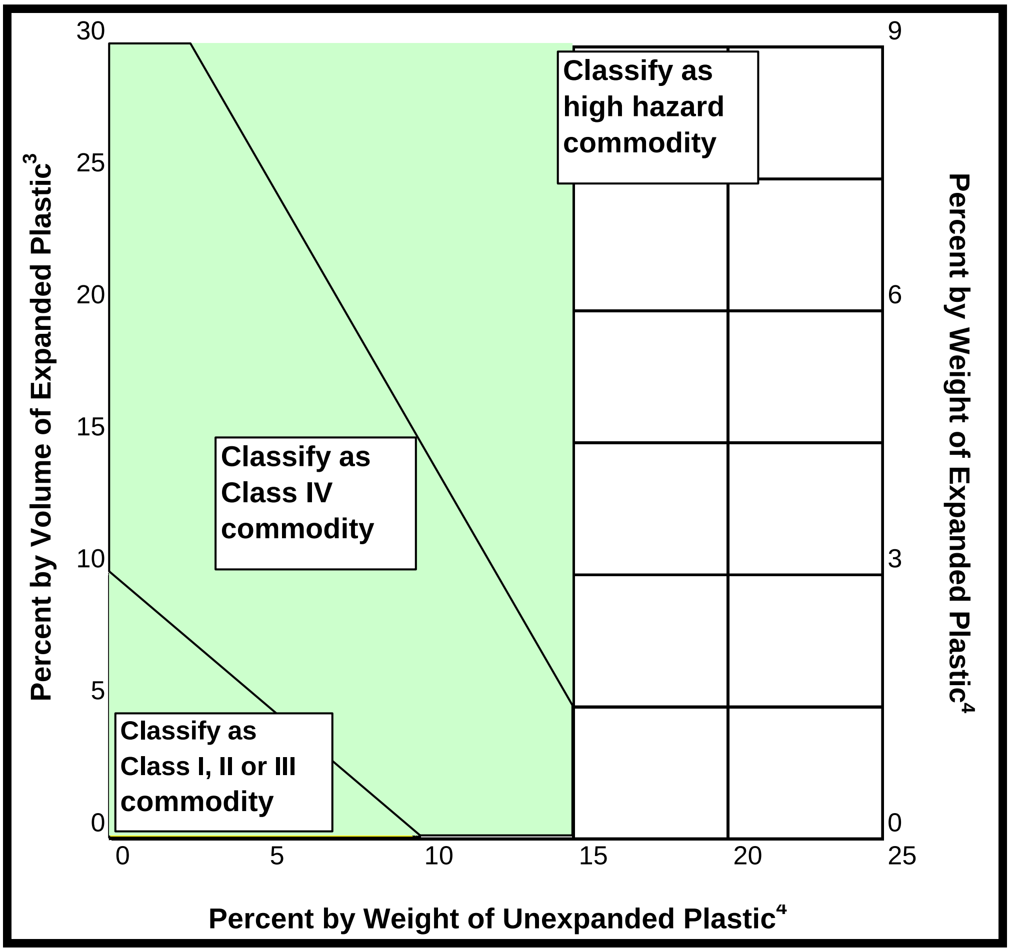

Figure 11 – General Commodity Classification

Notes

1. This table is intended to determine the commodity classification of a mixed commodity in a package, carton or on a pallet when plastics are involved.
2. The following is an example of how to apply the table: A package containing a Class III commodity which has 12 percent Group A expanded plastic by volume. The weight of the unexpanded Group A plastic is 10 percent. This commodity is classified as a Class IV commodity. If the weight of the unexpanded plastic is increased to 14 percent, the classification changes to a high-hazard commodity.
3. Percent by volume = Volume of plastic in pallet load **/** Total volume of pallet load, including pallet
4. Percent by weight = Weight of plastic in pallet load **/** Total weight of pallet load, including pallet

Plastics are further classified as per Figure 12 below.

	Group A	Group B	Group C
Heat of combustion	Much higher than ordinary combustibles	May be as high or higher than Group A	Same as ordinary combustibles
Burning Rate	Higher than Group B	Lower than Group A	Same as ordinary combustibles
Example	Polystyrene	Polypropylene	Most thermosets

Figure 12 – Classification of Plastics

Accordingly, it is imperative that the classification of the goods being stored is determined.

Additional commodity storage constraints include a reduction in allowable storage height for open topped cartons and uncartoned plastic commodities.

Storage Layout

This is the least understood and most often ignored area of the NFPA13, FM Global and AS2118.1 (2006) requirements and constraints in addition to the constraints on rack height, flue spaces and aisle width.

The least understood and most often contravention to ESFR installation rules is the inclusion of low level storage or other process activities in the ESFR protected area, as depicted in Figure 13 below.

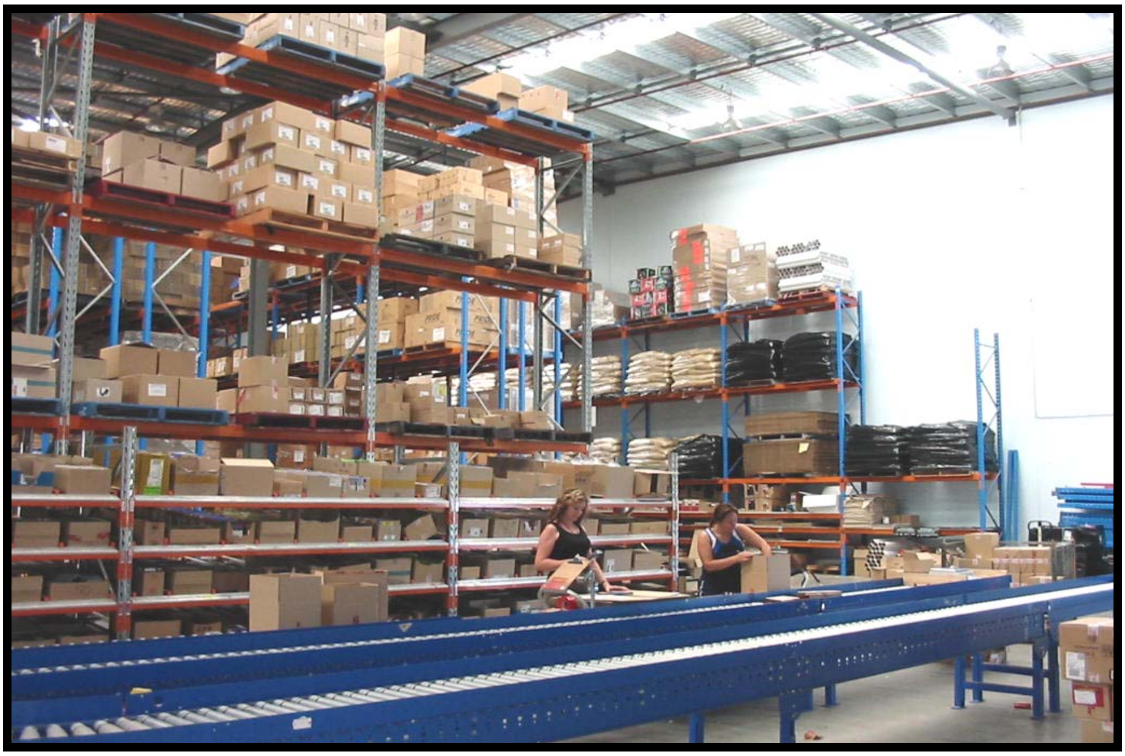

Figure 13 – Open cartons and low level areas not suitable for ESFR

These usually include low level “pick and pack” packing areas, palletising areas and work stations. Where such features exist which are not addressed properly and without specific attention to design detail, an EFSR system cannot be contemplated.

This will seriously compromise the efficacy of an ESFR sprinkler system which is specifically designed, tested and approved for a **specific** occupancy and **cannot** be juggled to include other activities.

Where low level activities are contemplated and the racking does not occupy the full extent of the warehouse floor. FM data sheet 8.9, clause 3.3.7.4.2 on page 75 requires that where the clearance between sprinklers and storage exceeds 6.1m, certain additional barriers and sprinklers are required. This clause is reproduced below

> *3.3.7.4.2* *Excessive Clearance*
>
> When clearance between ceiling sprinklers and the top of storage exceeds 20 ft (6.1 m), either: 1) install horizontal barriers extending to the full length and width of storage 3 to 5 ft (0.9 to 1.5 m) above the top of storage, and provide sprinklers beneath the barriers; or 2) provide protection needed for the storage height which would result in 20 ft (6.1 m) of clearance within the existing building height.
>
> When option 1) is chosen, the sprinkler system under the barrier should be designed for the hazard being protected beneath the barrier. Additionally, the sprinkler system at the roof should provide at least 0.15 gal/min sq ft (6.1 mm/min) over 2000 sq ft (186 sq m) for Class 1 commodities, and 0.20 gal/min/sq ft (8.2 mm/min) over 2000 sq ft (186 sq m) for Class 2, 3, 4 and plastic commodities. Water demands for the sprinkler systems at the ceiling and beneath the barriers should be available concurrently.

A possible option is to separate the high rack areas from the low level activity area by ceiling mounted draft curtains and a separation distance of between 0.6 and 1.2m. Then provide ESFR sprinkler protection to the rack areas and standard NFPA13 sprinkler protection to the other areas. This is allowable under NFPA Clause 5-4.6.4 reproduced below. A typical arrangement of mixed storage and low level activities is shown in Figure 14 below.

> **5-4.6.4**
>
> Where ESFR sprinkler systems are installed adjacent to sprinkler systems with standard response sprinklers, a draft curtain of noncombustible construction and at least 2 ft (0.6 m) in depth shall be required to separate the two areas. A clear aisle of at least 4 ft (1.2 m) centered below the draft curtain shall be maintained for separation.

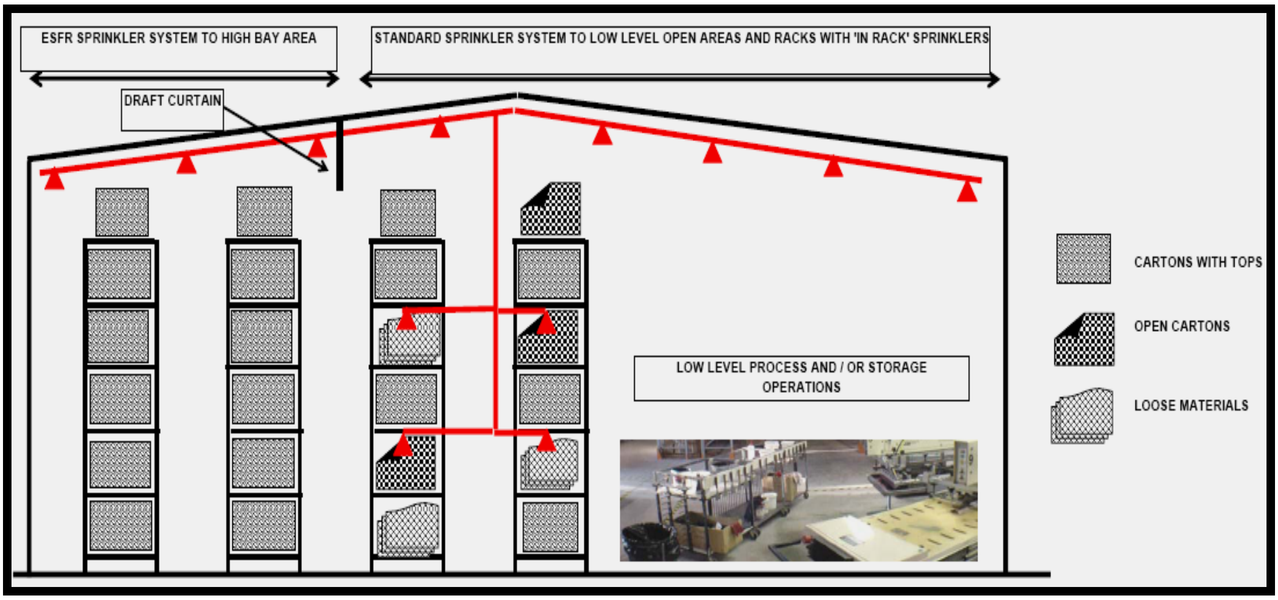

Figure 14 – Mixed Storage

Storage and Roof Heights - Warehouse.

After assessing the commodity classification and packaging method, FM Global Data Sheet 8.9 needs to be closely examined as to the allowable storage and roof height for a complying ESFR system.

Close attention should be made to the commodity assessments as generally, the plastics allowed to be stored are unexpanded, and the inclusion of packing in the form of expanded plastics in the form of polystyrene pacing foam may nullify the approvals.

Roof heights up to 13.7 m MAY be allowable dependant on the commodity being stored.

The 13.7m roof height is applicable only to k25.2 ESFR sprinklers where the manufacturer has appropriate approvals and that there are limitations on the storage, i.e. NO open boxes or uncartoned plastics.

Figure 15 indicates the limits of protection for single-, double-, and multiple row rack storage of Classes I to IV cartoned or uncartoned plastics.

Table 7-9.5.1.2 ESFR Protection of Rack Storage without Solid Shelves

Type of Storage*	Commodity	Maximum Height of Storage		Maximum Ceiling/Roof Height of Building		Nominal K-factor	Sprinkl Desig Pressu	
		ft	m	ft	m		psi	
Single-row rack storage, double-row rack storage, multiple-row rack storage	1. Cartoned unexpanded plastic 2. Cartoned expanded plastic 3. Exposed unexpanded plastic 4. Classes I, II, III, and IV commodities, encapsulated or unencapsulated 5. Idle wood and plastic pallets	25	7.6	30	9.1	14	50	
	1. Cartoned or exposed unexpanded plastic 2. Classes I, II, III, and IV commodities, encapsulated or unencapsulated 3. Idle wood and plastic pallets	35	10.7	40	12.2	14	75	
	1. Cartoned or exposed unexpanded plastic 2. Classes I, II, III, and IV commodities, encapsulated or unencapsulated	35 40	10.7 12.2	45 45	13.7 13.7	14 14	90 90	
	1. Cartoned unexpanded plastic 2. Classes I, II, III, and IV commodities, encapsulated or unencapsulated	20 25 30 35 40	6.1 7.6 9.1 10.7 12.2	25 30 35 40 45	7.6 9.1 10.7 12.2 13.7	11.2 25.2 25.2 25.2 25.2	50 20 30 40 50	

* No open-top containers

Figure 15 – NFPA 13 – General ESFR Protection Criteria

Flue Spaces

For certain storage heights, flue spaces are imperative. The following is an extract from FM Global Data Sheet 8-9.

3.2.2.1 Rack Storage

Flue spaces are necessary to allow sprinkler water penetration down through the racks. Without sufficient water penetration to burning commodities stored on the lower tiers of the racks, fire control may not be achieved.

Rack storage up to and including 25 ft (7.6 m) and without solid shelves does not require longitudinal flue space. Maintain at least 3 in. (75 mm) transverse flue space between loads or at rack uprights to allow sufficient sprinkler water penetration. Random variations in the width of the flue spaces or in their vertical alignment are permissible.

Rack storage higher than 25 ft (7.6 m) and without solid shelves requires both transverse and longitudinal flue spaces (except in single-row racks). Maintain at least 3 in. (75 mm) longitudinal flue space. Maintain at least 3 in. (75 mm) transverse flue spaces between loads or at rack uprights. Maintain vertical alignment of flue spaces as closely as possible. For multiple-row racks higher than 25 ft (7.6 m), loads may be butted in one direction if 6 in. (150 mm) flues are maintained in the other direction.

Obstructions

ESFR systems are very sensitive to obstructions to the discharge of the water spray. Accordingly the various installation codes have detailed information as to the required clearances. Figure 16 below from FM Global Data Sheet 2-2, depicts the general required clearance from sprinklers.

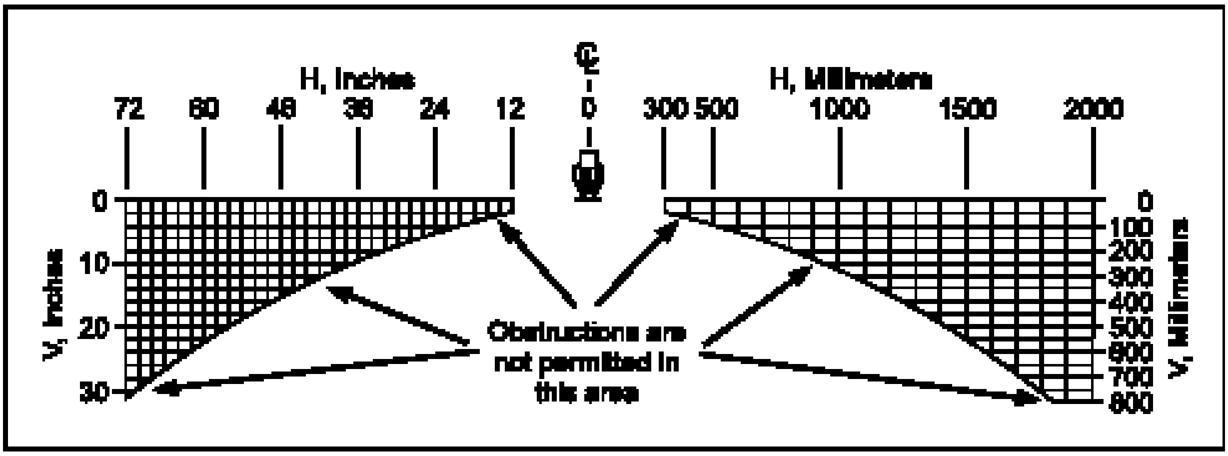

Figure 2.4.5.1.1 Area where obstructions are not permitted.

Figure 16 – General Obstruction Limitations

I trust that this paper provides information that you will find helpful.

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