

Developing Sprinkler System Design Criteria for Flammable and Combustible Liquid Storage

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Introduction

Safe handling and storage of flammable and combustible liquids requires a multi-faceted risk management strategy that includes prevention and mitigation measures. These measures should account for a potential incident to cause injuries, illness, environmental damage, property damage, and business interruption.

Proper material handling is necessary to prevent or minimize unwanted liquid spills or releases. This is the most important fire safety objective during a liquid handling or storage operation. While an exposing fire involving Class A materials is always possible, a liquid spill or release is necessary for a fire to occur involving only liquids. Spills and releases are easier to manage than controlling ignition sources.

A suggested list of prevention and mitigation measures follows:

- Material Handling
- Control of Ignition Sources
- Product Inventory Classification and Control Systems
- Building Construction Features (Fire Resistance, and Liquid Containment and Drainage)
- Spatial Separation
- Manual Fire Protection
- Administrative Controls and Emergency Planning
- Proper Fire Protection System Design Criteria

While all of the aforementioned needs to be considered, this abstract will focus on proper fire protection system design criteria.

In terms of codified criteria, the 1996 edition of NFPA 30 is the only code that lists the specific fire test basis for the sprinkler protection criteria in each of the protection tables. A companion document for NFPA 30, the *“Directory of Fire Tests Involving Storage of Flammable and Combustible Liquids in Containers, 3rd Edition”*, abstracts 155 sprinklered fire tests involving flammable and combustible liquids. This directory, which is referenced in Appendix D.2 of NFPA 30, is available from the Society of Fire Protection Engineers.

Brief History of Sprinkler Protection Criteria

Over the past 10 years, there have been significant changes within NFPA 30 for containerized storage. The sprinkler protection design criteria in the 1993 and earlier editions were not based upon full-scale fire tests. When polled at that time, the NFPA 30 committee membership could not state the basis for the “original” protection criteria. Among other important issues, the criteria that did exist was lacking in guidance on ceiling height limits and container types. Additionally, the criteria were located in the Appendix of the code, using the caveat “This Appendix is not a part of the requirements of this NFPA

document, but is included for information purposes only.” This portion of the code was not credible, was not utilized by informed professionals, and was unenforceable by authorities having jurisdiction.

A watershed event occurred in 1987 involving a fire at a paint warehouse in Dayton, Ohio. This \$50 million loss called attention to the inadequacies of NFPA 30. In the wake of this fire, numerous full-scale fire tests were conducted. Thereafter, individual fire test based proposals that were submitted to the NFPA 30 committee were met with mixed results. In light of this, a protection criteria task group was formed to develop fire test based sprinkler system design criteria. This task group presented to the NFPA 30 committee a proposal that included re-written protection criteria tables. After significant debate, the committee accepted this proposal for introduction into the 1996 edition of the code.

Beginning with the 1996 edition of the code containerized storage of Class IB through IIIB liquids are addressed with:

- 6 protection tables in Section 4.8 of the 1996 edition that are based upon 85 sprinklered fire tests
- 10 protection tables in Section 4.8 and 1 protection table in Appendix D.4 of the 2000 edition that are based upon 136 sprinklered fire tests
- 11 protection tables in Section 6.8 and 1 protection table in Appendix D.4 of the 2003 edition that are based upon 155 sprinklered fire tests
- 11 protection tables in Section 16.5 and 1 protection table in Appendix D.4 of the 2007 (Proposed) edition that are based upon 160 sprinklered fire tests

For more information on the 2003 edition sprinkler protection tables, Appendix A contains a summary of these tables.

The fire tests used for substantiation were conducted over a period of decades at FM Global Research, Underwriters Laboratories, or Southwest Research Institute and were supported by numerous financial sponsors.

These tests used a variety of water miscible and immiscible liquids that were packaged in steel, plastic, or glass containers. Storage arrays consisted of palletized/solid pile, rack (with and without barriers), and shelf storage arrangements at various heights. Sprinkler systems utilized either water or foam-water with various combinations of ceiling-mounted and in-rack sprinklers. The effectiveness of different sprinkler types and discharge flows were also explored.

Test results include the number of operating sprinklers and operating times, ceiling gas and ceiling steel temperatures, damage assessment, and whether or not the tests were controlled.

In 1996, the concept of “Protected Storage” was first utilized. The 1996 and later editions of the code now make a distinction between different container types, such as metal and plastic. This was introduced along with specific criteria for relieving style and non-relieving style metal containers. Other improvements have also been made in successive editions of this code. The sprinkler protection criteria in the 2003 edition of NFPA 30:

- Are still based upon on sprinklered fire tests
- Offers more liquid, container, and protection options
- Are more user-friendly
- Has improved decision trees, drawings, and appendix materials

Sprinkler Design and Storage Criteria Development

The integration of new criteria for warehouse designs into NFPA 30 requires several phases before it is adopted. The generation of commodity specific sprinkler system design and storage criteria is one of the latter phases of the process. It is desirable to codify these criteria in a nationally recognized code, such as NFPA 30 (See Appendix E, NFPA 30 for more details on this process).

These criteria are most reliably generated using full-scale sprinklered fire tests, which are still being conducted. They are performed in specially designed facilities under controlled conditions.

Small- and intermediate-scale fire tests are useful for preliminary or interpolated results. Computer fire models cannot replicate the data from full-scale fire tests. Preference is typically given to full-scale fire tests using a “credible worst-case scenario.” The objective of these tests is to develop an insight into what might be expected in real life fire situations. These tests attempt to simulate actual conditions to reasonably predict fire growth rate, fire magnitude, and the effect of sprinkler operation. When utilizing criteria developed from these tests it is essential that users understand assumptions and limitations associated with this criteria. It is also important to recognize that there are no guarantees when using design criteria in these protection tables, as an out-of-control fire can still occur.

Primary Fire Test Drivers

The results generated during these tests are affected by the following:

- Material Properties (Physical and Combustion)
- Container Design and Size
- Packaging Material
- Ignition Scenario
- Storage Arrangement
- Mixed Storage
- Sprinkler System Design Parameters

Burning Behavior of Flammable and Combustible Liquids

The burning behavior of flammable and combustible liquids can include:

- Pool Fires
- Jetting
- Ruptures
- 2 and 3 Dimensional Spill Fires

Pass/Fail Criteria

A fire test is generally considered unsuccessful if any of the following conditions are met:

- Sustained (7 to 10 min.) Ceiling Steel Temperatures Above 1000°F
- Excessive Number of Operating Sprinklers (sprinkler-type dependent)
- Fire Travel Across Open Aisle and Significant Involvement of Target Commodity
- Significant Fire Travel and Involvement of Test Commodity in Main Array
- Insufficient Fire Involvement of Test Commodity
- Storage Array Collapse

- Severe Jetting
- Violent Rupture of a Container
- Exceeding predetermined pressure and temperature limits on certain large containers

Limitations and Assumptions

Based upon the current available body of knowledge, certain limitations and assumptions must be understood. These limitations and assumptions should be factored into the overall risk management strategy when utilizing the sprinkler system design criteria in NFPA 30:

- Flash Point - The current NFPA classification system for flammable and combustible liquids is based upon the flash point, and in some instances, the boiling point of a liquid. This ranking system only addresses the ease of ignition of a liquid and to some degree its volatility. Other important properties related to the control of fires involving these liquids, such as heat release rate, miscibility, viscosity, and reactivity, are not included.

Additionally, fires involving high flash point oils (Class IIIB liquids) should not be underestimated as they can be very severe, if the fire becomes well developed. On the other end of the spectrum, Class IA liquids have not been subject to full-scale sprinklered fire tests. Tests have not been conducted as these materials have limited use in containerized products. Additionally, Class IA liquids can produce extremely severe fires. Therefore, the protection criteria tables for Class IA liquids in Appendix D.3 of NFPA 30 are not based upon full-scale sprinklered fire tests. These tables in Appendix D.3 were carried over from the Appendix D-2 in the 1993 edition of NFPA 30.

- Water Miscibility – Diluting a water miscible flammable liquid with water may have a positive effect on fire controllability. While this is not always a practical protection strategy, a flammable or combustible liquid will not have a fire point above a certain water concentration. At that concentration which is unique to each material, while a flash may propagate across the surface of the liquid, the liquid will not undergo sustained combustion if exposed to an ignition source. During sprinklered fire testing, the effect of dilution has been most pronounced in fire tests using small plastic containers. Although not yet tested, if these small plastic containers were replaced with small metal containers, a greater improvement in controllability would be expected.
- Heat Release Rate – The “worst-case” Class IB liquid of choice thus far has been heptane. While it is a “worst-case” Class IB hydrocarbon, other non-hydrocarbon liquids may be “worst-case” Class IB liquids.
- Fire Protection Agent – When utilizing a foam-water sprinkler system, the important role foam-water plays in controlling a fire should not be minimized. Therefore, when designing a foam-water sprinkler system, adequate duration must be supplied. If the foam-water supply is depleted before control is achieved, an out of control fire may still result.
- Chemical Reactivity – Certain reactive monomers, such as styrene and the family of acrylates, may self-react exposed to fire. Although never subjected to full-scale sprinklered fire tests, these materials will likely have a synergistic effect on fire growth and severity. It should also

be noted that Table 6.8.2(k) does contain sprinkler system design criteria for unsaturated polyester resins (with $\leq 50\%$ by vol. IC, II, or IIIA liquid constituents).

- Sprinkler System Reliability – System reliability should be considered when making a selection. More complicated systems, such as foam-water sprinkler systems, may provide a higher degree of fire controllability. However, more complicated systems will also be inherently less reliable.
- Storage Array Stability – In the event of a storage array collapse during a fire, a much larger fire will likely ensue. This may result in an out of control fire. The protection criterion in NFPA 30 does not anticipate a storage array collapse.
- Limitations of Liquid Release Rate – The protection criterion in NFPA 30 will not control fires involving large or a sudden release of heat. Violent ruptures, large pool fires, and fires with severe “jetting” will likely not be controlled without significant manual fire fighting as a back-up. This of course presents a life-safety hazard to the fire fighters.
- Ignition delay – An extended ignition delay during a “significant” flammable liquid spill may result in a deflagration-type explosion. The vapor generated, particularly if it is a 3 dimensional spill, may place the enclosure within the limits of flammability before ignition.
- Test Conditions with 1st Generation of Tests – Some of the tests conducted in the early 1990’s were conducted in UL’s old test facility that had a footprint of 1,600 sq. ft. Also, some of these same tests utilized spill igniters over 2 gals and mixed commodities. Recent test results have raised issues that may question the results of these tests due to these test conditions. These concerns raise questions about the sprinkler system design and storage criteria based upon these aforementioned tests.

Challenges with Full-Scale Testing of Flammable and Combustible Liquids

Reoccurring challenges with full-scale fire testing are as follows:

- Funding for full-scale sprinklered fire testing remains an ever present obstacle. To overcome this, consortiums are often formed to provide the necessary funding. However, success using this approach requires a consensus among a group of sponsors that may have differing objectives.
- Full-scale fire testing has been conducted over many years involving many disparate groups. Each of these groups has focused on objectives relevant to their group and not followed objectives outlined in a “master plan.” Therefore, the sprinkler system design criteria, listed in the 1996 and later editions of NFPA 30, does not address all possible scenarios found in storage facilities.
- Access is not always given to experimental data from previous tests. Many fire test reports are not placed within the public domain for various reasons. This includes results that may offer a competitive advantage to the sponsor or results that may shed an unfavorable light on a given product.

- Fire testing with flammable and combustible liquids presents challenges not associated with “ordinary commodities.” Therefore, the test facility may not be able or willing to explore all of the desired unknowns given the associated risks.

Additional Testing

Currently, there are 2 distinct areas where additional fire tests are warranted as follows:

- Developing additional sprinkler protection strategies for liquids stored in intermediate bulk containers (IBC’s)
- Retesting with K25 EC (Extended Coverage) sprinklers and possibly other spray sprinklers with mixed storage (1st generation tests at UL)

In summary, developing effective sprinkler system design criteria for flammable and combustible liquid storage is a complicated, multi-step process. As new data is developed and released into the public domain, the NFPA 30 committee continues to challenge the original assumptions and revise the advice offered.

Appendix A

NFPA 30 Protection Table Summary

Table	NFPA Liquid Class	Liquid Miscibility (1)	Sprinkler Protection Type (2)	Storage Array (3)	Container Types (4) RS-Relieving Style Non-RS Non Relieving Style
6.8.2.(a)	IB, IC, II, IIIA & IIIB	Miscible & Non-Miscible	Water	Single- & Double-Row Rack	RS & Non-RS Metal Containers, Portable Tanks, & IBC's
6.8.2.(b)	IB, IC, II, IIIA & IIIB	Miscible & Non-Miscible	Water	Palletized	RS & Non-RS Metal Containers, Portable Tanks, & IBC's
6.8.2.(c)	IB, IC, II, IIIA & IIIB	Miscible & Non-Miscible	Foam-Water	Single- & Double-Row Rack	RS & Non-RS Metal Containers, Portable Tanks, & IBC's
6.8.2.(d)	IB, IC, II, & IIIA	Miscible & Non-Miscible	Foam-Water	Palletized	RS & Non-RS Metal Containers, Portable Tanks, & IBC's
6.8.2.(e)	IIIB	Miscible & Non-Miscible	Water	Single-, Double-, & Multi-Row Rack	≤ 5 gal. Plastic Containers
6.8.2.(f)	IB, IC, II, IIIA & IIIB	Miscible & Non-Miscible	Water	Shelf	≤ 1 gal. Non-RS Metal Containers
6.8.2.(g)	IB, IC, II, IIIA & IIIB	Miscible	Water	Single- & Double-Row Rack	Plastic Containers
6.8.2.(h)	IB, IC, II, IIIA & IIIB	Miscible & Non-Miscible	Water	Palletized & Rack	≤ 5 gal. or ≤ 1 gal. RS Metal Containers
6.8.2.(i)	II, IIIA & IIIB	Miscible & Non-Miscible	Water	Palletized	≤ 793 gal. Rigid Nonmetallic IBC
6.8.2.(j)	II, IIIA & IIIB	Miscible & Non-Miscible	Water	Single- & Double-Row Rack	≤ 793 gal. Rigid Nonmetallic IBC
6.8.2.(k)	Unsaturated Polyester Resins (with ≤ 50% by vol. IC, II, or IIIA Liquid Constituents)	Non-Miscible	Water	Palletized	> 5 gal. and < 60 gal. Metal Containers
D.4(a)	IIIB (≥450 °F)	Non-Miscible or Miscible Combustible Liq. w/ Conc. >50% by Vol.	Water	Single-, Double-, & Multi-Row Rack	≤ 5 gal. Plastic Containers

- Notes: (1) For miscible liquids with flammable or combustible liquid concentration > 50% by vol.
 (2) Sprinkler protection design criteria in actual NFPA 30 tables varies
 (3) Storage heights in actual tables varies
 (4) Container sizes in actual tables varies, except as noted

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