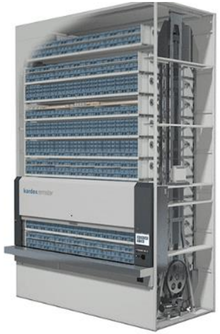
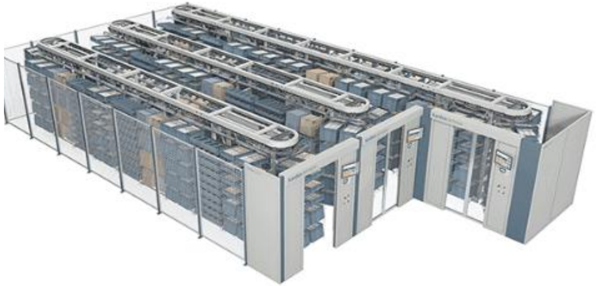
RESEARCH FOUNDATION
RESEARCH FOR THE NFPA MISSION

FPRF Sprinkler Research to Support Modern Day Fire Challenges

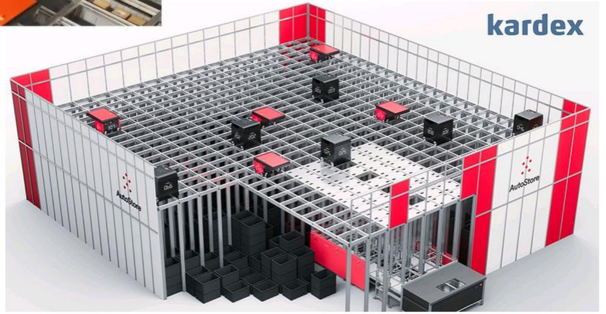
Fire Sprinkler International 2023

May 31, 2023 | Victoria Hutchison, Senior Research Project Manager, FPRF



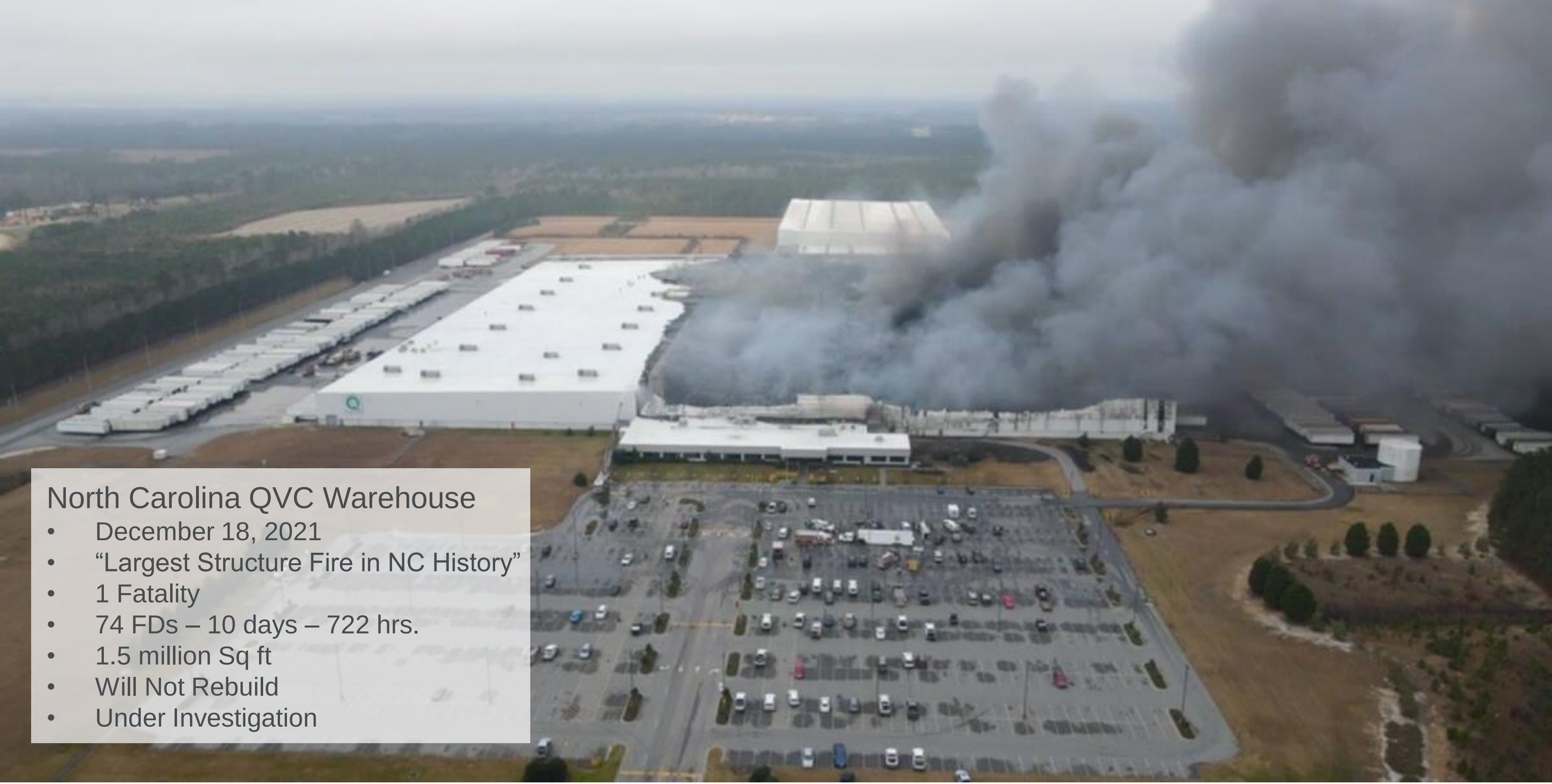



Shuttle
041


kardex
AutoStore
AutoStore

Redlands, CA | June 5, 2020

 |



North Carolina QVC Warehouse

- December 18, 2021
- “Largest Structure Fire in NC History”
- 1 Fatality
- 74 FDs – 10 days – 722 hrs.
- 1.5 million Sq ft
- Will Not Rebuild
- Under Investigation

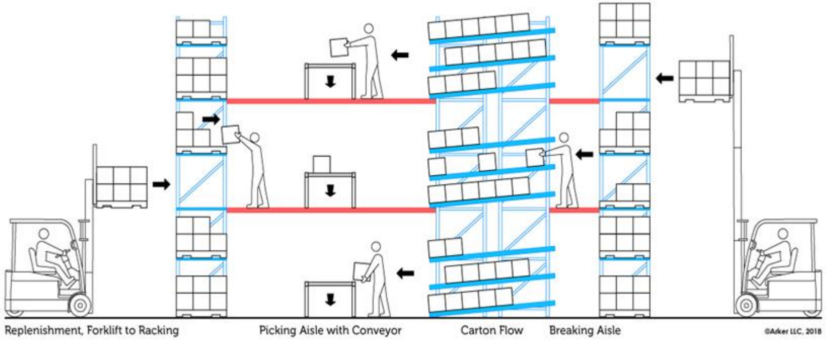
IL Records Storage Warehouse

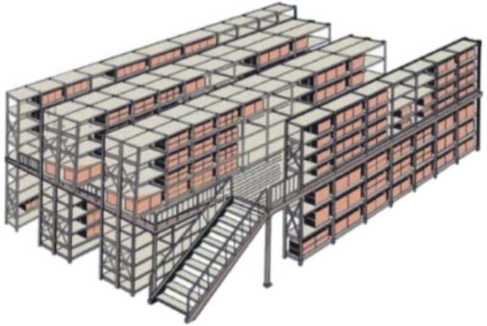
- February 2, 2022
- 250,000 ft^2 Records Storage in Corrugated Boxes to >50 ft
- ESFR sprinklers
  - 9:44 - Initial waterflow alarm
  - 9:50 – Working Fire
  - 10:14 – First Collapse
  - 11:30 – Sprinklers Shut Down
  - 12:20 – AS turned back on
  - 12:55 – 2nd major collapse and compromise of sprinkler system

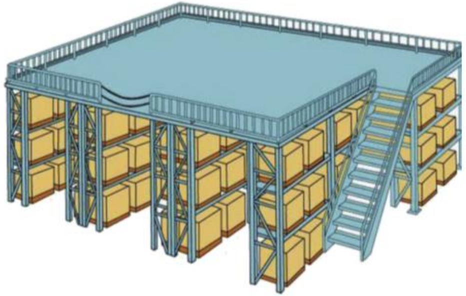
Agenda

- Landscape of Modern Warehouse Characteristics and Challenges with High Hazard Storage:
  - Impact of Elevated Walkways in Storage on Sprinkler Protection
  - Protection for Multi-Row Rack Storage Arrangements
  - Automated Storage and Retrieval Systems
  - Firefighting Guidance for Sprinklered High-Hazard Storage Facilities
- Fire Protection Challenges associated with Electrification
  - EVs and ESS
  - Impact on infrastructure (e.g., parking structures, RoRo’s, etc.)

Impact of Elevated Walkways on Sprinkler Protection



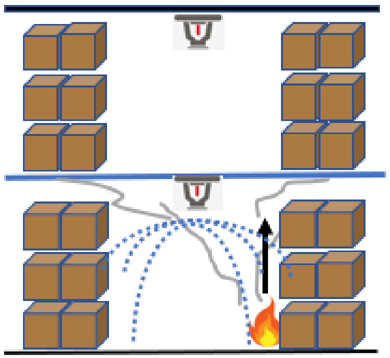




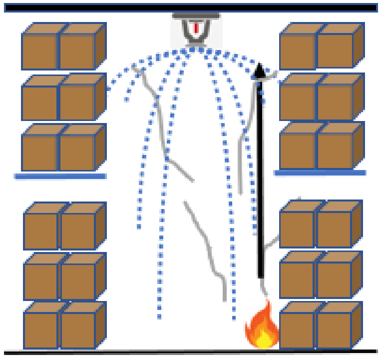
- *When is this type of installation considered a problem from a sprinkler protection standpoint (i.e. water isn't delivered to intended surface)?*
- *At what point do walkways interfere with pre-wetting of adjacent arrays?*

 |

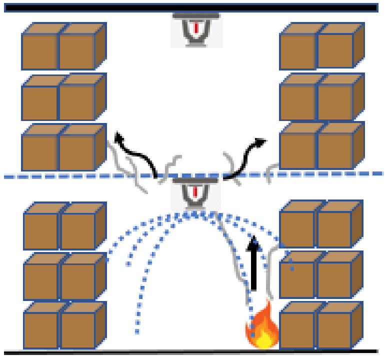
Rack/Mezzanine Configuration Examples



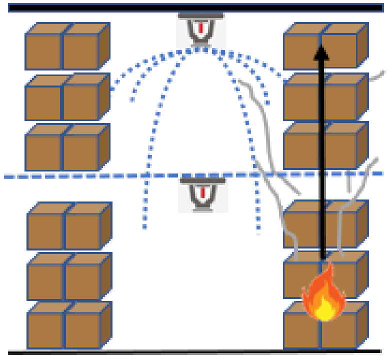
Solid Shelf/Walkway



Solid Shelving



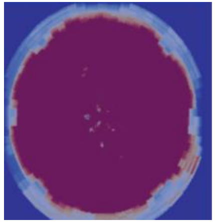
Perforated Shelf/Walkway



Perforated Shelf/Walkway

No Obstructions

Actual Delivered
Density to Floor



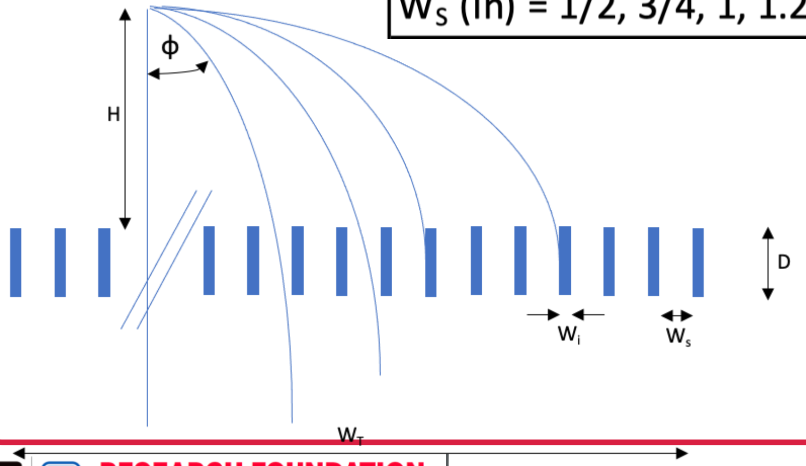
With Obstructions

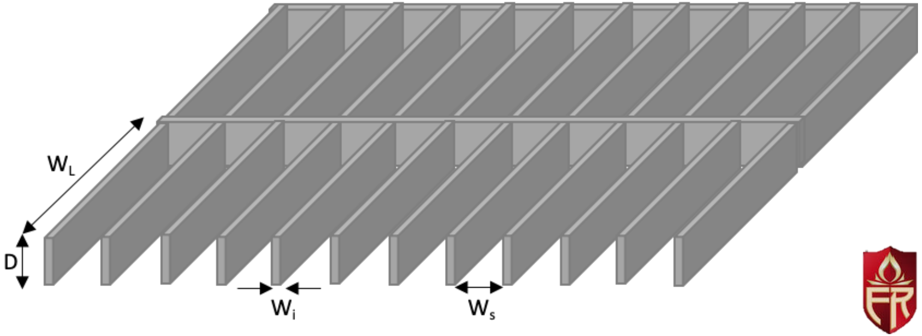
Actual Delivered
Density to Floor

 |

Experiments

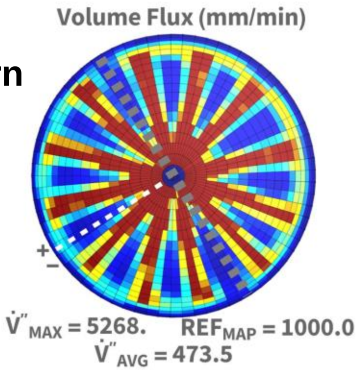
		K-Factor	11.2	17	22
Modeling Parameters		**Sprinkler**	1	2	3
Baseline No Mezzanine	**Pressure (psi)**	7, 20, 50	NA		
D (in) = 1/4, 3/8, 1/2, 3/4, 1.0		7, 20, 50	W_T = 36, 44, 52, 60		
L (in) = 1, 1.5, 2, 3, 4, 5, 6					
W_i (in) = 1/8, 1/4, 3/8					
W_S (in) = 1/2, 3/4, 1, 1.25, 1.5					

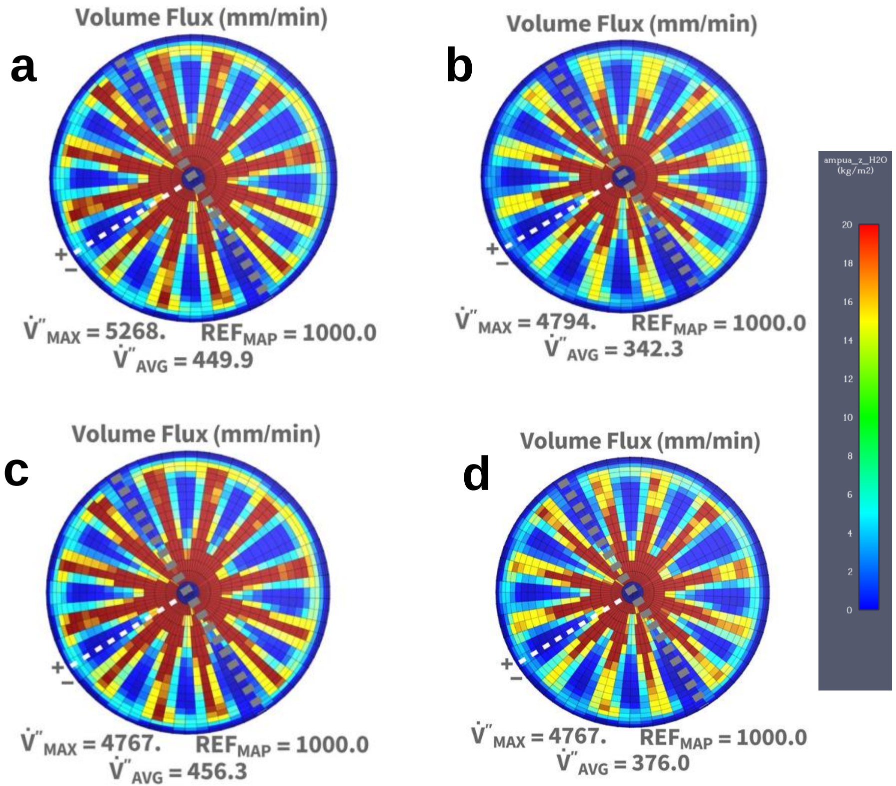




Effect on Volume Flux: K16.8 (35 psi)

Original Pattern

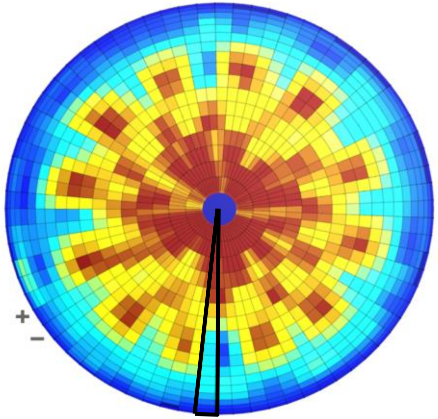


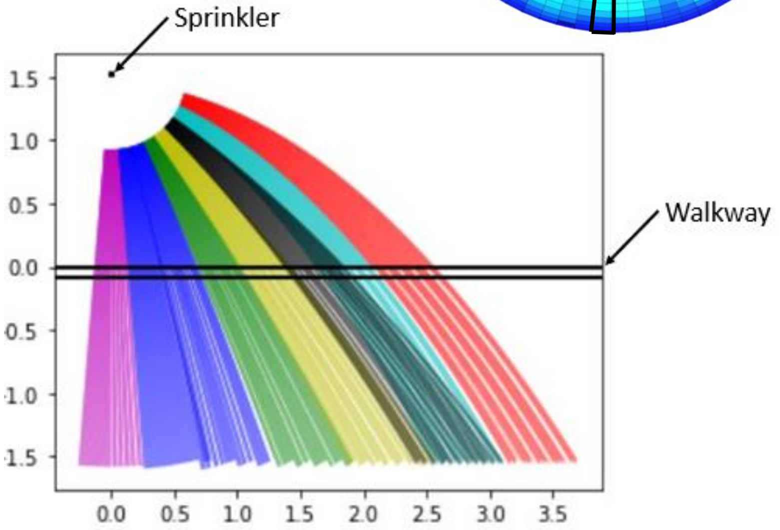


	Height (ft)	Bar Depth (in)	Bar Thickness (in)	Bar Spacing (in)	Volume Passed
a	8	1	0.1875	1	94.8%
b	8	6	0.1875	1	72.0%
c	20	1	0.1875	1	96.3%
d	20	6	0.1875	1	79.4%

Simulation Visualization

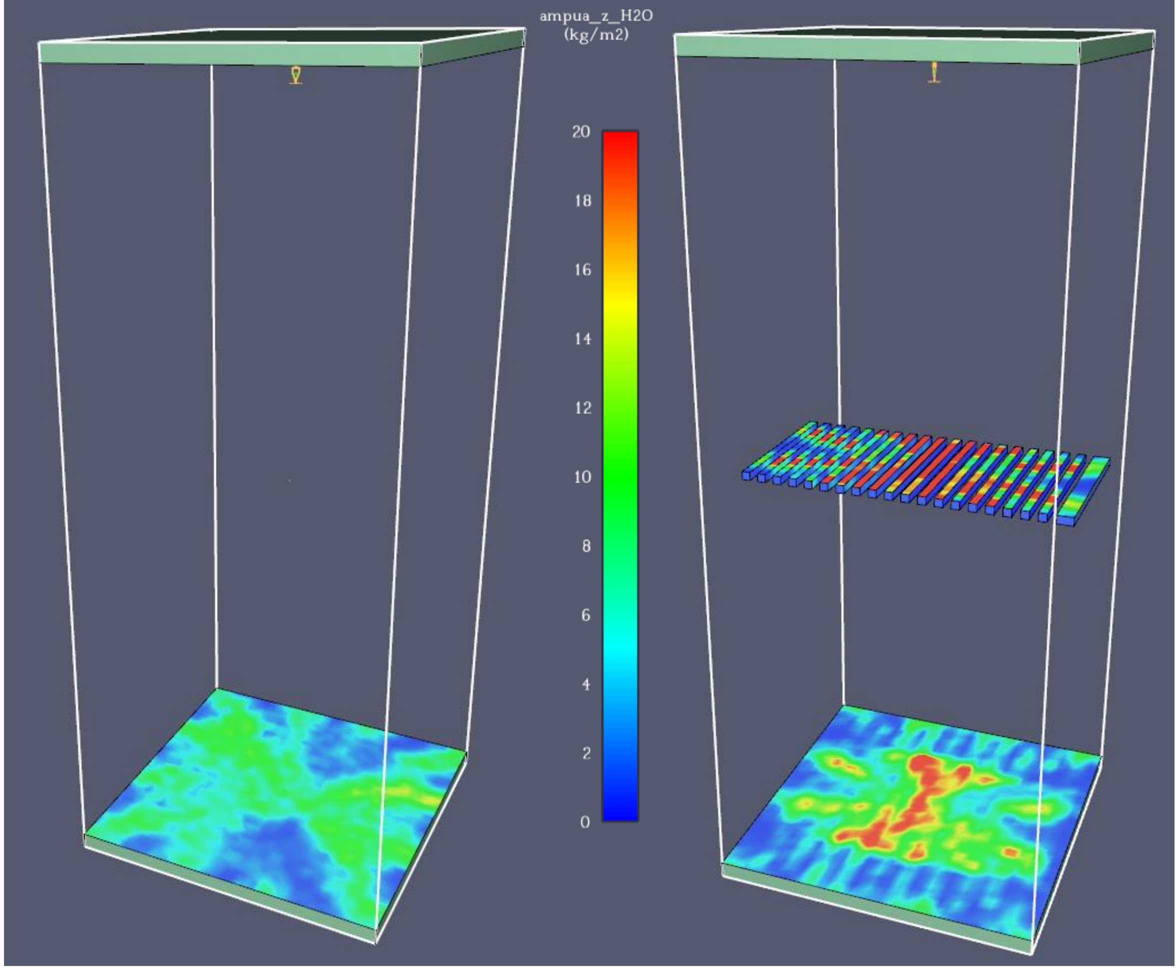
	180	170	160	150	140	130	120	110	100	90
0	0.87	0.98	0.87	0.92	0.88	0.78	0.79	0.81		
5	0.87	0.98	0.85	0.92	0.86	0.79	0.8	0.75		
10	0.87	0.98	0.83	0.92	0.81	0.87	0.76	0.81		
15	0.87	0.98	0.85	0.86	0.84	0.83	0.77	0.85		
20	0.87	0.96	0.87	0.85	0.81	0.79	0.75	0.8		
25	0.87	0.96	0.91	0.85	0.87	0.76	0.77	0.8		
30	0.87	0.96	0.91	0.87	0.86	0.79	0.7	0.75		
35	0.87	0.96	0.91	0.92	0.85	0.85	0.77	0.8		
40	0.87	0.96	0.91	0.92	0.81	0.87	0.75	0.8		
45	0.87	0.94	0.91	0.86	0.84	0.82	0.78	0.8		
50	0.87	0.94	0.86	0.86	0.85	0.87	0.74	0.8		
55	0.87	0.94	0.91	0.86	0.81	0.79	0.8	0.81		
60	0.87	0.96	0.91	0.85	0.86	0.73	0.71	0.8		
65	0.87	0.96	0.87	0.92	0.86	0.78	0.8	0.85		
70	0.87	0.96	0.87	0.92	0.8	0.86	0.75	0.85		
75	0.87	0.96	0.91	0.91	0.81	0.86	0.79	0.75		
80	0.87	0.96	0.86	0.86	0.87	0.86	0.8	0.81		
85	0.87	0.96	0.86	0.85	0.87	0.78	0.74	0.84		
90	0.87	0.96	0.91	0.84	0.86	0.79	0.79	0.87	0.68	





FDS Simulation

Simulation Details	
Domain	2 m x 2 m x 5 m 6.5 ft x 6.5 ft x 16.4 ft
Mesh Size	0.025 m x 0.025 m x 0.025 m 0.082 ft x 0.082 ft x 0.082 ft
Heatmap Quantity	Accumulated mass of water per unit area
Sprinkler Elevation	4.8 m (15.75 ft) (centered)
Walkway Dimensions	1 m wide / 0.05 m x 0.05 m cross section / 0.05 m gaps
Walkway Elevation	2.5 m (8.2 ft)
Modeled Sprinkler	K16.8/ 45 psi



Key Takeaways

- What % of spray altered is acceptable to the industry, needs to be determined (15%, 25%, 35%, ???)
- Sprinklers with strong downward central cores (170-190°) less impact to spray
- Smaller droplets (less momentum) transition to primarily vertical velocity component earlier, larger drops later
- Percentage of openness is not only driver of blockage, horizontal component of droplet velocity also what drives obstruction with grating
- Phase I and forthcoming Phase II report will be available at www.nfpa.org/foundation

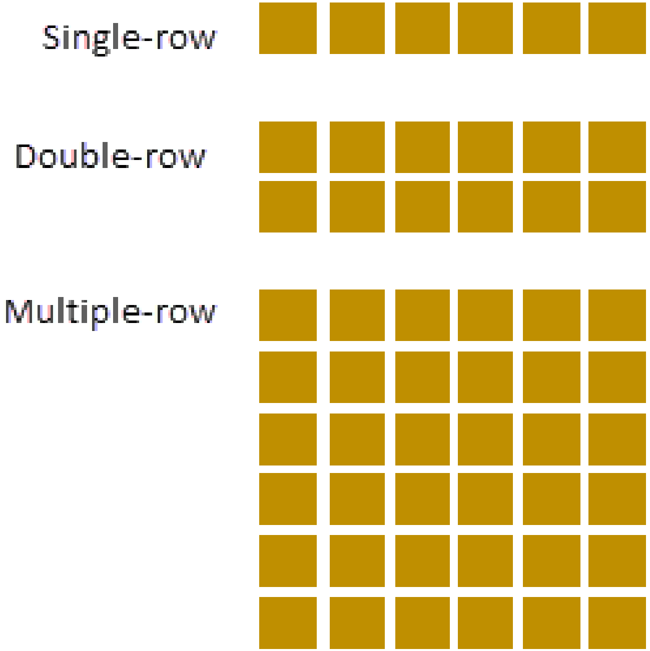
Resources & Future Work

- All content accessible at www.nfpa.org/foundation
  - Research Reports → Suppression
- Phase II report will be published: **June 2023**
- **<u>Future Work</u>**
  - Phase III: Large Scale Testing and Model Validation
  - June 2023 – June 2024

Sprinkler Protection for Multiple-Row Rack Storage Systems – Phase I

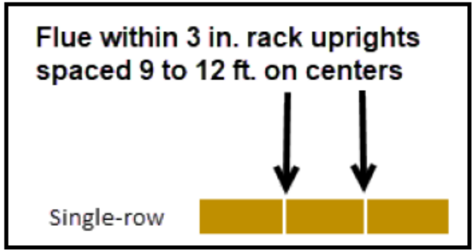
 |

Racking Arrangements Commonly Used Today

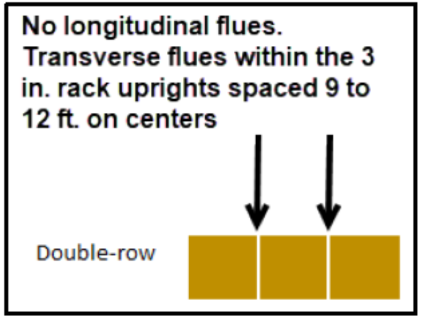


 |

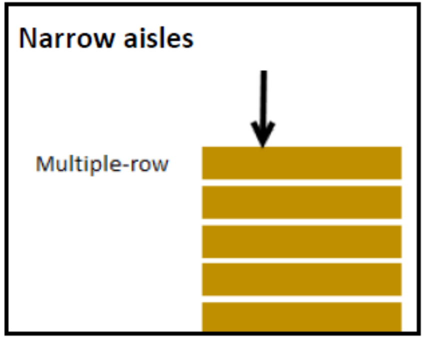
Deviations from Traditional Open Frame Configurations



A) Single-row racks storage individual cartons or bin boxes



B) Multiple-row racks with only transverse flues (often referred to as flow racks)



C) Multiple-row racks with only longitudinal flues (narrow aisles)

 |

 |

Fire Protection Guidance Questions

Guidance for the protection of multiple-row rack storage configuration exists
Is it adequate?

Some of the questions raised by the NFPA 13 committee, and other stakeholders are:

- What is the minimum flue/aisle size and spacing needed to stop horizontal fire spread for the different storage configurations?
- How to identify storage configurations where in-rack sprinkler protection is needed, versus when ceiling-only sprinkler protection is adequate? This includes when storage heights are exceeded, flue spacing does not meet minimum requirements, and storage depths are exceeded.
- What other potential mitigation options could be applied (e.g., aisles/aisle width, vertical barriers, leaving pallet positions open to simulate an aisle/a break in the storage, etc.)?
- What tools/resources can be provided to inform fire service response to a fire in a multiple-row rack storage warehouse? How does the fire service get access to the storage?
- Clarify the definition of net flue spacing established in Data Sheet 8-9 versus nominal flue spacing established in NFPA 13.

Research Goal

- The overall goal of this research program is to develop guidance on sprinkler protection for multiple-row racks including determining a scientifically based definition of open racking for multiple-row racks as well as developing guidance on appropriate sprinkler protection and/or other mitigation options (e.g., aisle spacing, vertical barriers) for multiple-row racks that do not meet the definition of open racking.
- There will be an emphasis on identifying storage configurations where results from large-scale fire tests with double-row racks can be applied to multiple-row racks.
- This project is a Phase 1 that involves a literature review, gap analysis, and development of a research plan to work toward the overall goal.

Final Report: Nov 2023

Project Tasks

1. Review of technical substantiation for existing **regulatory requirements**.
2. **Past Fire Test Data**. Identify, clarify, and review any past fire tests in the literature that are relevant to multiple-row rack storage.
3. **Develop definitions** for storage arrangements that could be classified as open racking for multiple-row racks.
4. Identify **knowledge gaps** regarding the fire behavior and sprinkler protection of multiple-row racks
5. **Test Plan**. Develop a prioritized plan for full-scale fire testing to inform sprinkler protection guidance for storage with multiple-row racks that will be implemented in a future phase. The goal of the testing will be to develop protection recommendations for storage in multiple-row racks.

Guidance for Fighting Fires in High Hazard Storage Facilities: Review of Best Practices & Research Plan

Background

- Sprinklers are commonly used in high-hazard storage facilities and must be accounted for during firefighting efforts.
- Sprinklers are intended to “control” the fire, and sometimes suppress.
- Most incidents will require fire service intervention to achieve final fire extinguishment.
- To achieve final extinguishment, a complex sequence of events occurs, starting with a pre-incident plan and ends with final extinguishment and completion of salvage operations.

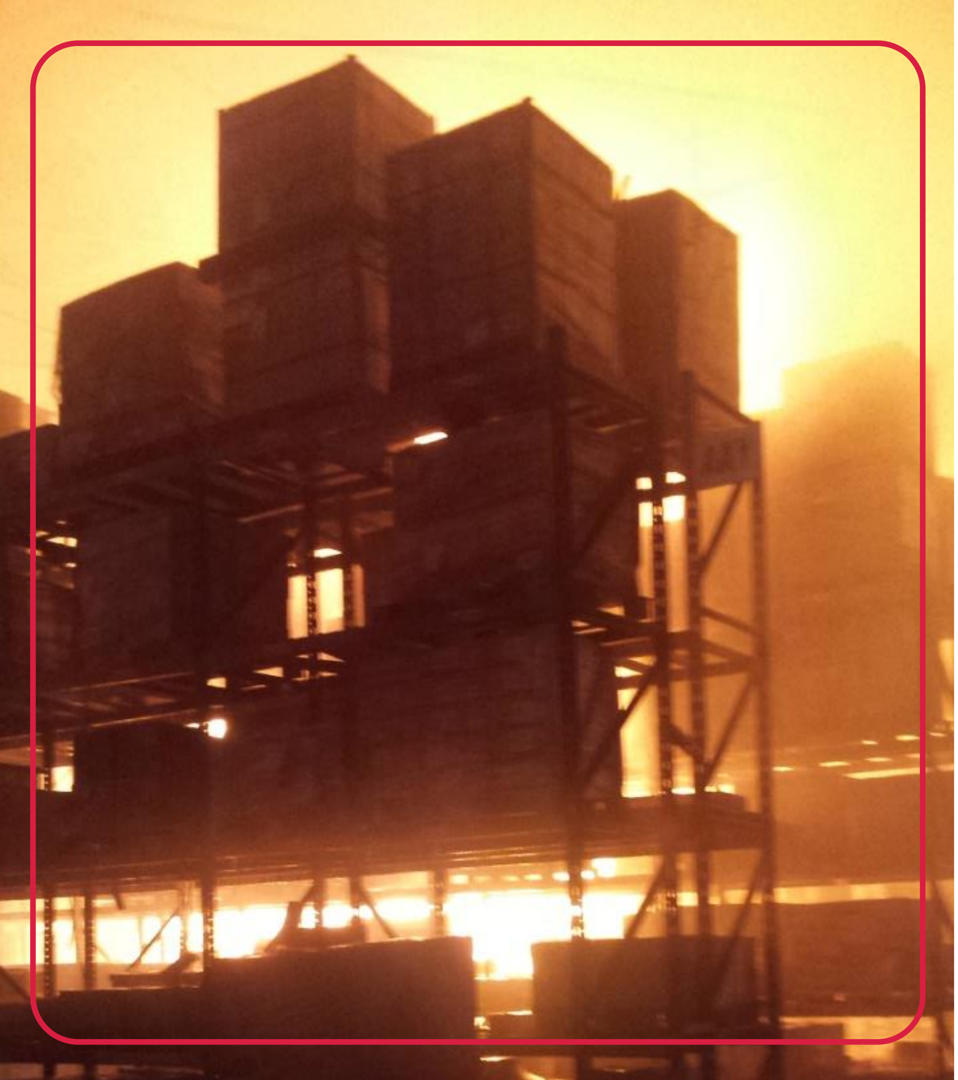
Project Need

- How to identify goals of property protection and life safety of firefighters?
- How to assess capabilities of the fire service responding to the incident?
- What are the minimum details required for the Pre-Incident Plan?
- How to identify the resources/tools available to fight the fire?
- How to identify when it is safe to perform an interior attack on a fire?
- How to identify rescue operations?
- When is the fire considered extinguished?
- When should automatic sprinklers be turned off and fire pump returned to standby mode?
- When and how should the building be ventilated?
- How will areas of high-rack storage (fixed racking & Automatic Retrieval Systems) be accessed?
- How will the fire-damaged stock be handled?

Research Goal

Program Goal: The overall goal of this research program is to develop guidance for fighting fires in high hazard storage facilities, including large warehouses and big box retail stores protected by automatic sprinklers.

Phase Goal: The goal of this project is to compile and review information on best practices for fighting fires in high hazard storage facilities and develop a research plan.



Project Tasks

Task 1: Literature Review & Gap Analysis

- Guidance/best practices for fighting fires in sprinkler protected buildings, to validate the role of the fire service, property owners, facility managers and the insurance industry on pre-incident planning.
- Literature on the final fire extinguishment of storage fires.
- Literature review of best practices of fire service ventilation on large commercial structures.
- Case study interviews demonstrating success stories from various perspectives.

Task 2: Gap Analysis

Task 3: Focus Group Meetings

Task 4: Research Plan (research projects to fill gaps)

Protection for Lithium-ion Battery Applications

Impact of Lithium-ion Batteries











Battery Research at the Research Foundation

General Hazard Characterization

Heat Release Rate (HRR)

Fire load/ Fire behavior

Gas Release / Toxicity

Vapor Cloud Explosion

Fire Spread Potential

Impact on Infrastructure

Commercial Environments
(e.g., parking garages, warehouses, manufacturing plants)

Residential Environments
(e.g., home garages, etc)

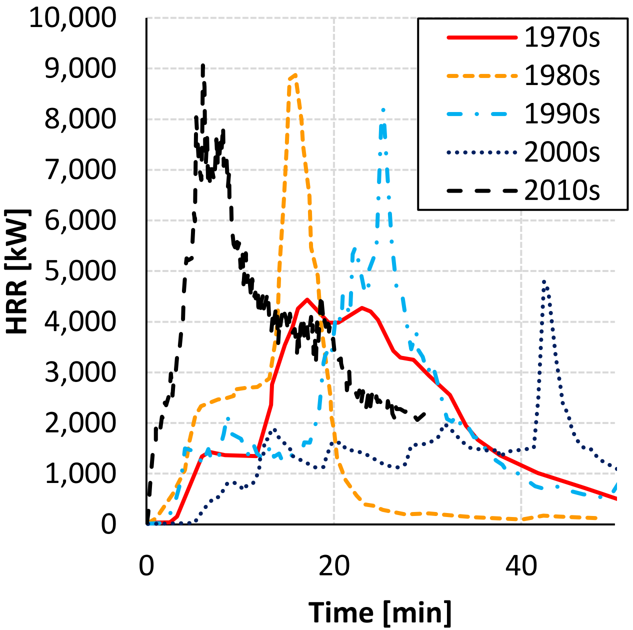
Marine Environments
(e.g., RoRo’s, containerships, ferrys)

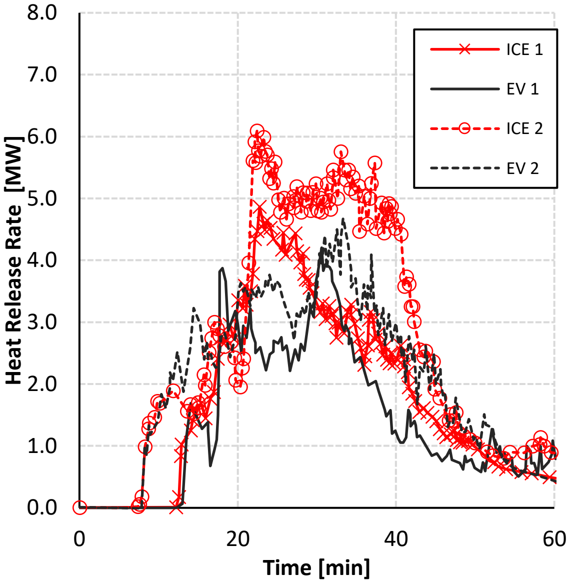
Emergency Response Considerations

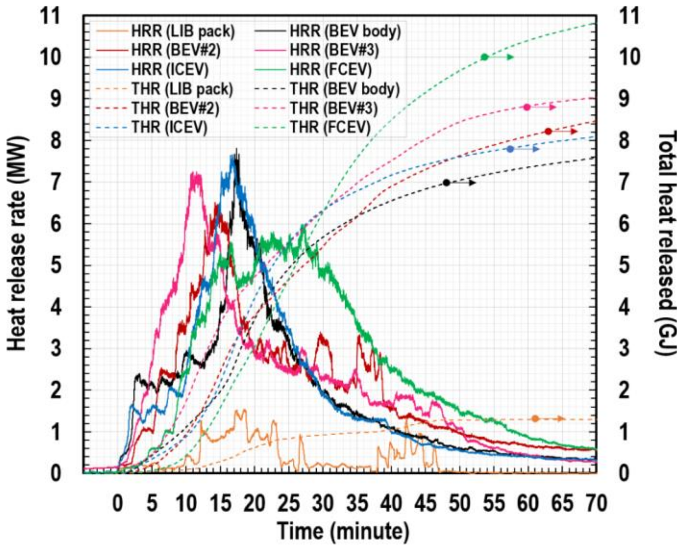
Tactical considerations
(e.g., various suppression strategies, cooling efficiency, impact on stranded energy risk)

Training

Define the Hazard - Vehicle Fire Test Data







Source: Kang (2023)

HRR is driven by:

Ignition source | Ignition location | Vehicle size | Vehicle Material Composition | Fuel source (e.g., Battery Capacity) | Ventilation

 |

Impacts on Infrastructure

- Larger Cars
- Less spacing
- Denser Configurations (e.g., stackers)
- Higher plastic content (+91%)
- Introduction of alternative fuels

→

- Older vehicles are different from modern vehicles today in:
  - Curb weight
  - Plastic type and content
  - Chemical energy from plastic (it has doubled since 1970s)
  - Spread potential (modern vehicles can spread prior to FD arrival).
- However, vehicles from any decade can yield 8 MW+ (pending test configuration)
- Greater probability of fire spread beyond vehicle of origin

Parking Garage fires are still **relatively rare**. But have huge potential for **significant consequences** and **large economic losses** if left unmitigated.

 |

Impact on Infrastructure

- Fire can generally spread from one vehicle to another within **10 min**; Spreads faster as more vehicles get involved.(as fast as **30 s per vehicle**, once multiple are involved (Liverpool experience)
  - **EV tests have shown heat flux measurements of 40 – 100+ kw/m^2**
  - Critical heat fluxes for other items::
    - Bumper: 17.5 kW/m^2
    - Fuel tank: 16.5 kW/m^2
    - Tires: 11 kW/m^2
- **1000°C+ ceiling jet temperature** pre-heats vehicle and aids spread
- **Concrete spalling** can occur at ~**374 - 380 C** (material temp); **Weakening of steel at 550 C** steel temperature exposure
  - Many tests have observed these temperatures after **5 min.**
- Evidence of **sprinkler systems being effective** at controlling a vehicle fire, and preventing spread.

Non-sprinklered at 10 min

Sprinklered at 1 hr 23 min

 |

Parking Garage Fire Experience with Sprinklers

2014 – 2018 Annual Averages

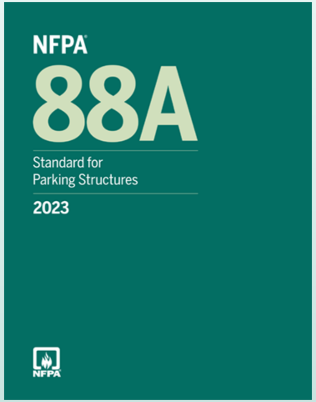
Summary of automatic extinguishing system (AES) presence and type in reported parking garage structure fire incidents

AES Presence of Type	Fires		Civilian Injuries		Direct Property Damage (in Millions)	
AES present	**28**	**(6%)**	**3**	**(35%)**	**$1.3**	**(9%)**
Sprinkler present	26	(5%)	3	(35%)	$1.3	(9%)
Wet	*13*	*(3%)*	*2*	*(25%)*	*$1.3*	*(9%)*
Dry	*12*	*(3%)*	*1*	*(10%)*	*$0*	*(0%)*
Other	*1*	*(0%)*	*0*	*(0%)*	*$0*	*(0%)*
Unclassified AES present	2	(0%)	0	(0%)	$0	(0%)
Partial system AES of any type	2	(0%)	0	(0%)	$0	(0%)
No AES present	**447**	**(94%)**	**5**	**(65%)**	**$14.2**	**(91%)**
Total	**476**	**(100%)**	**8**	**(100%)**	**$15.6**	**(100%)**

↓ **Fires (Annual Averages)**
1994 – 1998: 630 fires
2014 – 2018: 476 fires

Property Damage (Annual Averages): ↑
1994 – 1998: $6 Million
2014 – 2018: $14.2 Million

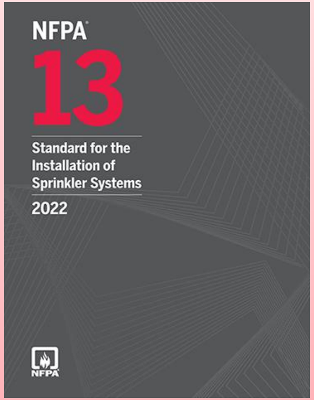
Updates to Codes & Standards



- Now requires sprinklers in **ALL** garages

- 2021 ed. Requires sprinklers only for **enclosed** garages (406.6.3)

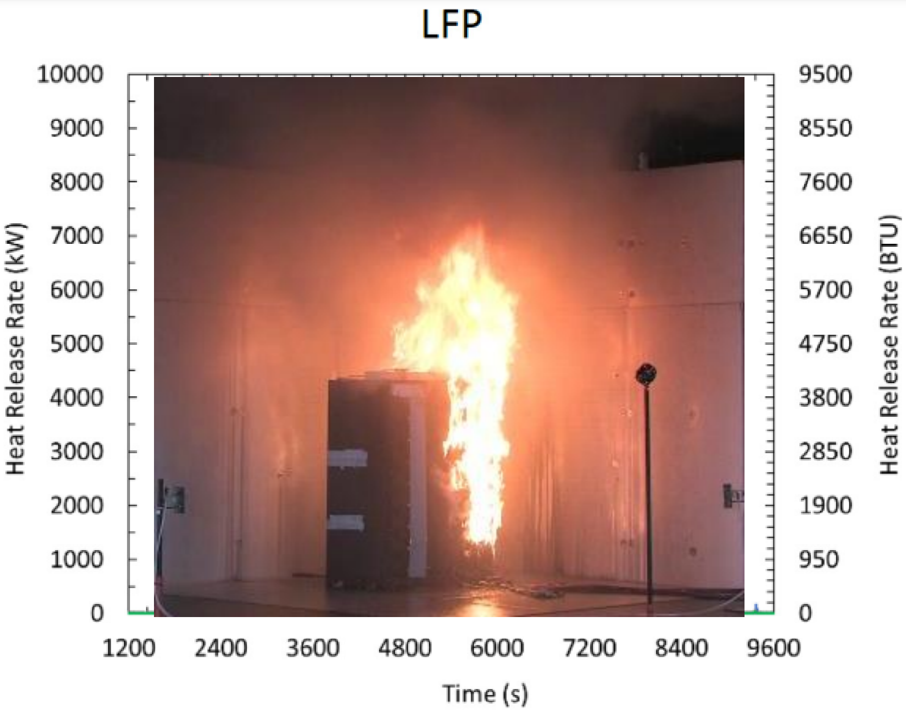
- Requires sprinklers where the fire area of the open parking garage (per IBC 406.5), exceeds **48,000 sf.**

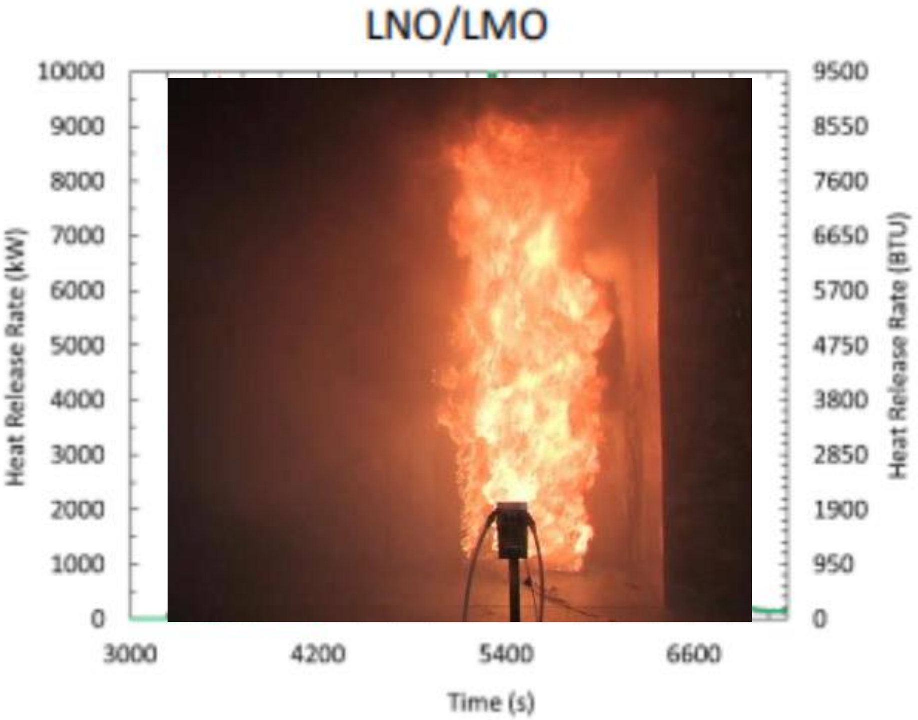


- Changed classification of parking garages from OH-1 to **OH-2**
- Car Stackers now classified as **EH-2**

- Changed classification of parking garages from HC-2 → HC-3
- 0.2 to 0.3 gpm/ft²

Define the Hazard – ESS Fire Test Data

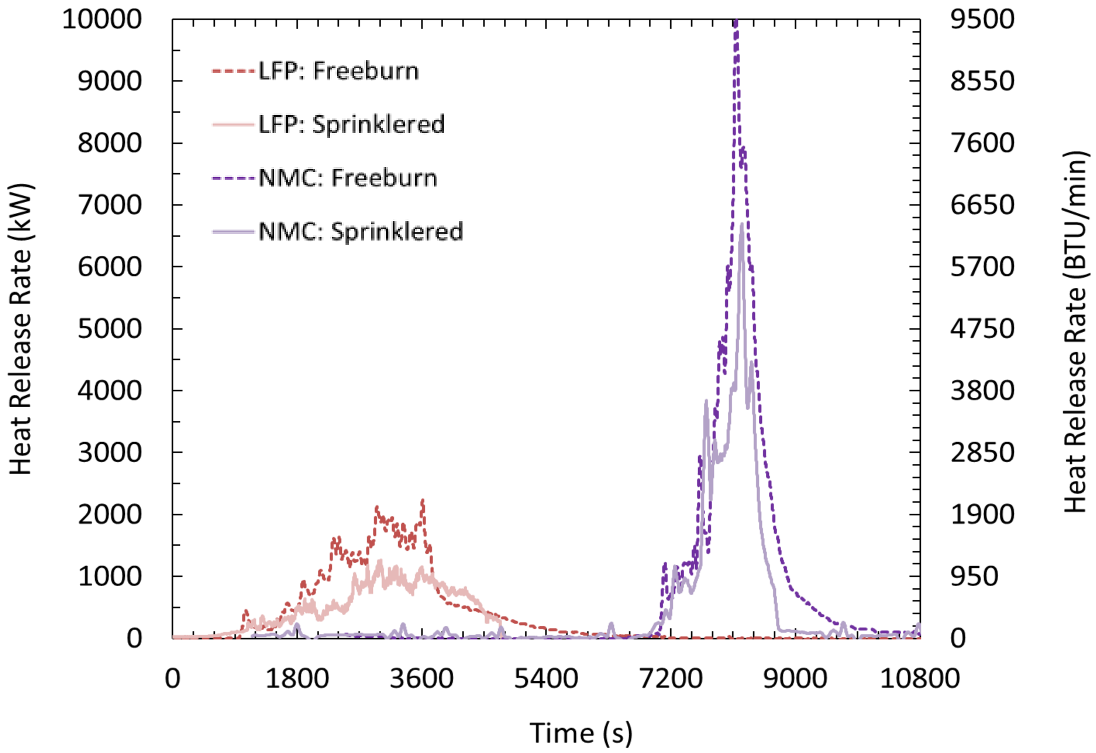




 |

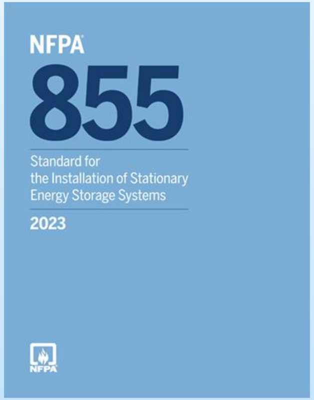
Sprinkler Performance

- LFP ESS Unit
  - HRR reduced by **45%** through sprinkler protection
  - No propagation to second rack.
- NMC ESS Unit
  - HRR reduced by **34%** through sprinkler protection
  - Caused propagation to adjacent rack



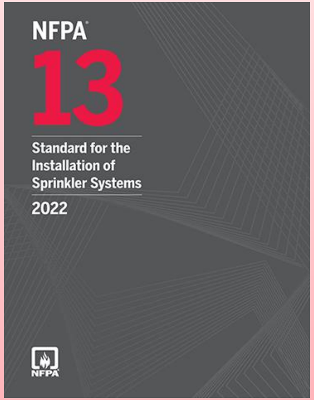
 |

What’s going on in the NFPA Standards for ESS?



NFPA 855, 4.9.2.1 and 4.9.2.2 – Sprinkler System Requirement:

- ESS units with a **maximum capacity of 50 kWh:**
  - minimum density of **0.3 gpm/ft²** based over the area of the room or **2500 ft²,** whichever is smaller
  - lower density can only be approved based on fire and explosion testing, in accordance with 9.1.5.
- ESS units (groups) **> 50 kWh:**
  - density based on fire and explosion testing in accordance with 9.1.5.
- **NFPA 855, 4.9.3.1* and 4.9.3.2 – Other automatic fire control and suppression systems:**
  - **Permitted** based on reports issued as a **result of fire and explosion testing** in accordance with 9.1.5.
  - These systems shall comply with the following standards, or their equivalent, as appropriate: NFPA 12, NFPA 15, NFPA 750, NFPA 770, NFPA 2001, and NFPA 2010



NFPA 13, Table A.20.4(a) provides examples of commodities not addressed by the classifications in Section 20.4. The commodities listed in Table A.20.4(a) are **outside the scope of NFPA 13 protection**.

TableA.20.4(a) **Commodities Not Addressed by Classifications** in Section 20.4

- **Lithium-ion** and other rechargeable batteries that contain combustible electrolyte

 |

Role of Sprinklers on Battery Fires

What **can** sprinklers do?

- Reduce the fire severity
- Delay or prevent fire spread
- Protect the surroundings

What **can't** sprinklers do?

- Extinguish the fire
- Avoid collateral (thermal / non-thermal) damage

Active Research Studies at FPRF

EV Research

- Assessment of EV firefighting tactics, techniques and technologies and the impact on stranded energy
- Classification of Modern Vehicle Hazards in Parking Structures – Phase II
- LIB Electric Bus and Depot Fire Prevention & Risk Management
- (*Pending*) Protection guidance for li-ion battery manufacturing, and EV assembly plant facilities.

ESS Research

- Landscape of Energy Storage System Hazards and Mitigation Strategies (Report & Workshop Proceedings)
- Development of Explosion Prevention/ Control Guidance for Energy Storage Systems – Phase I
- Environmental Impact of Li-ion Battery Fires compared to other common fires.
- Hazard Assessment of ESS being transported in enclosed spaces on marine vessels.

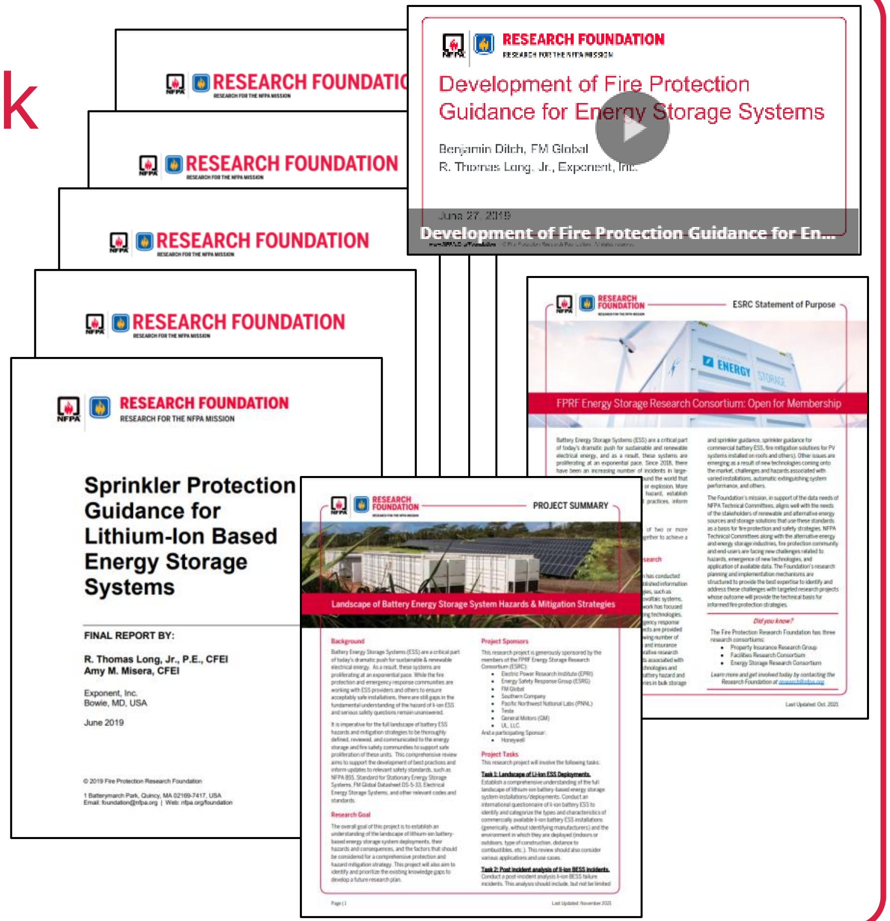
Resources & Future Work

All resources accessible at
www.nfpa.org/ess or
www.nfpa.org/foundation

New FPRF Consortium:

Energy Storage Research Consortium

Focused on delivering credible research and test data on ESS to the public

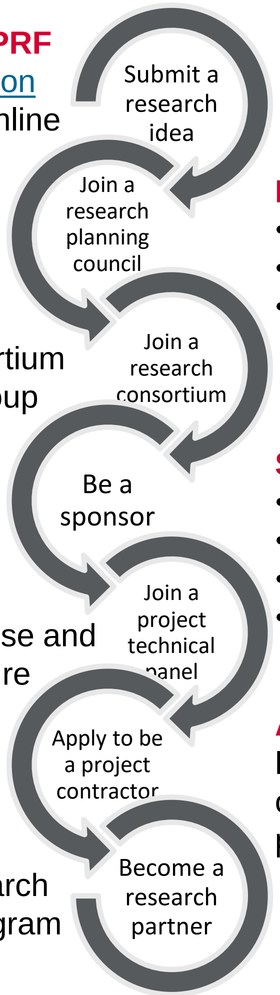


 |

How to get involved?

Submit a research idea to FPRF

- Visit www.nfpa.org/foundation
- Submit research idea via online submission portal



FPRF Research Planning Councils

- Detection and Signaling Research Council
- Automatic Sprinkler Research Council
- Electrical Safety Research Advisory Council

FPRF Research Consortiums

- Energy Storage Research Consortium
- Property Insurance Research Group
- Facilities Research Consortium

Sponsor FPRF projects, webinars, or events

- Provide input on project scope and direction
- Provide input over the course of the project
- Get early access to results
- Brand visibility

Serve on a project technical panel

Let FPRF know your areas of expertise and interest in being considered as a future panelists

Apply to be the research lead for FPRF Projects

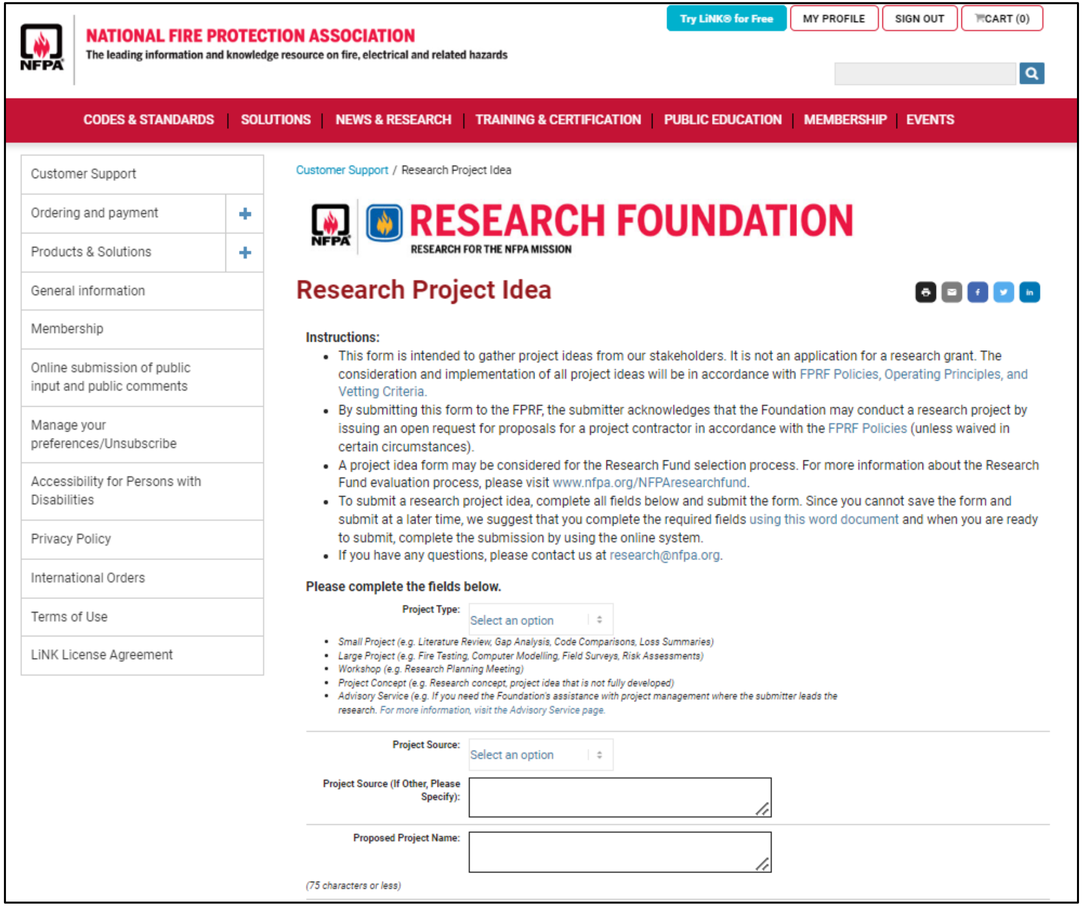
Bid on FPRF “Requests for Proposals” to have the opportunity to become a contractor on FPRF projects

Partner with FPRF

Partner with FPRF on future research through our advisory services program

Submit a Project Idea

www.nfpa.org/foundation



NFPA

NATIONAL FIRE PROTECTION ASSOCIATION

The leading information and knowledge resource on fire, electrical and related hazards

Try LiNK® for Free | MY PROFILE | SIGN OUT | CART (0)

CODES & STANDARDS | SOLUTIONS | NEWS & RESEARCH | TRAINING & CERTIFICATION | PUBLIC EDUCATION | MEMBERSHIP | EVENTS

- Customer Support
- Ordering and payment +
- Products & Solutions +
- General information
- Membership
- Online submission of public input and public comments
- Manage your preferences/Unsubscribe
- Accessibility for Persons with Disabilities
- Privacy Policy
- International Orders
- Terms of Use
- LiNK License Agreement

Customer Support / Research Project Idea

NFPA RESEARCH FOUNDATION

RESEARCH FOR THE NFPA MISSION

Research Project Idea

Instructions:

- This form is intended to gather project ideas from our stakeholders. It is not an application for a research grant. The consideration and implementation of all project ideas will be in accordance with FPRF Policies, Operating Principles, and Vetting Criteria.
- By submitting this form to the FPRF, the submitter acknowledges that the Foundation may conduct a research project by issuing an open request for proposals for a project contractor in accordance with the FPRF Policies (unless waived in certain circumstances).
- A project idea form may be considered for the Research Fund selection process. For more information about the Research Fund evaluation process, please visit www.nfpa.org/NFPAresearchfund.
- To submit a research project idea, complete all fields below and submit the form. Since you cannot save the form and submit at a later time, we suggest that you complete the required fields using this word document and when you are ready to submit, complete the submission by using the online system.
- If you have any questions, please contact us at research@nfpa.org.

Please complete the fields below.

Project Type: Select an option

- *Small Project (e.g. Literature Review, Gap Analysis, Code Comparisons, Loss Summaries)*
- *Large Project (e.g. Fire Testing, Computer Modelling, Field Surveys, Risk Assessments)*
- *Workshop (e.g. Research Planning Meeting)*
- *Project Concept (e.g. Research concept, project idea that is not fully developed)*
- *Advisory Service (e.g. If you need the Foundation's assistance with project management where the submitter leads the research. For more information, visit the Advisory Service page.*

Project Source: Select an option

Project Source (If Other, Please Specify):

Proposed Project Name:

(75 characters or less)

 |

Thank you!

Victoria Hutchison
Senior Research Project Manager | Fire Protection Research Foundation
vhutchison@nfpa.org

RESEARCH FOUNDATION
RESEARCH FOR THE NFPA MISSION