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Making Piping Systems Fire-Safe– Simple Solutions for Preventing a Disaster

THE AUTHORS

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ABSTRACT

Loss of life and property losses totaling tens of billions of dollars have piping engineers scrambling to specify "fire-safe" components in fire-prone locations: on board ships, and in power plants, refineries, and other perilous applications.

Fire-safe valves, the first line of defense in containing a fire, were introduced some 25 years ago, with fire-safe actuators following soon afterwards. Little attention has been given, however, to designing and selecting the other piping components such as flanges, gaskets, bolting, and fittings to ensure their integrity in a fire. Just like in an electric circuit where, if a single component in series fails, the flow of electricity stops; likewise, the failure of a single piping component could result in a fire of catastrophic proportions. This paper discusses the availability of critical fire-safe components for Navy shipboard piping systems and provides some simple solutions which, if implemented, could prevent such a disaster. Discussion is provided on how a fire starts and how it reaches catastrophic proportions, the definitions of survivability and fire-safe components, materials of construction, component design, fire-safe valves and actuators, gaskets, pipe flanges, flange bolting, pipe fittings and unions, brazing and welding, insulation, composite piping materials, and other related subjects. Details are also provided on 78 fires that have occurred on Navy surface ships in the last ten years and their causes.

INTRODUCTION

Historically, shipboard fires have caused considerable damage to hardware, fighting capability, and personnel. Thus, over the past decade, shipboard piping component requirements for fire hazard prone systems have increased significantly. Imagine an electric circuit where several electrical components are connected in series. If a single component fails, the flow of electricity ceases. Likewise, it is imperative that not one single piping component failure should start a fire. Failure of the weakest link in a critical system could result in a catastrophic fire. Numerous U.S. as well as some European engineering societies have responded to this problem by developing special fire-testing standards. With direct property losses totaling tens of billions of dollars and the additional expense of insurance and compensation, piping engineers are scrambling to specify "fire-safe" components in fire-prone locations: on board ships, and in power plants, oil platforms, refineries, and other perilous applications.

COST IN DOLLARS AND INJURY/LOSS OF LIFE TO U.S. NAVY

Piping component failures have resulted in several recent fires onboard U.S. Navy ships. On *Conyngham* (DDG-17), a wiper shaft ejected from one side of the fire-safe fuel-oil strainer (FSFOS) causing a 3/4 inch hole in the 400-psi fuel system. An immediate fire resulted in the overhead of the fire room as a 75-gpm gush of fuel sprayed out. The fire raged out of control for about 20 minutes during which time a silver-brazed joint in a fire main melted, resulting in a ruptured fire main.

Failure of the ship service turbine generator (SSTG), control lube-oil filter vent plug caused major fires on both *Inchon* (LPD-12) and *Dahlgren* (DDG-43). On *America* (CV-66) a fire broke out in the JP-5 pump room where heat recoverable coupling (HRC) were installed in the Halon CO_2 actuation piping. These are essentially mechanically-attached fittings (MAFs) made from nickel-titanium "shape memory alloys." As a result of the elevated temperatures from the fire, the fittings expanded and the fitting material became annealed causing the fitting to take a permanent set at the expanded condition. Upon cooldown, the pipe contracted causing the fittings to become loose, allowing leakage. Many more such fires have occurred on Navy ships, resulting in millions of dollars in damages and in injury and loss of life. Table 1 provides a summary of the damages and injuries resulting from fires caused by piping/piping component failures.

HOW A FIRE STARTS

Before we discuss how we can minimize the effects of a fire, we need to first analyze how a fire starts.

Prior to ignition, the environment needs three ingredients for a fire: 1) oxygen, 2) an ignitor, and 3) fuel. Items 1 and 2 are abundantly available in any machinery space aboard ship. All ships have piping systems containing flammable fluids or fuel such as fuel oil, lube oil, and hydraulic oil. Thus, wherever a leak of these flammable fluids occurs, there is sure to be a fire. Fire develops when fuel and heat of ignition combine with the oxygen in the air. As the piping system is exposed to fire, the system materials, especially if metallic, will transfer the heat to the system fluid, increasing its temperature. Normally, the system fluid protects the piping as it continues to flow through the system, carrying the heat away. However, if the fluid is not flowing, the system temperature will rise as the temperature of the fire rises. A typical fire temperature rise can be very rapid and steep. Figure 1 illustrates a rapid rise of temperature to 1600°F just after 130 seconds in a typical fire test of 1/2-inch 70-30 Cu-Ni uninsulated pipe coupling (pipe pressurized with nitrogen gas).

Table 1. Summary of Fire-test Standards.

MISHAP	PERSONNEL INJURY	COST ($K)
FSFOS Stem Ejection	17 injured/1 fatal	2200
Fuel Trans Pipe Leak	8 injured	201
Fuel Filter Failed	0	299
Fuel Filters Overpressurized	0	300

HOW A FIRE REACHES CATASTROPHIC PROPORTIONS

A fire begins to reach catastrophic proportions with a steep rise in temperature over a short period of time. Under dry conditions, after 2 to 4 minutes, any silver-brazed fittings would completely fail. (Laboratory tests in hydrocarbon fires by Navy showed failure of silver-brazed 70-30 Cu-Ni joints within 4 minutes under dry conditions. Under stagnant water conditions, Cu-Ni silver-brazed joints began leaking after 16 minutes, and failed completely after 18 minutes.) Packing, O-rings, and gaskets would also typically fail after 2 to 4 minutes.

As the flanged joint is heated, the threaded fasteners holding the joint together expand, reducing their clamping force and allowing the joint to separate, and thus, create a leak path. Eventually, the gasket itself may disintegrate due to the high temperature, or if system pressure is high enough, the gasket will blow out. The next components likely to fail would be the valves and electric actuators. If a valve starts leaking flammable fluid, the fuel flow cannot be shut off to prevent the spread of fire. On the other hand, if the valve starts leaking water which is needed to supply fire protection, the pressure at the fire hose or automatic sprinkler may drop so low that the fire cannot be extinguished rapidly.

DEFINING SURVIVABILITY

Of the 78 fires the authors studied onboard Navy surface ships occurred in the last 10 years; 24 were related to fuel or JP-5 systems; 33 to boilers, engines and gas turbines; 5 to exhaust stacks, and 14 to residual fuel ignited by hot work or grinding.

Now that we know how a fire starts, the next logical question is: how do we define survivability in a fire? Survivability can be defined on several levels. The level desired depends on the criticalness of a particular ship system.

Survivability can be defined as surviving such that the system:

Level 1.	Does not feed the fire.
Level 2.	Does not feed the fire and also remains operational long enough for the system to be secured and/or isolated from the area of the fire.
Level 3.	Does not feed the fire and also remains operational during and after the fire.

It is ideal to have level 3 survivability, but we may have to settle for level 1 or 2 depending on the criticalness of the

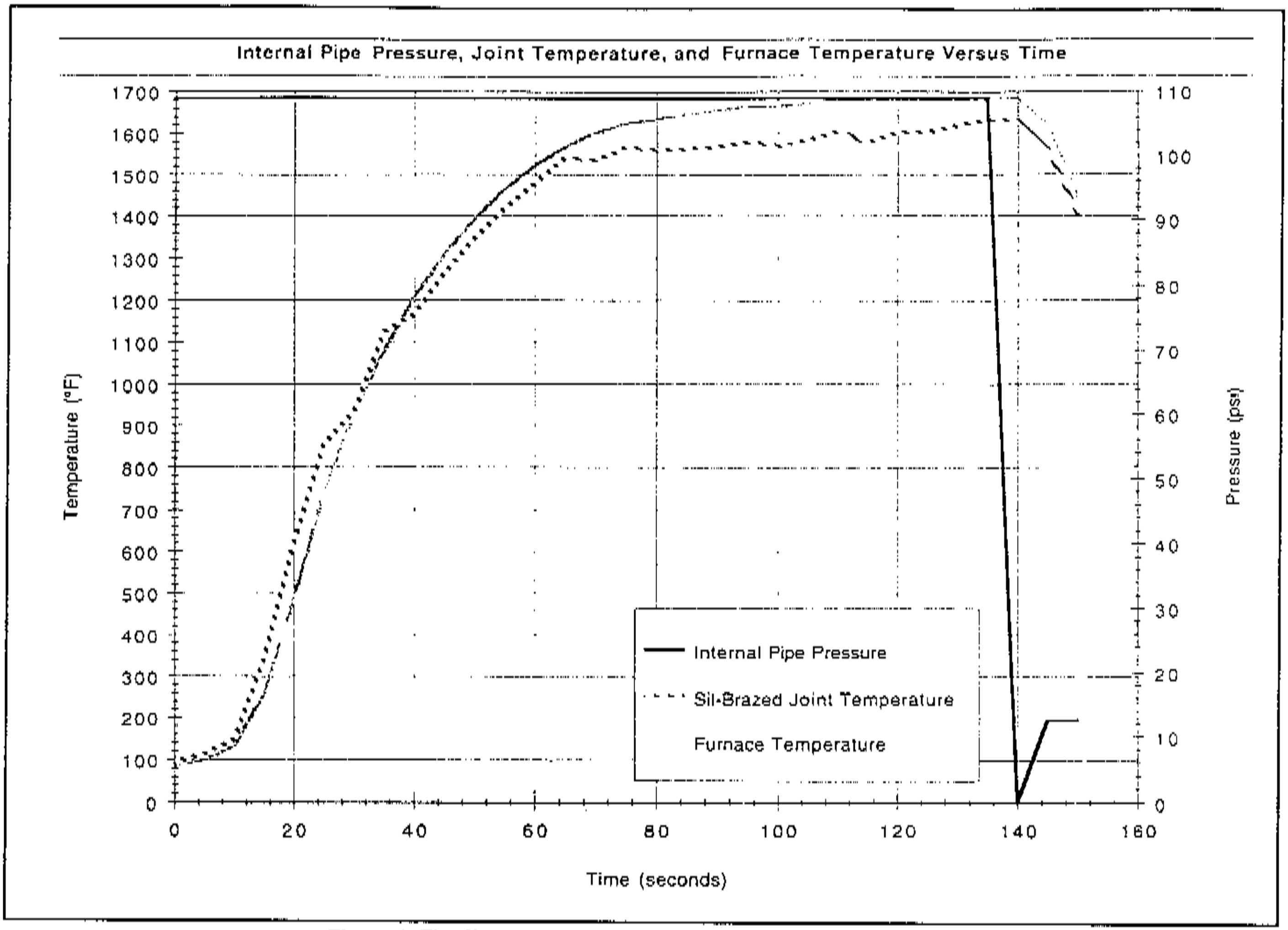

Figure 1. Fire Test Results (1/2-inch, 70-30 CuNi; No Insulation).

system. In most cases, survivability may also be limited by technical capability and cost.

DEFINING "FIRE-SAFE"

Having defined survivability, as engineers, we now need to know what design criteria should be used to design "fire-safe" components for "fire-safe" systems.

Ideally, a fire-safe component must be leak-free, not only at its normal service temperature, but also during and after a fire. (In addition, critical piping components, such as actuated valves must be able to open and close. Actuators must also continue providing adequate force/torque for valve operation). In reality, a small amount of leakage and slight performance degradation can be expected (and may also be tolerable) during and after a fire. Fire-safe components satisfy survivability levels 1 and 2 (see previous section). There is strong disagreement within industry about the use of the term "fire-safe." Many prefer to use the term "fire-tested," implying that components have been tested to meet certain leak criteria per a certain industry test standard under a typical fire scenario. Numerous fire test standards have been developed by nationally accredited institutions such as the American Petroleum Institute (API), Exxon, Factory Mutual (FM), Underwriter Labs (UL), British Standards Institute (BSI), and American Society for Testing & Materials (ASTM), with each one using its own definition of a typical fire. API 607 is the most commonly used fire-test standard for fire-safe valves by the Navy and the industry. Fire-safe standards vary significantly in the testing procedures and acceptance criteria used (see Table 2); however, all the standards do attempt to predict valve operation at extremely high temperatures. These standards set limits on the maximum leakage/performance over a designated period of time and fire-temperature. Beyond these designated time and temperature limits, it is impossible to design a system to withstand a fire as material properties do have their own limits. The general consensus is that if a fire lasts longer than the designated times, further efforts to contain the fire in that system are futile.

WHAT COMPONENTS NEED PROTECTION

To approach this problem systematically, we must first

Table 2. Summary of fire-test standards.

TEST SPECIFICATION	OCMA FSV.1	EXXON BP3-14-1	API 607 THIRD EDITION	FM 6033
Stem position	Vertical	Vertical	Horizontal	Not specified
Bore position	Horizontal	Horizontal	Horizontal	Not specified
Valve open or shut	Open	Open	Shut	Shut
Test pressure during burn	30 psi	25 psi	Depends upon valve pressure rating	125 psi
Test media	Kerosene or diesel fuel	Liquid hydrocarbon	Water	Not specified
Valve body temperature	Sufficient to destroy soft seat	1200°F minimum	130°F minimum	Not specified
Burn duration	15 min.	15 min.	30 min.	15 min.
When seat leakage measured	After test	After test	During test and after test	During test
Maximum external leakage	No appreciable leakage	Leakage shall be negligible	200 ml/min in. dia.	0.1 qt/min (94.6 cc/min)
Maximum seat leakage	10 ml/min/in. diameter*	10 ml/min/in. diameter*	400 ml/min/in diameter	Individual drops
Operability	3 cycles open to shut	3 cycles open to shut	1 cycle open to shut	Must be operable

* In no case shall leakage rate exceed 100 ml/min.

** Based on the table from Lyon's Valve Designers Handbook by Jerry L. Lyons, PE-1982.

*** OCMA, API and FM designate Oil Companies Mutual Association, American Petroleum Institute and Factory Mutual respectively.

look at the components/parts that make up a typical piping system. They include the following:

- Valves
- Piping
- Fittings
- Strainers
- Actuators
- Gaskets
- O-rings
- Hangars
- Pumps
- Heat Exchangers
- Packing
- Flexible Hose

The U.S. valve industry introduced fire-safe valves some 25 years ago. Fire-safe valve actuators followed soon after that. Surprisingly, little attention has been given to designing and selecting the balance of the piping components (gaskets, fittings, etc.) to ensure their integrity in a fire. This paper will discuss the present availability of critical fire-safe components and introduce some simple solutions, which if implemented, could prevent a disastrous fire from occurring. The same design philosophy/rules we applied to the critical components/parts can be extended to the piping system components not specifically discussed herein.

MATERIALS OF CONSTRUCTION

Generally speaking, the most commonly used shipboard ferrous materials (both carbon and stainless steel) have proven satisfactory because of their relatively high strength at the temperatures experienced in fires. Plastics, composites, and some nonferrous materials are routinely specified where greater corrosion resistance to seawater is required. Unfortunately, however, plastics and nonferrous materials such as bronze, copper, and aluminum will distort excessively or may even melt when subjected to shipboard fire temperatures, which can easily reach 2000°F. Where both corrosion and high-temperature resistance are required, nonferrous alloys such as nickel-aluminum-bronze, nickel-chromium-molybdenum-columbium (Inconel 625), or nickel-copper (Monel) alloy should be specified because of their greater resistance to high temperatures.

Furthermore, it should be noted that high temperatures reduce the hardness of materials, which is often needed for dynamic applications where surfaces rub against each other. As such, high hardness can be maintained by specifying hard Stellite coatings, or chrome or electroless-nickel platings to minimize the possibility of galling. Avoid oil or plastic-based lubricants. Instead, use high-temperature, dry film, lubricants such as molydisulfide, or graphite-based lubricants.

COMPONENT DESIGN

Components should be designed for flammable service with minimum body penetrations to minimize external leakage. An example of such an improved design is a relief valve for liquid applications. Mil-V-24624 previously allowed the use of valves that experienced leakage of flammable fluids through their body/bonnet penetrations. Valve manufacturers typically allow an opening in the valve body for a blowdown ring to adjust the blowdown pressure. They also vent the bonnet to improve the valve flow capacity. Recognizing the potential for a fire due to flammable fluid spilling out of these openings, the Navy revised Mil-V-24624, disallowing any such penetrations (the Navy realized that some flow capacity would be sacrificed and the valve would have to operate with higher blowdown).

Furthermore, designers should not specify a mix of materials whose coefficients of thermal expansion vary greatly. Uneven thermal expansion during fire temperatures may cause internal seizing or result in externally leaking joints.

FIRE-SAFE VALVES [1]

Valves are considered the first line of defense in containing the spread of a fire. If a fire starts, valves can be quickly opened or closed to divert the flow of line medium to another part of the system to protect vital areas. Yet valves are also the most prone to fail at the high temperatures encountered in a fire because they contain moving parts difficult to seal at fire temperatures.

Most fire-safe valves have dual-seats. The primary seat is non-metallic, with a secondary (or backup) metal seat installed next to it in "series." The primary seat ensures a tight (zero leak) seal during normal service. If a fire destroys the primary seat, the secondary seat allows only minimal leakage through the valve. In addition, fire-safe valves have stem packing or other static body seals of graphite or carbon-fiber based materials capable of withstanding temperatures up to 2000°F. These valves are generally quarter-turn, rotation-type ball and butterfly valves. When specifying butterfly valves, use the "lug" design instead of the "wafer" design. It affords greater protection because the pipe-flange bolts would not be directly exposed to fire. Similarly, avoid three-piece ball valves; they require very long studs that cause the valve to leak at high temperatures because of their excessive elongation (see detailed discussion below under FLANGE BOLTING). Additionally, use of butt-weld or socket-weld connections is preferable over the flanged-end connection to minimize gasket leaks.

Fire-safe valves also require a considerably higher operating torque, necessitating larger actuators. These valves are also very sensitive to flow direction. The valve must be installed for the proper flow direction, per the manufacturers recommendations, or it will leak at fire temperatures. This is extremely important when the valve is reinstalled in the pipe after valve/actuator servicing (note, these valves would not leak at normal service temperatures and thus, an improper installation could easily go undetected).

FIRE-SAFE ACTUATORS

Although many industry standards for testing fire-safe valves are available, none exist for fire-safe actuators. Standard non-fire-safe actuators, when mounted on today's fire-safe valves, cannot operate these valves because their design and materials of construction are inadequate to handle high fire temperatures. Fire-safe actuators have steel internals and housing and special seals, bearings, and lubricants to withstand high temperatures. Some actuator housings are also coated with thick, intumescent epoxy material which, when subjected to a fire, swells to form an insulating char under a glazed surface to reduce thermal conductivity. Some actuator designs incorporate a fail-safe mechanism consisting of a compression spring and a fusible link in the valve-actuator interface. The fusible link melts during a fire and releases the spring to open or close the valve as desired.

Navy electric actuators with the manual over-ride feature are specified per DoD-V-24657, which does require a fire test, but only the manual override feature has to remain operational during and after the fire. The electric drive is not required to continue operation during or after the fire.

Hydraulically-operated actuators should be avoided because hydraulic fluid is often flammable; use NEMA class VII enclosed, electric actuators in hazardous locations. (It should be noted that pneumatic-operated actuators may also be used provided a reliable supply of air can be assured. The Navy currently uses these actuators on limited applications, such as dry docks).

FIRE-SAFE CERTIFICATION

With so much at stake, how do the users know whether or not they are getting the right valve or actuator that will meet their needs should a fire start? Consider the following criteria:

(a) Has the product passed a variety of fire tests as outlined in Table 1? The more fire tests the product passes, the better the chances are that it will meet your needs under a wide variety of fire scenarios.
(b) Were the fire tests independently witnessed and certified by uninterested parties?
(c) Does the product manufacturer continue to subject production valves to repeated fire tests to ensure that changes in design, manufacturing, and quality assurance standards do not alter its quality?

GASKETS

Flat, conventional gaskets made of rubber, cork, or plastic will disintegrate rapidly during a fire. High-temperature gaskets made of graphite, asbestos, or all-metallic high-temperature material will operate satisfactorily. However, asbestos is currently being phased out due to environmental considerations. The best gasket design for fire resistance has proven to be a "spiral-wound" gasket, consisting of a solid outer metal ring and an inner flexible core. The core consists of stainless steel windings separated by laminated graphite material. The outer metal ring aligns the gasket inside the flange bolts and also prevents excessive gasket compression when the flange bolts are tightened. When replacing flat sheet gaskets with spiral-wound gaskets, the flange-to-flange dimension should be increased by 1/16 inch to accommodate the 1/8-inch-thick spiral-wound gaskets (as opposed to the 1/16-inch-thick flat sheet gaskets). Furthermore, note that the spiral-wound gasket necessitates a much higher gasket compression stress, and thus would need additional flange bolting torques and flange design/material considerations.

PIPE FLANGES

It has been recognized that ANSI Class 150 flanges are prone to flange leakage. Their flange geometry and thickness provide marginal allowance to accommodate externally applied bending moments and forces, nonuniformly applied flange bolt loads, and thermal transients. ANSI Class 150 flanges can easily be "over stressed" and distorted by overtorquing of fasteners. These problems are currently being studied by the Pressure Vessel Research Council (PVRC) Committee on Bolted Flanged Connections (as part of Welding Research Council). As a result, the committee may recommend derated ANSI flange pressure ratings or new rules for establishing pressure ratings for different types of flange gaskets. Undoubtedly, the gasket leakage problem would be accentuated at elevated fire temperatures. As such, it is advisable to keep the externally applied loads to a minimum and also to upgrade flanges to ANSI Class 300 should the pipe pressure approach the ANSI Class 150 rating maximum.

Raised-face flanges should be used instead of flat-face flanges to increase flange joint reliability. Raised-face flange design permits use of the considerably higher gasket stresses needed for spiral-wound gaskets. Gasket manufacturers recommend a surface finish between 100- to 500-AARH roughness, with an optimum finish of 250 AARH. A smooth finish provides better sealing; however, a very smooth finish of under 125-AARH roughness degrades the blow-out performance of compressed fiber-type gaskets. These gaskets are apt to blow-out (rupture) because of internal pressure spikes. (At present, the authors are not aware of any fire testing of Navy Standard flanges which are nonferrous. These flanges have a very different geometry and flange bolting pattern than ANSI flanges and thus, their behavior in fires may be quite different than ANSI flanges.)

FLANGE BOLTING

While of paramount importance, the subject of flange bolting is often neglected. Consider a valve body installed between two pipe flanges. Flange bolts come in direct contact with the flames of a fire. When exposed to such extremely high temperatures, these bolts heat up rapidly and elongate. The valve body also heats up and would also expand somewhat, though not as rapidly as the flange bolts (because of its greater mass, it will take longer to heat the body; also, the line medium would help dissipate heat and would keep the body cool). Since the bolts would elongate faster than the body, they would rapidly lose their preload. Furthermore, the mechanical properties (ultimate and yield strength) of bolt materials are also severely degraded at higher temperatures. This has the compounding effect of reducing the bolt net preload (residual stress) at high temperatures. This dramatic reduction in bolt residual stress would result in a severe drop in the flange gasket compressive stress, causing gasket leakage.

To illustrate this point, just a 200°F temperature differential between the flange steel bolts and a steel valve body is enough to reduce the bolt preload stress by 38,000 psi, considering the fact that most bolts are initially preloaded to 40-45,000 psi. Furthermore, at elevated fire temperatures, most bolting materials will experience a severe degradation of mechanical properties and a decrease in the capability to retain the preload. This is evidenced in Table 3.

All these actions point to the need to increase the bolt preload (and thus require the use of high-strength bolt materials) to a considerably higher magnitude so that a drop in preload due to a rise in temperature is offset by the higher initial preload.

The use of alloy steel, high-strength bolts per ASTM A193, grade B7 (or preferably alloy steel, high-strength, high-temperature bolts per ASTM A193, grade B16; or stainless steel, high-strength bolts per ASTM F593, alloy 630, type 17-4PH) is recommended. (The authors' extensive experience with a valve/actuator manufacturer in the fire testing of soft-seated butterfly valves using 17-4PH bolting, with graphite-filled spiral-wound gaskets, and a 60,000-psi bolt preload yielded satisfactory results.) For applications requiring nonferrous materials, do not use bronze bolts; use high-strength, nickel-copper-aluminum alloy (K-monel) or Inconel 625 bolts instead. High-strength ferrous and certain nonferrous bolts permit preloading to 60,000 psi which is considerably more than the yield strength of low-strength bolts (note that at 60,000 psi many bolting materials are susceptible to stress rupture at 1200°F; however, most bolts may not achieve these high temperatures). The bolt preload

Table 3. Typical mechanical properties.

Bolt Material	Ultimate Strength at 100°F	Yield Strength at 100°F	Ultimate Strength at 1200°F	Yield Strength at 1200°F
ASTM A193 Grade B7	125 ksi	105 ksi	35 ksi	10 ksi
ASTM A193 Grade B16	125 ksi	105 ksi	50 ksi	30 ksi
ASTM A307 Grade A (Low Carbon Steel)	60 ksi	40 ksi	20 ksi	10 ksi

problem can also be minimized by insulating the bolts/body so that the rise in the temperature can be minimized (see succeeding section on insulation).

Pipe Fittings and Unions

Particularly vulnerable items during a fire are pipe fittings, especially silver-brazed fittings. During a fire, this type of connection would usually fail within a few minutes. There will be a total separation of the piping with resulting uncontrolled system fluid leakage.

Recent ship designs have prohibited the use of silver-brazed fittings in hazardous fluid systems and substituted welded fittings or fireproof MAFs. However, as of this date, very few manufacturers have qualified their MAFs to the new ASTM F1387-92 specification for fire test. Another option is to add insulation for protection. These options are discussed in more detail in the following two sections.

Brazing and Welding

In 1988, an electrical fire started onboard *Bonefish* (SS-582). The heat of the fire melted a brazed joint in the hydraulic fluid line and joints in the compressed air line. The ignition of leaking hydraulic fluid, when fanned by the leaking compressed air, resulted in a funnel-type flame 30 feet long.

As mentioned earlier, nonferrous materials are commonly used on board ships where good corrosion resistance is required. Piping materials generally used are copper, copper-nickel, or nickel-copper; pipe fittings are made of leaded bronze or aluminum bronze. Since copper and leaded bronze lack good weldability, brazing has been used to join piping and fittings made for these materials. Furthermore, brazing is used because some piping may have poor accessibility for welding; brazing can be performed with somewhat limited access. Another reason for using a brazed joint is that the joint can be dismantled quickly by heating which is not possible with a welded joint. Commonly used brazing alloys for naval piping are silver alloys [BAg-1 (grade VIII), BAg1-a (grade IV), and BAg-5 (grade I)] and a copper-phosphorous silver alloy [BCuP-5 (grade III)]. BAg1-a, a low-melting temperature alloy, has been most commonly used for ease of brazing.

One problem with brazing, however, is that brazed piping joints lose their strength at high fire temperatures (they are not recommended for use in systems normally operating above 425°F per NavSea 0900-LP-001-7000, "Fabrication and Inspection of Brazed Piping Systems"). BCuP-5 melts at 1450°F and silver-brazing alloy can melt at temperatures as low as 1100°F. Flammable fluids (such as gasoline, fuel oil, hydraulic oil, lubricating oil, and oxygen) and fluids that support combustion (such as hydraulic fluid and high-pressure air) leaking from a failed, brazed joint would further intensify a fire.

In addition to the piping joints, it should be noted that many non ferrous valves onboard ships also employ some type of brazing. Smaller sized valves (up to 2 inches) are typically silver-brazed to the pipe. In addition, many of these valves have external as well as internal brazed joints (including some diaphragm-operated check valves or magazine sprinkler valves with a tube connecting the top chamber above the diaphragm to a downstream port in the valve body). These brazed joints will fail in a fire. For this reason, brazed piping joints are not a good choice, and another means of joining should be explored.

At present, NavSea is revising Mil-Std-777, "Schedule of Piping, Valves, Fittings and Associated Piping Components for Naval Surface Ships," and Mil-Std-438, "Schedule of Piping, Valves, Fittings and Associated Piping Components for Submarine Service." One of the major changes to these two documents will be that brazed joints for critical systems will not be acceptable. Where possible, brazed joints will be replaced by welded joints or by some other means of joining. Welded joints can withstand high temperatures, as high as the piping. However, welding poses some problems for joining certain materials. For example, leaded bronze, which has been used for brazed-end connection valves as well as brazed fittings, has poor weldability. Leaded bronze valves should either be replaced by valves with flanged-end connections, or the valve material changed to a weldable grade of nickel-aluminum-bronze. Similarly, the fitting material should also be changed to copper-nickel, which is weldable.

Insulation

Because piping system materials have limited physical properties as far as withstanding the high temperatures caused by a fire, insulation can be added to protect pipe fittings and unions and flange bolting as discussed previously. Insulation can also be used on silver-brazed joints. Tests have shown that insulation improves the fire survivability of copper-nickel, silver-brazed pipe joints, providing a low-cost alternative to backfitting existing piping systems with welded or mechanically-attached pipe-fitting technologies.[2] Carderock Division, Naval Surface Warfare Center recently conducted a study (August 1993, performed per ASTM P1387 test standard) of the effectiveness of several commercial insulation materials (3M, APM) for improving the fire survivability of copper-nickel, silver brazed pipe joints.

In these tests, the pipe was pressurized with N_2 gas and the pipe/joint was exposed to a hydrocarbon fire. When a leak in the pipe joint was detected, the test was aborted. These tests evaluated the following factors: (a) insulation type, (b) insulation thickness, and (c) insulation length extending beyond the length of coupling the joint. Figure 1 illustrates that in the absence of any fire protective coating, the silver-brazed joint leaks after just 130 seconds. Figure 2 shows a tremendous improvement in the fire hardening of the joint, lasting over 800 seconds when using a 1-inch diameter insulation. Figure 3 further shows that extending the insulation length one pipe diameter beyond the coupling/fitting joint produces tremendous improvement in the fire hardening capability. The test results show that the use of 0.4-inch thick "E-5A" insulation from the 3M Company, in combination with "Firedam 150" caulk, also from 3M, effectively protects copper-nickel, silver-brazed pipe joints from failure for at least 13 minutes when this insulation is applied around and near (one inch or one pipe diameter,

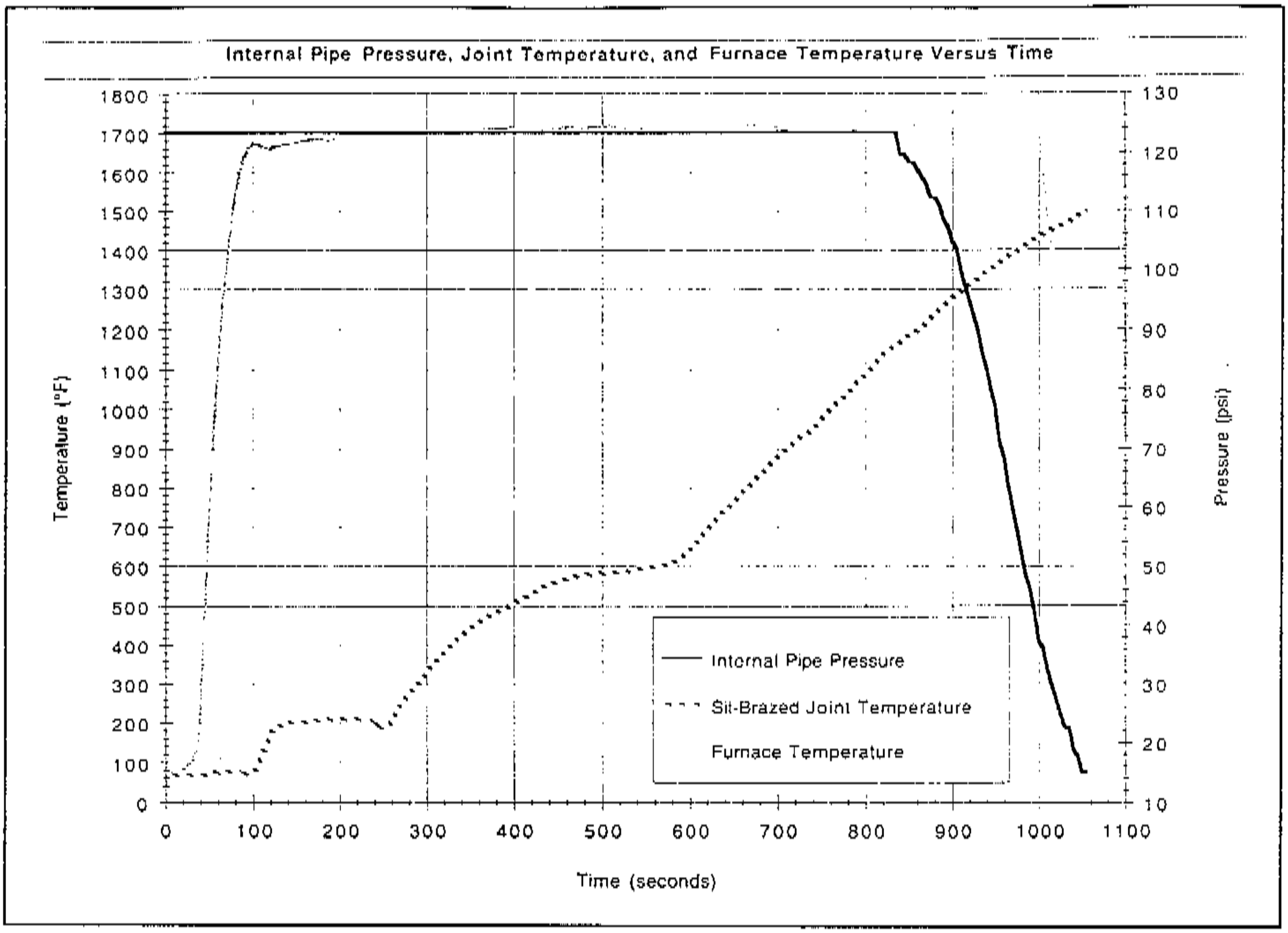

Figure 2. Fire Test Results (1/2-inch, 70-30 CuNi; 1 Diameter Insulated with 3M)

whichever is greater) the pipe joint. Figure 4 shows time to failure of a 1/2-inch and a 2-inch pipe for various types of insulations when subjected to the fire tests.

Composite Piping

Driven by the need to reduce operating costs, improve performance reliability through elimination of corrosion and erosion, and reduce weight, the oil industry, the Coast Guard, and the Navy are beginning to use glass-reinforced plastic (GRP) piping on board oil platforms and on commercial and naval vessels. At this time, several organizations such as the oil industry [under the leadership of the United Kingdom Offshore Operators Association (UKOOA) and the Norwegian Oil Industry Association (OLF)], the International Maritime Organization (IMO), the American Society of Mechanical Engineers (ASME), the U.S. Coast Guard, and the U.S. Navy [3] are busy developing fire performance standards and researching the use of GRP piping for various applications. Although any of the fire safety factors can be derived from experience in fire testing metallic piping, additional factors must be considered for composite materials such as ignitability, surface spread of flame, and emission of smoke and toxic combustion products.

Since each of the organizations previously mentioned would ultimately develop their own standards, each composite piping user would have to decide which standards he should specify. The following discussion is provided to familiarize the user with the work currently being conducted under the auspices of some of these organizations.

(a) Oil Platform Industry: The UKOOA draft standard calls for subjecting candidate GRP piping to a hydrocarbon pool fire or to a gas jet fire, simulating rupture of gas piping. UKOOA lists the following factors for consideration when using GRP piping:

- Fire risk in the location of use and the likely fire exposure intensity and duration.
- Consequences of failure in a fire (e.g., for pipes or tanks containing combustible liquids or gases or structures supporting such).
- Fire endurance to provide the necessary fire integrity of the structure or piping system.
- Combustibility and ignitability.

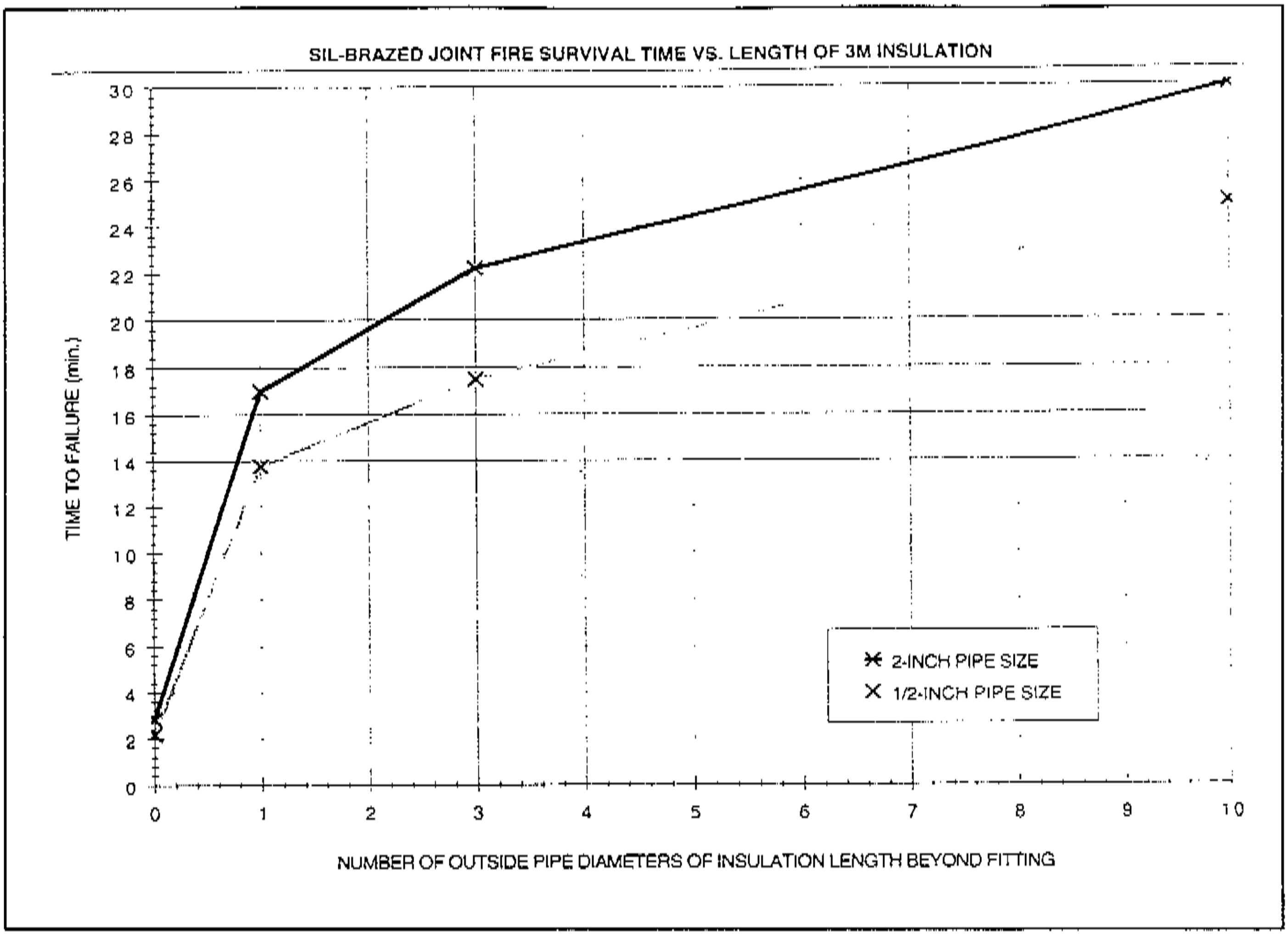

Figure 3. Effects of Piping Size and Insulation Length.

- Surface spread of flame.
- Emission of smoke and toxic combustion products, especially for applications within enclosed space likely to be occupied by personnel.

(b) International Maritime Organization (IMO): IMO is also developing fire performance requirements based on the type of system (or service) and its location. IMO also prescribes a fire endurance test for GRP piping where the use of insulation is permitted. The test specifies a furnace test with a fast temperature rise likely to occur in fully developed liquid hydrocarbon fire under dry conditions, and a propane multiple burner test for piping in the wet condition. In all cases, the acceptance criteria is no leakage from the piping system after the fire.

The IMO guidelines also include three levels of fire performance requirements for use with GRP piping depending on the type of system (or service) and its location. Level 1 is the most demanding test. It includes piping systems that are essential to the safety of the ship and those systems outside machinery spaces where the loss of integrity may cause an outflow of flammable fluid. Piping must pass a fire endurance test for a minimum of one hour without loss of integrity under dry conditions.

Level 2 includes piping systems essential to the safe operation of the ship and designed to ensure a fire without loss of the capability to restore the system function after the fire has been extinguished. Piping must pass a fire endurance test for a minimum of 30 minutes under dry conditions.

Level 3 piping includes piping essential to the safe operation of the ship and is designed to endure a fire without loss of the capability to restore the system function after the fire has been extinguished. Piping must pass the fire endurance test for a minimum of 30 minutes under wet conditions.

(c) Navy: The Navy is currently attempting to establish fire performance requirements for surface ship composite piping systems and other composite components such as valves and pumps. One approach being proposed is to tailor performance requirements based on the IMO guidelines, many of which are being incorporated into ASTM F1173, "Epoxy Resin Fiberglass Pipe and Fittings to be Used for Marine Applications."

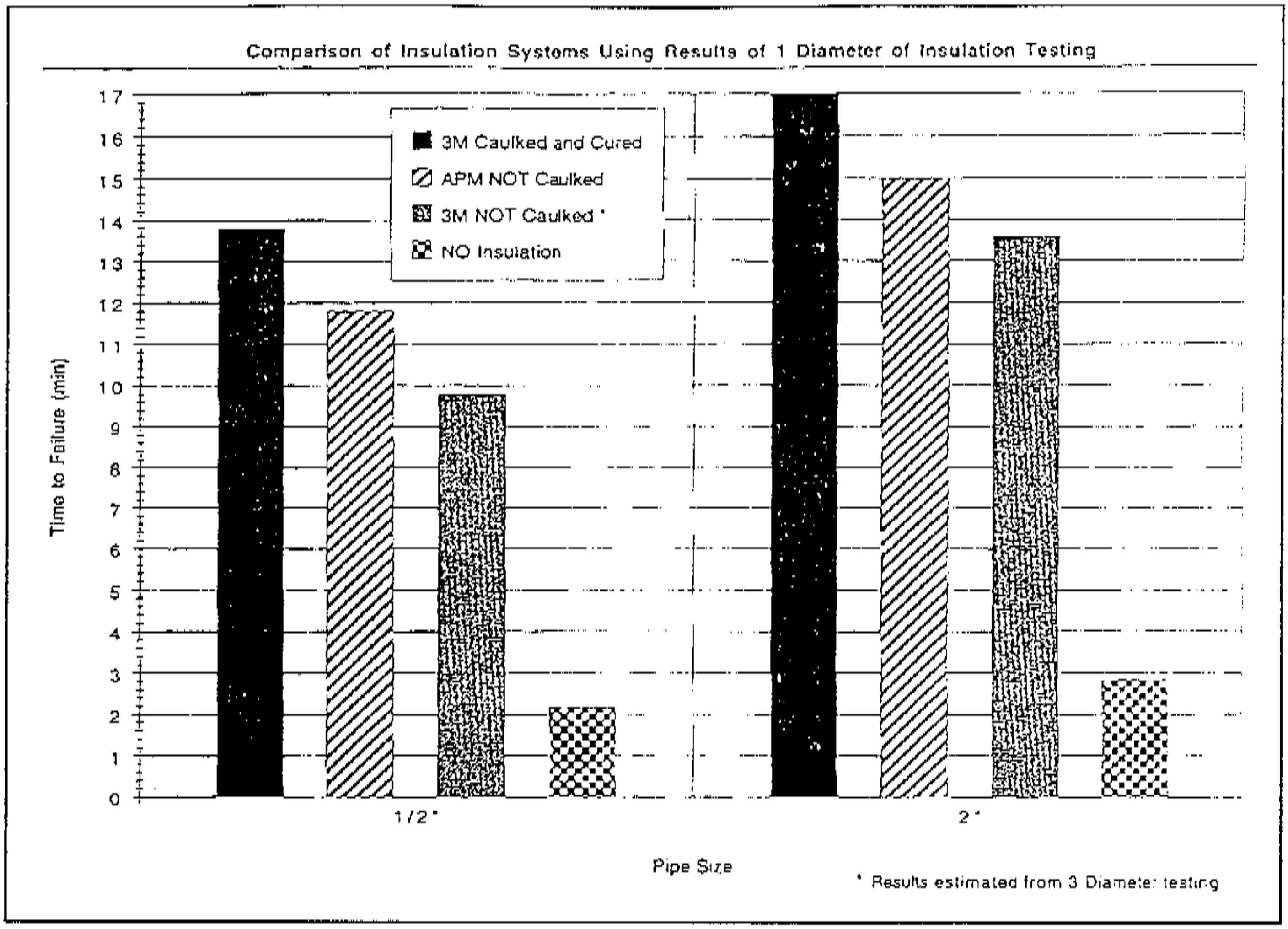

Figure 4. Comparison of Insulation Systems.

The Navy categorizes fire issues into two groups: (a) "small-scale" fire performance, and (b) "full-scale" fire performance. If a candidate passes the small-scale fire test, it is then considered for a full-scale fire test. Protective coatings applied to the outside of GRP piping, such as insulations and intumescent coatings, undergo small-scale fire testing separately and in combination with various composite substrates.

Small-scale fire test data includes flame spread testing per ASTM E162, smoke chamber testing per ASTM E662, and cone calorimeter testing per ASTM E1352. These tests require relatively small samples of material and are inexpensive to conduct.

Full scale fire testing is done to assess the fire survivability or integrity of composite components by burning full size components per ASTM 1387-92, usually in a hydrocarbon pool fire of 1500°F to 1800°F. Evaluations have been done under dry, stagnant water, and flowing water conditions. These conditions have a significant impact on the survivability of the component. The required survival time for passing the test is 30 minutes. Figure 5 shows a fire evaluation of a 2-inch GRP pipe that was protected by a variety of fire protective coatings. As the test indicates, the most effective insulator was 0.125-inch thick elastomeric ablative wrap, consisting of inorganic salts added to a polyisobutylene base material. This material, known as APM (Ablative Protective Material), works by releasing chemically-bound water in an endothermic reaction that absorbs energy and helps protect the substrate. APM showed promising results in an earlier small-scale fire test and thus was selected as a desirable candidate for full-scale fire test.

SUMMARY/CONCLUSIONS

The U.S. Navy has experienced millions of dollars in damages as well as injury/loss of life because of shipboard fires. Few fires were caused by piping component failures; however, as a result of the fire, components have failed thus increasing the intensity of the fire. Fire-safe valves and actuators tested to various industry standards have been used for some time to help prevent fire damage. Other features can be designed into a piping system to minimize the effects of a fire such as materials of construction, component design, flanges, flange gaskets, and flange bolting, brazed and welded joints, pipe insulation and composite piping. Present design deficiencies can be corrected as well. Nothing can make

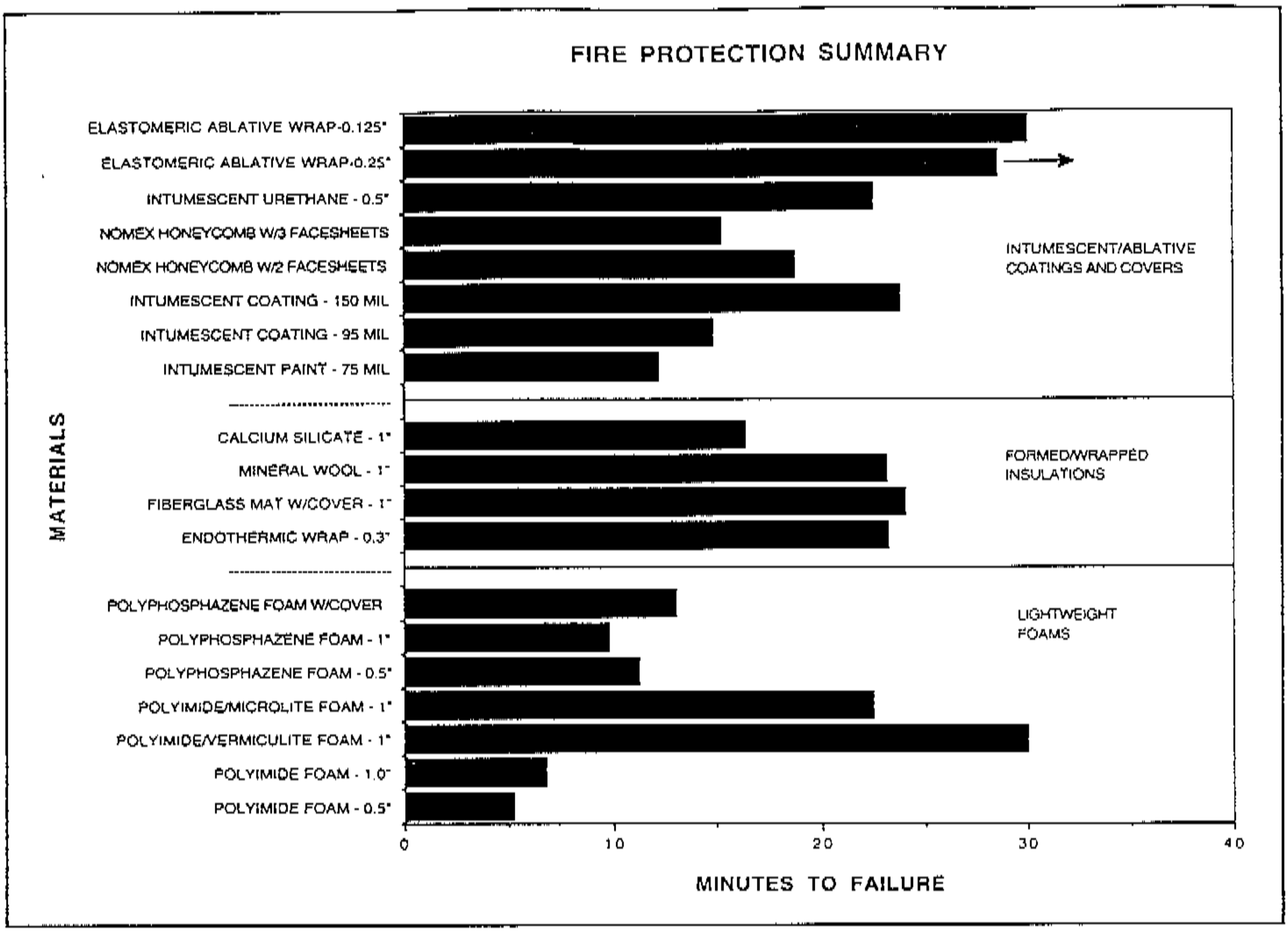

Figure 5. Fire Survival rates of Fire Protective Coatings on GRP.

a piping system absolutely fire-safe, however. Human error in the form of operational mistakes or improper maintenance procedures/parts replacement also occurs as well as battle damage to piping systems, which is difficult and impractical to predict. What we can accomplish is to slow the spread of a fire on board ship, minimizing damage and most important, injury/loss of life. The risk-criticality-cost and hazard analysis for each shipboard system should be conducted and components selected to achieve optimum results at minimum cost. Where fire-resistant components are not available or possible, then use of insulation should be considered.

REFERENCES

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[2] Conroy, P. D., and Murphy, L. P. "Evaluation of an Insulation material to Improve Fire Survivability of Cu-Ni Sil-Brazed Joints," Carderock Division, Naval Surface Warfare Center, August 1992.

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