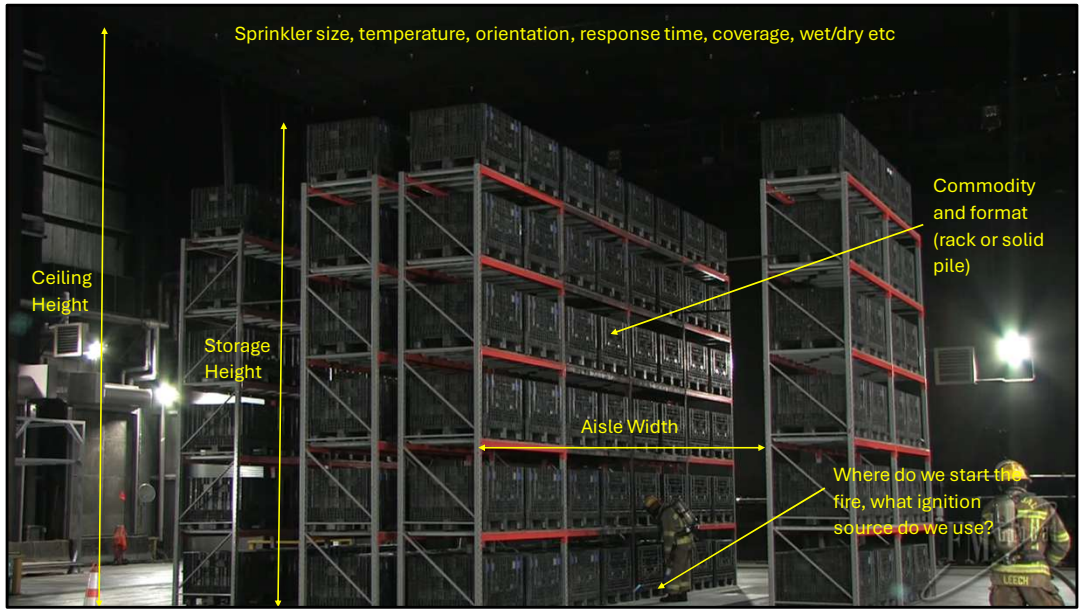

Sprinkler Fire Tests

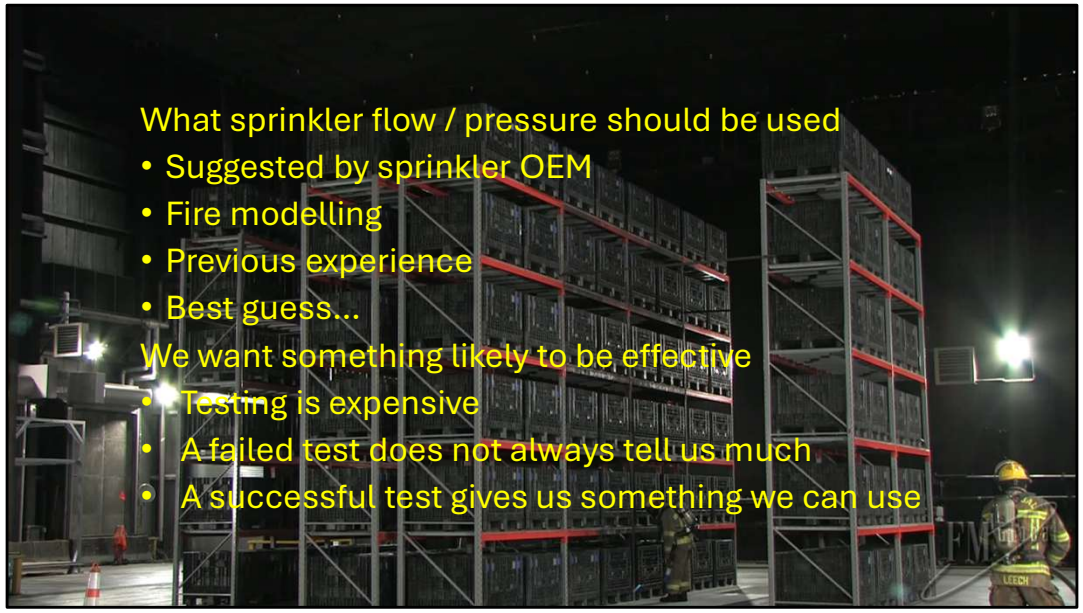

Anatomy of a Fire Test



This picture is taken from a fire test video of open top plastic containers. This is a very challenging commodity and in this instance the test failed.



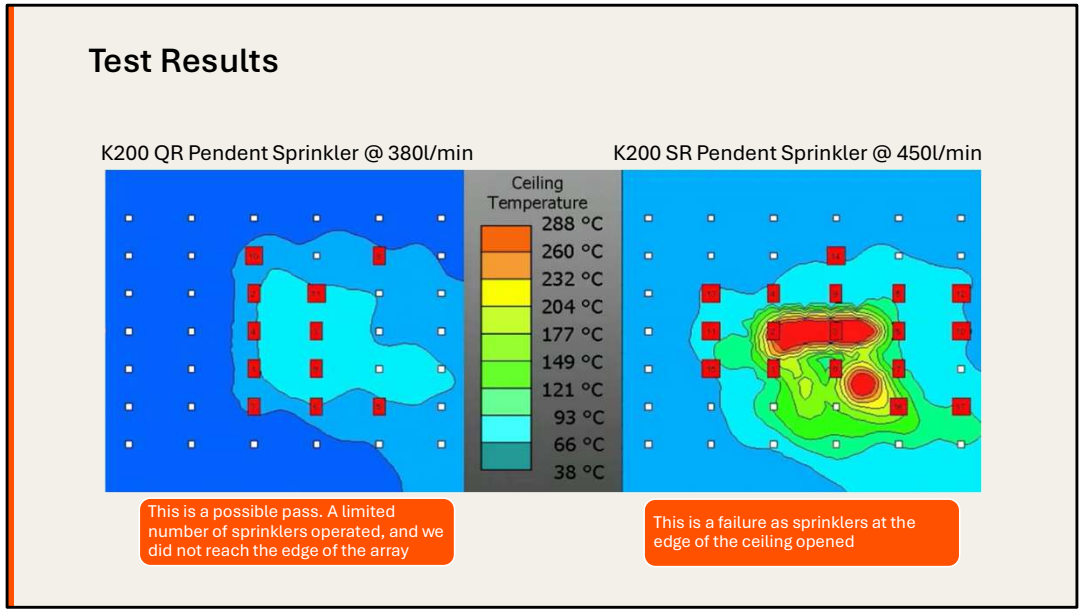
This slide shows key predefined parameters of a storage test.



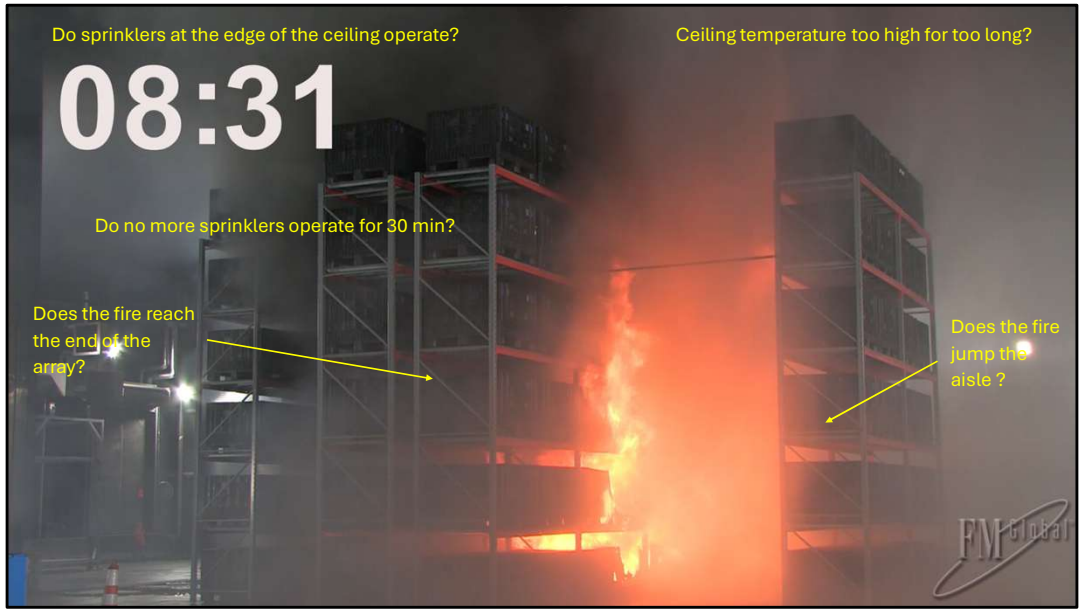
Tests are run so that how ever many sprinklers operate they are all at the same pressure. The pressure is chosen before the test based on what is thought is likely to be successful.

Pass/Fail Criteria





This slide shows a still from an animated overhead view of two tests. It shows ceiling temperatures and which sprinklers are operating. If sprinklers at the edge of the ceiling operate then the test is a fail as we have to assume more sprinklers could have continued to operate until the water supply was depleted.



This pictures shows other reasons a test might be rated unsuccessful.


It Passed! Now What?

SPRINKLER FIRE TESTS

So it passed...

Number of sprinklers that operated in the test plus safety factor – Chat GPT says 50%

Table 8. Ceiling-Level Protection Guidelines for Class 4 and Cartoned Unexpanded Plastic Commodities in Open-Frame Rack Storage Arrangements with Minimum 4 ft (1.2 m) Aisles

Protection of Class 4 and Cartoned Unexpanded Plastic Commodities in Open-Frame Storage Racks; No. of AS @ psi (bar)

Max. Ceiling Height, ft (m)	Wet System, 160°F (70°C) Nominally Rated, Pendent Sprinklers										Wet System, 160°F (70°C) Nominally Rated, Upright Sprinklers							Dry System, 280°F (140°C) Nominally Rated, Upright Sprinklers		
	Quick Response							Standard Response			Quick Response				Standard Response			Standard Response		
	K11.2 (K160)	K14.0 (K200)	K16.8 (K240)	K22.4 (K320)				K19.6 (K280)	K25.2 (K360)		K11.2 (K160)	K14.0 (K200)	K16.8 (K240)	K25.2EC (K360EC)	K11.2 (K160)	K16.8 (K240)	K25.2 (K360)	K11.2 (K160)	K16.8 (K240)	K25.2 (K360)
10 (3.0)	12 @ 7 (0.5)	9 @ 7 (0.5)	9 @ 7 (0.5)	9 @ 20 (1.4)					9 @ 7 (0.5)		12 @ 7 (0.5)	9 @ 7 (0.5)	9 @ 7 (0.5)	6 @ 20 (1.4)	12 @ 7 (0.5)	9 @ 7 (0.5)	9 @ 7 (0.5)	16 @ 7 (0.5)	16 @ 7 (0.5)	16 @ 7 (0.5)
15 (4.5)	15 @ 16 (1.1)	12 @ 16 (1.1)	12 @ 11 (0.8)	9 @ 20 (1.4)					10 @ 7 (0.5)		15 @ 16 (1.1)	12 @ 16 (1.1)	12 @ 11 (0.8)	6 @ 20 (1.4)	15 @ 16 (1.1)	12 @ 11 (0.8)	10 @ 7 (0.5)	20 @ 16 (1.1)	20 @ 7 (0.5)	20 @ 7 (0.5)
20 (6.0)	12 @ 30 (2.1)	12 @ 18 (1.2)	12 @ 13 (0.9)	9 @ 20 (1.4)					12 @ 7 (0.5)		12 @ 30 (2.1)	12 @ 18 (1.2)	12 @ 13 (0.9)	6 @ 22 (1.5)	12 @ 30 (2.1)	12 @ 13 (0.9)	12 @ 7 (0.5)	20 @ 30 (2.1)	20 @ 13 (0.9)	20 @ 7 (0.5)
25 (7.5)	15 @ 65 (4.5)	9 @ 35 (2.4)	9 @ 24 (1.7)	9 @ 20 (1.4)	9 @ 20 (1.4)	6 @ 22 (1.5)	15 @ 65 (4.5)	15 @ 42 (2.9)	9 @ 16 (1.1)	12 @ 10 (0.7)	15 @ 65 (4.5)	12 @ 50 (3.5)	12 @ 35 (2.4)	6 @ 22 (1.5)	15 @ 65 (4.5)	15 @ 29 (2.0)	12 @ 20 (1.4)	20 @ 65 (4.5)	20 @ 29 (2.0)	20 @ 13 (0.9)
30 (9.0)		12 @ 50 (3.5)	12 @ 35 (2.4)	9 @ 20 (1.4)	9 @ 20 (1.4)	6 @ 30 (2.1)			9 @ 16 (1.1)	12 @ 15 (1.0)				6 @ 30 (2.1)			12 @ 20 (1.4)			30 @ 20 (1.4)
35 (10.5)		12 @ 75 (5.2)	12 @ 52 (3.6)	12 @ 29 (2.0)	12 @ 23 (1.6)	6 @ 60 (4.1)[a]			15 @ 25 (1.7)	9 @ 30 (2.1)				8 @ 40 (2.8)						
40 (12.0)		12 @ 75 (5.2)	12 @ 52 (3.6)	9 @ 50 (3.5)	9 @ 40 (2.8)					9 @ 30 (2.1)										

[a] An acceptable alternative design is 8 @ 40 (2.8) when a 12 ft (3.6 m) maximum linear spacing is used

If a test passes then the pressure used may be used to develop protection criteria that appears in Data Sheets.

Why Safety Factors?



FM Standard Uncartoned Unexpanded Plastic Test Commodity



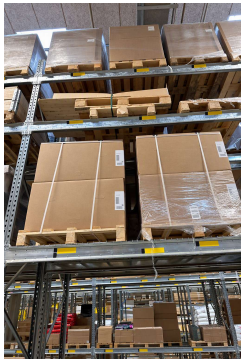
Also an Uncartoned Unexpanded Plastic Commodity

Testing uses our standard test commodities. In the case of uncartoned, unexpanded plastics this is stacked plastic pallets. Some plastic commodities may burn slightly more fiercely. Safety factors help cover this.

Why Safety Factors?



Typical FM test – well aligned, 150mm flues



Real life

Rack storage testing uses well aligned, 150mm wide transverse and longitudinal flues. In actual situations flues may be more irregular. Testing with somewhat irregular flues has shown this to be acceptable but not every storage combination is tested with and without irregularities.

Why Safety Factors?

With adequate ceiling only protection which storage is more hazardous?

In some tests lower storage opened more sprinklers than higher – what if on the day of a fire the warehouse is only half-full?

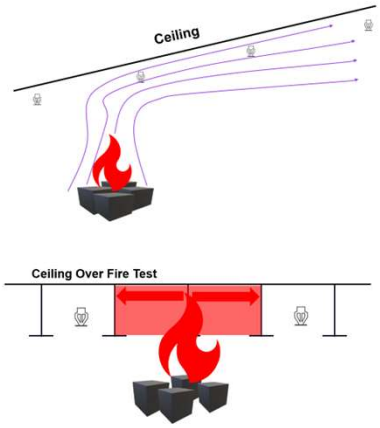


Conventionally we generally think higher storage is a bigger fire protection challenge and testing seeks to establish maximums for different commodities, configurations and sprinklers. However, in some tests for a given ceiling height the lower storage can be the tougher case. Although the heat release rate is lower sprinklers take longer to operate and discharge has a taller fire plume to penetrate before hitting storage. Testing has shown this effect to be within safety factors.

Why Safety Factors?



FM Fire Test Hall – smooth, level ceiling



Real life

FM tests are typically under one of the moveable ceilings in our Large Burn Lab. This ceiling is flat and smooth. Real life ceilings are often sloped and obstructed which effects the performance of sprinklers. Specific testing has established limits and mitigation approaches for slope and obstructions but not every combination of storage, slope etc has been tested. Safety factors provide a cushion against worst case combinations.

SPRINKLER FIRE TESTS

Reducing the Safety Factors

Safety Factors are there to account for normal variations in conditions

Are the safety factors known?

Is the erosion of safety margin understood – does the end user know what they are getting?

Will others such as local authorities, acceptance bodies and insurers agree?



The picture is from a test of roll tissue paper using K200 quick response storage sprinklers. Technically it was a pass but it, along with other tests, showed that this is an extremely challenging commodity and finding practical solutions may mean accepting lower than typical safety factors. Further reductions in the safety factors could mean loss of control if too many negative factors are present.

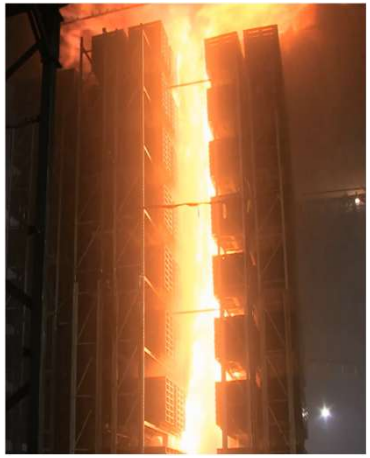
SPRINKLER FIRE TESTS

Reducing the Safety Factors

Failure may not be gradual

Storage protection is quite "pass / fail" – fail means an uncontrolled fire

End result may be loss of a facility



It is not always apparent from successful fire tests that they "only just worked". A small reduction in discharge might mean a fire is not controlled. We don't always know where we "fall off the sledge".

FM Approach to Existing Situations

When evaluating existing protection FM will take account of what we know from research and testing

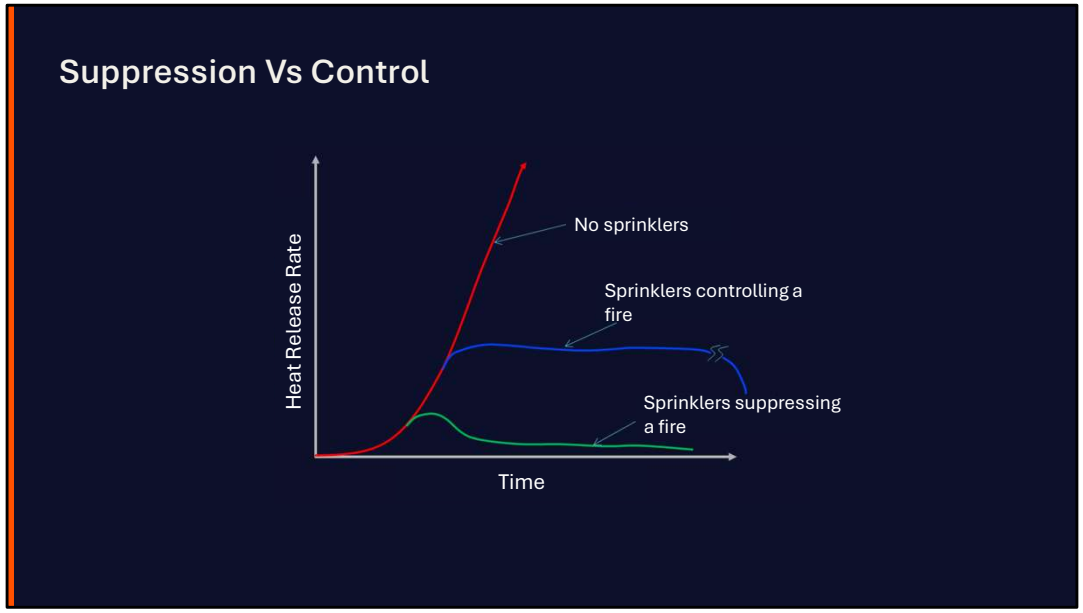
- The potential property protection impact of less than fully adequate protection will be assessed and communicated to the client
- Might recommend to the client that they continue with the existing design
- Might recommend partial or full upgrades

FM does not support new installations not fully per Data Sheets

General advice is to follow the Data Sheets

Source Citation/Footnotes (optional)


Top Loading ASRS
- Putting the Fire Out



This graph illustrates the heat release rates of uncontrolled, controlled and suppressed fires. Even with successful suppression sprinklers do not typical extinguish fires in the desired time frame. Usual a firefighter with a hose is needed for final extinguishment.

Top-Loading ASRS

Boxes stack on each other in an array

“Robots” on top of grid, raise and lower boxes and deliver to pick points

Boxes may be solid or open sided

- Solid sided easier to protect

World's Fastest AS/RS | 4x Space & 99.8% Uptime | AutoStore

OSP Fulfilment: A winning ecosystem | Ocado Group

Fire Test – Top Loading ASRS

Configuration

- Area: 19 m^2
- Height: 5.5 m
- Ceiling: 12 m

Ignition

- Base of storage
- Beneath robot
- Under 1 sprinkler

Sprinkler Protection

- K200, QR
- 5.2 bar ≈ 49mm/min
- Applied for at least 30 min



In this test sprinklers successfully controlled the fire.

[+30 min] Sprinklers turned off



But when no more sprinklers operated after 30mins they were turned off as is normal in testing. The emergence of smoke showed the fire was still burning.

Fire extinguished by adding monitors



Sprinklers were turned back on and remote water monitors were added and succcessfully extinguished the fire.

Protection Challenge

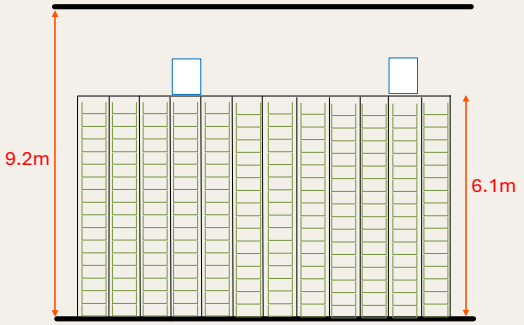
- At present there are no proven protection solutions for buildings taller than 13.5m.
- For up to 9m high ceilings FM have developed protection schemes which in tests extinguished the fire
- For taller ceilings (or buildings with weaker sprinkler protection) hoses are needed for final extinguishment
  - Hose streams need to be able to reach all parts of the array
  - Hoses can probably only reach 15m
  - This is likely to require a lot of infrastructure

Protection Solution Less Likely to Need Manual Extinguishment

Ceiling at 9m

Strong sprinkler design

In testing fire was extinguished by sprinklers alone



TL ASRS – Final Extinguishment

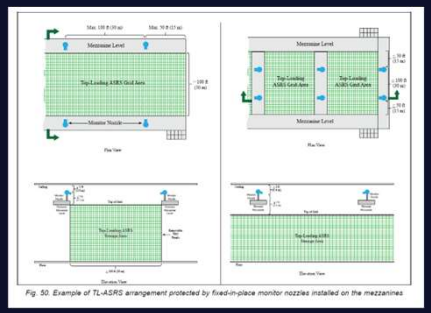


Fig. 50. Example of TL-ASRS arrangement protected by fixed-in-place monitor nozzles installed on the mezzanines

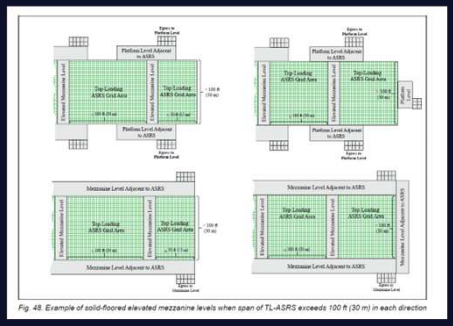
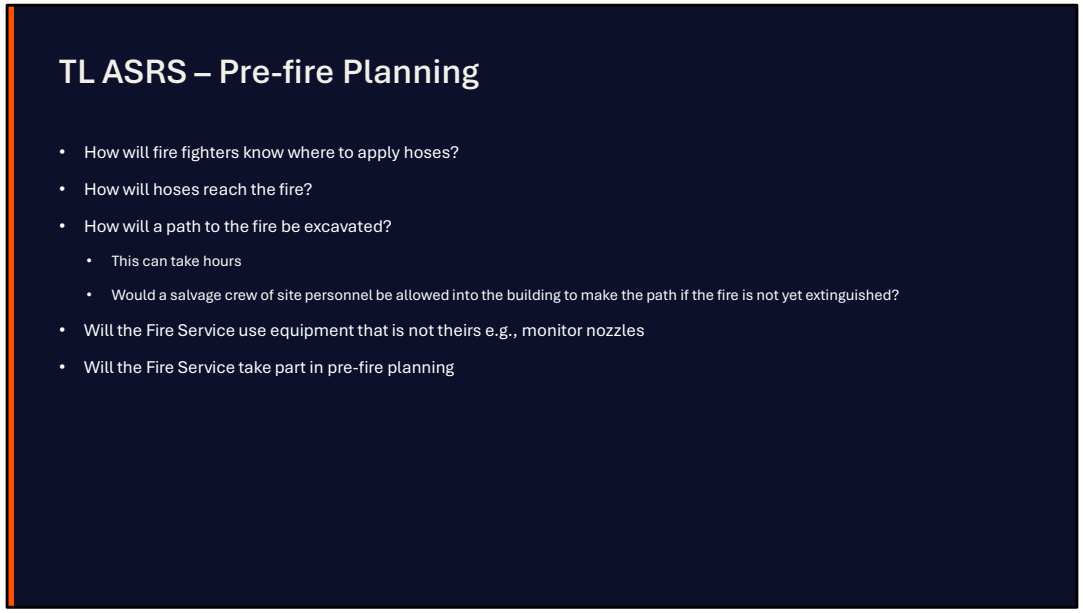


Fig. 48. Example of solid-floored elevated mezzanine levels when span of TL-ASRS exceeds 100 ft (30 m) in each direction

If sprinklers are not going to extinguish the fire then we need a way to get hoses on it. For manual hoses this mean mezzanine platforms level with the top of the storage are needed. If the array is large then it may need to be subdivided by walkways to provided access.



With or without a sprinkler design expected to extinguish the fire (but especially without) it will be necessary to cut a path through the storage system to get to the seat of the fire to ensure it is extinguished and to start salvage and repairs. For a large array this can take hours and is arduous physical work. A well trained team and the co-operation of the Fire Service is essential.

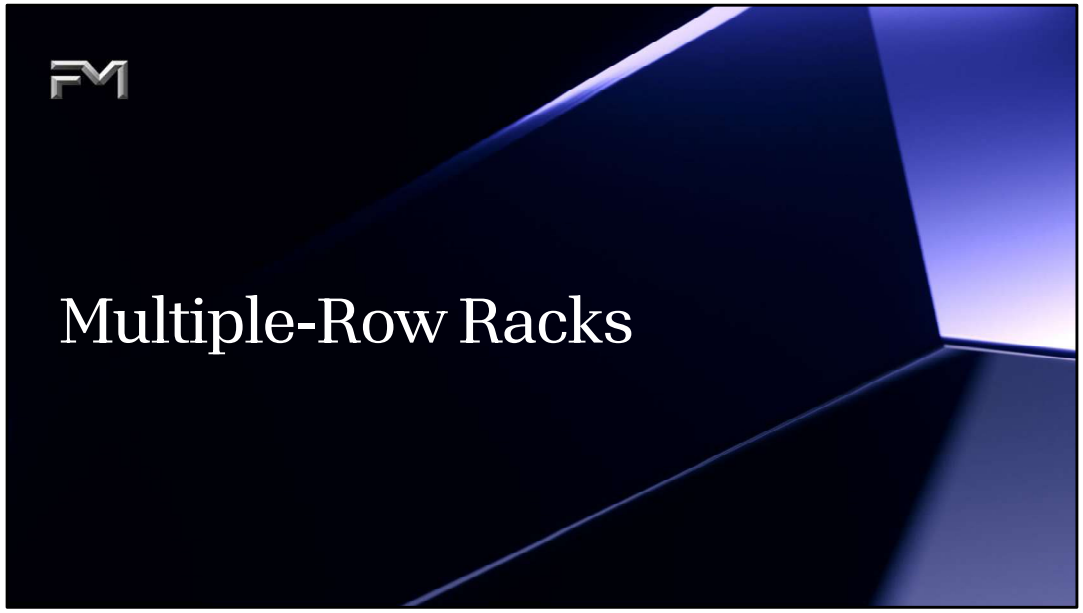
TL ASRS – Final Extinguishment

- Without an extinguishing design or thorough, exercised pre-fire plan FM advise clients that a fire is ultimately likely to grow out of control
  - If you cannot get to it, you cannot put it out
  - If you cannot put it out, then eventually the water supply will be exhausted
  - Uncontrolled fire spread likely
- Solutions
  - A ceiling at 9m and upgrade sprinkler protection
  - IR cameras and remotely controlled steerable monitor nozzles
  - Self targeting monitor nozzles?
  - Non-propagating, solid sided totes e.g., steel



FM Approved Fire Rover Monitor Nozzle System

Remotely controlled monitor nozzles and infra-red cameras can be a solution for final extinguishment. The system shown is the FM Approved Fire Rover system. This is controlled manually by trained operators working from a remote central station.


Multiple-Row Racks

Topic: Multiple-Row Racks

Multiple-Row Rack Project

- Initiated by the Fire Protection Research Foundation (FPRF)
- Sponsored by the Property Insurance Research Group (PIRG)
- Testing conducted at FM

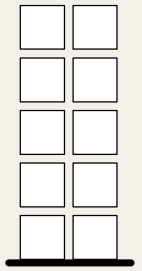
Literature review (Phase 1) completed by Telgian

Ceiling-only protection availability (Phase 2) has been recently completed

Topic: Multiple-Row Racks

Fire Testing in the 1970s

- Class 2 commodity
- 7.6m
- Double Row Rack
- Successful test



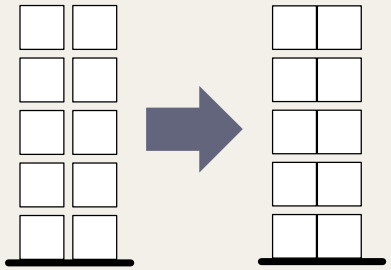
End Elevation

Systematic fire tests of rack storage at FM started in the 1970s. One of the earliest was that shown. A simple double row rack with class 2 commodity (double walled cardboard cartons around metal boxes) was tested and a protection solution found.

Topic: Multiple-Row Racks

Fire Testing in the 1970s

- Class 2 commodity
- 7.6m
- Double Row Rack
- Successful test
- What about multiple-row racks?



Test was still successful – benchmark for multiple-row racks

To assess multiple row racks the storage was pushed together and the test re-run. It still worked so it became a solution for multi-row racks. This was the benchmark until well into the 2000s. There was a clear need for more testing which suggest that unless 150mm flues were present in both transverse and longitudinal directions then storage should be limited to 6m deep runs with 150mm transverse flues or in-rack sprinklers should be installed over every tier. Since in roller and push through racking it is not possible to provide longitudinal flues and racking is often deeper than 6m this is not ideal.

Topic: Multiple Row Racks



vs



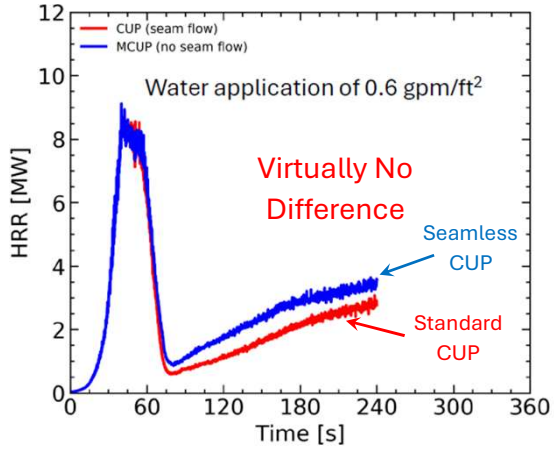
Seamless CUP

Standard CUP

How do they compare?

One of the first challenges was that early indications were that our standard cartoned unexpanded plastic (CUP) commodity might need to be modified for multi-row rack testing. The standard commodity is non-expanded polystyrene cups (such as you might find at a water cooler) in cartons, with eight cartons to a pallet This presents seams between cartons that sprinkler discharge can penetrate and assist in fire control.

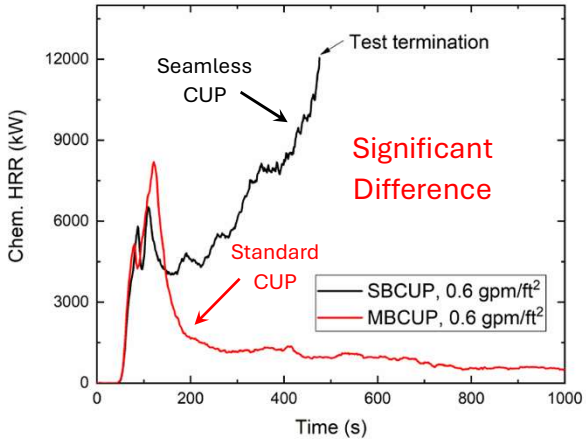
Topic: Multiple Row Racks



Computer Modeling Results for Double-Row Rack

Computer modelling suggested this was not a major issue for double-row racks (and well covered by the safety factors!) but might be for multi-row racks.

Topic: Multiple Row Racks



Intermediate-Scale Test Results for Multiple-Row Rack

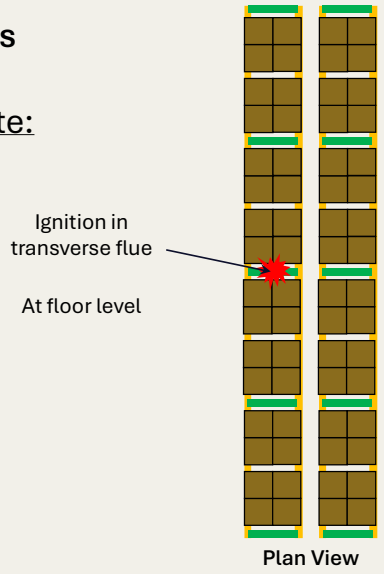
And in an actual test we found the seamless CUP (same commodity with a continuous cardboard sheet over the top of the cartons) presented a significantly more serious fire challenge. As a result, further testing for MRR was done using “seamless CUP”.

Topic: Multiple-Row Racks

Test Parameters to Evaluate:

- Test commodity
- Ignition location

Worst-case for MRR?



The normal ignition point for tests is at ground level in a transverse flue. This is typically the worst case for double row racks but what about multi-row racks?

Topic: Multiple-Row Racks

Test Parameters to Evaluate:

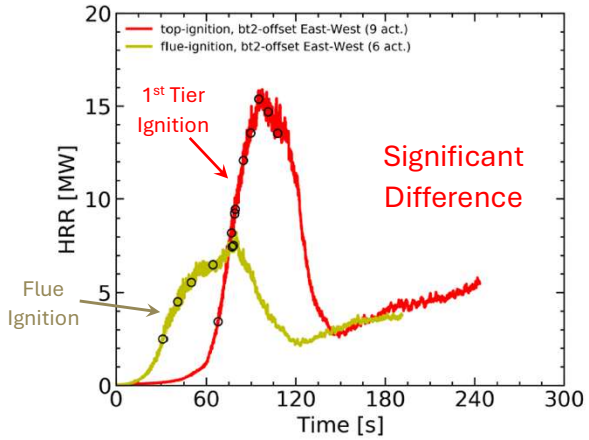
- Test commodity
- Ignition location



What if shuttle robot with Li-Ion battery fails?

Multi-row racks are increasingly using lithium-ion battery powered retrieval systems. These can present a very strong ignition source with a tendency for burning electrolyte (typically a ignitable liquid) to escape. This might pour down through a rack if the fire starts at a higher level.

Topic: Multiple Row Racks



Computer Modeling Results

Computer modelling showed that starting the fire at an upper tier was significantly more challenging than at ground level for multi-row racks so this was used in the testing.

Topic: Multiple-Row Racks

Test Variables Held Constant:

- Commodity: Cartoned unexpanded plastics (seamless)
- Storage Height: 10.4 m
- Ceiling Height: 12.2 m
- Transverse Flue Spaces: 150 mm every 1.5 m
- Ignition between 2 sprinklers
- Top-load ignition location (1st tier)

Topic: Multiple-Row Racks

Summary of Tests:

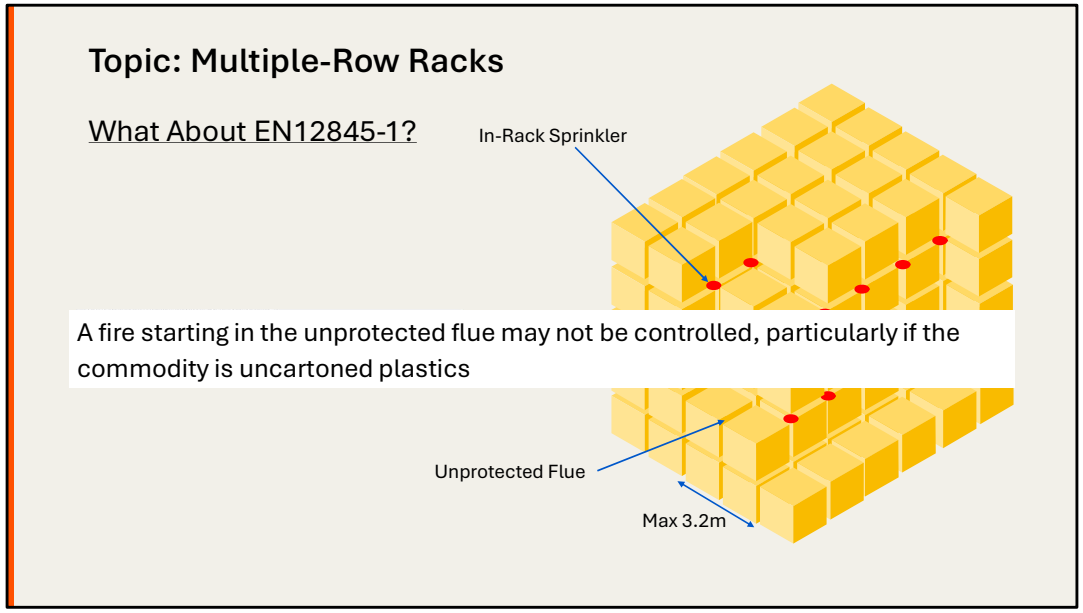
Existing acceptable design per NFPA 13

Existing acceptable design per DS 8-9
Existing NFPA 13 design is 25 psi (1.7 bar)

Test No.	1	2	3	4	5
Aisle Width, ft (m)	1.2	2.4	2.4	2.4	1.2
Ceiling Sprinkler	QR K240 Pendent	QR K360 Pendent	QR K360 Pendent	QR K240 Pendent	QR K240 Pendent
Operating Pressure, psi (bar)	3.6	5.2	2.8	3.6	6.2
No. of Operating Sprinklers	19	1	1	15	2

Existing acceptable design per DS 8-9

Testing saw failures of existing designs in NFPA Standards and FM Data Sheets for K240 QR sprinklers. A test at higher pressure was a success. Since most systems will be fed by pumped water supplies much higher pressures are typically available at the first two or three sprinklers to operate so without other negative factors fire suppression would still be likely.



EN12845 has largely adopted FM designs when using large orifice quick response sprinklers however what about the older designs that use K80 and K115 ceiling sprinklers at the ceiling together with in-rack sprinklers. The concern here is that multiple-row racks are not covered very explicitly. There is simply a statement that for racks wider than 3.2m, lines of in-rack sprinklers should be provided every 3.2m across the width of the rack. There is no recommendation to stagger alternate levels so that all transverse flues are covered. This would typically every other transverse flue with no in-rack sprinklers in them. This is likely to lead to a fire growing out of control especially if it starts in one of the unprotected flues.

Topic: Multiple-Row Racks

Test Result Conclusions:

- Test results based on double-row racks may not be adequate for new designs for multiple-row racks
- Existing designs for multiple-row racks may be acceptable if initial high flows are available
- Ceiling-only designs available for ceiling heights up to 12.2 m when maximum commodity hazard is cartoned, unexpanded plastics (CUP)
- In-rack sprinklers will not be needed at every tier level
- In-rack sprinkler design and installation per Section 2.3.6.6 with increased flow rates anticipated

An interim revision of Data Sheet 8-9 will be published shortly with a full revision planned in 2027.

Topic: Multiple-Row Racks

Unanswered Questions:

- What are protection recommendations for ceiling heights other than 12.2 m?
- What are protection recommendations for commodities other than cartoned unexpanded plastics (CUP)?
- What in-rack sprinkler designs should be used?

Research and testing continues!

Thank you.
Any questions?

allan.macpherson@fm.com

Free at:

FM Data Sheet 8-9

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