Marina and Boatyard
Indoor Rack Storage Sprinkler Protection

Literature and Data Review

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FOREWORD

Indoor rack storage is desired by boat owners and marinas to protect vessels from weather and extreme temperatures. A major concern is protection of the boats and the storage structure from fire. The nature of the boat construction materials results in a potentially high fire load, and the storage configuration can present significant challenges to activation and water distribution patterns of automatic sprinkler systems.

Specific criterion for the design and installation of fire protection for boats stored on racks inside of buildings is currently lacking. NFPA 303, *Fire Protection Standard for Marinas and Boatyards* requires that automatic sprinklers systems comply with the provisions of Chapter 12 of NFPA 13, *Standard for the Installation of Sprinkler Systems* for Group "A" Plastics. However, NFPA 13 does not specifically address indoor rack storage of boats. Fire test data of boats in rack storage is needed to establish more specific requirements for fire control and protection of this type of vessel storage.

This project recognizes and addresses this problem by providing a literature review, documenting loss history, and carrying out a hazard analysis of fires involving indoor rack storage of marine vessels in boatyards and marinas. The information helps to clarify additional research needs that, if addressed in a subsequent research project and ultimately completed, would establish important design parameters such as water demand, automatic sprinkler placement and other essential design requirements for the control and extinguishment of unwanted fires. The results this study, and such a follow-up research project, are of direct interest to the Technical Committees responsible for NFPA 303, *Fire Protection Standard for Marinas and Boatyards* and NFPA 13, *Standard for the Installation of Sprinkler Systems.*

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The content, opinions and conclusions contained in this report are solely those of the author.

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INTRODUCTION

Prior to the 2003 edition of NFPA 303, *Fire Protection Standard for Marinas and Boatyards,* there was no specific sprinkler system design guidance for rack storage of boats in NFPA 303 or NFPA 13, *Standard on the Installation of Sprinkler Systems*. NFPA 303 technical committee members recognized that this was an area where improvement was needed and as a result developed a requirement that now appears in the 2003 and 2006 editions of NFPA 303[1, 2]. Section 6.3.4.4 now states that automatic sprinkler systems shall be designed per Chapter 12 of NFPA 13 - 2002 edition for Group A Plastics stored on solid shelves. This requirement represents a best effort judgment by the Committee to provide some guidance to the designers and developers of these facilities; however, there is no current large or full scale fire test data that substantiates if this criterion is adequate, inadequate or too conservative for indoor rack-style boat storage, also known as, dry stack storage.

Indoor storage is desired by boat owners because these facilities are usually close to, or on the water and they provide protection from the weather (sun, rain, wind, snow, hail, etc) as well as from extreme temperatures. A major concern is protection of the boats and the storage structure from fire. The nature of the boat construction materials (e.g., fiberglass, wood, and rubber) combined with the stack configuration results in a "fuel package" that can produce a significant fire.

Typical warehouse "high challenge" fires are best protected by automatic systems that provide sprinklers at the roof structure plus in-rack sprinklers or sprinklers at the roof structure only (i.e., ESFR sprinkler systems). The design of these systems has been developed and proven by a large number of full scale fire tests. In contrast, the sprinkler systems in dry stack boat storage buildings have no full scale testing as a basis of design.

The lack of full scale tests data for the protection of rack storage of boats is significant in that the performance of any sprinkler design scheme will likely not be known without full scale testing. One area that is lacking is an understanding of the credible fire scenarios that may impact the protection scheme. Also, there are a number of unique factors that may impact the protection scheme and related risks for boats stored in racks.

- Typical warehouse storage creates obstructions to the fire plume that "channels" the heated gases and flames up narrow flue spaces created by the rack structure, shelves and storage commodity. In boat storage configurations flue spaces are not well defined or consistently narrow, and the dimensions can vary significantly. Consequently, the flow of heated gases and flames is not expected to exhibit the known behavior of narrow flue spaces associated with conventional rack storage facilities.

- Fire spread on boat materials [typically fiber reinforced plastic (FRP) resins], as well as, spread within boat compartments and from boat-to-boat in rack storage arrays is not well understood.

- Storage arrangements for indoor boat storage facilities can vary widely in type of rack arrangement, boat size, and boat length. Therefore, the variety of storage arrays that can result must be carefully considered to arrive at sprinkler criteria that serves credible worst case scenarios, or allows development of some classification of hazards among the possible variety of storage arrays.

- The characteristics of stored boats can be important. Smaller boats may not have large concealed compartments, while larger boats may have relatively large compartments which can presents a shielded fire situation. Such a scenario presents a potentially more challenging situation given that a fire in a boat cabin is shielded from the direct discharge of sprinklers. However, it should be recognized that boat cabins in addition to being water tight are also near air tight which can result in cabin fire scenarios that self-extinguish or suffocate due to lack of air supply.

- The issue of water collection in the boats is of concern because the additional weight of water could result in a collapse of the rack structure. There must be consideration of balancing concerns for limited structural failure due to water accumulation in the boats and providing a greater density of water application that could fail the rack system. Some have suggested that this water collection problem can simply be solved by designing the rack structure to support the boats even when completely filled with water. Although it is physically possible, it is known to be economically unfeasible for boat storage facilities to design the rack structure for such large loads (boats filled with water).

- Most boats in dry stacked storage today are stored with filled or partially filled fuel tanks. The significance of this in the total risk picture is an unknown. For example, fuel tanks in parked cars is not viewed to be a major risk/hazard based on parking garage history; however, the risk in boat storage arrangement has not been vetted through statistically analysis of marina/boat fires, as has been done for parking garages.

- To economically build indoor boat storage facilities the building structural system is typically integrated with the boat rack storage system. The ability of the fire suppression system to provide structural integrity in steel structures for some period of time is a consideration related to appropriate sprinkler protection schemes.

The task of this report is to provide additional information and data relevant to understand the nature of boat storage facilities; the nature of the fuel loads; and review and report on data regarding fire statistics for boats and boat storage facilities. It is the further purpose of this report to review information on other types of vehicle storage facilities, specifically, automobile parking garages and aircraft hangar facilities for information related to fire risks, fire hazard, and protection schemes of fueled vehicles in a storage situation.

RECREATIONAL BOAT CONSTRUCTION & MATERIAL PROPERTIES

Overview of Boat Construction

There are approximately 17 million recreational boats in the U.S. According to the U.S. Coast Guard and the National Marine Manufacturer's Association (NMMA)[3], about half are outboard power boats; stern drive boats are 9% of the fleet; and personal watercraft, inboards, and sailboats each have about a 7% market share. This study does not consider personal watercraft and sailboats, since they are rarely stored in enclosed rack storage marina facilities.

Marina storage facilities are overwhelmingly populated with recreational boats as apposed to commercial vessels. Due to cost, appearance, and durability issues, these boats are mostly built with composite construction. NMMA reports that for engine-driven boats, 58% use fiberglass (FRP-composite) construction; 37% are built with aluminum or steel and around 1% are wood. Anecdotally, we know that the percentage of boats stored in marinas that are built with composites is even higher than the overall population. Likewise, aluminum boats in this environment would greatly outnumber steel ones.

Geometric Configurations

The geometric configuration of boats stored in indoor marina facilities is mostly a function of the type of boat being considered. The configuration will affect how the boats behave in fires. Table 1 provides an overview of the types of recreational powerboats. Note that the largest boats are probably beyond the capacity of most vertical storage facilities. One of the key boat characteristics to consider is whether a boat has a cabin or an open layout. Table 1 shows how this varies based on boat type. Data in Table 1 was derived from the DiscoverBoating.com Web site and Eric Sorensen's book *Sorensen's Guide to Powerboats*.[4]

Most of the boats shown in Table 1 are built using composite construction (e.g. fiberglass), with the exception of Jon boats and Pontoon Boats, which are typically aluminum. The photographs in Table 1 are provided to illustrate how recreational boats are outfitted. Outfit items include seating, upholstery, awnings, floor coverings, electronics and other amenities. These items can influence performance in fires and will be discussed later in this section.

Table 1. Types of Boats Stored in Indoor Facilities

Type of Boat			Typical Power	Length
Bass Boats Bass boats have low, sleek profiles and are built to fish with two or three anglers on board. The minimum length of bass boats starts with 16 feet and can go up to 25 feet.			outboard 130 to 300 hp	16 - 25 feet
Bowriders These family boats are the most popular in the runabout/sportboat category and are equipped with extra seats and forward access to the bow, a convenient spot to relax and sun.			sterndrive	16 - 28 feet
Center Console These open fishing boats are built to take rough offshore waters in pursuit of ocean fish. Rod holders, outriggers and other gear are common fittings onboard.			outboard	18 - 28 feet
Cuddy Cabins These are great day cruisers and overnighters for small groups and family boating. Ideal for skiing, tubing and wakeboarding, they are most often powered with sterndrive engines, but outboard power is becoming popular, too.			sterndrive	18 - 28 feet
Deck Boats Deck boats have wide deck to carry 8 to 12 or more passengers (like pontoons) but look and perform more like runabouts. They are powerful, too, making them excellent boats for skiing, tubing and wakeboarding.			outboard	18 - 28 feet
Fish and Ski This craft allows boaters to enjoy the two most popular on-water activities; fishing and skiing. This family fishing and recreational boat has enough power to pull a skier or two, and to get to the fishing spot in short order.			inboard	15 - 22 feet
Flat Boats These boats are popular in costal areas where sea trout and redfish live. They can float and run in water less than two feet deep and are ideal for fishing with two to three people on board.			outboard	17 - 25 feet
Inboard Cruisers Inboard cruisers tend to be 30-feet long or longer and are great for sleeping, cooking and have plumbing facilities. They feature a simpler drive mechanism that is often considered easier to maintain in salt water.			inboard	26 - 75 feet
Inboard Ski Boats Inboard ski boats accelerate rapidly to "pop" skiers from the water and turn very crisply recovering a downed skier easily. These boats are great for skiing, racing and other watersports activities.			inboard	16 - 28 feet

Table 1. Types of Boats Stored in Indoor Facilities (continued)

Type of Boat			Typical Power	Length
Inboard Wakeboard Boats Powered by inboard engine, these boats "throw" a perfect wake for very serious wake boarders. With the engine set back against the transom, seating is more comfortable and open like a bowrider.			inboard	16 - 28 feet
Jon Boats A Jon Boat is a multi-purpose camping, freshwater fishing and hunting craft, typically aluminum and powered by a small to moderate outboard. They may be customized with added fishing features like trolling motors and driver consoles.			outboard	8 - 20 feet
Motor Yachts Motor yachts are ideal for ocean cruising or navigating large rivers or the Great Lakes, as well as entertaining at the dock. Two engines, usually fueled with diesel and a generator for electricity make them self-sufficient in terms of living accommodations.			inboard	26 - 100 feet
Multi-Hull Power Boats Catamarans are the most popular multi-hull boats and are usually offered as an alternative to center consoles. Most catamarans are designed for hardcore angling, but some models offer recreational and cruising amenities.			outboard	16 - 30 feet
Performance Boats Performance boats are the sleek sports cars of the boating world, offering high speeds and precise handling to boaters who prefer their thrills full throttle. Marrying big horsepower with sleek hulls results in boats that are equally at home slicing through ocean swells or tearing up inland lakes.			inboard	19 - 50 feet
Pontoon Boats Pontoon boats give families with younger boaters a secure place to enjoy the ride or toddle about when at anchor, thanks to wide decks and "lay pen-like" side rails and gates. When equipped with larger engines they can be as quick as runabouts.			outboard	16 - 30 feet
Stern Drive Cruisers Great for freshwater fishing, watersports, cruising and much more, these boats have all the comforts expected from recreational cruising boats including sleeping, cooking and plumbing equipment.			sterndrive	20 - 40 feet
Walkaround These boats may be the ultimate family fishing boats and are most popular in coastal waters, large bays and the Great Lakes where anglers pursue salmon or offshore ocean species. They are equipped with rod holders, livewells and steps to the forward deck to make it easy to follow a big fish around the boat.			outboard	18 - 28 feet

Hull Structure

Composite recreational boat hulls will either use solid laminates with stiffeners or sandwich construction. Figure 1 shows examples of these types of construction.

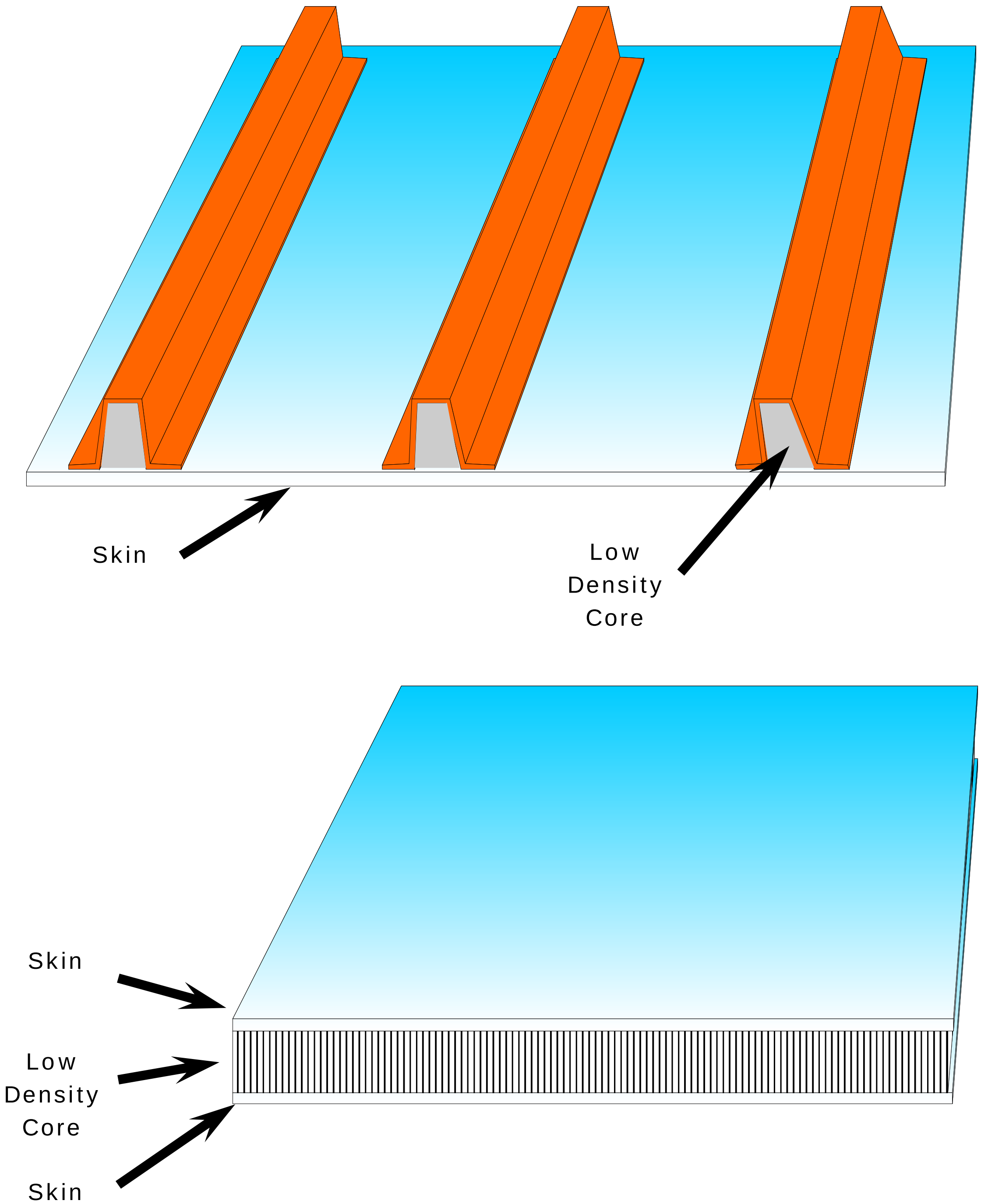


Figure 1. Solid (top) and Sandwich (bottom) Construction

Solid laminates are best suited for resisting in-plane loads using thick-skinned, E-glass laminates; and provide maximum puncture resistance. Sandwich laminates are best for resisting out-of-plane loads; used with higher strength/modulus skins; and provide maximum insulation characteristics. As a rule, sandwich construction is used on larger, high-performance boats, but there are many exceptions to this trend. Sandwich construction requires a higher worker skill level and thus is associated with “higher end” boats.

Beyond the choice of plating arrangement, the hull internal support structure will vary dramatically from builder to builder. The need to incorporate floatation foam in boats under 20 feet[5] will often influence internal structure. Many builders use structural grid systems that are created on specialized molds and subsequently bonded to the laminated hull. Figure 2 shows an example of a hull structural grid system being fabricated.

Figure 2. Hull Structural Grid System

Most recreational boat hulls have a gel coat finish, although some older and custom boats are painted. This will be important when we look at the performance of hulls in fires.

Deck Structure

Recreational small boat deck structure refers to both cabin overheads and more predominantly cockpit floors. As with hulls, both solid and sandwich construction is used. With cabin overheads, the depth of stiffeners must be limited to maximize headroom. Conversely, floor stiffeners can be quite tall, especially when they also serve as hull stiffeners.

While smaller boats have relatively planar deck structures, larger boats feature complex geometry to maximize the layout and exploit the capability of composite construction. Figure 3 is an example of a complex deck structure designed to maximize interior space.

Figure 3. Complex Deck Part Built by Sabre Yachts

Much deck structure is constructed with similar materials as hulls, although specialized surface treatments are often used, such as non-skid or carpeting on decks and decorative overhead liners below decks. Composite materials used for decks will be discussed in the next section but it should be noted here that deck structure for smaller boats is often built with plywood.

Interior Structure

The interior structure of boats consists of bulkheads and joinery (woodwork). Marine plywood is most commonly used but sandwich laminates can be used when weight is at a premium. Decorative laminates are often used to finish off interior structure.

Outfitting Elements

Often overlooked, when considering the flammability of boats, are outfitting elements. Items such as upholstery, canvas, carpeting, electronics, and auxiliary equipment may incorporate fire retardant properties when located below decks to protect passengers. However, outfitting above decks and for open boats is not designed to minimize fire risk because rapid passenger egress in the case of a fire would minimize their exposure. As with structure, the fire performance of outfitting elements is a function of geometry as well as construction material. As a rule-of-thumb, elements with a large amount of surface area compared to their volume tend to contribute to fire growth more than compact elements.

Marine Composite Materials

Over 40 years of FRP boat building experience stands behind today's pleasure boats. Complex configurations and the advantages of seamless hulls were the driving factors in the development of FRP boats. FRP materials have gained unilateral acceptance in pleasure craft because of light weight, vibration damping, corrosion resistance, impact resistance, low construction costs and ease of fabrication, maintenance and repair.

Fiberglass construction has been the mainstay of the recreational boating industry since the mid 1960s. After about 20 years of development work, manufacturers seized the opportunity to mass produce easily maintained hulls with a minimum number of assembled parts. Much of the early FRP structural design work relied on trial and error, which may have also led to the high attrition rate of startup builders. Current leading edge marine composite manufacturing technologies are driven by racing vessels.

Racing sail and power events not only force a builder to maximize structural performance through weight reduction, but also subject vessels to higher loads and greater cycles than would normally be seen by vessels not operated competitively. However, the vast majority of contemporary recreational boat designs are driven by styling and cost.

Although the geometry of a structure will influence the way it behaves in a fire, the overwhelming parameter are the materials used. This section will describe the composite materials used in boat construction.

Materials form an integral part of the way composite structures perform. Because the builder is creating a structural material from diverse constituent compounds, laminates from different builders using the same materials are often unique. This section reviews three broad groups of composite materials:

- Resins
- Reinforcements
- Core Materials

Descriptions of representative marine materials are presented in the order in which they become relevant in fires. As with all composite material system design, the reader is cautioned not to draw conclusions about materials from each group without regard for how a system will perform as a whole. Material suppliers are often a good source of information regarding compatibility with other materials.

Resin systems are probably the hardest material group for the designer and builder to understand. Fortunately, chemists have been working on formulations since Bakelite in 1905. Although development of new formulations is ongoing, the marine industry has generally based its structures on polyester resin, with trends to vinyl ester and epoxy for structurally demanding projects and highly engineered products. A particular resin system is affected by formulation, additives, catylization and cure conditions. Characteristics of a cured resin system such as a structural matrix of a composite material system is therefore somewhat problematic. However, certain quantitative and qualitative data about available resin systems exists and is given with the caveat that this is the most important fabrication variable to be verified by the “build and test” method.

Reinforcements for marine composite structures are primarily E-glass due to its cost for strength and workability characteristics. In contrast, the aerospace industry relies on carbon fiber as its backbone. In general, carbon, aramid fibers and other specialty reinforcements are used in the marine field where structures are highly engineered for optimum efficiency. Architecture and fabric finishes are also critical elements of reinforcement selection.

Core materials form the basis for sandwich composite structures, which clearly have advantages in marine construction. A core is any material that can physically separate strong, laminated skins and transmit shearing forces across the sandwich. Core materials range from natural species, such as balsa and plywood, to highly engineered honeycomb or foam structures. The dynamic behavior of a composite structure is integrally related to the characteristics of the core material used.

Resins

Polyester: The percent of manufacturers using various resin systems is represented in Figure 4. Polyester resins are the simplest, most economical resin systems that are easiest to use and show good chemical resistance. Almost one half million tons of this material is used annually in the United States. Unsaturated polyesters consist of unsaturated material, such as maleic anhydride or fumaric acid that is dissolved in a reactive monomer, such as styrene. Polyester resins have long been considered the least toxic thermoset to personnel, although recent scrutiny of styrene emissions in the workplace has led to the development of alternate formulations. Most polyesters are air inhibited and will not cure when exposed to air. Typically, paraffin is added to the resin formulation, which has the effect of sealing the surface during the cure process. However, the wax film on the surface presents a problem for secondary bonding or finishing and must be physically removed. Non-air inhibited resins do not present this problem and are therefore, more widely accepted in the marine industry.

The two basic polyester resins used in the marine industry are orthophthalic and isophthalic. The ortho-resins were the original group of polyesters developed and are still in widespread use. They have somewhat limited thermal stability, chemical resistance, and processability characteristics. The iso-resins generally have better mechanical properties and show better chemical resistance. Their increased resistance to water permeation has prompted many builders to use this resin as a gel coat or barrier coat in marine laminates.

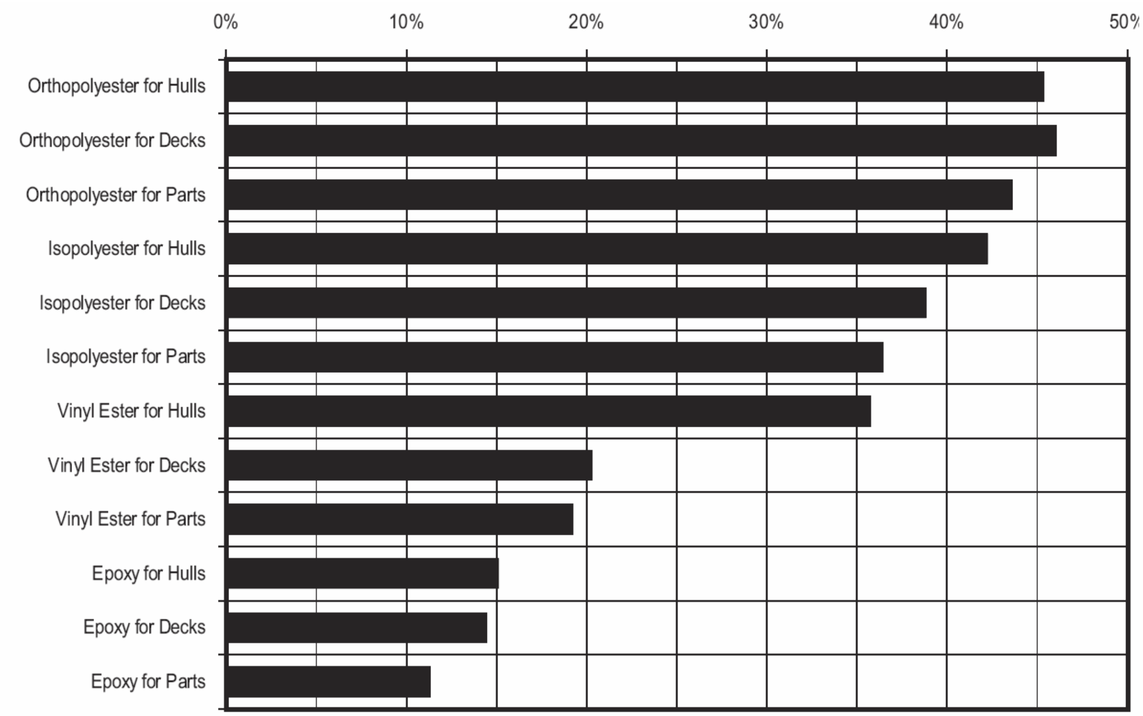


Figure 4. Resin Use from Marine Industry Survey

Vinyl Ester: Vinyl ester resins are unsaturated resins prepared by the reaction of a monofunctional unsaturated acid, such as methacrylic or acrylic, with a bisphenol diepoxide. The resulting polymer is mixed with an unsaturated monomer, such as styrene. The handling and performance characteristics of vinyl esters are similar to polyesters. Some advantages of the vinyl esters, which may justify their higher cost, include superior corrosion resistance, hydrolytic stability, and excellent physical properties, such as impact and fatigue resistance. It has been shown that a 20 to 60 mil layer with a vinyl ester resin matrix can provide an excellent permeation barrier to resist blistering in marine laminates.

Epoxy: Epoxy resins are a broad family of materials that contain a reactive functional group in their molecular structure. Epoxy resins show the best performance characteristics of all the resins used in the marine industry. Aerospace applications use epoxy almost exclusively, except when high temperature performance is critical. The high cost of epoxies and handling difficulties have limited their use for large marine structures.

Thermoplastics: Thermoplastics have one- or two-dimensional molecular structures, as opposed to three-dimensional structures for thermosets. The thermoplastics generally come in the form of molding compounds that soften at high temperatures. Polyethylene, polystyrene, polypropylene, polyamides and nylon are examples of thermoplastics. Their use in the marine industry has generally been limited to small boats and recreational items. Reinforced thermoplastic materials have recently been investigated for the large-scale production of structural components. Some attractive features include no exotherm upon cure, which has plagued filament winding of extremely thick sections with thermosets, and enhanced damage tolerance. Processability and strengths compatible with reinforcement material are key areas currently under development.

Reinforcements

Fiberglass: Glass fibers account for over 90% of the fibers used in reinforced plastics because they are inexpensive to produce and have relatively good strength to weight characteristics. Figure 5 shows the distribution of reinforcement systems used in the marine industry. Additionally, glass fibers exhibit good chemical resistance and processability. The excellent tensile strength of glass fibers, however, may deteriorate when loads are applied for long periods of time. Continuous glass fibers are formed by extruding molten glass to filament diameters between 5 and 25 micrometers. Individual filaments are coated with a sizing to reduce abrasion and then combined into a strand of either 102 or 204 filaments. The sizing acts as a coupling agent during resin impregnation.

E-glass (lime aluminum borosilicate) is the most common reinforcement used in marine laminates because of its good strength properties and resistance to water degradation. S-glass (silicon dioxide, aluminum and magnesium oxides) exhibits about one third better tensile strength, and in general, demonstrates better fatigue resistance. The cost for this variety of glass fiber is about three to four times that of E-glass.

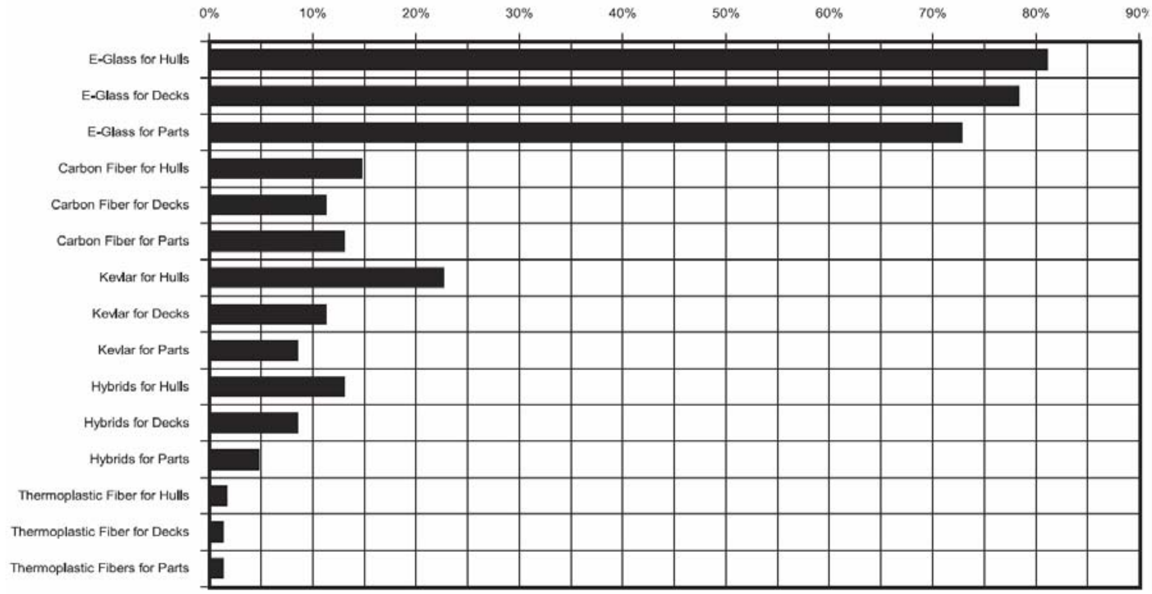


Figure 5. Reinforcement Use from Marine Industry Survey

Polymer Fibers: The most common aramid fiber is Kevlar® developed by DuPont. This is the predominant organic reinforcing fiber, whose use dates to the early 1970s as a replacement for steel belting in tires. The outstanding features of aramids are low weight, high tensile strength and modulus, impact and fatigue resistance, and weaveability. Compressive performance of aramids is not as good as glass, as they show nonlinear ductile behavior at low strain values. They are also harder to work with.

Water absorption of un-impregnated Kevlar® 49 is greater than other reinforcements, although ultra-high modulus Kevlar® 149 absorbs almost two thirds less than Kevlar® 49. The unique characteristics of aramids can best be exploited if appropriate weave style and handling techniques are used. Recent use of aramids in marine construction has fallen off due to an acute shortage of material because so much of it is being used for blast and ballistic protection.

Carbon Fibers: The terms "carbon" and "graphite" fibers are typically used interchangeably, although graphite technically refers to fibers that are greater than 99% carbon composition versus 93 to 95% for PAN-base fibers. All continuous carbon fibers produced to date are made from organic precursors, which in addition to PAN (polyacrylonitrile), include rayon and pitches, with the latter two generally used for low modulus fibers.

Carbon fibers offer the highest strength and stiffness of all commonly used reinforcement fibers. The fibers are not subject to stress rupture or stress corrosion, as with glass and aramids. High temperature performance is particularly outstanding. The major drawback to the PAN-base fibers is their relative cost, which is a function of high precursor costs and an energy intensive manufacturing process.

Core Materials

A variety of wood and foam materials are used as cores in sandwich structures. The low density cores are used to create thick, lightweight structures that resist bending loads well. Figure 6 shows the breakdown of core use by type in the marine industry.

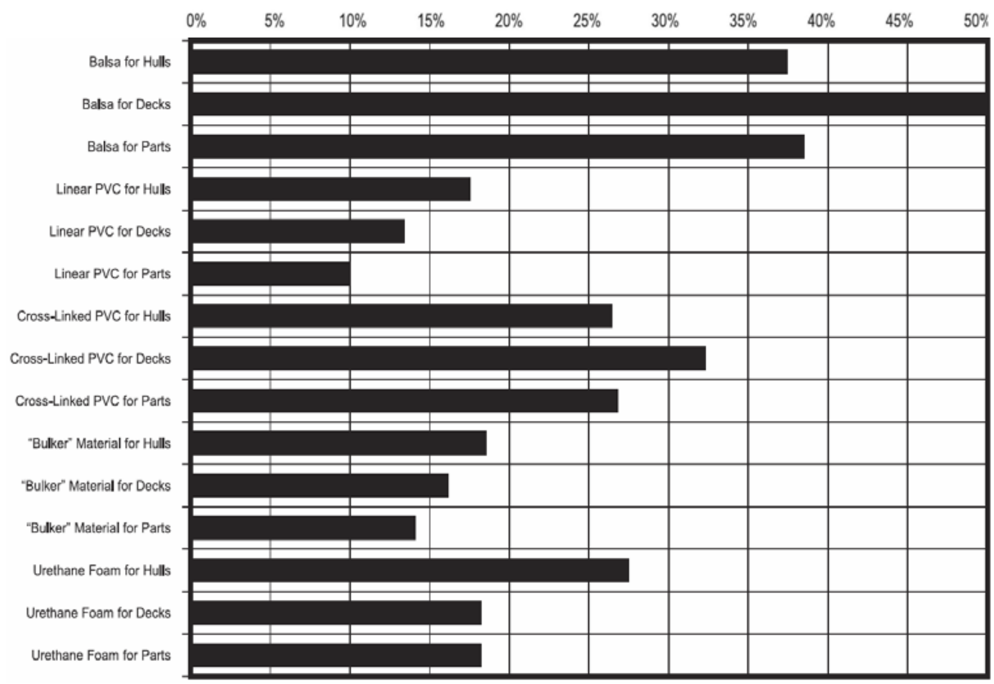


Figure 6. Core Use in the Marine Industry

Balsa: End grain balsa's closed-cell structure consists of elongated, prismatic cells with a length (grain direction) that is approximately sixteen times the diameter. In densities between 6 and 16 pounds per ft^3 (0.1 and 0.25 gms/cm^3), the material exhibits excellent stiffness and bond strength. Stiffness and strength characteristics are much like aerospace honeycomb cores Although the static strength of balsa panels will generally be higher than the PVC foams, impact energy absorption is lower. Local impact resistance is very good because stress is efficiently transmitted between sandwich skins. End-grain balsa is available in sheet form for flat panel construction or in a scrim-backed block arrangement that conforms to complex curves.

Thermoset Foams: Foamed plastics such as cellular cellulose acetate (CCA), polystyrene, and polyurethane are very light (about 2 lbs/ft^3) and resist water, fungi and decay. These materials have very low mechanical properties and polystyrene will be attacked by polyester resin. These foams will not conform to complex curves. Use is generally limited to buoyancy rather than structural applications. Polyurethane is often foamed in-place when used as a buoyancy material.

Syntactic Foams: Syntactic foams are made by mixing hollow microspheres of glass, epoxy and phenolic into fluid resin with additives and curing agents to form a moldable, curable, lightweight fluid mass. Omega Chemical has introduced a sprayable syntactic core material called SprayCore™. The company claims that thicknesses of 3/8" can be achieved at densities between 30 and 43 lbs/ft^3. The system is being marketed as a replacement for core fabrics with superior physical properties.

Cross Linked PVC Foams: Polyvinyl foam cores are manufactured by combining a polyvinyl copolymer with stabilizers, plasticizers, cross-linking compounds and blowing agents. The mixture is heated under pressure to initiate the cross-linking reaction and then submerged in hot water tanks to expand to the desired density. Cell diameters range from 0.010 to 0.100 inches (as compared to 0.0013 inches for balsa). The resulting material is thermoplastic, enabling the material to conform to compound curves of a hull. PVC foams have almost exclusively replaced urethane foams as a structural core material, except in configurations where the foam is "blown" in place. A number of manufacturers market cross-linked PVC products to the marine industry in sheet form with densities ranging from 2 to 12 pounds per ft^3. As with the balsa products, solid sheets or scrim backed block construction configurations are available.

Linear PVC and SAN Foams: Airex® and Core-Cell® are examples of linear PVC and SAN foam cores, respectively, produced for the marine industry. Unique mechanical properties are a result of a non-connected molecular structure, which allows significant displacements before failure. In comparison to the cross linked (non-linear) PVCs, static properties will be less favorable and impact will be better. For Airex,® individual cell diameters range from 0.020 to 0.080 inches.

Honeycomb: Various types of manufactured honeycomb cores are used extensively in the aerospace industry. High-end racing boats now use honeycomb cores as well. Constituent materials include aluminum, phenolic resin impregnated fiberglass, polypropylene and aramid fiber phenolic treated paper. Densities range from 1 to 6 lbs/ft^3 and cell sizes vary from 1/8 to 3/8 inches. Physical properties vary in a near linear fashion with density. Although the fabrication of extremely lightweight panels is possible with honeycomb cores, applications in the recreational marine environment are limited due to the difficulty of bonding to complex face geometries and the potential for significant water absorption.

Core Fabrics: Various natural and synthetic materials are used to manufacture products to build up laminate thickness economically. One such product that is popular in the marine industry is Firet Coremat, a spun-bound polyester produced by Lantor. Hoechst Celanese has introduced a product called Trevira®, which is a continuous filament polyester. The continuous fibers seem to produce a fabric with superior mechanical properties. Ozite produces a core fabric called Compozitex™ from inorganic vitreous fibers. The manufacturer claims that a unique manufacturing process creates a mechanical fiber lock within the fabric. Although many manufacturers have had much success with such materials in the center of the laminate, the use of a nonstructural thick ply near the laminate surface to eliminate print-through requires engineering forethought. The high modulus, low strength ply can produce premature cosmetic failures. Other manufacturers have started to produce "bulking" products that are primarily used to build up laminate thickness.

Plywood: Plywood should also be mentioned as a structural core material, although fiberglass is generally viewed as merely sheathing when used in conjunction with plywood. Exceptions to this characterization include local reinforcements in way of hardware installations where plywood replaces a lighter density core to improve compression properties of the laminate. Plywood is also sometimes used as a form for longitudinals, especially in way of engine mounts. Concern over the continued propensity for wood to absorb moisture in a maritime environment, which can cause swelling and subsequent delamination, has precipitated a decline in the use of wood in conjunction with FRP. Better process control in the manufacture of newer marine grade plywood should diminish this problem. The uneven surface of plywood can make it a poor bonding surface. Also, the low strength and low strain characteristics of plywood can lead to premature failures when used as a core with thin skins.

The technique of laminating numerous thin plies of wood developed by the Gougeon Brothers and known as wood epoxy saturation technique (WEST® System) eliminates many of the shortcomings involved with using wood in composite structures.

Fabrication Process Development

From the 1950s to today, advances in materials and fabrication techniques used in the recreational watercraft industry have helped to reduce production costs and improve product quality. Although every boat builder employs unique production procedures that they feel are proprietary, general industry trends can be traced over time, as illustrated in Figure 7.

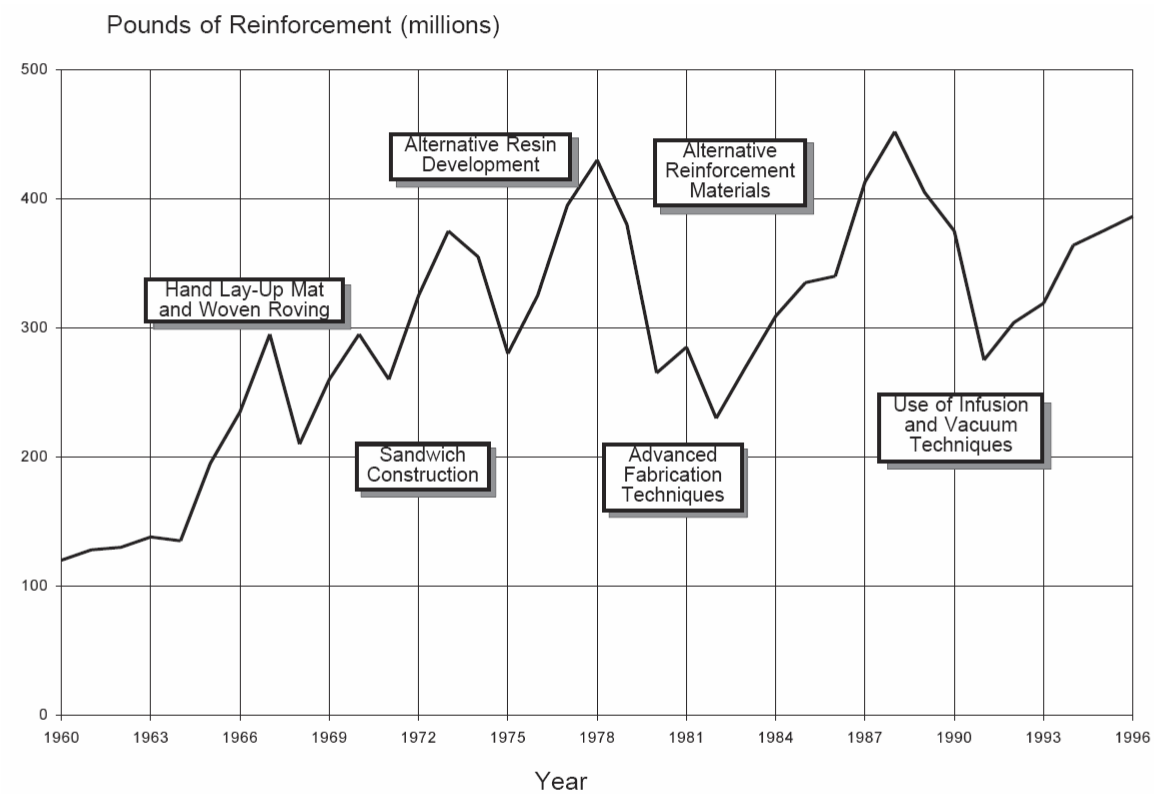


Figure 7. Annual Shipment of Reinforced Thermoset and Thermoplastic Resin Composites for the Marine Industry with Associated Construction Developments. Source: SPI Composites Institute

Single-Skin Construction: Early fiberglass boat building produced single-skin structures with stiffeners to maintain reasonable panel sizes. Smaller structures used isotropic (equal strength in x and y directions) chopped strand mat layed-up manually or with a chopper gun. As strength requirements increased, fiberglass cloth and woven roving were integrated into the laminate. An ortho-polyester resin, applied with rollers, was almost universally accepted as the matrix material of choice.

Sandwich Construction: In the early 1970s, designers realized that increasingly stiffer and lighter structures could be achieved if a sandwich construction technique was used. By laminating an inner and outer skin to a low density core, reinforcements are located at a greater distance from the panel's neutral axis. These structures perform exceptionally well when subjected to bending loads produced by hydrodynamic forces. Linear and cross-linked PVC foam and end-grain balsa have evolved as the primary core materials.

Resin Development: General purpose ortho-polyester laminating resins still prevail throughout the boating industry due to their low cost and ease of use. However, boat builders of custom and higher-end craft have used a variety of other resins that exhibit better performance characteristics. Epoxy resins have long been known to have better strength properties than polyesters. Their higher cost has limited use to only the most specialized of applications. Iso-polyester resin has been shown to resist blistering better than ortho-polyester resin and some manufacturers have switched to this entirely or for use as a barrier coat. Vinyl ester resin has performance properties somewhere between polyester and epoxy and has recently been examined for its excellent blister resistance.

Unidirectional and Stitched Fabric Reinforcement: The boating industry was not truly able to take advantage of the directional strength properties associated with fiberglass until unidirectional and stitched fabric reinforcements became available. Woven reinforcements, such as cloth or woven roving, have the disadvantage of “pre-buckling” the fibers, which greatly reduces in-plane strength properties. Unidirectional reinforcements and stitched fabrics that are actually layers of unidirectionals offer superior characteristics in the direction coincident with the fiber axis. Pure unidirectionals are very effective in longitudinal strength members such as stringers or along hull centerlines. The most popular of the knitted fabrics is the 45º by 45º knit, which exhibits superior shear strength and is used to strengthen hulls torsionally and to tape-in secondary structure.

Advanced Fabrication Techniques: Spray-up with chopper guns and hand lay-up with rollers are the standard production techniques that have endured for 40 years. In an effort to improve the quality of laminated components, some shops have adapted techniques to minimize voids and increase fiber ratios. One technique involves placing vacuum bags with bleeder holes over the laminate during the curing process. This has the effect of applying uniform pressure to the skin and drawing out any excess resin or entrapped air. Another technique used to achieve consistent laminates involves using a mechanical impregnator, which can produce 55% fiber ratios.

Alternate Reinforcement Materials: The field of composites gives the designer the freedom to use various different reinforcement materials to improve structural performance over fiberglass. Carbon and aramid fibers have evolved as two high strength alternatives in the marine industry. Each material has its own advantages and disadvantages, which was discussed above. Suffice it to say that both are significantly more expensive than fiberglass but have created another dimension of options with regards to laminate design. Some low-cost reinforcement materials that have emerged lately include polyester and polypropylene. These materials combine moderate strength properties with high strain-to-failure characteristics.

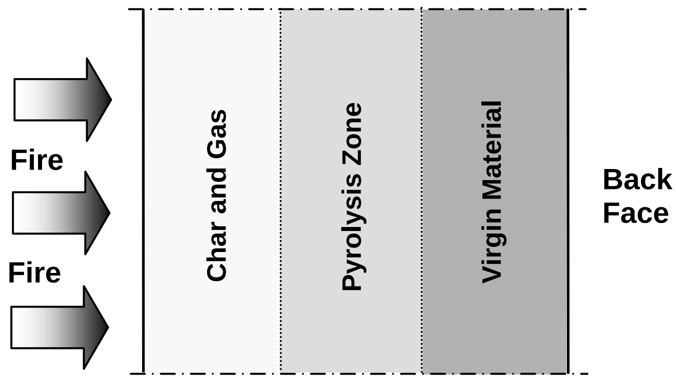
Infusion Methods: In an effort to reduce styrene emissions and improve the overall quality of laminates, some builders are using or experimenting with resin infusion techniques. These processes use traditional female molds, but allow the fabricator to construct a laminate with dry reinforcement material called preforms. Similar to vacuum methods, sealant bags are applied and resin is distributed through ports using various mediums. In general, fiber content of laminates made with infusion methods is increased.

BURNING BEHAVIOR

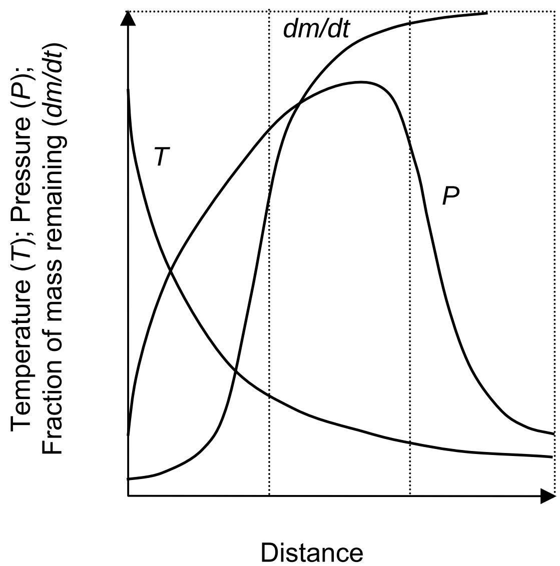
Behavior of Fiber Reinforced Plastics Exposed to High Temperatures

The majority of recreational boats are built of fiber reinforced plastics (FRP) and more specifically the majority are constructed of glass reinforced plastics (GRP) (see previous discussion on marine composite materials). A significant work done by Samanta et al [6] at the Robert Gordon University School of Engineering has addressed in detail the *Thermo-mechanical Assessment of Polymer Composites Subject to Fire*. This work points to the increased use of GRP materials in the offshore oil and gas industry due to GRP advantages of high strength, low weight and high-temperature behaviors. The authors of this work provide a detailed explanation of the behavior of GRP exposed to high temperatures such as in a fire environment. The following is partial text quoted from the authors work along with Figures 8(a) and 8(b) which illustrates the distinct zones of behavior in fiberglass based polymer composite materials.

> *When a thick GRP laminate is exposed to high temperature, the initial temperature rise (away from the exposed surface) is primarily due to transient heat conduction; the temperature response for this initial heating period is governed by the thermal properties of the virgin material. During this period, the material experiences no chemical reactions. When the material reaches 200 to 300°C, depending on composition and heating rate, chemical reactions, commonly referred to as pyrolysis, begin to occur. At these temperatures, the resin constituent undergoes thermo-chemical decomposition and the material breaks down to form gaseous products, solid carbon and glass residue. This results in charring between the pyrolysis zone and the heated surface.*
>
> *The pyrolysis zone moves from the heated surface through the material. Meanwhile, the pyrolysis gases diffuse back through the porous charring layer attenuating the conduction of heat to the pyrolysis zone. These gases carry heat energy providing a means for convective cooling. Simultaneously, the material experiences thermo-chemical expansion and/or contraction. With time when decomposition is still in its early stages, the pyrolysis gases are trapped due to low porosity and permeability of the material. Such an accumulation of the gases results in the internal pressurization of the material. For many high density GRP, the porosity and permeability are small enough to cause high internal pressures which in turn causes further expansion of the GRP laminate. As time progresses the pyrolysis zone widens and advances further into the virgin material. In the mean time, the porosity and permeability of the charring layer increase and the rate of gas flow becomes equal to and then surpasses the rate of gas production. As a result, energy is transferred between the pyrolysis gases and virgin material within the pore network by means of forced convection. This causes peaks in the internal pressure, expansion of the material and the amount of decomposition gases trapped in the material. Given sufficient incident energy, the charring layer penetrates deeper into the virgin material and further chemical reactions occur. These reactions are due to oxidation of the carbon residue and its reaction with the silica filler (present in the glass fibre) at temperatures over 900°C resulting in considerable additional mass loss so that the active material is eventually consumed at the surface of the material leaving a trace of glass fibres and an inert residue containing the pyrolysis gases. At such a time, there is no significant increase in the internal pressure as the permeability is large enough to allow the pyrolysis gases to flow through the pyrolysis and charring zones and eventually escape from the heated surface. It should be noted that the pyrolysis and carbon-silica reactions cause large changes in the thermal, kinetic and transport properties of the material. Once the decomposition process begins, the thermal behavior of the material changes, due to the chemical reactions, thermo-chemical expansion, variable thermal and transport properties and the presence of pyrolysis gases. During fire it is observed that when composites ignite they immediately start to char.*



8(a)



8(b)

Figures 8(a) and 8(b).

8(a) Represents the zones of GRP thermal decomposition when exposed to fire from one side.
8(b) Illustrates qualitatively the variations of temperature, pressure and mass fraction remaining as a function of distance relative to the GRP zones in 8(a)

Source: *Thermo-mechanical Assessment of Polymer Composites Subject to Fire*

Samanta *et al* also provided a literature review that notes the works of numerous other researchers that have identified the relative good fire resistive capabilities of FRP/GRP composites. These fire resistive properties are generally attributed to the endothermic decomposition of the composite matrix which slows down heat transmission through the laminate or what may be described alternatively as, the cooling action that results from the decomposition of the resin. Also important, is the fact that as the resin burns away from each ply, the thermo-conductivity of that ply is greatly reduced (dry fiberglass becomes a good insulator).

Performance of Recreational Boats in Fires

Composite materials based on organic matrices are flammable elements that should be evaluated to determine the potential risk associated with their use. In a fire, general purpose resins will burn off, leaving only the reinforcement, which has no inherent structural strength. "T-vessels" (vessels carrying 7 – 150 passengers) inspected by the U.S. Coast Guard must be fabricated using low flame spread resins. These resins usually have additives such as chlorine, bromine or antimony. Physical properties of the resins are usually reduced when these compounds are added to the formulation. There is also some concern about the toxicity of the gases emitted when these resins are burned.

Small-scale tests are quick, repeatable ways to determine the flammability characteristics of organic materials. Before a test program is developed to predict how a composite structure will behave in a fire, it is instructive to understand critical fire performance parameters. These parameters and associated test protocols are discussed in the order that they become relevant in a fire. When developing a fire test program it is important to keep in mind that structural "systems" are being evaluated, not individual materials systems. Also paramount is the understanding that the larger (and hence more expensive) fire tests will more accurately predict the performance of a structure in a fire.

It should be noted that recent marine composite fire research has focused on fires that start on ships and not boats in storage. Fire containment to the compartment of origin is an issue for on board vessel fires, whereas a primary focus of this document concerns how fires spread from one boat to the next in a storage array.

Ignitability

In the early stages of a fire, the key factor that influences the fire safety of a composite laminate is the time it takes to ignite. Fire scientists like to relate this to the size of the fire that the specimen is exposed to. Once a surface has ignited, an associate fire risk becomes a function of how fast the flame will spread. Over the years, numerous test methods have been used to determine ignitability. All test methods expose a sample to a "fixed" size fire and measure the time it takes to ignite. The Cone Calorimeter test has emerged as the internationally-accepted fire test to determine time-to-ignition. Fire test data from several resources for various composite materials is provided in Table 2 [7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24].

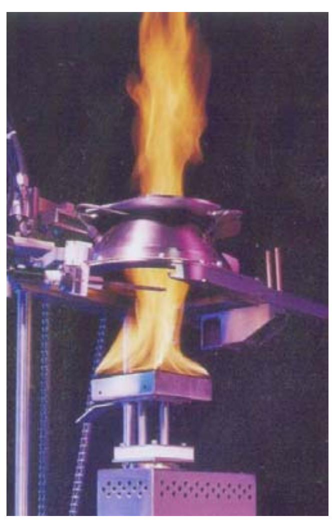


Figure 9. Cone Calorimeter

Table 2 . Fire Test Data for Some Composite Systems

		Cone Calorimeter, ASTM 1354						Steiner Tunnel Test, ASTM E 84		
		Ease of Ignition		Fuel Contribution to Fires				Flame Spread	Smoke Generation	
		Time to Ignition, secs		Peak Heat Release Rate, kW/m^2		5 min Avg Heat Release Rate, kW/m^2				
	Product	Incident Heat Flux		Incident Heat Flux		Incident Heat Flux		Flame	Smoke	
Material Description	Designation	25 kW/m^2	50 kW/m^2	25 kW/m^2	50 kW/m^2	25 kW/m^2	50 kW/m^2	Spread Index	Generation Index	Reference
E-glass/phenolic		28	8	4	140					Babrauskas (1987)
E-glass/epoxy		32	8	168	238			1 to 45		Babrauskas (1987), Silvergleit (1977)
Kevlar/epoxy		33	9	108	138					Babrauskas (1987)
Plywood		143	26	260	280					Swedish National Testing Institute (1990)
Southern pine, untreated			28		154		117	60		White (2004)
Particle Board, Veneer		216	28	102	231	60	125			NIST (1996)
Polyester, wet lay-up			29		334					Janssens (1998)
high-impact polystyrene (HIPS)	PFR-18	98	30	391	445	284	378			Morgan (2006)
high-impact polystyrene (HIPS)	BFR-2	87	31	304	461	16	283			Morgan (2006)
acrylonitrile-butadiene-styrene (ABS)	PFR-19	99	36	290	293	188	243			Morgan (2006)
poly vinyl chloride (PVC)	NVR-17	103	36	179	293	127	243			Morgan (2006)
E-glass/polyester, FR w/ Airex core	MIL-R-21607 FR resin	151	40	134	177	87	118			Grenier (1996)
E-glass/polyester, FR w/ basla core	MIL-R-21607 FR resin	238	48	128	172	89	116			Grenier (1996)
polypropylene (PP)	NH-15	140	48	380	487	256	361			Morgan (2006)
acrylonitrile-butadiene-styrene (ABS)	BFR-7	126	50	459	395	221	268			Morgan (2006)
E-glass/polyester, FR	Koppers 6692T	263	60	59	85	25	40			Brown (1988)
polypropylene (PP)	BFR-11	221	62	1650	2090	747	662			Morgan (2006)
Polyester			62		477		150			Scudamore (1994)
Polyester, FR, infusion			65		108					Janssens (1998)
polycarbonate (PC)	NH-1	193	67	576	531	333	385			Morgan (2006)
polycarbonate (PC)	BFR-10	461	72	225	210	10	124			Morgan (2006)
Vinylester, FR, infusion			74		116					Janssens (1998)
Vinyl Ester			74		222		140			Sastri et al. (1997)
Epoxy			88		363		147			Scudamore (1994)
Acrylic, FR, infusion			95		108					Janssens (1998)
Southern pine, FR			118		72		49	10		White (2004)
Epoxy, FR, wet lay-up			122		59					Janssens (1998)
Polyimide	insulation foam		175		40		27			Sastri et al. (1997)
Phenolic-siloxane			307		77		54			Koo et al (2000)
Phenolic, FR, wet lay-up			324		28					Janssens (1998)
Phenolic-polyester			349							Koo et al (2000)
IMO fire restricting material			NI		NI					Janssens (1998)
E-glass/epoxy ,FR								9		Silvergleit (1977)
Carbon/epoxy								20		Sorathia (1990)
Vinyl Ester, Brominated	Hetron 92FR							25	750	ATS Duct Company, http://www.atsduct.com/
E-glass/vinylester								156		Sorathia (1990)
Vinyl Ester, Brominated	Hetron 92FS							15-20	>250	ATS Duct Company, http://www.atsduct.com/
Nomex Honeycomb panel								19 to 23		Rollhauser (1991)
E-glass/polyester								31 to 39		Silvergleit (1977)
E-glass/polyester, FR								5 to 22		Silvergleit (1977)
Mahogany					174		89			White (2000)
Cherry					187		105	76		White (2000)
Birch					218		141	105 to 110		White (2000)
Oak, white					219		121	77		White (2000)
Ash					241		117			White (2000)
Teak					248		130			White (2000)
Mahogany veneer					395					White (2000)
Oak, white, veneer					523					White (2000)
Cherry veneer					525					White (2000)
Birch veneer					586					White (2000)
Ash veneer					648					White (2000)
E-glass/vinylester, FR	Derakane 510-40							15	1100	Rollhauser (1996)

Flame Spread

Once a surface becomes involved in a fire our next concern is how fast the flame will spread. Although influenced by structural geometry and the dynamics of the building of interest, flame spread (both vertical and horizontal) is very much a function of the material burning. Although small-scale tests exist to evaluate flame spread, much historical data and building standards are based on the Steiner tunnel fire test method (ASTM E84), which uses a 25-foot long sample.

Flame spread test data is a key parameter for predicting fire growth. This data takes the form of how long it takes the flame to spread a given distance. Test methods measure horizontal flame spread, but vertical flame spread is of interest to us when considering vertical boat storage facilities. Note that during flame spread testing a very controlled environment (fire source, air movement), which may not accurately model an actual full-scale fire.

Rate of Heat Release

Fires typically start from a small source and can grow only if additional fuel is provided. Fire protection engineers conduct fire risk assessments for a building in part by determining the total fuel load of the room contents. This parameter can be determined fairly accurately by using the Cone Calorimeter to determine the rate of heat release of a material system. The shortcoming of the Cone Calorimeter test is the small size of the sample being tested, which limits the ability to test very thick material systems or dynamic passive fire protection systems that may interfere with the heating coil (see Figure above).

Smoke Production

Fires, especially those in enclosed buildings, are difficult to combat when large quantities of black and/or toxic smoke are produced. Organic resin systems used to fabricate recreational boats inherently produce smoke in major fires. Indeed, some additives designed to reduce flammability can actually increase the amount of smoke produced once involved in a fire.

Burn-Through Resistance and Structural Integrity

Burn-through resistance is not a paramount parameter when considering small boats involved in marina fires. However, structural integrity can be an issue if we are concerned about boats falling apart during fires and creating hazards for firefighters. Figure 10 shows a composite laminate after a structural integrity fire test, exhibiting near complete pyrolysis of the laminate matrix resin system.

Figure 10. Composite Laminate after Structural Integrity Fire Test

BOAT STORAGE FACILITIES

Rack storage of boats or dry stack storage started in the 1960's in the southeastern United States. Initially, these facilities were capable of storing boats no longer than 25 feet. Loading was accomplished using standard commercial fork lifts to place boats into racks with three to four tiers of storage. By the 1990's facilities had improved capabilities to handle boats of over 40 feet in length. These improved facilities use forklifts specially adopted for marine use, or stacker cranes that can easily maneuver boats to heights as great as 50 feet providing four to five tiers of storage.[25] Today, facilities are being proposed with eight to ten tiers of storage for boats up to 50 feet in length, in buildings over 100 feet tall.

Boat storage facilities vary significantly in size and number of buildings, degree of building enclosure, storage arrangement and density. In warm, nonfreezing climates facilities may be simple steel structures having only a roof for sun shading. In winter climates indoor storage facilities provide protection against the extreme cold, snow and sun. Facilities may be relatively small facilities that accommodate smaller recreational boats. Typical moderate to large facilities are often one-story warehouses where boats and engine-driven sailboats are stored together.

Figure 11

Figure 12

The above photographs, Figures 11-12, show two typical one-story indoor boat storage facilities. In the winter these warehouses would be filled with boats nested together to allow for maximum utilization of the storage space. The facility in Figure 12 is heated as evidenced by the heating equipment seen along the wall. These facilities can accommodate a wide range of boats from fishing boats to cabin cruisers and sailboats with their masts removed.

Tall facilities using rack storage arrangements tend to have a more regular storage arrangement as compared to the nested boat storage situation found in one-story facilities. Also, rack storage facilities require large center aisles to accommodate the manually operated lift truck equipment used to load and unload boats from the rack supports.

Figure 13

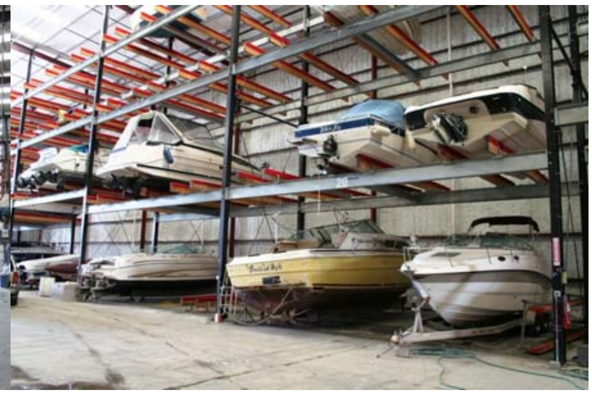


Figure 14

Figure 15

Figure 16

Figures (photographs) 13-16 illustrate the conditions typically encountered in a rack storage or dry stack boat facility. In this case there are four levels of boats, the lowest level being loaded by simple rolling boats on their trailers into position. The steel structural system supports both the shelf beams and the building's roof truss system. The two rack systems in this building are separated by a distance of approximately 60 feet. Figure 15 shows the lift truck equipment used to locate boats into the upper racks. Figure16 illustrates the method of support used; in this case carpet-covered wood joists are used to support the boats. The steel brackets that hold the wood [illegible]
[illegible]
of different boat designs.

The latest and most sophisticated rack storage facilities are those which allow boats to motor from the public waterways directly via a canal or channel into the storage facility. These facilities are fully automated using laser guided or other technology allowing for a boat afloat to be lifted from the water and quickly (2-5 minutes) located into a reserved rack storage location sized for the boat being stored. Such facilities allow for boat owners to routinely keep their boats in storage and sheltered from the elements and yet have the ability to retrieve their boat for a day on the water.

Figure 17

Photo Courtesy of Vertical Yacht Systems

Figure 18

Photo Courtesy of Vertical Yacht Systems

Figure 17 depicts the rack storage structural system and water channel of a fully automated dry stack storage facility. In this facility the steel columns supports both the racks structure and the steel roof trusses. Figure 18 illustrates the automated crane operating to place a 36 foot boat into a reserved rack storage location. These automated facilities required a large empty volume for the crane to operate and consequently there exists a large physical separation between the two vertical racks of storage.

BOAT FIRES - INCIDENT DATA COLLECTION & REVIEW

Four insurance companies that specialize in marina and boatyard coverage were contacted for loss information. For various reasons none of these insurance companies were able to provide any useful data. However, the Davis & Company, Ltd (Davis) database and sourcing information from the four major marina insurer clients was used to document loss history.

Additionally, the Fire Analysis and Research Division of NFPA did provide their report "*Selected Published Incidents Involving Marinas"*, which is attached as Appendix A to this report. Upon reviewing the incidents provided by NFPA it was noted that several were represented within the Davis database. Noted were fires reported in the Mt. Clemens, MI. area in 1998 at six marinas. All of these being a part of an arson spree by one individual later arrested. The condo/boat house fires in Ohio on Lake Erie are also represented in our multiple boat fire data of 40 and 60 individual boats in one event.

A review of the data of published incidents provided by NFPA indicates the identified cause/s to be consistent with that found in the Davis data search. This data provided insight into fire fighting assets and circumstances surrounding fire discovery not found elsewhere. There was no report wherein either a heat detection system or sprinkler system was present. In many instances the location of the fire was on a dock or at a remote location (island or storage building far from city resources) with limited hydrants or no hydrants, requiring fire departments to draft water from a river or lake. The set up of long hose lines or drafting lines delayed the response in combating the fire. Noted also was the time of the call to response arrival of only a few minutes (<10) yet the fire has propagated from the origin boat to two or three others. Fires that occurred in buildings or afloat with a roof over the slips are noted to more readily communicate the fire and involve more boats, likely due to the increased heat convection/radiation enhanced by the enclosing structure(s).

Several Boat US "Seaworthy" magazine articles[26], [27] illuminate the Davis data fire cause sort where boat electrical and or maintenance issues were determined causative in greater detail.

Davis Database Research

The Davis & Company, Ltd assignment database was searched for all cases classified as "Fire". This returned 1,097 records out of 51,512 or roughly 2%. This data reflects assignments where "Fire" was reported as the cause (See Davis data search spreadsheet attached).

These 1,097 records were manually searched for criteria identified in the tables below. In the process of this manual search items were deleted where the fire was not involving a boat, reopens of the same case, multiple cases for the same event and cancelled projects for a refined total of 931 or roughly 1.8 % of the total records.

Table 3 is a sort of the data based upon where the fire initiated, on the subject boat, communicated to the subject boat, with the boat afloat in a slip, onshore in a marina or underway. Some fires did not occur in a marina or storage facility so the location was not recorded for this study's purposes.

Table 3: Fire Origin and Boat Location per Event

On Boat	Communicated	Wet moored	Dry storage	Underway
598	333	90	192	210

In the majority of the cases there is only one boat involved in the event. Where more than one boat was involved, such as 40 or 60 boats, it is one occurrence at a Condo development with boat houses wherein the condo development burned and high winds communicated the fire to all of the buildings including the boat houses. The other high count events are marina fires where the fire initiated on one boat and communicated to others, usually due to winds. The number of multiple boat fires in a single event is reported in Table 4.

Table 4: Number of Multiple Boats Fire Events

Wet Slip/moored	Dry storage	Underway
42	46	03

The determined cause of fire was recorded from the data files (where available) and sorted into five categories with the results in Table 5. The "maintenance" category, as a matter of explanation, includes causes such as: Loose connection on a non-ignition protected battery charger; Transmission fire due to a lack of lubricant; Stuck carburetor float leaked fuel onto the intake manifold (a marine carburetor will not do this- a rebuild of the carburetor prior to the fire was completed using automobile parts, rather than marine); The fuel tank sending unit was loose on the tank; Battery was not secured in the tray resulting in loose connections and arcing at the posts; Corroded electrical wiring in the control panel. The "accidental" category includes causes attributable to the negligence of the boat owner or marina personnel such as: heat gun use during shrink wrapping igniting the wrap and boat, inattentive while cooking, smoking, communicated fire, as examples. "Boat Electrical" is indicative of a boat wiring or system failure as causative, rather than a 'shore' originating electrical problem, such as reverse polarity, lost neutral or ground, unbalanced load.

Table 5: Boat Fire Cause per Event

Accidental	Arson	Boat Elec.	Maintenance	Shore Elec.
443	74	160	209	07

The foregoing cause data is broken down based upon location of the boat, either afloat or in shore storage in Table 6.

Table 6: Fire Cause for Wet Moored and Dry Storage Locations

	Accidental	Arson	Boat Elec.	Maintenance	Shore Elec.
Wet moored	57	5	11	10	1
Dry stored	98	25	30	36	3

If all arson fires are excluded, the remaining fires' causes for boats in storage are attributable to human error where repair or maintenance activities had preceded the fire event. There are no reportable boat storage fire incidents where fires occurred while boats sat in idle storage.

Marina Operators Survey

The American Boat Builders and Repairers Association (ABBRA) and the International Marina Operators Association (IMO) forwarded an email survey to their members the content of which was provided by Schirmer and the programming of the form by Davis. Ten (10) members returned surveys (see attached compilation survey form and data spreadsheet). The survey request was sent to the membership of these organizations on three (3) separate occasions with completed survey forms received at each interval. The low return count was disappointing and perhaps a less complicated form would engender a better response. This should be considered in the future.

The majority of the respondents indicated they have roll in grade level fully enclosed storage structures. Where rack storage occurred roughly half of the respondents reported with a roof only. Storage Building construction was steel frame, roof and siding in most cases, with 2 reporting wood frame and roof, and one concrete with a steel roof system.

The boats stored ranged in size (length) from 23-100 feet. The building interior heights were reported from 10-35 feet. One half of the respondents reported the boats shrink[28] wrapped in plastic sheeting and drain plugs removed for storage, the batteries were disconnected in only one response.

The majority of the respondents reported completing maintenance and or repair work within the storage building/s ranging from minor cleaning and or all normal seasonal service work.

Only two reported having a sprinkler system with limited data returned by them on the system particulars. Noted is the fact that one obtains water from the public hydrant system and the other from the waterway.

Only one respondent reported heated storage. All reported freezing winter temperatures.

Three respondents reported fires occurring at their marina. One reported the fire within the steel storage building with a 5 alarm. One reported arson on a boat in outside storage and another reporting arson involving three boats via a heater igniting combustibles.

STORAGE FACILITIES FOR OTHER VEHICLES – AUTOMOBILES & PLANES

Parking Garages

Parking garages pose a hazard similar to motor boat storage occupancies in that both house vehicles with motors, fuel system and filled or partially filled fuel tanks. NFPA 13 considers parking garages as an Ordinary Hazard 1 occupancy requiring a sprinkler density of 0.10-0.15 gpm/ft^2 over a respective design area of 4,000-1,500 ft^2. From the perspective of boat storage, only boats stored on a single-level such as a roll-in storage facility should be considered as analogous to a parking garage with ceiling sprinkler protection.

A study by Denda[29] provided a statistical analysis of U.S. parking garage fires for 1986-1988. This study provides some insight into causes, spread and sprinkler performance for parking garages. Some of these findings may be relevant considerations for boat storage facilities, but are not necessarily directly related to boat storage facilities. Parking garage fire causes for 396 fire incidents during the 1986-88 period indicated the following:

- 80% of the garage fires involved a vehicle, most of which were automobiles
- 85% of the garage fires were accidental
- 15% of the garage fires were arson
- 66% of the garage fires were attributed to electro-mechanical design and worn-out parts factors in vehicles

Of those accidental fires eight specific areas of cause were noted:

•	Electrical overload/short:	47%
•	Fuel line leak:	19.9%
•	Backfire:	18.8%
•	Flammable substance near heat:	5.4%
•	Discarded Smoke Material:	4.7%
•	Exhaust System failure:	1.4%
•	Human Errors:	0.7%
•	Other causes:	1.4%

The area of origin for all 291 accidental and arson parking garage vehicle fires:

•	Engine Compartment	over 82%
•	Passenger Area	11%
•	Trunk/Loading Area	2%
•	Undercarriage	2.1%
•	Other	2.4%

Fire spread behavior is an issue for storage occupancies. In the case of vehicle fires studied by Denda, fires did not spread in 77% of the parking garage incidents, spread internally in 15% and externally in 8%. Denda specifically notes that fire spread occurred within a vehicle in 89 fires and spread from the vehicles in 28 fire incidents. Fire spread as used in this study was defined as ranging from proximity heat damage or direct flame damage to an adjacent vehicle, to a degree of partial or total involvement. This data encompasses both sprinklered and unsprinklered parking garage fires.

Further breakdown of the fire spread data per Denda is as follows:

- Of 257 engine compartment ignitions, 27.6% (71 incidents) spread within the vehicle of origin
- Of 36 passenger compartment fires 33.3% (12 incidents) spread within the vehicle of origin

For the 28 incidents where fire spread from the vehicle of origin Denda notes that a 96.1% of these vehicle fires originated in the engine or passenger compartments. Only one incident involved a fuel tank/arson event. For these 28 vehicle fire spread incidents it is noted that when spread occurred, that it was limited 93% of the time to affecting one or two adjacent vehicles. In only two of 28 incidents did more than two vehicles become involved with one incident involving three vehicles and the other involving four vehicles. This statistic showing that there is a high expectation of only 1 or 2 car involvement is consistent with a recent New Zealand study[30] of 101 vehicles on fire in parking garages where 93 incidents involved only a single vehicle and 3 incidents involved multiple vehicles. The New Zealand study shows a multiple vehicle involved rate of 3% as compared to Denda's Study indicating 7%. Another study in France[31] has shown a 15-20% rate of multiple vehicle involvement largely limited to a maximum of 3 vehicles. (Note: in one incident 7 cars were involved)).

Denda study also reviewed the performance of sprinkler equipment in the 1986-1988 parking garage fires indicating that 34% of the garages (110) had sprinkler systems. For 110 garages having sprinklers; the following performance figures are reported:

<u>For All Fires with Sprinklers Present</u>

- Fire controlled or extinguished 13.6% of incidents
- Sprinklers activated, but no help 36.3% of incidents
- Fire was too small 45.5% of incidents
- Sprinklers were not in area 35.54% of incidents (See Note)
- Sprinklers were not operational 1.8%

<u>Performance in Serious Fires with Sprinklers Present (34 incidents):</u>
(Serious = vehicle nearly destroyed or $10,000 non-vehicle property damage)

- Fire Controlled 20.6%
- Sprinkler Activated but no help 5.9%
- Fire was too small 29.4%
- Sprinklers were not in area 38.2% (See Note)
- Sprinklers were not operational 5.9%

<u>Performance in Spread Fires with Sprinklers Present (16 incidents):</u>

- Fire Controlled 31.3%
- Sprinkler Activated but no help 12.5%
- Fire was too small 12.5%
- Sprinklers were not in area 37.5% (See Note)
- Sprinklers were not operational 6.3%

Editor's Note: If sprinklers are "not in area" then it is questionable to consider these incidents in a sprinkler performance statistic given that "no sprinkler" means no opportunity for performance.

The above review of parking garage fires is perhaps of only limited use in understanding the fire risks and burning behavior of boat storage facilities. Parking garages are highly active storage facilities with a continuously changing population of operating vehicles and vehicle types.

It should be recognized that a key difference between parking garage and boat storage is that the car owner/driver is operating the vehicle in the storage facility (the exception is valet parking) whereas marine storage facilities have the operator turn over control of their boat to the boat storage facility operator. Consequently, the boats fuel and electrical systems are not active during (although maybe operational) the process of being placed into storage. Conversely, automobile fuel and electrical systems are combusting fuel, generating energy and heat during the parking operation.

A notable statistic from the several parking garage fire studies is that fire spread tends to be limited to one to two additional vehicles beyond the initial involved vehicle. Of course, this statistic considers that vehicles are parked on the driveway surface with 1-2 feet of separation and not in a tiered or rack storage arrangement. Also this statistic may be attributed to the body forming metal construction features (steel, metal doors, hoods, panels) of vehicles, whereas most recreational boats are of fiberglass reinforced plastic (FRP) or fiberglass construction.

The use of FRP construction suggests a higher expectation for fire spread between stored boats, due to the combustible nature of the resins, however, testing and analysis of FRP/GRP indicates FRP/GRP composites have excellent fire resistant properties attributed to their charring behavior and the coolant effect of the resin during decomposition under fire exposure [6].

Aircraft Hangars

The history behind the current provisions of NFPA 409, *Standard on Aircraft Hangars*, is that the standard has evolved over the years from an objective of providing fire protection capable of protecting solely the hangar structure using water only, via extra hazard pipe schedule systems and calculated deluge sprinklers. The current NFPA 409 [32], clearly recognizes the high dollar values of the aircraft, and; the risks related to fuel spills, fuel tank fire involvement and shielding of roof fire suppression systems by large winged aircraft. To cope with these risks NFPA 409 has developed four categories or "Groups" of hangars - Group I, II, III and IV, - which vary according to size of aircraft and the fire area allowed for various building construction types

Group I Aircraft Hangars - Group I hangars are designed to accommodate the largest types of aircraft with tail heights over 28 feet in single fire areas over 40,000 sq. ft. Examples would be a Boeing 737 (height of 37 feet) at the shorter end of the scale or a Boeing 747 at the larger end of the scale (height 63 feet). Fuel tank capacities are significant with approximately 56,000 gallons and 57,000 gallons of fuel for the Boeing 737 and 747 respectively.

Group II Aircraft Hangars – Group II Hangars are intended for aircraft with tail heights less than 28 feet with single fire areas of 40,000 sq. ft. or less. A DC-9 or Gulfstream IV are examples of aircraft with tail height just under 28 feet. Such aircraft have fuel tank capacities on the order of 3,600 to 4,200 gallons.

Group III Hangars - Group III Hangars are facilities typically housing smaller aircraft and in lighter framed, unprotected construction types. These facilities are much smaller in area than typical Group I or II facilities and NFPA 409 does not require fire suppression systems in Group III Hangars unless fuel transfer, torch cutting, spray painting, or similar hazardous activities transpire.

Group IV Hangars are by definition one-story, membrane covered, rigid-steel frame structures. This is a special category that addresses this type of weather protective structure for aircraft, and assumes as a fire protection scheme, that the fire will be self-venting as the membrane burns away. For Group IV facilities with a hangar area exceeding 12,000 sq. ft. that houses fueled aircraft either a low-expansion foam system or a high-expansion foam system is required. Group IV Hangar areas less that 12,000 sq. ft., do not require a fire suppression system.

As shown in Table 7 on page 32, NFPA 409 contains a menu of fire protection system options for fueled aircraft that fall into one of three principal categories:

- Foam-water deluge sprinkler systems with supplemental low or high expansion foam systems for wing areas greater than 3,000 sq. ft.
- Automatic closed-head sprinkler systems combined with low-level, low or high expansion foam systems to provide foam protection at the floor area.

- Automatic closed-head AFFF foam-water sprinkler systems at the roof.

NFPA 409 does have other options for non-fueled aircraft storage, however, such situations are not typically practical scenarios for consideration. Factory Mutual Data Sheets 7-93[33] consider a non-fueled aircraft as having residual fuel not in excess of 0.5% of the total fuel capacity of the aircraft (285 gallons for a 747). The process of draining and purging an aircraft fuel tank is generally impractical and the fuel handling operations likely pose greater risks than just allowing the fuel to remain in the aircraft fuel tanks.

The various options offered by NFPA 409 address the practical issues of protecting not only the building but also the aircraft.

Purpose of Roof Sprinklers – A deluge sprinkler system or closed-head sprinkler system is primarily intended to protect the hangar structure. Deluge sprinklers provided for cooling and flame knockdown over a large area for scenarios with largest aircraft hazards.

Purpose of Roof Sprinklers with Foam Discharge – A foam water sprinkler system is intended to provide an increased degree of protection for the hangar structure; prevents extension of fire beyond the area of fire origin and reduce appreciably the extent of any flammable liquid spill fire.

Purpose of Low Level/Floor Level Foam Systems – The discharge from overhead hangar protection systems might not protect the aircraft from a fire in the shielded areas beneath the wings and the wing center sections. Low Level foam systems are intended to provide protection in those shielded areas by controlling such fires quickly and preventing extensive damage to the aircraft.

The focus and intent of the fire protection systems (when required) in hangars is to handle primarily fire incidents that occur outside the aircraft fuselage. NFPA 409 recognizes, (see Annex A of NFPA 409) that if fire spreads to the aircraft interior or originates in the aircraft interior that it could seriously damage if not destroy the aircraft unless an automatic fire extinguishing system was present in the aircraft cabin.

Table 7 Summary of NFPA 409 Fire Protection System Requirements for Fueled Aircraft (Group IV Hangar excluded)

X = Minimum requirment per the selected Option		Group I Hangar - Fueled Tail Heights >28 ft. Fire Areas > 40,000 sq. ft. Example Aircraft: Boeing 747	Group II Hangar - Fueled Tail Heights <28 ft. Fire Areas < 40,000 sq. ft. Example Aircraft: DC9	Group III Hangar - Fueled Tail Heights >28 ft. Fire Areas 5,000-30,000 sq. ft. Example Aircraft: Cessna 650, Single Engine aircraft
Option 1	**Basic Design Criteria**			
Foam-water deluge sprinkler systems at roof	Deluge system max area 15,000 sq.ft., densities of 0.16 to 0.20 gpm/sq.ft	X	**Permitted in lieu of Options 4, 5, or 6**	**Not Required**
If wing areas < 3000 sq. ft.	Only Foam-water deluge system at roof required (see above)	X	**Permitted in lieu of Options 4, 5, or 6**	**Not Required**
If any single aircraft has wing areas > 3000 sq. ft. Supplementary low or high- expansion foam required to be applied below the wings and wing center section of the aircraft	Low-expansion foam or high-expansion foam to achieve control in 30 sec. and obtain extinguisment in 60 sec.; Low -ex.foam solution at 0.10 to 0.16, gpm/sq.ft.; High-ex. Foam to cover area in 1 min.	X	**Permitted in lieu of Options 4, 5, or 6**	**Not Required**
Option 2				
Automatic wet or preaction sprinklers at roof	System max area is 52,000 sq. ft., design area of 15,000 sq. ft. at 0.17 gpm/sq. ft., QR sprinklers required	X	**Permitted in lieu of Options 4, 5, or 6**	**Not Required**
Automatic low expansion foam	Low-expansion foam to cover storage and servicing area within 3 min. after actuation, foam solution at 0.10 to 0.16 gpm/sq.ft.; Foam discharge duration minimum 10 min.	X	**Permitted in lieu of Options 4, 5, or 6**	**Not Required**
Option 3				
Automatic wet or preaction sprinklers at roof	System max area is 52,000 sq. ft., design area of 15,000 sq. ft. at 0.17 gpm/sq. ft., QR sprinklers required	X	**Permitted in lieu of Options 4, 5, or 6**	**Not Required**
Automatic high-expansion foam	High-expansion foam to cover expected aircraft parking area, minimum application rate of 3.0 cubic ft./min./sq.ft.; Foam discharge duration minimum 12 min.	X	**Permitted in lieu of Options 4, 5, or 6**	**Not Required**
Option 4				
Automatic wet or preaction sprinklers at roof	System max area is 52,000 sq. ft., design area of 5,000 sq. ft. at 0.17 gpm/sq. ft.	**Option Not permitted**	X	Not required unless hazardous operations conducted, e.g. fuel transfer, torch cutting, spray painting
Automatic low-expansion foam	Low-expansion foam to cover storage and servicing area within 3 min. after actuation, foam solution at 0.10 to 0.16 gpm/sq.ft.; Foam discharge duration minimum 10 min.	**Option Not permitted**	X	Not required unless hazardous operations conducted, e.g. fuel transfer, torch cutting, spray painting
Option 5				
Automatic wet or preaction sprinklers at roof	System max area is 52,000 sq. ft., design area of 5,000 sq. ft. at 0.17 gpm/sq. ft.	**Option Not permitted**	X	Not required unless hazardous operations conducted, e.g. fuel transfer, torch cutting, spray painting
Automatic high-expansion foam	Low-expansion foam to cover storage and servicing area within 3 min. after actuation, foam solution at 0.10 to 0.16 gpm/sq.ft.; Foam discharge duration minimum 12 min.	**Option Not permitted**	X	Not required unless hazardous operations conducted, e.g. fuel transfer, torch cutting, spray painting
Option 6				
Closed head AFFF foam-water sprinkler system at roof	System max area 15,000 sq.ft., densities of 0.16 gpm/sq.ft foam solution	**Option Not permitted**	X	Not required unless hazardous operations conducted, e.g. fuel transfer, torch cutting, spray painting

SPRINKLER PROTECTION FOR BOAT STORAGE

NFPA 303 Provisions

The 2006 edition of NFPA 303, *Fire Protection Standard for Marinas and Boatyards*, contains several provisions regarding the installation of automatic fire-extinguishing systems for buildings exceeding 5000 ft^2 as quoted below.

> **6.3.2* Buildings Exceeding 5000 ft^2 (465 m^2).**
>
> **6.3.2.1** Marina and boatyard buildings in excess of 5000 ft^2 (465 m^2) in total area shall be protected by an approved automatic fire-extinguishing system unless otherwise permitted by 6.3.2.2.
>
> **6.3.2.2** Existing facilities shall not be required to be protected by an automatic fire-extinguishing system where acceptable to the authority having jurisdiction.
>
> **6.3.4 Indoor Rack Storage.**
>
> **6.3.4.1** Where boats are stored on multileveled racks in buildings, an approved automatic fire-extinguishing system shall be installed throughout the building unless otherwise permitted by 6.3.4.2 or 6.3.4.3.
>
> **6.3.4.2** An automatic fire-extinguishing system shall not be required for buildings less than 5000 ft^2 (465 m^2) having multilevel racks where provided with the following:
>
> (1) An automatic fire detection and alarm system supervised by a central station complying with *NFPA 72, National Fire Alarm Code*.
> (2) An automatic fire detection and alarm system supervised by a local protective signaling system complying with *NFPA72, National Fire Alarm Code,* if the provisions of 6.3.4.2(1) are not technically feasible.
> (3) A full-time watch service if the provisions of 6.3.4.2(1) are not technically feasibility.
>
> **6.3.4.3*** Existing facilities shall not be required to be protected by an automatic fire-extinguishing system where acceptable to the authority having jurisdiction.
>
> **6.3.4.4** The design of automatic sprinkler systems shall comply with the provisions of Chapter 12 of NFPA13, *Standard for the Installation of Sprinkler Systems,* for Group A plastics stored on solid shelves.

The noted provisions do not mandate that automatic sprinkler systems be used; however, automatic sprinklers are generally the most common, practical approach to providing fire protection when required by NFPA 303. Other types of automatic fire-extinguishing systems are potentially applicable and are discussed in the following sections of this report. This report section focus is on sprinkler criteria as it may be applicable to boat storage facilities.

NFPA 13 – Basic Hazard Class Provisions

Boats vary widely in size and degree of compartmentation (i.e. cabin, engine spaces). Fish and ski boats may be on the order of 20 feet in length with an open top design, whereas inboard cruisers may be 40 or more feet in length with enclosed quarters for sleeping, cooking, and restroom facilities. The facilities that store boats also will vary by the nature and size of boats housed, ranging from one-story facilities which house only small to large boats, or more sophisticated vertical dry stack or rack storage facilities. Given these wide-ranging variations in boats and boat storage facilities, it is useful to first review the basic sprinkler criteria of NFPA 13 [34] relative to the wide range of boat and storage configurations that exist.

Table 8 provides an overview of the basic hazard classifications of NFPA 13, which would apply in situations where ceiling sprinklers are installed to protect the combustible hazard (typical only up to heights of 12 feet).

From the perspective of roll-in or grade level boat storage, and depending on the size and compartmented nature (with or without enclosed cabins) of the boats, it is possible that any of the categories – OH1, OH2, EH1, or EH2 – could be applied. From a practical perspective, it can generally be expected that single level or roll-in storage facility will house a mix of boats, varying in size and some having enclosed cabin space. This would suggest that such single level storage facilities, if sprinklered, need to provide a water density and area of coverage consistent with the EH1 or EH2 hazard classes in order to address the largest boats with substantial compartmented spaces. Currently, there is no large or full scale fire test data that substantiates if this criterion is sufficient protection or not for single level, one-story type boat storage facilities. Multi-level rack storage facilities pose different challenges compared to single level or roll-in storage facility and until recently NFPA 303 provided no criteria for the application of sprinklers for rack storage of boats.

Table 8
Summary of NFPA 13 Basic Hazard Class Protection Criteria

		NFPA 13 Characterization of Hazard			
NFPA 13 Hazard Class	**Occupancy Examples for Comparison to Boat Storage**	**Fuel Quantity**	**Fuel Combustibility**	**Heat Release Rate**	**Protection Crteria**
Light	offices, residential	Low	Low	Low	0.1 gpm/ft^2 over 1500 ft^2 to 0.07 gpm/ft^2 over 3000 ft^2
Ordinary Hazard 1 (OH 1)	automobile parking, automobile showrooms	Moderate, stockpiles < 8 ft.	Low	Moderate	0.15 gpm/ft^2 over 1500 ft^2 to 0.1 gpm/ft^2 over 4000 ft^2
Ordinary Hazard 2 (OH 2)	mercantile, resin application areas	Moderate to high	Moderate to high	Moderate for stockplies < 12 ft., high for stockpiles < 8ft.	0.20 gpm/ft^2 over 1500 ft^2 to 0.15 gpm/ft^2 over 4000 ft^2
Extra Hazard 1 (EH 1)	aircraft hangars(except as regulated per NFPA 409), upholstering with plastic foams	Very high, dust, lint or other similiar materials present	Very high	High, but no combustible or flammable liquids	0.3 gpm/ft^2 over 2500 ft^2 to 0.2 gpm/ft^2 over 5000 ft^2
Extra Hazard 2 (EH 2)	manufactured homes; modular building assembly; 'Miscellaneous' palletized, shelf or rack storage of Group A plastics	Moderate to substantial amounts of flammable or combustible liquids present, <u>or</u> where shielding of combustibles is extensive			0.4 gpm/ft^2 over 2500 ft^2 to 0.3 gpm/ft^2 over 5000 ft^2

NFPA 13 – Rack Storage Provisions

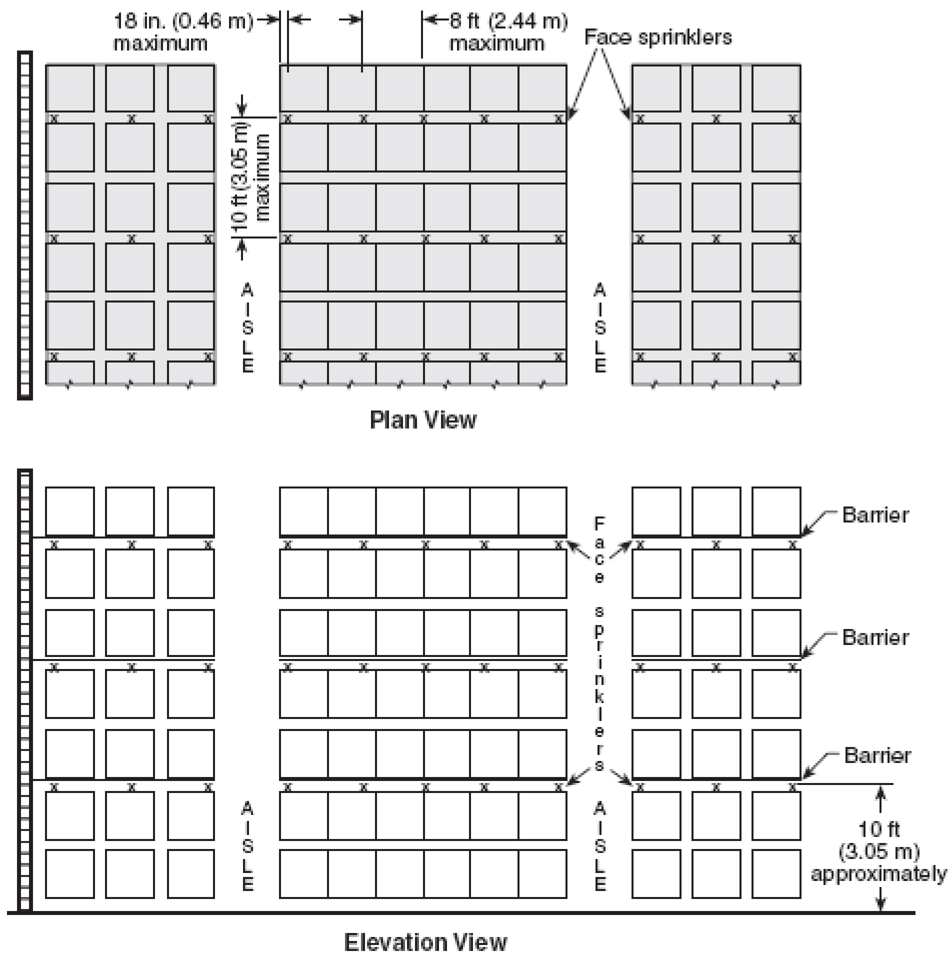
Prior to the 2003 edition of NFPA 303, Fire Protection Standard for Marinas and Boatyards, there was no specific sprinkler system design guidance specifically for rack storage of boats in NFPA 303 or NFPA 13 (Standard on the Installation of Sprinkler Systems). NFPA 303 technical committee members recognized that this was an area where improvement was needed and as a result developed a requirement that now appears in the 2003 and 2006 editions of NFPA 303. As quoted above, Section 6.3.4.4 now states that automatic sprinkler systems shall be designed per Chapter 12 of NFPA 13 – 2002 Edition for Group A Plastics stored on solid shelves. This requirement represents a best effort judgment by the Committee to provide some guidance to the designers and developers of these facilities; however, there is no current large or full scale fire test data that substantiates if this criterion is adequate, or inadequate; and, correspondingly with too much or too little conservatism for indoor rack -style boat storage.

NFPA 303 has, in their best judgment, attempted to cite specific criteria for rack storage of boats. Recognizing two basic factors: (1) boats are made of resins that classify as Group A Plastics, and (2) boats in rack storage array are solid obstructions similar to solid shelves in conventional rack storage arrays. Although these comparisons are very general, the analogy provided a basis for the NFPA 303 Committee to reference the requirements of NFPA 13 for Group A Plastics stored on solid shelves. Although NFPA 303 references the 2002 edition of NFPA 13, the following requirements for Group A Plastics on solid shelves are taken from the 2007 edition of NFPA 13, given that the 2006 edition represents the most current provision for this storage scenario.

Table 9
Summary of Key NFPA 13 Requirements
Group A Plastics in Rack Storage with Solid Shelves

	Storage Height Under 25 ft.	**Storage Height Over 25 ft.**
Sprinklers required	Ceiling and below each level of shelving (i.e. in the rack)	Ceiling and below each level of shelving
Maximum horizontal spacing between in-rack sprinklers	8 ft.	8 ft.
Minimum distance between in-rack sprinkler and top of storage in the tier	6 in.	6 in.
Flue spaces required	No for shelf storage	No for shelf storage
Sprinkler position when flue spaces provided	If provided, at intersection of transverse & longitudinal flues	If provided, at intersection of transverse & longitudinal flues
Staggered sprinkler requirements	Required for some storage configurations (with open shelves)	Required for some storage configurations (with open shelves)
Face sprinklers required	No	Yes, within 18 in. from aisle face of storage
Ceiling sprinkler density	0.30 - 0.45 over 2000 ft^2	0.30 - 0.45 over 2000 ft^2
In-rack sprinkler design	8 sprinklers where only one level of in-rack sprinklers; 14 sprinklers (seven on each top two levels) where more than one level installed	8 sprinklers where only one level of in-rack sprinklers; 14 sprinklers (seven on each top two levels) where more than one level installed
Ceiling clearance limitations of criteria **(clearance is measured from top of storage to ceiling sprinkler deflectors)**	Maximum of 5 -10 ft. depending on ceiling density selected	Maximum of 5 -10 ft. depending on ceiling density selected

NFPA 13 requires sprinklers to be installed below every level of solid shelving when the solid shelves exceed 64 feet in area (area defined by perimeter aisles or flue spaces on all four sides) or when solid shelves are vertically six feet apart. In most cases, the projected area of a stored boat will exceed 64 feet in area and require a vertical space greater than six feet to be stored; consequently, sprinklers would be required at each level or tier of boats stored in racks. Such under-shelf sprinklers are required by NFPA 13 to be spaced a maximum of eight feet apart. For storage racks greater than 25 feet in height, the first shelf sprinkler is to be installed as a "face" sprinkler where the "face" sprinkler is no greater than 18 inches off the aisle. Figures 19 and 20 illustrate several of the concepts of racks storage protection for Group A plastics. Note the example provide considers both open racks and solid shelf arrangements as depicted by the term "barriers" notation in Figures 19 and 20.



Note: Each square represents a storage cube measuring 4 ft to 5 ft (1.22 m to 1.53 m) on a side. Actual load heights can vary from approximately 18 in. (0.46 m) up to 10 ft (3.05 m). Therefore, there could be as few as one load or as many as six or seven loads between in-rack sprinklers that are spaced 10 ft (3.05 m) apart vertically.

Figure 19 – Plan and Elevation View of a Rack Storage Array with Sprinkler Locations (Source: NFPA 13 Handbook)

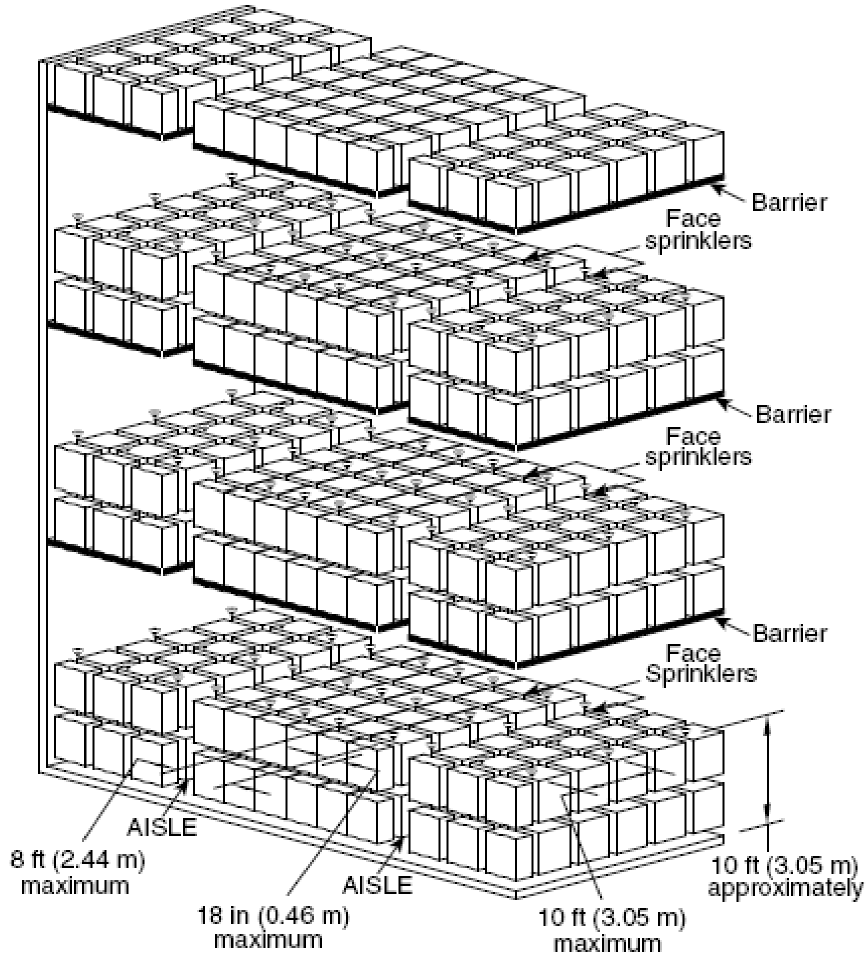


Figure 20 – Exploded Isometric View of Rack Storage Features
(Source: NFPA 13 Handbook)

The assumption that rack storage of boats is analogous to rack storage of Group A Plastics on solid shelves raises some questions given that a side-by-side visual comparison the storage arrays are clearly different in many respects. Figures 21, 22 and 23 illustrate a typical rack storage fuel array conditions used for sprinkler system fire testing. The boxes as shown in Figure 21 contain the standard Group A plastic commodity (16 oz. polystyrene plastic jars) used for validating Group A plastics sprinkler design criteria. Figures 24 and 25 depict a typical boat rack storage facility.

Figure 21. Prototypical Class A Commodity, 16 oz. polystyrene plastic jars in corrugated carton

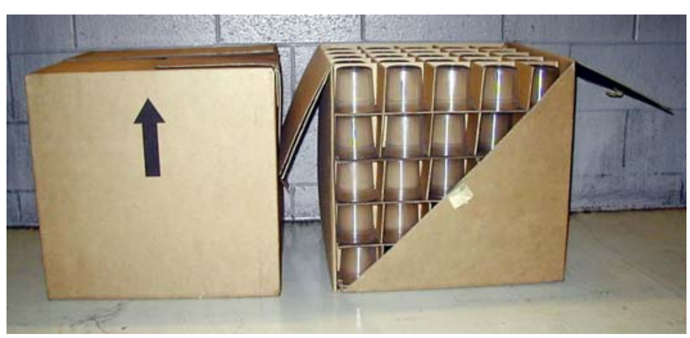


Figure 22. Example of Shelf Storage Array **Figure 23.** Example Fire Test Rack Storage Array

Figure 24. Boat Storage Array **Figure 25.** Rack Storage of Boats Showing Spacing

In addition to the clear differences apparent from a visual perspective there are also a variety of technical differences and practical issues regarding the installation of sprinklers in a dry stack boat storage facility. Several observations and comparisons are provided in Table 10 comparing the typical Group A plastics rack storage array with the boat storage array shown in the above figures.

Table 10 Comparison of Boats in Rack Storage Verses Standard Group A Plastics in Shelf Storage		
	Standard Group A Plastics	**Boats in Storage**
Commodity	16 oz. polystyrene plastic jars individually separated by cardboard dividers in a corrugated carton, paper and plastics in an easily ignitable configuration, plastic cups are thermally thin materials. Polystyrene heat-of-combustion ~39.9 kJ/g (Tewarson 1995)	Boat construction is mostly fiberglass reinforced plastics(FRP), a thermally thick material and more difficult to ignite than polystyrene jars, FRP materials are known for their fire resistant properties; boat shrouds, encapsulation covers, seating and finishes are likely more susceptible to ignition than the FRP; boats also are typically stored will filled or partially filled fuel tanks FRP heat-of–combustion ~12.9 – 26.0 kJ/g (Tewarson 1995)
Water Absorption	The initial surface to encounter water is corrugated carton which readily absorbs water & is easily wet by sprinklers	Boats are built to shed water, but will collect water that falls inside the shell, some of which can be drained through open drain plugs
Storage Configuration	Typical Group A plastics considers closely packed piles with narrow flue spaces, flue spaces are considered important to be maintained for the purpose of allowing heat to rise to ceiling sprinklers, slowing the horizontal spread of fire through the rack and for allowing ceiling sprinkler discharge to penetrate into the storage array. If flue spaces are not provided, in-rack sprinklers are required for each level of storage	Boats kept in storage require clearances that will generally exceed the flue space requirements of NFPA 13, however, the boats are large obstructions to water discharge from ceiling sprinklers. Flue spaces exceeding 24 in. are viewed as aisles and not flue spaces (FM Global Data Sheet 8-9). Providing sprinklers at each level of boat storage is complex design issue due to variations in boat size and geometry, and the variability possible in the case of flexible/movable boat racks.
Nature of Shelves	Shelves may be of wood or metal but are not viewed as the stored commodity driving the sprinkler requirements	The boats are not stored on solid shelves but are the actual commodity that would burn, the v-shaped hulls may not act to direct flames/hot gases horizontally in the same fashion that solid shelves do in the typical Group A plastics closed array.
Rack System	Racks for typical storage occupancies are independent of the building structure	Racks for boat storage facilities may be independent rack systems, but generally are integrated with the building structural system
Placement of sprinklers	If provided, at intersection of transverse & longitudinal flues, Face sprinklers required with 18 in. of aisle face.	The flue spaces in boat storage can be much greater than the 6 in. flues found in closely packed piles of Group A plastics and may not line up vertically due to variations in the racking system. The flue or open spaces between boats do not readily accommodate sprinklers since clearance is needed to allow proper maneuvering space to place boats in the racks. Face sprinklers are not readily implemented since boats will vary several feet in length and will interfere with the maneuvering space needed to place boats in the racks.
Encapsulation	Encapsulation is the method of packaging using a plastic sheet that encloses the tops and sides of a combustible fuel load. In some cases such as Class I – IV commodities, but not Group A plastics, encapsulation has been shown to impact sprinkler performance.	Although boats are typically a Group A plastic commodity, the practice of encapsulating boats kept in storage may or may not have an impact on fire development and associated sprinkler performance.

Loss History for Rack Storage

FM Global Property Loss Data Sheets 8-9, *Storage of Class 1, 2, 3, 4 and Plastic Commodities*, offers several general observations regarding rack storage losses.[35] The following is the quoted loss history from page 114 of the 2008 Data Sheets 8-9. The loss history is relevant to control mode density area sprinklers (CDMA) which over the period of the study would have been the most common type of sprinkler technology used.

Some general deductions can be made from a study of rack storage losses that occurred in a recent 18-year period, and in which no protection defects were identified. (Solid-piled/palletized losses have not been studied in similar detail.) These losses involve CMDA sprinklers exclusively. The basic findings are as follows:

1. *In-rack sprinklers, used in conjunction with ceiling sprinklers, are overwhelmingly successful.*

2. *Both damage and the number of sprinklers opened increase with higher storage/building heights.*

The percentage of rack storage fires controlled by a given number of sprinklers is shown in the table below:

Number of Sprinklers Opened	*Percentage of Fires Controlled*
1	14
2 or fewer	32
3 or fewer	41
4 or fewer	49
5 or fewer	54
10 or fewer	77
25 or fewer	98

For ceiling sprinklers only, the average number of sprinklers opened was eight. For ceiling plus in-rack sprinklers, the average was three ceiling and three in-rack sprinklers.

Hose stream use was identified in 87% of the incidents that operated ten or fewer sprinklers and, when hose streams were used, they were applied either before sprinklers operated or before fire control was achieved in a little more than 50% of the cases. This strong correlation suggests early application of hose streams has a significant effect on the average number of sprinklers that operate in rack storage fires (it would follow that this is also true for solid-piled/palletized storage fires), and that provision of small hose stations is a key element in the overall protection scheme. It is impossible to say how many catastrophic fires may have been prevented by early intervention using hose streams.

Stookey[36] summarized another analysis by Factory Mutual that reviewed 1076 incidents representing $171 million dollars in property damage and business interruption for a five year period in the 1980s. The summary provides the following information related to high-piled combustible storage for all types of commodities as follows:

Table 11 - High-Piled Combustible Storage – 1980s Events Loss Analysis (Source: ICC High Piled Combustible Storage Application Guide)	
Storage Height	**Fire Loss Findings –Sprinklered incidents**
< 15 ft.	Storage for this height category involved 76 % of the reported incidents but resulted in only 47 % of the dollar loss. Average dollar loss was approximately $97,000. The insurer attributed the low dollar loss to automatic sprinkler systems being capable of controlling fires for this storage height category where a reasonable good water supply is available.
15 – 26 ft.	This height category involved 20 % of the reported incidents but resulted in only 42 % of the dollar loss. Average dollar loss was approximately $327,000. The insurer concluded that the storage is also subjected to the overall effects of the fire (burning, prewetting, and smoke contamination) for longer periods of time since it requires a longer time period for sprinkler water to reach the fire and begin controlling a fire.
26 – 75 ft.	This height category involved only 1.4 % of the reported incidents and no losses were reported for storage heights over 30 ft. One-third of the losses were rolled paper storage.. Average dollar loss was approximately $1 million. High-piled combustible storage using automated retrieval equipment enjoyed the lowest fire loss experience due to the reduced ignition sources from smoking, hot work, and the operation of industrial lift trucks.

The FM data points to two potentially relevant findings. First, the application of small hose streams appears to have influenced rack storage fire scenarios in a positive manner and could be a consideration as a provision in boat storage facilities. However, having personnel trained to use small hose a line is an important occupational safety concern for facility owners. Secondly, there is an apparent reduced risk of large loss fires in storage facilities with automated retrieval systems due to reduced ignition sources from smoking, hot work, and the operation of industrial lift trucks. This would suggest that automated boat storage facilities would be subject to lower risk of fire occurrence than more conventional storage facilities.

COLLECTION OF SPRINKLER WATERFLOW IN STORED BOATS

The practice of dry stack or rack boat storage has been in use for many years. Where dry stack storage buildings are protected by automatic sprinkler, there is a concern that water collection in the boats will cause collapse of the rack structure due to weight of the "collected" water. This is a understandable concern, however, there is no known information as to the amount of water that actually collects within stored boats.

To develop some limited understanding, Schirmer Engineering conducted an investigation to determine the amount of water collected in boats representative of those expected to be stored in a proposed dry stack facility. This investigation developed quantitative data regarding the water collected when subjected to waterflow from the sprinkler system proposed for this structure.

The issue of water collection in the boats is of concern because the additional weight of water could result in a collapse of the rack structure. A structural collapse would endanger building occupants, firefighters, and cause damage to boats not involved in the fire. Where the rack structure is integral to the support of the building, such a collapse could result in a major building structural failure.

Some have suggested that this water collection problem could be solved by designing the rack structure to support the boats even when completely filled with water. Water weighs 8.345 pounds per gallon and any significant retention of water weight due to fire suppression efforts can push the structural design limits of the dry stack support system. Although it is physically possible, it is economically impractical to design the rack structure for such large loads (boats filled with water). Discussions with dry stack boat facility developers indicate that such projects would not be financially viable if the structural design of dry stack facilities was required to support water-filled boats. There are no dry stack facilities known to have been designed to meet such criteria.

To protect the boats from water collection, it is common practice to remove the bilge drain plug, cover each boat with some type of wrap, or store the boats upside down. It is doubtful that the removal of the bilge plug will drain water from the boat as fast as it collects from the sprinkler discharge. The latter two practices are not practical for larger boats.

There have been attempts to calculate the added weight due to water collection in stored boats relative to the drainage from the bilge plug. The problem is that some of the <u>values</u> to be entered into certain variables of these calculations must be estimated. One such example is how much water from the sprinklers enters the boat versus how much sprays beyond the sides of the boat? Another unknown is how much of the water that sprays into the boat actually stays in the boat? This is an unknown because boats are designed to "shed" water from waves by virtue of their shape and from scuppers that return the water back to the ocean/lake. Also, boats that are damaged from fires originating within a cabin space could allow water to enter the bilge and not be managed by the scuppers.

Concerning the collection of water in the boats, NFPA 303 requires:

> ***Section 7.2.3.2*** *Where boats are stored in multilevel racks, either inside or outside, for seasonal storage or for in-out operation, the following precautions shall be taken:*
>
> *(1) Drain plugs shall be removed (in sprinklered buildings).*

Water Filling Investigation

This investigation was conducted by installing a single sprinkler branchline with four sprinklers above a boat rack structure located outdoors. A boat was supported by a fork lift truck equipped with a digital scale to determine the weight of "collected" sprinkler water. The sprinkler system was activated (all four sprinklers had their operating elements removed before the test) and allowed to flow for 30 minutes. The weight of the collected water was recorded every five minutes. There were no operational bilge pumps on the boats.

Description of Boats

One test was conducted with a non-self bailing boat and a second test was conducted with a self bailing boat design.

Boat Number 1: 27-foot Magnum Marine, non-self bailing design, single ½-inch bilge drain hole open. The cabin of this boat has two parallelogram shaped port holes on each side (four total) with an area of 140 square inches each. The forward hatch is 24 inches by 24 inches (576 square inches). Pre-test boat weight was 5,750 pounds.

Boat Number 2: 28-foot Bow Rider Formula, non-self bailing design, dual ½-inch bilge drain holes open. Pre-test boat weight was 8,180 pounds.

Sprinkler System Mock-Up

The "mocked up" system consisted of a single sprinkler branchline with four sprinklers located along the centerline of the boat and elevated 9-feet above the bow of the boat. The sprinklers were spaced 10-feet on centers along the branchline and were Tyco Model TY-FRB, quick response type, K=8.0, 175° F. The glass bulb operating elements of each sprinkler were removed before the test.

This single branchline was connected to the existing sprinkler system at an existing marina through the building's exterior wall. A 2.5-inch globe valve and pressure gauge were provided at the exterior wall to "throttle" the sprinkler system to achieve the design flow (30 gpm minimum per sprinkler) anticipated for the sprinkler system. See Figure 26 below.

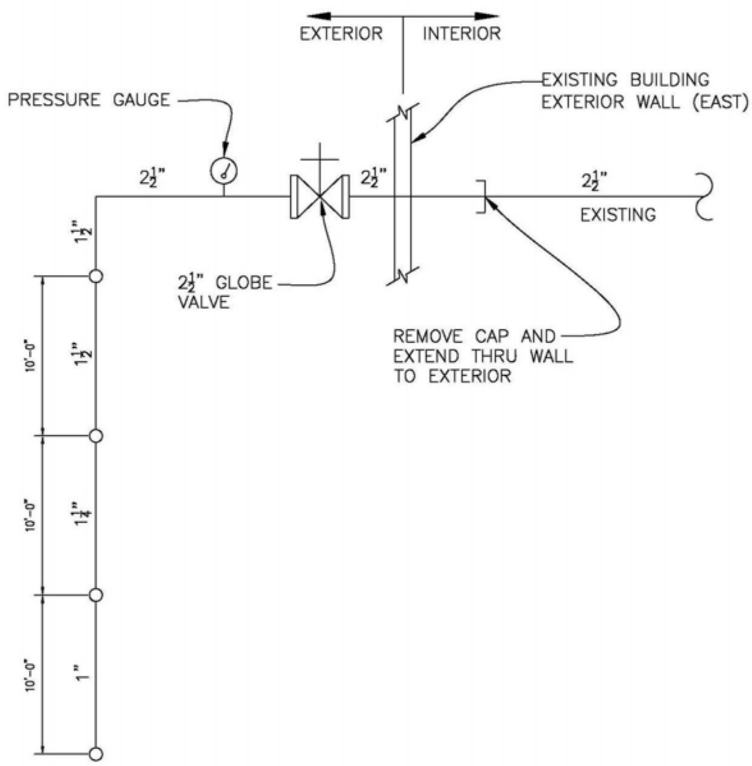


Figure 26 – Schematic of Sprinkler System "Mock-Up"

Fork Lift & Water Weight Measurement

A forklift used to position/support the boats below the mocked-up sprinkler system. The forklift simulated the boat rack storage structure and provided measurement of the boat's weight. The forklift used was a Wiggins Marina Bull, Model: W230M234/12, with a 32,000 pound capacity and digital scale.

Test Details

Table 12 provides the details of each test configuration. It is important to note that an engine compartment fire was not simulated because boats stored in this facility will be required to be provided with a self contained suppression system in the engine compartment.

Table 12 - Test Configurations

Test Number	Boat	Condition	Comments
1	Magnum Marine (Boat #1)	Water tight (cabin completely closed)	Simulates normally stored condition
2	Magnum Marine (Boat #1)	Port holes and forward hatch open; companionway closed	Simulates cabin fire flashover that causes port holes and forward hatch to fail/open
3	Magnum Marine (Boat #1)	Port holes, forward hatch, and companionway open	Simulates advanced cabin fire flashover that causes port holes, forward hatch, and companionway to fail/open
4	Bow Rider Formula (Boat #2)	Water tight (cabin completely closed)	Simulates normally stored condition

Table 13 - Test Results in Weight of "Collected" Water

Test Number	Weight of "Collected" Water (pounds)						Comments
	5 Minutes	10 Minutes	15 Minutes	20 Minutes	25 Minutes	30 Minutes	
1	350	480	680	680	780	730	
2	220	552	718	918	1,100	1,130	Closed companionway door impeded waterflow towards the stern and eventually to drain
3	313	579	679	810	977	1,060	Open companionway door allowed waterflow towards the stern and eventually to drain
4	16	16	16	Note 1	Note 1	Note 1	Note 1: Test discontinued due to no change in values

Analysis

The total waterflow rate from the four sprinklers was 136.4 gpm. Although the minimum design flow per sprinkler is 30 gpm, the system discharged more that 4 times 30 gpm because of balancing within the sprinkler system (causing more than 30 gpm to discharge from sprinklers that are closer to the water supply). Therefore the total weight of water discharged from the system at the intervals when the boat was weighed is shown in Table 14.

Table 14 - Weight of All Water Discharged from Sprinkler System

Weight of all Water Discharged from Sprinkler System					
5 Minutes	10 Minutes	15 Minutes	20 Minutes	25 Minutes	30 Minutes
682	1,164	2,046	2,728	3,410	4,092

When comparing Table 13 to Table 14 it is clear that only a fraction of the total water discharged is actually collected in the boats. In the worst case, Test Number 2 after 30 minutes only 27.6 percent of the total water collected in the boat. This is mainly due to the significant amount of water that is sprayed beyond the sides of the boat. The spray pattern of the most remote sprinkler was 24-feet in diameter at the floor level while the test boats are 7-feet at their widest point (referred to as the "beam"). The result is that approximately the outer 8.5-feet of the 24-foot diameter or 34 percent of the water "missed" the boat. To a lesser degree, some of the water collected in the boats was discharged through the bilge drain hole.

There are two advantages to water "missing" the boat. First, this water does not contribute to over loading the rack structure. Second, much of this water will contact the rack structural columns and can provide a cooling-factor for the exposed steel. The steel columns of the rack storage system also are structural columns that support the building.

The substantial amount of water that contacts the steel columns is a function of the large spray pattern and the proximity of these sprinklers to the columns. The face of the steel columns is no more than 8.5 feet from any in-rack sprinkler system and the sprinklers in this test produced a 24-foot spray pattern. Such a substantial amount of waterflow onto the columns provides a level of fire resistance where additional sprinklers dedicated to column fire resistance should not be necessary.

Non-self Bailing Boats

Test Number 2 with the companionway door closed actually resulted in more collected water because water was observed being impeded from readily flowing to the stern and subsequently discharging out the bilge drain hole.

As can be seen in Table 13 in the worst condition (Test Number 2), the weight of collected water after 30 minutes is less than 20 percent of the weight of the boat. In terms of structural design of the rack structure, designing for this additional weight plus a safety factor is potentially an economically feasible design.

Self Bailing Boats

In the case of the self-bailing boat design (Test Number 4) the boat weight increased by only 16 pounds at the 5 minute mark and remained at this weight to the 15 minute mark. It was concluded that the self-bailing design was able to discharge water from the vessel as fast as it entered and the 16 pounds represented the weight of the water that was on the vessel at it traveled to the discharge point (i.e., scuppers or bilge drain). Due to the steady state nature of the results in the first 15 minutes, the second 15 minutes of the test was aborted.

The availability of boats for this investigation did not allow for the removal of the cabin windows or other modifications to the vessel, therefore only one test configuration was conducted on the self bailing boat.

Firefighter Hose Streams

The testing conducted for this investigation centered on the amount of weight due to water collected in the boats from the sprinkler system. It is also important to address the weight due to water collected in the boats from to firefighter hose streams. Waterflow due to hose streams differs from sprinkler as follows:

1. Amount: typical Sprinklers discharge approximately 20 -50 gpm, depending upon the available pressure. Firefighter hose streams can range between 90 gpm to 250 gpm depending upon the size of the hose/nozzle.

2. Application: Sprinklers apply the water uniformly in distributed umbrella pattern and firefighter hose streams apply water in a highly directed manner or non-uniformly depending upon how the firefighters are positioned relative to the fire and type of nozzles being utilized.

During manual fire fighting efforts, there is no way to estimate the amount of water that could accumulate in a boat from fire hose streams. Such fire fighting streams produce much higher flow rates than typical sprinklers and these high flow rates can easily be concentrated on one area. As a result, the operational pre-plan of fire departments for manual suppression needs to consider and implement appropriate tactics when approaching dry stack facilities.

Conclusions – Water Filling Analysis

For the above investigation, four full scale tests were conducted to determine the collection of automatic sprinkler system water in boats stored in a rack structure. The testing was limited to two boats of similar size; one non-self bailing and one self bailing design. The findings are limited due to having only two boats and a specific sprinkler arrangement, but do provide some insight into how rapidly water may accumulate in boats due to sprinkler discharge. The data provides the following conclusions for the boats and scenarios tested:

A. The worst case condition for water collection in the boats from sprinkler flow was for a non-self bailing boat. Non-self bailing boats are older designs therefore should be a very low percentage of the total number of boats in a modern dry stack storage facility.

B. In self bailing boats (the most prevalent type), their designed ability to shed water results in an insignificant amount of collected water.

C. Approximately 34 percent of the sprinkler discharge spray pattern travels beyond the perimeter of the boat and does not contribute to additional loading (weight) of the rack structure.

D. A significant amount of water is available and can reach the steel rack structural uprights. This provides a cooling effect for the steel members by transferring heat away from the steel.

E. In non-self bailing boats, 55 percent more sprinkler water was retained when the cabin enclosure was breached (e.g., port holes or forward hatch fail due to flashover).

F. In non-self bailing boats, a closed companionway door resulted in more collected sprinkler water because the water could not readily flow to the stern to drain from the boat. Then the companionway door was open, less water was retained.

G. In the worst case configuration, non-self bailing boats collected an additional 1,130 pounds of weight in the boat from sprinkler water.

H. The weight due to water collected in the boats from firefighter hose streams can easily be much greater than from sprinkler discharge. It is suggested the exclusive use of AFFF type foam or compressed air foam automatically supplied to fire hose valves in such structures is a viable way to limit the weight added to the boats as a result of water application during suppression activities.

ALTERNATIVE TECHNOLOGIES FOR BOAT STORAGE/DRY STACK FACILITIES

The primary focus of this project is automatic sprinkler protection for rack storage of boats; however, there are a number of other technologies that could be considered to provide fire protection solutions for dry stack facilities. Several of these technologies are not new and have been suggested for dry stack facilities in the past (e.g. high expansion foam systems, foam-water sprinkler systems). Other technologies represent recent fire protection system developments which have not been tested for dry stack facilities, but are potential fire protection solutions. The following discussion briefly identifies several of the fire systems technologies that could be considered for dry stack facilities, however, the list is not all inclusive and other technologies may be viable. It is noted that the relative costs and benefits of the various fire systems is beyond the scope and analysis of this project.

New Technology Sprinklers

Boat storage facilities vary in building area, may or may not utilize racks, and those having racks will vary by the number of levels. Sprinkler manufacturers now offer a wide variety of high-challenge sprinklers for storage applications. These include Early Suppression Fast Response (ESFR) sprinklers and various control mode extended coverage sprinklers. The capabilities of these sprinklers to suppress any of the variety of boat storage configurations is not currently known, but there exists the potential for these high challenge sprinklers to provide effective fire protection solutions for boat storage. The large water flow capabilities of these newer sprinklers needs to evaluated in conjunction with the risk of too rapidly filling boats in rack storage with water and quickly overloading the structural system.

High Expansion Foam Systems

High expansion foam systems are a potential consideration for dry stack boat storage facilities. Such systems use high expansion foam generators that use an air blower to develop a massive flow of air-filled bubbles. The foam generators develop a foam solution having a foam-to-solution ratio ranging from 100 to 1 up to 1000 to 1. The foam solution serves to extinguish the fire by conversion of water in the foam to steam, prevention of air entrainment to the fire by blanketing the burning commodity, and cooling due to application of the wet foam. The typical application for dry stack facility would be to use a total-flooding high expansion foam system, with the intent of filling the entire building storage volume to just above the highest level of boat storage.

There are a number of considerations related to applications of high expansion foam systems. Total-flooding systems need to cover the protected volume in a timely manner and maintain sufficient foam discharge to compensate for breakdown due to sprinkler discharge, shrinkage of the foam, fire degradation of the foam or other factors. Doors to confine the foam need to be closed automatically, but vents need to be located up high in the protected volume to allow for displacement of air and escape of foam. Personnel hazards for occupants who may become trapped in a high expansion foam discharge. The basic requirements for the design of high expansion foam systems are found in NFPA 11, *Standard for Low-, Medium-, and High Expansion Foam.*

AFFF Foam-Water Systems

Aqueous Film-Forming foams (AFFF) systems are systems using synthetic foams that are recommended for their capability to provide a thin aqueous film over flammable liquids. This floating film works to suppress combustible vapors and provide a cooling effect to the fuel substrate. Due to AFFF's good surface-spreading characteristics it has been recognized as a key fire protection solution for aircraft fuel spill scenarios, and has been suggested and reportedly used as agent for dry stack facilities due to the potential fuel release hazard associated with stored boats. AFFF can be applied from hose systems or sprinkler systems using specialized air-aspirating sprinklers or conventional water sprinklers. Other equipment required includes foam concentrate storage tanks, proportion and pumps. AFFF normal temperature range limitations are 35 – 120˚ F (1.7 - 49˚ C).The basic requirements for the design of foam-water sprinkler systems are found in NFPA 16, *Standard for the Installation of Foam-Water Sprinkler and Foam-Water Spray Systems.*

Compressed-Air Foam Systems

Compressed-air foam (CAF) systems include both manual fire fighting systems and fixed-pipe fire suppression systems. CAF is a fire suppression is a foam medium created via the injection of compressed air into a foam solution. The benefit of CAF is the fire suppression efficiency that results due to the expanded surface-to mass ratio of water droplets (more small droplets with more water surface area than fewer large droplets), a reduced surface tension which allows water to penetrate to fuel faster and an enhanced ability for the water to cling to materials. One example of the efficacy of CAF medium at work is a fully involved house fire that is fully extinguished by a hose stream application in 30 seconds with only 40 gallons of water. This example points to the benefit of CAF systems in areas with poor water supplies.

Recent studies [37, 38, 39] have reported on the performance of CAF fixed-pipe systems verses foam-water sprinkler systems for flammable liquids hazards and power transformers (2004 Crampton, kim) (2004 kim CRampton, Asselin) showing effectiveness with only 25% of the water needed for standard foam water sprinkler systems . Such systems have emerged only during the last 7 years. CAF fixed-pipe systems have been considered for boat storage facilities, but have not yet been implemented. Implementation of the current CAF fixed-pipe technology in a dry stack facility is complicated by the fact that current technology must be designed using a balanced pipe system and specialized open nozzles. These limitations require that large systems be zoned and activated with an associated zoned detection system.

Water Mist Systems

Water mist systems are well recognized capable fire suppression systems that have been implemented for a wide variety of applications ranging from machinery spaces with combustible/flammable liquids hazards, to passenger ships and art galleries. The design and installation of water mist systems is addressed in detail by NFPA 750, *Standard on Water Mist Fire Protection Systems*. Water mist systems vary widely in their nozzle design, operating pressures, and application parameters. An advantage over standard sprinklers is the reduced water quantities needed to effect suppression or extinguishment. Implementation of water mist systems in a large boat storage facility is expected to be considerably more complex than a conventional sprinkler system with in-racks.

Hybrid Water-Based Inert Gas System

Boat storage facilities are relatively large volume buildings and routinely have large doors open. Due to these conditions gaseous, or clean agent systems are not practical for boat storage facilities. However, a new technology using water and nitrogen discharged simultaneously via a high-velocity atomization emitter has shown to be effective for normal combustible fuels and flammable liquid fires. The validity of this technology for a dry stack boat storage facility is plausible depending on the nature of the dry stack facility and offers the benefit of needing far less water than required for a conventional rack storage sprinkler system. Also, the nitrogen component is capable of extinguishing small fires in large rooms in fully ventilated environments. This type of system would require that large systems be zoned and activated with an associated zoned detection system. [40, 41]

Aerosol Systems

Fixed aerosol fire extinguishing systems are a new category of fire protection systems that develop by chemical combustion reaction an extinguishing medium of finely divided solid particles, known as a condensed aerosol. Another type of aerosol system is that which uses fine particles of solid chemicals suspended in a halocarbon or inert gas, known as dispersed aerosol. In both cases, such particles are typically less than 10 microns in diameter work to extinguish fire through several mechanisms including flame inhibition, heat absorption, cooling, and oxygen dilution. Rather than supplying a fire suppression agent through a network of pipes condensed aerosol systems rely on aerosol generators. These devices are fixed canisters that use either a local or remote means of activation. Other aerosol systems use a storage container arrangement that distributes agent through a pipe system to discharge nozzles. Aerosol systems have primary application for enclosed or localized spaces and are recognized for commercial marine applications (engine rooms, machine spaces), although some systems have been suggested for large continuous rooms. Condensed aerosol systems could potentially play a role in dry stack facilities for boats with large interior cabins, if concerns for a concealed fire initiated in the cabin or compartment of a recreational boat were a credible fire scenario issue (credible in the dry stack context) that could not be addressed by other means. In August 2005 NFPA approved the first edition of NFPA 2010 (2006 edition), *Standard for Fixed Aerosol Fire–Extinguishing Systems*, which provides installation criteria for aerosol systems.

Wireless Detection Systems

The dry stack marina industry is continuously evolving from those early facilities having the capability of handling boats of 25 feet in length, to today's facilities that will handle boats in excess of 50 feet in length. The largest boats have significant interior spaces or compartments that pose the risk for having a significant compartment fire (although loss history doesn't support this as a commonly expected scenario) and commercial wireless detection systems are a potential consideration for placing fire detection in a stored boat. Such systems could be effective detection option for boats in storage since they could be placed into a boat being moved into storage, yet could be readily removed when a boat is withdrawn to the water. Wireless detection systems use smoke or heat detectors and are addressable to locate any boat that may be see fire activity onboard during storage. There can be technical issues due to limitations in signal transmission distances and interference sources, such as the metal structural system of a boat storage facility, as well as, restrictions on using wireless detectors in below freezing temperatures.

FIRE FIGHTING AGENTS ENVIRONMENTAL AND TOXICITY ISSUES

Dry stack marina facilities are typically adjacent to waterways and consequently, such operations should not overtly threaten the environment within the waterway. The NFPA Standard for Low-, Medium-, and High-Expansion Foam (NFPA 11-2005) does not address the environmental and toxicity issues with foam in the body of the Standard, but does cover this in some detail in Annex F of the Standard. A portion of this reads as follows:

> "*However, with the every-increasing environmental awareness, recent concern has focused on the potential adverse environmental impact of foam solution discharges. The primary concerns are fish toxicity, biodegradability, treatability in wastewater treatment plants, and nutrient loading. All of these are of concern when the end-use foam solutions reach natural or domestic water systems. Additionally, the U.S. Environmental Protection Agency (EPA) has highlighted a potential problem with some foam concentrates by placing glycol ethers and ethylene glycol, common solvent constituents in some foam concentrates, on the list of hazardous air pollutants under the 1990 Clean air Act Amendments."*

The Material Safety Data Sheets (MSDS) for AFFF[42, 43,] indicate the presence of Diethylene Glycol Monobutyl Ether, Tertiary Butyl Alcohol, and Hexylene Glycol

All AFFF mixtures also contain fluorinated surfactants.[42, 43, 44] Fluorinated surfactants used in AFFF are produced from fluorochemicals manufactured by two methods: electrochemical fluorination and telemerization. The electrochemical process, used since the 1950's, produces perfluorooctane sulfonyl fluoride (POSF). The degradation of POSF-derived fluorchemicals as well as the hydrolysis or neutralization of POSF results in the formation of perfluorooctyl sulfonate (PFOS) PFOS is currently a major focus of the U.S. EPA's regulatory activities.[44] One company, 3M has voluntarily phased out manufacture of POSF-derived fluorochemicals for use in products including AFFF.[44] Other AFFF manufacturers, whose products do not contain PFOS, continue to manufacture AFFF for both commercial and military use.[45] However the use of fluorotelomer compounds replacing PFOS foams has come under question as scientists warn that not enough is known about these replacements.[46] The Fire Fighting Foam Coalition (an AFFF industry organization) has responded to raised concerns and provides information related to the environmental acceptability of currently manufactured fire fighting foams.[47]

The design of boat storage facilities would normally incorporate open channels of water, within the structure, that would be connected to an open body of water, thus increasing the likelihood that discharged foam solution will enter the open body of water. The MSDS[42, 43] also contain the following caution "As much as possible, keep from being washed into surface water. Dispose of in compliance with national, regional, and local provisions that may be in force."

Reported release of fluorinated surfactants to surface water, as a means of disposal for AFFF wastewater are limited, however AFFF wastewater released to a Florida river in 1993 has been investigated as a possible cause of sea bird illnesses and deaths.[48] Other studies have shown that it is not necessarily safer for the environment to use foam agents that do not contain fluoride, as illustrated by the higher aquatic toxicity of non-fluoridated foams as compared to AFFF.[49]

FINDINGS AND SUMMARY

The focus of this project is automatic sprinkler protection for rack storage of boats or dry stacks. To develop a thorough understanding of the issues and complexities related to rack storage of boats several topic areas have been identified and reviewed.

- Recreational Boat Construction and Material Properties
- Burning Behavior of Fiber Reinforced Plastic (FRP) Composites
- History and Characteristics of Boat Storage Facilities
- Collection and Review of Boat Fire Loss Data
- Other Vehicle Storage Facilities – Automobiles and Planes
- Current Sprinkler Protection Requirements for Boat Storage
- Investigation of the Amount of Water Collected in Boats due to Sprinkler Discharge
- Alternative Technologies for Boat Storage Facilities
- Fire Fighting Agents' Environmental Issues

Recreational Boat Construction and Material Properties

Marina storage facilities are overwhelmingly populated with recreational boats as opposed to commercial vessels. Due to cost, appearance, and durability issues, these boats are mostly built with composite construction. NMMA reports that for engine-driven boats, 58% use fiberglass (FRP-composite) construction; 37% are built with aluminum or steel and around 1% are wood. Anecdotally, we know that the percentage of boats stored in marinas that are built with composites is even higher than the overall population. There is a wide variety of recreational boats ranging from fish and ski boats of 15 -22 feet in length to motor yachts of 26 -100 feet in length with significant enclosed cabin spaces.

Fiber Reinforced plastic (FRP) composites a.k.a. fiberglass construction has been the mainstay of the recreational boating industry since the mid 1960s. FRP materials have gained unilateral acceptance in pleasure craft because of light weight, vibration damping, corrosion resistance, impact resistance, low construction costs and ease of fabrication, maintenance and repair. Three broad groups of materials are common elements of composite boat construction:

- Resins
- Reinforcements
- Core Materials

The marine industry has generally based its structures on polyester resin, with trends to vinyl ester and epoxy for structurally demanding projects and highly engineered products. Reinforcements for marine composite structures are primarily E-glass (lime aluminum borosilicate) due to its cost for strength and workability characteristics. In contrast, the aerospace industry relies on carbon fiber as its backbone. In general, carbon, aramid fibers and other specialty reinforcements are used in the marine field where structures are highly engineered for optimum efficiency. Core materials form the basis for sandwich composite structures, which clearly have advantages in marine construction. A core is any material that can physically separate strong, laminated skins and transmit shearing forces across the sandwich. Core materials range from natural species, such as balsa and plywood, to highly engineered honeycomb or foam structures.

Burning Behavior of Fiber Reinforced Plastic (FRP) Composites

The majority of recreational boats are built of fiber reinforced plastics (FRP) and more specifically the majority are constructed of glass reinforced plastics (GRP). A significant work done by Samanta *et al* at the Robert Gordon University School of Engineering has addressed in detail the Thermo-mechanical Assessment of Polymer Composites Subject to Fire. This work points to the increased use of GRP materials in the offshore oil and gas industry due to GRP advantages of high strength, low weight and high- temperature behaviors. Samanta *et al* also provide a literature review that notes the works of numerous other researchers that have identified the relative good fire resistive capabilities of FRP/GRP composites. These fire resistive properties are generally attributed to the endothermic decomposition of the composite matrix which slows down heat transmission through the laminate or what may be described alternatively as, the cooling action that results from the decomposition of the resin. Also important, is the fact that as the resin burns away from each ply, the thermo-conductivity of that ply is greatly reduced (dry fiberglass becomes a good insulator).

History and Characteristics of Boat Storage Facilities

Rack storage of boats or dry stack storage started in the 1960's in the southeastern United States. Initially, these facilities were capable of storing boats no longer than 25 feet. Loading was accomplished using standard commercial fork lifts to place boats into racks with three to four tiers of storage. By the 1990's facilities had improved capabilities to handle boats of over 40 feet in length, using forklifts specially adopted for marine use or stacker cranes that could more easily maneuver boats to heights as great as 50 feet providing four to five tiers of storage. Today, facilities are being proposed with eight to ten tiers of storage for boats up to 50 feet in length, in buildings over 100 feet tall.

Boat storage facilities vary significant in size and number of buildings, degree of building enclosure, storage arrangement and density. In warm, nonfreezing climates facilities may be simple steel structures having only a roof for sun shading. In winter climates indoor storage facilities provide protection against the extreme cold, snow and sun. Facilities may be relatively small facilities that accommodate smaller recreational boats. Typical moderate to large facilities are often one-story warehouses where motorized boats and/or sailboats are stored together. In the winter one-story warehouses would be filled with boats nested together to allow for maximum utilization of the storage space. These facilities can accommodate a wide range of boats from fishing boats to cabin cruisers and sailboats with their masts removed.

Tall facilities using rack storage arrangements tend to have a more regular storage arrangement as compared to the nested boat storage situation found in one-story facilities. Also, rack storage facilities require large center aisles to accommodate the manually operated lift truck equipment used to load and unload boats from the rack supports. The latest and most sophisticated rack storage facilities are those which allow boats to motor from the public waterways directly via a canal or channel into the storage facility. These facilities are fully automated using laser guided or other technology allowing for a boat afloat to be lifted from the water and quickly (2-5 minutes) located into a reserved rack storage location sized for the boat being stored. Such facilities allow for boat owners to routinely keep their boats in storage and sheltered from the elements and yet have the ability to quickly retrieve their boat for a day on the water.

Collection and Review of Boat Fire Loss Data

The Davis & Company, Ltd (Davis) database and with sourcing information from the four major marina insurer clients was used to document boat fire loss history. Also, the Fire Analysis and Research Division of NFPA did provide their report "*Selected Published Incidents Involving Marinas"*, which is attached as Appendix A to this report. Upon reviewing the incidents provided by NFPA it was noted that several were represented within the Davis database. A review of the data of published incidents provided by NFPA indicates the identified cause/s to be consistent with that found in the Davis data search. This data provided insight into fire fighting assets and circumstances surrounding fire discovery not found elsewhere. There was no report wherein either a heat detection system or sprinkler system was present. In many instances the location of the fire was on a dock or at a remote location (island or storage building far from city resources) with limited hydrants or no hydrants requiring fire departments to draft water from a river or lake. The set up of long hose lines or drafting lines delayed the response in combating the fire. Noted also was the time of the call to response arrival of only a few minutes (<10) yet the fire has propagated from the origin boat to two or three others. Fires that occurred in buildings or afloat with a roof over the slips are noted to more readily communicate the fire and involve more boats, likely due to the increased heat convection/radiation enhanced by the enclosing structure/s.

Other Vehicle Storage Facilities – Automobiles and Planes

Parking garages pose a hazard similar to motor boat storage occupancies in that both house vehicles with motors, fuel system and filled or partially filled fuel tanks. NFPA 13 considers parking garages as an Ordinary Hazard 1 occupancy requiring a sprinkler density of 0.10-0.15 gpm/ft^2 over a respective design area of 4,000-1,500 ft^2. From the perspective of boat storage, only boats stored on a single-level such as a roll-in storage facility should be considered as analogous to a parking garage with ceiling sprinkler protection.

The review of parking garage fires is perhaps of only limited use in understanding the fire risks and burning behavior of boat storage facilities. Parking garages are highly active storage facilities with a continuously changing population of operating vehicles and vehicle types. Also, It should be recognized that a key difference between parking garage and boat storage is that the car owner/driver is operating the vehicle in the storage facility (the exception is valet parking) whereas marine storage facilities have the operator turn over control of their boat to the boat storage facility operator. Consequently, the boats fuel and electrical systems are not active during (although maybe operational) the process of being placed into storage. Conversely, automobile fuel and electrical systems are combusting fuel, generating energy and heat during the parking operation.

A notable statistic from the several parking garage fire studies is that fire spread tends to be limited to one to two additional vehicles beyond the initial involved vehicle. Of course, this statistic considers that vehicles are parked on the driveway surface with 1-2 feet of separation and not in a tiered or rack storage arrangement. Also this statistic may be attributed to the body forming metal construction features (steel, metal doors, hoods, panels) of vehicles, whereas most recreational boats are of fiberglass construction.

The history behind the current provisions of NFPA 409, *Standard on Aircraft Hangars*, is that the standard has evolved over the years from an objective of providing fire protection capable of protecting solely the hangar structure using water only, via extra hazard pipe schedule systems and calculated deluge sprinklers. The current NFPA 409, clearly recognizes the high dollar values of the aircraft, and; the risks related to fuel spills, fuel tank fire involvement and shielding of roof fire suppression systems by large winged aircraft. To cope with these risks NFPA 409 has developed four categories or “Groups” of hangars - Group I, II, III and IV, - which vary according to size of aircraft and the fire area allowed for various building construction types.

NFPA 409 contains a menu of fire protection system options for fueled aircraft that fall into one of three principal categories:

- Foam-water deluge sprinkler systems with supplemental low or high expansion foam systems for wing areas greater than 3,000 sq. ft.
- Automatic closed-head sprinkler systems combined with low-level, low or high expansion foam systems to provide foam protection at the floor area.
- Automatic closed-head AFFF foam-water sprinkler systems at the roof.

NFPA 409 does have other options for non-fueled aircraft storage, however, such situations are not typically practical scenarios for consideration. Factory Mutual Data Sheets 7-93 consider a non-fueled aircraft as having residual fuel not in excess of 0.5% of the total fuel capacity of the aircraft (285 gallons for a 747). The process of draining and purging an aircraft fuel tank is generally impractical, and the fuel handling operations likely pose greater risks than just allowing the fuel to remain in the aircraft fuel tanks.

Current Sprinkler Protection Requirements for Boat Storage

The 2006 edition of NFPA 303, *Fire Protection Standard for Marinas and Boatyards*, contains several provisions regarding the installation of automatic fire-extinguishing systems for buildings exceeding 5000 ft^2. The noted provisions do not mandate that automatic sprinkler systems be used; however, automatic sprinklers are generally the most common, practical approach to providing fire protection when required by NFPA 303. Other types of automatic fire-extinguishing systems are potentially applicable. Boats vary widely in size and degree of compartmentation (i.e. cabin, engine spaces). Fish and ski boats may be on the order of 20 feet in length with an open top design, whereas inboard cruisers may be 40 or more feet in length with enclosed quarters for sleeping, cooking, and restroom facilities. The facilities that store boats also will vary by the nature and size of boats housed, ranging from one-story facilities which house only small to large boats, or more sophisticated vertical dry stack or rack storage facilities.

From the perspective of roll-in or grade level boat storage, and depending on the size and compartmented nature (with or without enclosed cabins) of the boats, it is possible that any of the categories – OH1, OH2, EH1, or EH2 – could be applied. From a practical perspective, it can generally be expected that single level or roll-in storage facility will house a mix of boats, varying in size and some having enclosed cabin space. This would suggest that such single level storage facilities, if sprinklered, need to provide a water density and area of coverage consistent with the EH1 or EH2 hazard classes in order to address the largest boats with substantial compartmented spaces. Currently, there is no large or full scale fire test data that substantiates if this criterion is sufficient protection or not for single level, one-story type boat storage facilities.

Multi-level rack storage facilities pose different challenges compared to single level or roll-in storage facility and until recently NFPA 303 provided no criteria for the application of sprinklers for rack storage of boats. NFPA 303 Section 6.3.4.4 now states that automatic sprinkler systems shall be designed per Chapter 12 of NFPA 13 – 2002 Edition for Group A Plastics stored on solid shelves. This requirement represents a best effort judgment by the Committee to provide some guidance to the designers and developers of these facilities; however, there is no current large or full scale fire test data that substantiates if this criterion is adequate, or inadequate; and, correspondingly with too much or too little conservatism for indoor rack-style boat storage. The assumption that rack storage of boats is analogous to rack storage of Group A Plastics on solid shelves raises some questions given that the storage arrays are clearly different in many respects. A number of these differences are listed and discussed in Table 10 of this report.

FM Global loss statistics provide some insight into the performance of all rack storage facilities. The loss history is relevant to control mode density area sprinklers (CDMA) which over the period of the study would have been the most common type of sprinkler technology used. The basic findings are as follows: 1) In-rack sprinklers, used in conjunction with ceiling sprinklers, are overwhelmingly successful. 2) Both damage and the number of sprinklers opened increase with higher storage/building heights. The FM data also points to two potentially relevant findings. First, the application of small hose streams appears to have influenced rack storage sprinklered fire scenarios in a positive manner and could be a consideration as a provision in boat storage facilities. However, having personnel trained to use small hose line is an important occupational safety concern for facility owners. Secondly, there is an apparent reduced risk of large loss fires in storage facilities with automated retrieval systems due to reduced ignition sources from smoking, hot work, and the operation of industrial lift trucks. This would suggest that automated boat storage facilities would be subject to lower risk of fire occurrence than more conventional storage facilities.

Investigation of the Amount of Water Collected in Boats Due to Sprinkler Discharge

Four full scale tests were conducted to determine the collection of automatic sprinkler system water in boats stored in a rack structure. The testing was limited to two boats of similar size; one non-self bailing and one self bailing design. The findings are limited due to having only two boats and a specific sprinkler arrangement, but do provide some insight into how rapidly water may accumulate in boats due to sprinkler discharge. The data provides the following conclusions for the boats and scenarios tested:

A. The worst case condition for water collection in the boats from sprinkler flow was for a non-self bailing boat. Non-self bailing boats are older designs therefore should be a very low percentage of the total number of boats in a modern dry stack storage facility.

B. In self bailing boats (the most prevalent type), their designed ability to shed water results in an insignificant amount of collected water.

C. Approximately 34 percent of the sprinkler discharge spray pattern travels beyond the perimeter of the boat and does not contribute to additional loading (weight) of the rack structure.

D. A significant amount of water is available and can reach the steel rack structural uprights to provide cooling to the steel members by transferring heat away from the steel.

E. In non-self bailing boats, 55 percent more sprinkler water was retained when the cabin enclosure was breached (e.g., port holes or forward hatch fail due to flashover).

F. In non-self bailing boats, a closed companionway door resulted in more collected sprinkler water because the water could not readily flow to the stern to drain from the boat. Then the companionway door was open, less water was retained.

G. In the worst case configuration, non-self bailing boats collected an additional 1,130 pounds of weight in the boat from sprinkler water.

The weight due to water collected in the boats from firefighter hose streams can easily be much greater than from sprinkler discharge. It is suggested the exclusive use of AFFF type foam or compressed air foam automatically supplied to fire hose valves in such structures is a viable way to limit the weight added to the boats from due to water application during suppression activities.

Alternative Technologies for Boat Storage Facilities

The primary focus of this project is automatic sprinkler protection for rack storage of boats; however, there are a number of other technologies that could be considered to provide fire protection solutions for dry stack facilities. Several of these technologies are not new and have been suggested for dry stack facilities in the past (e.g. high expansion foam systems, foam-water sprinkler systems). Other technologies represent recent fire protection system developments (e.g. water mist, CAF fixed-pipe systems) which have not been tested for dry stack facilities, but are potential fire protection solutions. This report identifies several of the fire systems technologies that could be considered for dry stack facilities, however, the list is not all inclusive and other technologies may be viable. It is noted that the relative costs and benefits of the various fire systems is beyond the scope and analysis of this project.

Fire Fighting Agents' Environmental Issues

Dry stack marina facilities are typically adjacent to waterways and consequently, such operations should not overtly threaten the environment within the waterway. The NFPA Standard for Low-, Medium-, and High-Expansion Foam (NFPA 11-2005) does address the environmental and toxicity issues in some detail in Annex F of the Standard.

Particular emphasis has been placed on AFFF mixtures which contain fluorinated surfactants. Fluorinated surfactants used in AFFF are produced from fluorochemicals manufactured by two methods: electrochemical fluorination and telemerization. The electrochemical process, used since the 1950's, produces perfluorooctane sulfonyl fluoride (POSF). The degradation of POSF-derived fluorchemicals as well as the hydrolysis or neutralization of POSF results in the formation of perfluorooctyl sulfonate (PFOS) PFOS is currently a major focus of the U.S. EPA's regulatory activities. One company, has voluntarily phased out manufacture of POSF-derived fluorochemicals for use in products including AFFF. Other AFFF manufacturers, whose products do not contain PFOS, continue to manufacture AFFF for both commercial and military use. However the use of fluorotelomer compounds replacing PFOS foams has come under question as scientists warn that not enough is known about these replacements. The Fire Fighting Foam Coalition (an AFFF industry organization) has responded to raised concerns and provides information related to the environmental acceptability of currently manufactured fire fighting foams.

Summary

Boat storage facilities pose a number of unique fire protection issues. The fire protection needed is complicated by the fact that the stored commodity can vary significantly given that boats range in size from 20 feet in length with an open top design, to inboard cruisers of 40 or more feet in length with enclosed cabins. The storage facilities also can vary from one-story, roll-in facilities to sophisticated automated rack storage buildings. Most boats in dry stack storage are stored with filled or partially filled fuel tanks.

Various sprinkler protection schemes are possible given the types of boats stored and height or number of tiers of storage. Currently, NFPA 303 requires that automatic sprinkler systems for dry stacks be designed for Group A Plastics stored on solid shelves. However, there is no current large or full scale fire test data that substantiates if this criterion is adequate, or inadequate; or what degree of conservatism exists. The assumption that rack storage of boats is analogous to rack storage of Group A Plastics on solid shelves raises some questions given that the storage arrays are clearly different in many respects. An additional complication is the issue of water collection in the boats. This is a concern because the additional weight of water could result in a collapse of the rack structure. Hence, there must be consideration for balancing concerns for limited structural failure due to water accumulation in the boats and providing a greater density of water application that could fail the rack system.

The greatest risk of fire in boat storage facilities is attributable to human error during repair or maintenance operations and an emphasis on fire prevention should be an important goal for boat storage facilities. Given a fire ignition, there is no specific data available to fully understand the burning behavior of boats in a rack storage array or the appropriate sprinkler criteria for the hazard especially given the wide variations in boat construction and storage methods. At this time several recommendations have been developed to address many of the unknowns of boat storage including dry stacks. These recommendations intend to highlight areas of concern that include maintenance /repair operations in the storage facility, effectiveness of fire detection systems and standpipe systems, automatic sprinkler/suppression system effectiveness and fire department pre-incident planning.

RECOMMENDATIONS

1. **Considerations for Boat Maintenance or Repair Operations in the Storage Facility:** The greatest risk of fire in boat storage facilities is attributed to human error during repair or maintenance operations. The 2006 edition of NFPA 303 requires that when work is performed on a boat in an unsprinklered storage facility that management is to perform an inspection to ensure no hazards result from the days work. Also, NFPA 303 does prohibit repairs to boats that are on racks and also prohibits repairs to boats that are inside an in-out dry storage building (NFPA 303 Section 7.2.3). Based on surveys of existing facilities it is common to find repair and maintenance work being done on boats in all types of facilities. For example in rack storage buildings it is common to find the main aisles with a boat out of the racks on the floor of the facility and having maintenance work or repairs done. It is recommended that the NFPA 303 Committee consider reviewing their current provisions and if necessary develop new recommendations or guidance language to address protection measure or precautions to be taken when maintenance/repair work is to be done. The review and development of new recommendations or guidance language should account for factors such as but not limited to the following:

   a. Facilities with or without automatic fire suppression systems
   b. Separated or segregated area for boat repair/ maintenance
   c. New or existing facility (limitations)
   d. Physical distance separation of boats from racks
   e. Management inspection procedures (akin to NFPA 303 Section 7.2.2.1)
   f. Protection measures or precautions when repair or maintenance work is done
   g. Proximity and type of manual fire extinguishers; and, extent of extinguisher training for staff or others as deemed appropriate or necessary

2. **Considerations for Fire Detection Systems in Facilities:** The 2006 edition of NFPA 303 requires that fire detectors be installed in interior or covered locations that are not protected by a fixed automatic sprinkler system. Such areas include those used for enclosed or covered storage of vessels, and areas used for enclosed or covered maintenance of vessels. Currently, the recommendation for any type of fire detection for these areas is absent and there is no data to support the selection of any type of technology as more or less effective for the boat storage or maintenance areas of boat storage facilities It is recommended that any fire testing program include potential types of fire detection technologies (e.g. heat, smoke, video, linear heat, flame, photoelectric beam) to understand the performance of such technologies in the boat storage environment. This recommendation is intended to help develop data for the NFPA 303 Committee that would support future NFPA 303 recommendations or guidance language for selection of fire detectors appropriate for initiating as early a fire department response as possible without introducing false alarms.

3. **Fire Testing for Standpipe Effectiveness:** Larger recreational boats with cabins and compartments can be substantially more challenging for the fire department responders to extinguish. Fires on such boats can also be complicated by potential large fuel tank breaches. Given the unique hazards of large boats in storage it is recommended that a study of the effectiveness of standpipe systems be conducted. This testing would compare and address the effectiveness of standard Class I standpipe and hose systems, and systems using AFFF hose systems and compressed air foam hose systems on boat fires. This testing could be integrated with a program of fire testing for rack storage configurations (See Item 4).

4. **Fire Testing For Rack Storage Configurations:** Due to the variety of types and sizes of recreational boats found in dry stack storage facilities any full scale testing that can be done will need to be customized to the types and number of boats that can be acquired for a testing program. Recognizing that the universe of boats is varying the initial direction of a testing program would be to characterize the burning behavior of individual and /or stacked boats relative to the Group A plastics storage of comparable volume and storage height. Such testing may include the following:

a. A water collection analysis should be performed for boats that are acquired. This analysis may include single boats and /or an arrangement of boats in a stacked configuration with in-rack sprinklers and with ceiling sprinklers. The intent would be to identify the potential water accumulation in the boats with simultaneous operation of both in-rack and ceiling sprinklers. Multiple tests would be conducted to evaluate the impact of drain plugs (removed or in-place) and other possible conditions (open/closed windows) that may impact water accumulation for a given boat.

b. Full scale freeburn tests of one or more boats in a large scale calorimeter. This will be compared to a storage array of Group A plastics of similar volume and area. This will provide data on actual heat release rate and total heat release of boat fuel packages. If multiple boats of the same type are available for testing then multiple burns test would be conducted to determine the impact of varying ignition source locations – specifically, ignition locations exterior to the boat hull and ignition locations within the boat cabin or compartments.

c. With regard to Item b., samples of the boat hulls would be cut (cuts would be made with consideration not to impact the full scale free burn tests) from the actual boats to be tested. These samples would be tested in the cone calorimeter or other selected bench-scale apparatus to identify ignition and flame spread properties of the boat hull materials. This data would be used to correlate full scale test behavior with ignition and flame spread properties identified in bench scale tests.

d. Conduct boat commodity hazard comparison tests where boats of different types and sizes would be burned in a large scale calorimeter with a water applicator apparatus to simulate the application sprinkler water sprays. Sprinkler arrangements used for this testing would be consistent with the ADD-RDD concept (ADD= actual delivered density, RDD= required delivered density) used to determine the water flux that needs to be delivered to achieve fire control or suppression of combustible fuel arrays. The water applicator apparatus would need to be configurable to consider known types of in-rack sprinkler installation arrangements used in dry stack boat storage facilities. A goal of this testing would be to identify the optimum sprinkler densities and sprinkler types that could be effective for fire control while minimizing the accumulation of water weight in a given type of boat. Alternative fire suppression systems could also be used to judge their effectiveness in these tests If a sufficient number of boats were available for this testing, multiple tests would be conducted with test ignition locations exterior to the boat hull and ignition locations within the boat cabin or compartments.

e. Implement a full scale rack storage test based upon the results of tests conducted in Tasks a. to d. above. The rack storage arrangement would ideally consist of three tiers of rack storage with three vertical stacks. Sprinklers, alternative suppression systems, and/or various fire detection devices would be installed to test system operations and effectiveness. The tests would be instrumented to identify heat flux levels and sprinkler /detection devices operating times, steel temperatures, steel deflections or other critical measurement parameters. The tests would be sequenced in a manner using the most capable fire protection schemes first. Using this method the available boats would be conserved and available for a following test using a reduced criteria or protection scheme.

5. **Pre-Incident Planning:** Indoor boat storage facilities whether dry stack or single level warehouse buildings pose unique fire risks and hazards to emergency responders. The current state of knowledge regarding the performance of fire protection systems for these facilities is currently limited and only future full scale testing will be able to provide answers and increased levels of confidence about the performance of protection systems in these buildings. Given the unknowns for a fire event in these facilities, it is recommended that the NFPA Technical Committee on Pre-Incident Planning develop specific guidance/recommendations on boat storage facilities for incorporation into NFPA 1620, *Recommended Practice for Pre-Incident Planning.*

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APPENDIX A

SUMMARY OF LOSS DATA FOR

MARINAS AND BOATYARDS

BY

NFPA FIRE ANALYSIS AND RESEARCH DIVISION

Summary of Loss Data for Marinas and Boatyards

(Based on information from NFPA Fire Analysis and Research Division, August 2008)

Incident	Date	State	Incident #	Description
Boat Storage	2/1972	OH	06597	10 boat houses stored out of water were destroyed along with a workshop. The building was made of sheet iron and a wood frame. There were no fire walls between the stored boats. Each boat also contained a large amount of gasoline in their tanks.
Motor Boat Club	4/1972	PA	06359	Fire engulfed an entire boathouse made of metal and wood. The boathouse stored yachts but had no fire stops or wood partitions. The flammable liquids and wood floors aided the spread of the fire.
Boat Yard	5/1972	LA	01379	Gasoline vapors ignited after a short in the engine starter. The open boat stalls and wood frame of the building increased the speed of the fire. Also there was gasoline in the surrounding water. 17 boats were involved.
Marina	8/1973	MI	05192	Boat explosion destroyed 10 boats along with a building. The lack of fire walls and the wood construction allowed the fire to grow rapidly.
Boat Storage Facility	2/1974	NY	00526	Wood frame boat storage facility destroyed by fire. 26 boats inside were also destroyed.
Marina	2/1974	NY	01625	Wood frame building housing 100+ boats completely destroyed during fire.
Marina	3/1974	FL	00565	Steel framed building storing hundreds of boats was completely destroyed due to 4 separate fires. 70-80 boats were inside. Racks 3 boats high collapsed during fire. $1.5 million in damages.
Marina	4/1974	IN	00814	Fire destroyed storage shed in a marina. Building housed many boats and collapsed due to structural failure during fire.
Boat Storage	5/1975	MI	03832	Boat storage building along with 82 boats was completely engulfed in fire. The one story steel building had no dividers in the three boat tall storage racks. Live coals in a charcoal stove caused the fire. The building collapsed after one hour of burning.
Yacht Storage Area	5/1975	WI	06743	Building constructed of wood and concrete burned during a fire at a yacht storage area. There were no fire sprinklers. Fire fighters were not able to salvage anything.
Boathouse	8/1975	MD	04362	Boathouse constructed of steel and wood was destroyed in a fire as well as a carpenter house. The large open area and the lack of a sprinkler system allowed the fire to grow rapidly. 5 boats were destroyed. Photos are available in the fire report.
Boat Storage Building	7/1976	FL	07297	Dry boat storage building of steel construction was a total loss after fire. Fire started from lightning. Flammable liquids and hydrogen vapors allowed the fire to grow quickly. There were no partitions in the building, no windows, and the open building plan also aided in the fire growth. About 80 boats were destroyed.
Boat Storage Building	4/1977	CT	00731	Fuel explosions at a boat marina resulted in the loss of over 70 boats and a building. The large open areas, lack of a fire sprinkler system, and the large amount of

Incident	Date	State	Incident #	Description
				combustibles lead to the rapid growth of the fire.
Boat Storage Building	1/1978	NY	00598	Explosion in a boat storage facility resulted in the loss of about 30 boats. Batteries and gasoline in boats allowed fire spread. Photos are available in the fire report.
Boat Storage Shed	4/1978	NY	02767	16 boats and a storage shed were destroyed in a fire. No detection services, tin walls, dirt floor. Gas tanks were full in the 16 boats. One FF Fatality.
Marina	4/1978	TN	02841	Fueling accident resulted in a boat explosion and led to 8 boats being destroyed.
Yachts	11/1978	FL	03123	5 boats were destroyed after burning for one hour without being reported.
Marina	11/1978	FL	03317	Boat Storage facility was damaged by a fire. Boats were stacked on racks. All boats in the upper tier of the rack were destroyed. The facility had no partitions, flammable liquids, and large amounts of fiberglass material.
Shipyard	5/1979	FL	00099	Gasoline residue ignited and caused a flash fire on a barge which was being repaired in a shipyard.
Marina	2/1980	FL	00648	Boat storage area made of steel and concrete without windows. 2 hour delay in reporting the fire. Melted wires caused the ignition. No sprinklers. High piled storage of boats with gasoline in their tanks.
Marina	5/1980	FL	04809	Roof collapsed after an explosion at a marina. Fire destroyed 270 boats stored in the building. There was no fire suppression and an estimated $5.5 million worth of damages.
Marina	9/1980	MI	02952	Short in an air compressor caused a fire to ignite in the wood floors and paints used in the marina. The fire spread to sidewalls and to 22 boats which were completely destroyed. 300 gallon fuel oil tank exploded.
Marina	1/1981	OH	01132	Boat dock was completely burned upon the arrival of the fire department. There was an estimated 3-4 hour delay in reporting the fire. The boat dock had no walls, steel and concrete construction, and a steel roof. 22 boats were destroyed. Heat sources came from electrical/gas heaters on house boats. There was no fire suppression.
Boat Moorage	1/1981	OR	01182	65’ cruiser caught fire while stored in a boathouse. Fire did not spread.
Marina	1/1982	MI	00891	During blizzard conditions, the building caught fire and was destroyed. The building was constructed of corrugated steel and unprotected steel beams which failed early in the fire. 52 boats were destroyed. $4 million in estimated damages.
Marina	3/1982	OH	01228	Storage building and 40 boats were destroyed in the fire. Building was constructed with wood and had asphalt shingles. The large amounts of stored fiberglass, plastics, and the building material all contributed to the rapid growth of the fire.
Boat Storage Building	4/1982	CT	01953	Boat storage building and 36 boats were destroyed in the fire. The building was constructed of steel and tin. There were no detectors of fire suppression equipment. The open layout of the facility allowed the fire to spread rapidly.

Incident	Date	State	Incident #	Description
Boat Storage Building	9/1983	OH	03211	Wood frame storage facility fire. Building held 7 boats, a truck, and scrap metal. Fire sprinkler system was installed. Dry pipes, ordinary hazard pipe schedule, side feed, three and four head branch lines, old type ½ inch orifice. 165 degree heads – 115 sq ft/head. Fire alarms were also installed. Local bell only. Water was provided from 100,000 gallon elevation tank and 4 fire pumps. Heads activated above the fire and caused heavy smoke. 2 pumps were manually activated. Fire spread in space between asphalt coated corrugated metal roof and the wood fiberboard ceiling. The water from the sprinklers did not reach the fire until the water had eroded away the fiberboard. 37/55 heads operated. 8,000 sq ft of fiberboard ceiling was charred or sagged. 1,000 linear feet of ceiling was consumed. The boats, scrap metal and the truck were all saved.
Boat Storage Building	10/1983	AL	00854	Boat storage facility fire. Building was metal type IV construction. It measured 314' x 91' and stored boats on racks 4 boats high. Investigations revealed many code violations. According to the 1973 Southern Standard Building Code, a sprinkler system should have been installed in the facility. NEC and NFPA 303 code violations were also found.
Boat House	9/1984	WA	03173	Wood piling and wooden floor boat house was destroyed in a fire. The boathouse stored 216 boats that were also all destroyed. The fire spread under the raised wooded floor.
Boat Storage Building	3/1986	NY	01338	Six boats were destroyed.
Marina	4/1986	FL	01571	Boathouse explosion destroyed 200 boats. Estimated $5.2 million in damages.
Boat Storage Area	4/1986	MI	01703	Boat storage area-unknown cause.
Boat Storage Building	7/1986	FL	02322	Boat storage facility-2 separate buildings both destroyed in fire. Together they stored 47 boats that were destroyed.
Boat Storage Building	9/1986	GA	03938	
Boat Storage Building	10/1986	FL	02689	Bilge pump testing resulted in a fire that spread from boat to boat in the storage facility. Gas tanks exploded. The large metal structure with no fire stops made the fire spread rapidly. The fiberglass fumes from the boats made it difficult for firefighters to fight the fire.
Boat Storage Building	10/1986	RI	02900	Discarded oil soaked rags ignited building walls. Fire spread vertically and then through walls to storage room. One sprinkler head activated in this room. Fire continued to spread vertically and through a 2nd story wall. A 2nd sprinkler head activated in this room. Sprinklers stopped the horizontal spread of the fire but did not stop the fire from reaching the ceiling. Fire was extinguished in the ceiling by fire fighters.

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Marina	4/1987	MI	01629	Boat fire spread to one additional boat. Estimated $70,000 in damages.
Boat Showroom	6/1987	OH	01682	Boat showroom was destroyed. 7 new boats and boating materials were also destroyed. The facility was built of wooden pole construction.
Marina	7/1988	OH	02020	Carpet glue fumes ignited and fire engulfed the entire marina. 15 boats and 7 vehicles were all destroyed.
Boat Club Storage Building	10/1988	VA	02507	26 vessels destroyed.
Boat Storage Warehouse	10/1988	WA	02515	Marine warehouse – heavy timber and concrete building. Sawdust on the floor of the building ignited. The building was equipped with a wet fire sprinkler system throughout the entire building. $1.2 million in estimated damages.
Marina	12/1988	TX	02652	2 boats were engulfed when firefighters arrived. Fire spread through the heavy timber piers and destroyed 45 boats and 2 piers.
Boat Storage Building	1/1989	MD	01144	Heating device caused a fire that spread to more than 100 boats at the yacht harbor. Halon systems were on yachts but no automatic systems were in use.
Boat Storage Building	2/1989	WA	01436	3 story marine storage facilities were destroyed in a fire. Sprinkler system was shut off due to freezing conditions. The building was made of heavy timber.
Boat Storage Building	5/1989	MA	01521	Smoking material ignited boat cushions and destroyed the boat.
Boat Storage Building	3/1991	CA	00934	Wooden frame boat storage facility was destroyed. Large open structure, heavy post and glue-lam beams allowed the fire to spread rapidly.
Boat Storage Building	9/1991	NC	01393	Boat storage facility built of non-combustible materials. The majority of boats being stored at the facility were destroyed. Steel I-beams suffered structural damage due to high temperatures.
Marina	3/1992	MO	00916	Wood and metal constructed building was destroyed. No fire protection systems.
Marina	3/1992	OH	00973	Electric heater ignited combustible furnishings in the marina. 2 boats were destroyed. The common roof and unprotected steel I-beams allowed the fire to spread.
Boat Storage Building	4/1992	NY	01193	Steel truss constructed boat storage facility was destroyed along with the 30 boats it housed.
Boat Storage Building	5/1992	OR	01289	Boat explosion in the marina caught the pier on fire. 100' of the pier was engulfed along with 17 additional boats.
Marina	6/1993	NY	00979	13 boats were destroyed along with an additional 10 damaged. 16 dock fingers and 8 head docks were also damaged in the fire. The fire started in a boat tied to the dock. When the fire burned through the ties, the boat drifted away from the dock and then back into another section of the dock. After burning through the head dock, another boat drifted and spread the fire to another head dock. Pictures are included in the fire report.

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Boat Storage Building	7/1994	AR	01342	40+ boats were destroyed in a dock fire.
Marina	7/1994	AR	01342	40 boats were damaged due to fire. All boats were docked on a metal frame dock with low density foam.
Marina	1/1995	FL	02028	Wood construction (wood joists and frame with metal roof) Fire started in boat on the dock
RV & Boats	6/1995	CA	01327	Fire started on canvas cover of pleasure boat. Fire spread to numerous recreational vehicles stored in the facility.
Marina	4/1997	NJ	01560	Fire started in a boat docked in a marina. Fire did not spread.
Boat Store	8/1997	MD	02069	Fire started from possible accidental flare in boat store. Fire spread to nearby 4 story boat storage rack. Destroyed many boats.
Jet Ski Warehouse	5/1998	FL	01764	No fire report. Jet ski warehouse fire.
Boat House	5/1998	FL	00964	No fire report. News articles reported large marina storage fire.
Boat House	6/1998	FL	02033	No fire report. Faulty boat lift caused 2 million in damage. 4 boat houses and 4 boats destroyed.
Boat Storage	10/1998	MI	02311	5 boats stored out of water damaged by fire. No building.
Marina	10/1998	MI	02312	Accelerant poured into cockpit of boat and ignited. Fire spread throughout boat and into nearby boats on each side. Building was of Type 2 construction unprotected. One story: 100' x 50 ft. Building had metal walls, concrete floor, and a metal framing. $25,000 estimated loss.
Boat Repair	10/1998	MI	02315	Undetermined ignition. No building was involved in the fire.
Marina	2/1999	ME	00631	Fire destroyed 9,000 sq ft wood frame building and 8 boats. Fire started from a kerosene portable heater and spread to poly spray curtain and continued into the unprotected trusses.
Boatel	9/1999	VA	01578	Fire destroyed entire marina storage warehouse. Building was unprotected metal clad construction. Building was equipped with a security system and a fire alarm/smoke detection system. 540 boats were destroyed in this fire. Estimated $10 million loss.
Marina	1/2000	CA	00743	House boats, jet skis, storage shed, and fueling area were all destroyed in fire.
Marina	3/2000	MA	00925	No fire report. Boat Storage fire (from news article)
Marina	5/2000	FL	01024	Marina fire in storage building. Building was of pole construction with metal cladding.
Boatel	7/2000	MD	1135	Marina fire in storage area- steel construction. 100+ boats damaged.
Marina	1/2001	KY	00619	Fire in a winter storage area destroyed 15 boats. They were stored in individual slips with an aluminum roof. Estimated 2 million dollars in damages.
Marina	2/2001	FL	00630	No fire report. News article claims that a fire destroyed 7 boats in the water and 7 boats on trailers. The two store wood frame structure burnt due to a possible electrical fire.
Boatyard	4/2001	ME	0831	30 boats were damaged or destroyed in a storage building. 90'x40' one story building made of heavy timber

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				construction. The building had a tin roof. There are photos available in the news articles.
Moorage	5/2001	WA	01014	Boat fire ignited boat house and other nearby boats. The moorage was made of wood frame construction with a metal roof. It was one story and covered 30,000 sq ft.
Boat Warehouse	9/2001	CT	01355	No fire report. News article claims that a fire destroyed 6 boats in a storage warehouse used to hold 200 boats. The sprinkler system knocked down the main fire but also added weight to the boats stored on racks causing them to collapse and endanger the firefighters.
Yacht Club	1/2002	WA	00808	Covered pier fire destroyed 20 pleasure boats. Pictures are available in the fire report. Estimated damages are in the ten million dollar range.
Marina	5/2002	FL	01347	Luxury yacht caught on fire while being welded in a dry dock. Estimated 5.8 million dollars in damages.
Yacht Yard	12/2003	MA	01686	Fire destroyed 24 boats, 4 boat sheds, and 7 houses. Damages are estimated to be $6,340,665.
Yacht Club	1/2006	OR	01150	Three boat houses and three boats were destroyed in a yacht club fire. Damages are estimated to be $2,807,000.
Boat Storage Facility	3/2006	TN	01214	Fire damaged 12+ boats docked at a boat storage facility. Metal boat dock. Wood decking.
Boat Warehouse	5/2008	Neth		No fire report. News article (with video) claims that three volunteer fire fighters from the fire brigade in Eelde, Netherlands (Europe) killed fighting a fire in boat storage warehouse.
Boatyard	7/2008	ME		No fire report. News article claims that a large commercial boatyard was destroyed, leaving 100 employees out of work.
Marina	10/2008	MA		No fire report. News article claims that one person perished on a single boat fire aboard a 38 foot yacht moored in a marina.