Fireproofing Practices in Petroleum and Petrochemical Processing Plants

API PUBLICATION 2218
SECOND EDITION, AUGUST 1999

American Petroleum Institute

Helping You Get The Job Done Right.SM

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Health, Environment and Safety General Committee
Safety and Fire Protection Subcommittee

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FOREWORD

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Fireproofing Practices in Petroleum and Petrochemical Processing Plants

1 Introduction

1.1 PURPOSE

This publication is intended to provide guidance for selecting, applying, and maintaining fireproofing systems that are designed to limit the extent of fire related property loss in the petroleum and petrochemical industries.

1.2 RETROACTIVITY

The provisions of this publication are intended for use in designing new plants or considering major expansions. It is not intended that the recommendations in this publication be applied retroactively to existing plants. This publication can be used as guidance if there is a need or desire to review existing capability or provide additional fire protection.

1.3 SCOPE

This publication uses a risk-based approach to evaluate fireproofing needs for petroleum and petrochemical plants in which hydrocarbon fires could rapidly expose structural supports to very high temperatures. Fireproofing can protect against intense and prolonged heat exposure that could cause collapse of unprotected equipment and lead to the spread of burning liquids and substantial loss of property. This guideline specifically addresses property loss protection for pool fires scenarios but not jet fires or vapor cloud explosions. Fireproofing may also mitigate concerns for life safety and environmental impact. Additional fire-resistance measures may be appropriate for fire protection where hazardous chemicals could be released with the potential for exposure of persons on site or outside the plant. Regulatory compliance is not addressed by this publication.

Although widely used, the term “fireproofing” is misleading as almost nothing can be made totally safe from the effects of fire. Fireproofing refers to the systematic process (including materials and the application of materials) that provides a degree of fire resistance for protected substrates. This document specifically addresses fireproofing in process units, especially structural supports and related equipment (such as tankage, utilities and relevant off-site facilities). It does not address fire prevention (which is addressed in API 2001) nor fireproofing of buildings.

Fireproofing is a complex subject; and API Publ 2218 is not a design manual. As a guideline, it doesn’t specify fireproofing requirements applicable to particular units or plants. It should help site management understand fireproofing issues and help them define protection needs and facilitate effective relationships with fireproofing experts, material suppliers, and installers. This publication assists in the evaluation of options available, and where and to what extent fireproofing might be applied to mitigate the effects of a severe fire.

This publication applies to onshore processing plants. Where comparable hazards exist, and to the extent appropriate, it may be applied to other petroleum properties that could experience similar fire exposure and potential losses.

This publication is concerned only with passive fireproofing systems. It does not address active systems (such as automatic water deluge) used to protect processing equipment, including exposed structural steel supports. Fixed water spray systems are the subject of API Publication 2030, *Application of Water Spray Systems for Fire Protection in the Petroleum Industry*, and NFPA 15, *Water Spray Fixed Systems for Fire Protection*. The general subject of Fire Protection in Refineries is addressed in API RP 2001. API RP 14G, *Fire Prevention and Control on Open Type Offshore Production Platforms*, provides guidance on general fire protection for offshore platforms, and includes some discussion of passive fireproofing.

2 Referenced Publications

The most recent edition or revision of each of the following standards, codes, and publications are referenced in this Recommended Practice as useful sources of additional information supplementary to the text of this publication. Additional information may be available from the cited Internet World Wide Web sites.

API[1]	
RP 14G	*Fire Prevention and Control on Open Type Offshore Production Platforms*
RP 750	*Management of Process Hazards*
Publ 760	*Model Risk Management Plans for Refineries*
RP 2001	*Fire Protection in Refineries*
Publ 2030	*Application of Water Spray Systems for Fire Protection in the Petroleum Industry*
Std 2510	*Design and Construction of LPG Installations*
Publ 2510A	*Fire Protection Considerations for the Design and Operation of Liquefied Petroleum Gas (LPG) Storage Facilities*
AIChE[2](CCPS)	
	Guidelines for Engineering Design for Process Safety
	Guidelines for Hazard Evaluation Procedures, Second Edition

[1]www.api.org

[2]American Institute of Chemical Engineers, Center for Chemical Process Safety, 345 East 47th Street, New York, New York 10017. www. aiche.org/docs/ccps

	Guidelines for Safe Automation of Chemical Processes

ANSI[3]

A 2.1	*Methods for Fire Tests of Building Construction and Materials*

ASTM[4]

E 84	*Method of Test for Surface Burning Characteristics of Building Materials*
E 119	*Method for Fire Tests of Building Construction and Materials*
E 136-96a	*Standard Test Method for Behavior of Materials in a Vertical Tube Furnace at 750°C.*
E 1529	*Standard Test Methods for Determining Effects of Large Hydrocarbon Pool Fires on Structural Members and Assemblies*
E 1725	*Standard Test Methods for Fire Tests of Fire-Resistive Barrier Systems for Electrical System Components*

EPA[5]

40 *CFR* 68	*Risk Management Programs*

IRI[6]

IM.2.5.1	*Fireproofing for Hydrocarbon Fire Exposures*

NFPA[7]

15	*Water Spray Fixed Systems for Fire Protection*
30	*Flammable & Combustible Liquids Code*
58	*Standard for the Storage and Handling of Liquefied Petroleum Gases*
101	*Life Safety Code*
251	*Fire Tests for Building Materials*
255	*Method of Test of Surface Burning Characteristics of Building Materials*

OSHA[8]

1910.119	*Process Safety Management of Highly Hazardous Chemicals*

UL[9]

263	*Fire Tests of Building Construction and Materials*
1709	*Standard for Rapid Rise Fire Tests of Protection Materials for Structural Steel*

3 Definitions

Terms specific to fireproofing or in less common use are defined in 3.1 through 3.31. Definitions of terms used in this standard which are in general use in the petroleum industry are found in Appendix A.

3.1 ablative: Dissipation of heat by oxidative erosion of a heat protection layer.

3.2 active protection: Requires automatic or manual intervention to activate protection such as water spray or monitors.

3.3 cementitious mixtures: As defined by UL in "Spray Applied Fire Resistive Materials" (SFRM), cementitious mixtures are binders, aggregates and fibers mixed with water to form a slurry conveyed through a hose to a nozzle where compressed air sprays a coating; the term is sometimes used for materials (such as sand and cement) applied by either spray or trowel.

3.4 char: A carbonaceous residue formed during pyrolysis that can provide heat protection.

3.5 endothermic fire protection: Heat-activated chemical and/or physical phase change reaction resulting in heat absorption by a noninsulating heat barrier.

3.6 fire-hazardous areas: Areas where there is a potential for a fire.

3.7 fire performance: Response of a material, product or assembly in a "real world" fire, as contrasted to laboratory fire test results under controlled conditions.

3.8 fireproofing: A systematic process, including materials and the application of materials, that provides a degree of fire resistance for protected substrates and assemblies.

3.9 fire-resistance rating: The number of hours in a standardized test without reaching a failure criterion.

3.10 fire-scenario envelope: The three-dimensional space into which fire-potential equipment can release flammable or combustible fluids capable of burning long enough and with enough intensity to cause substantial property damage.

3.11 fire-test-response characteristic: A response characteristic of a material, product, or assembly to a prescribed source of heat or flame as in a standard test.

[3]American National Standards Institute, 11 West 42nd Street, New York, New York 10036. www. ansi.org
[4]American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428. www.astm.org
[5]U.S. Environmental Protection Agency, 401 M Street, S.W., Washington, D.C. 20460. www.epa.gov.
[6]HSB Industrial Risk Insurers, 85 Woodland Street, Hartford, Connecticut 06103.www.industrialrisk.com
[7]National Fire Protection Association, 1 Batterymarch Park, Quincy, Massachusetts 02269. www.nfpa.org
[8]U.S. Department of Labor, Occupational Safety and Health Administration, 200 Constitution Avenue, N.W., Washington, D.C. 20210. www.osha.gov
[9]Underwriters Laboratories, 333 Pfingsten Road, Northbrook, Illinois 60062. www.ul.com

3.12 functionally equivalent performance: Ability to perform a given function under specific conditions in a manner equivalent to alternatives at the same conditions.

3.13 hazard: An inherent chemical or physical property with the potential to do harm (flammability, toxicity, corrosivity, stored chemical or mechanical energy).

3.14 hours of protection: Fire-resistance rating in a specified standard test; in this publication, UL 1709 (or functional equivalent) test conditions are presumed unless otherwise stated.

3.15 intumescent fire protection: A chemical reaction occurring in passive materials, when exposed to high heat or direct flame impingement, that protects by expanding into an insulating layer of carbonaceous char or glasseous material.

3.16 mastic: A pasty material used as a protective coating or cement.

3.17 passive fire protection (PFP): A barrier, coating or other safeguard which provides protection against the heat from a fire without additional intervention.

3.18 perlite: Natural volcanic material that is heat-expanded to a form used for lightweight concrete aggregate, fireproofing, and potting soil.

3.19 pool fire: A buoyant diffusion flame in which the fuel is configured horizontally.

3.20 qualitative risk assessment: An experience-based evaluation of risk (as discussed in CCPS Guidelines for Hazard Evaluation Procedures).

3.21 risk: The probability of exposure to a hazard that results in harm.

3.22 risk assessment: The identification and analysis, either qualitative or quantitative, of the likelihood and outcome of specific events or scenarios with judgements of probability and consequences.

3.23 risk-based analysis: A review of potential needs based on a risk assessment.

3.24 spalling: Breaking into chips or fragments which may separate from the base material.

3.25 spray applied fire resistive materials (SFRM): Includes two product types previously UL classified as Cementitious Mixtures and Sprayed Fiber Materials.

3.26 sprayed fiber materials: Binders, aggregates and fibers conveyed by air through a hose to a nozzle, mixed with atomized water and sprayed to form a coating; included by UL in “Spray Applied Fire Resistive Materials” (SFRM).

3.27 substrate: The underlying layer being protected by a fireproofing barrier layer.

3.28 subliming: Going directly from a solid state to a gaseous state without becoming a liquid.

3.29 thermal diffusivity: Conduction of heat through an intervening layer.

3.30 vermiculite: Hydrated laminar magnesium-aluminum-iron silicate which is heat-expanded 8 to 12 times to produce a light noncombustible mineral material used for fireproofing and as aggregate in lightweight concrete.

3.31 W10 x 49 column: A steel “I-beam” with a 10-in.-wide flange weighing 49 lb/ft, that is the *de facto* standard for industrial fireproofing tests.

4 Units of Measurement

Values for measurements used in this document are generally provided in both English and SI (metric) units. To avoid implying a greater level of precision than intended, the second cited value may be rounded off to a more appropriate number. Where specific test criteria are involved, an exact mathematical conversion is used.

5 General

5.1 THE FUNCTION OF FIREPROOFING

While design, location, spacing, and drainage are of substantial importance in minimizing equipment involvement in a fire, additional protective measures may still be necessary. One protective measure is to improve the capacity of equipment and its support structure to maintain their structural integrity during a fire. Another is to shield essential operating systems when they are exposed to fire. Fireproofing achieves these objectives with passive protection (PFP) in contrast to fixed water spray systems, monitors, or portable hose lines, which provide active protection.

The principal value of fireproofing is realized during the early stages of a fire when efforts are primarily directed at shutting down units, isolating fuel flow to the fire, actuating fixed suppression equipment, and setting up cooling water streams. During this critical period, if nonfireproofed pipe and equipment supports lose their strength due to fire-related heat exposure, they could collapse and cause gasket failures, line breaks, and hydrocarbon leaks. In addition, if control or power wiring is incapacitated, it may become impossible to operate emergency isolation valves, vent vessels, or actuate fire-damaged automatic or manually activated water spray systems.

Fireproofing does not extinguish fires and may have no significant effect on the final extent of property damage if intense fire exposure persists significantly longer than designed into the fireproofing system. If activated while fireproofing is still protective, cooling from fixed or portable firewater can extend the effective time of passive fire protection beyond its nominal fire resistance rating, provided that the

force of the firewater application does not damage or dislodge the fireproofing material.

When properly implemented, fireproofing systems can help reduce losses and protect personnel and equipment by providing additional time to control or extinguish a fire before thermal effects cause equipment or support failure.

5.2 DETERMINING FIREPROOFING NEEDS

Determining fireproofing requirements for a petroleum or petrochemical facility involves experience-based or formal risk-based evaluation that includes developing fire scenarios from which the needs analysis evolves. An approach for selecting fireproofing systems is illustrated by Figure 1 and includes the following:

a. Hazard evaluation, including quantification of inventories of potential fuels.

b. Development of fire scenarios including potential release rates and determining the dimensions of fire-scenario envelopes.

c. Determining fireproofing needs based on the probability of an incident considering company or industry experience, the potential impact of damage for each fire-scenario envelope, and technical, economic, environmental, regulatory and human risk factors.

d. Choosing the level of protection (based on appropriate standard test procedures) that should be provided by fireproofing material for specific equipment, based on the needs analysis.

The fireproofing process, including installation and surveillance, is described in the subsequent sections of this document.

5.2.1 Fire Hazard Evaluation

The first step in evaluating fireproofing requirements is to identify the location and types of fire-hazard areas. Factors to consider include quantities, pressures, temperatures, and the chemical composition of potential fuel sources. Much equipment to be considered for fireproofing is located in areas subject to some form of hazard evaluation procedure. This evaluation may be based on owner choice or regulatory requirements such as OSHA 29 *CFR* 1910.119, *Process Hazard Management of Highly Hazardous Chemicals*, or EPA 40 *CFR* 68, *Risk Management Programs*. A variety of qualitative and quantitative procedures that can be helpful in developing hazard analysis scenarios are outlined in API RP 750, *Management of Process Hazards* and CCPS *Guidelines for Hazard Evaluation Procedures*.

Some fire protection personnel use qualitative "fire-potential" categories to assist in hazard determination. This division of equipment into high, medium, low, and nonfire potential, as described in 5.2.1.1 through 5.2.1.4, has proven useful to some companies in determining fireproofing needs. These categories are based on experience, which shows that some types of equipment have a higher fire potential than others, based on historical incident frequency and/or severity. These fire potential definitions are intended to include most types of hydrocarbon-handling equipment that can release appreciable quantities of flammable fluids.

5.2.1.1 High Fire-Potential Equipment

The following are examples of equipment considered to have a high fire potential:

a. Fired heaters that process liquid or mixed-phase hydrocarbons, under the following conditions:

1. Operation at temperatures and flow rates that are capable of causing coking within the tubes.
2. Operation at pressures and flow rates that are high enough to cause large spills before the heater can be isolated.
3. Charging of potentially corrosive fluids.

b. Pumps with a rated capacity over 200 US gpm (45 m^3/hr) that handle flammable liquids or combustible liquids above or within 15°F (8°C) of their flash point temperatures.

c. Pumps with a history of bearing failure or seal leakage (where engineering revisions have been unsuccessful at eliminating these as significant potential fuel sources).

d. Pumps with small piping subject to fatigue failure.

e. Reactors that operate at high pressure or might produce runaway exothermic reactions.

f. Compressors, together with related lube-oil systems.

Note: While compressors do not have a high liquid-fire potential, they can generate a fire-scenario envelope if there is a prolonged release of gas and an intense fire in the vicinity of important structural supports. If the compressor is equipped to be remotely shut down and isolated from gas supplies during an emergency, its potential for becoming involved in a serious fire should be lower.

g. Specific segments of process piping handling flammable liquids or gases in mixtures known to promote pipe failures through erosion, corrosion, or enbrittlement. These include hydrocarbon streams that may contain entrained catalyst, caustics, acids, hydrogen, or similar materials where development of an appropriate scenario envelope is feasible.

h. Vessels, heat exchangers (including air cooled exchangers), and other equipment containing flammable or combustible liquids over 600°F (315°C) or their auto-ignition temperature, whichever is less.

i. Complex process units such as catalytic crackers, hydrocrackers, ethylene units, hydrotreaters, or large crude distilling units typically containing high fire-potential equipment.

5.2.1.2 Medium Fire-Potential Equipment

The following are examples of equipment considered to have a medium fire potential:

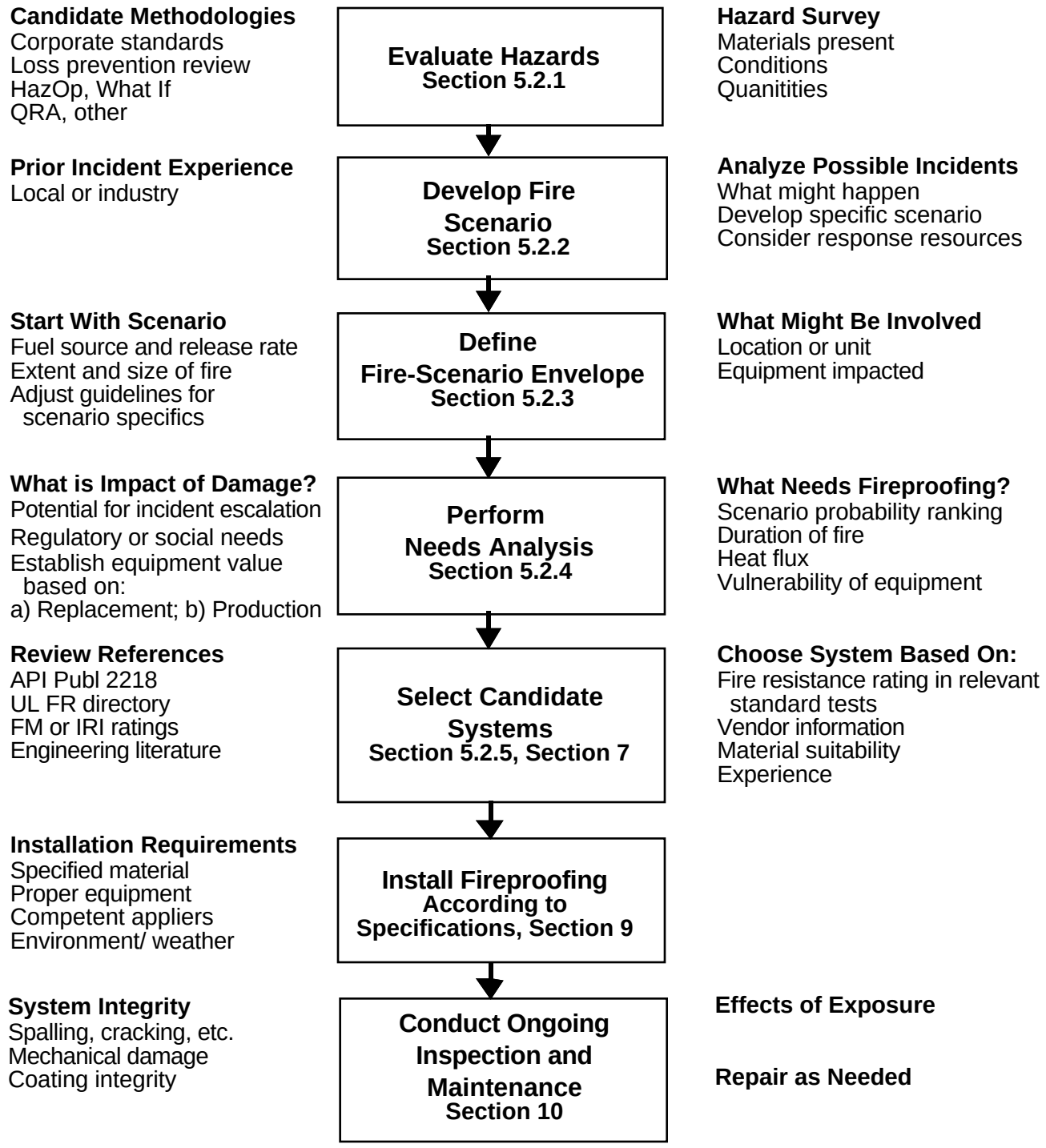

Figure 1—Selecting Fireproofing Systems

a. Accumulators, feed drums, and other vessels that may leak as a result of broken instrumentation, ruptured gaskets, or other apparatus.
b. Towers that may leak as a result of broken gauge columns or gasket failure on connected piping and bottom reboilers.
c. Air-cooled fin fan exchangers that handle flammable and combustible liquids.
d. Highly automated and complex peripheral equipment such as combustion air preheaters.

5.2.1.3 Low Fire-Potential Equipment

The following are examples of equipment considered to have a low fire potential:

a. Pumps that handle Class IIIB liquids below their flash points.
b. Piping within battery limits which has a concentration of valves, fittings, and flanges.
c. Heat exchangers that may develop flange leaks.

5.2.1.4 Nonfire-Potential Equipment

Nonfire-potential equipment has little or no chance of releasing flammable or combustible fluids either prior to or shortly after the outbreak of a fire. Piping and other equipment that handles noncombustible fluids are considered to be nonfire-potential equipment.

Note: Although classified as nonfire-potential equipment, water supply lines to active fire protection equipment within the envelope should be considered for fireproofing protection if analysis shows they are vulnerable.

5.2.2 Fire-Scenario Development

Development of a fire scenario uses information from hazard evaluations to determine what a fire would be like if it occurred. It seeks to define what sequence of events might release materials that could be fuel for a fire. Then, what elements affect the nature of the fire. The fire scenario considers what the situation would be if unabated. For each scenario the following data set should be developed:

a. What might happen to released materials that could fuel a fire?
b. Where is the potential fuel-release scenario located?
c. How much material might be released?
   1. Hydrocarbon hold-up capacity.
   2. Releasable inventory.
d. How fast (flow rate) might potential fuel be released?
   1. Pressure and temperature of source.
   2. Size of opening.
   3. Nature of potential leaks.
e. Will the fuel be impounded locally by berms or diking?
f. What is the capacity of the drainage system to remove a hydrocarbon spill?
g. If ignited, what would be the character and extent of fire?
   1. Volatility.
   2. Burning rate.
   3. Heat of combustion.
   4. Physical properties of materials that may be released.
h. How much heat would be released if ignited?
i. How long might the fire burn if unabated?

This information defines the fire scenario based on both qualitative and quantitative information regarding plant configuration, appropriate for a "What If" approach to hazard analysis. Similar useful information may already exist in preincident, fire-suppression planning documents.

5.2.3 Fire-Scenario Envelope

Based on the fire scenario, a fire-scenario envelope can be developed. The fire-scenario envelope is the three-dimensional space into which fire-potential equipment can release flammable or combustible fluids capable of burning long enough and with enough intensity to cause substantial property damage. The definition of the fire-scenario envelope, along with the nature and severity of potential fires within the envelope, becomes the basis for selecting the fire-resistance rating of the fireproofing materials used.

An integral part of defining the fire-scenario envelope is determining the appropriate dimensions to use for planning fire protection. For liquid hydrocarbon fuels, a frequently used frame of reference for the fire-scenario envelope is one that extends 20 ft to 40 ft (6 m to 12 m) horizontally, and 20 ft to 40 ft (6 m to 12 m) vertically, from the source of liquid fuel. For pool or spill fires, the source is considered to be the periphery of the fire where the periphery is defined by dikes, curbing, or berms; in other instances, estimates of the fire-scenario envelope should be used based on spill quantity and knowledge of unit topography, as discussed in 6.2.1.2.

LPG vessels are considered to be the source of a fire-scenario exposure, and require fireproofing unless protected by a fixed water spray system. API 2510 recommends fireproofing pipe supports within 50 ft (15 m) of the LPG vessel, or within the spill containment area.

Table 1 provides a summary of typical fireproofing guideline values describing the dimensions of the fire-scenario envelope. Table 2 cites guidance for the UL 1709 (or functional equivalent) fire-resistance rating for selected equipment. Section 5.2.4 discusses factors that might suggest modifying the size of the fire-scenario envelope, based on the fire-risk needs analysis.

5.2.4 Needs Analysis

The *needs analysis* determines what level of protection (if any) equipment needs. This analysis starts with factors relating to *severity and duration* of exposure developed in the scenario analysis for an area. It then considers which specific

Table 1—Dimensions of Fire-Scenario Envelope

Hazard Concern	Horizontal	Vertical	Section in API 2218 or other Reference
A fire-scenario source of liquid fuel release—general	20 to 40 ft (6 to 12 m)	20 to 40 ft (6 to 12 m)	5.2.3
Fire-potential equipment	20 to 40 ft (6 to 12 m)	Up to highest level supporting equipment	6.1.1.1
Nonfire-potential equipment Above-fire potential equipment	20 to 40 ft (6 to 12 m)	Up to level nearest 30 ft (9 m) above grade	6.1.1.3
LPG vessels as potential source of exposure	Pipe supports within 50 ft or within spill containment area	Up to level nearest 30 ft (9 m) above grade	5.2.3, API 2510
Fin-fan coolers on pipe racks within fire-scenario envelope	20 to 40 ft (6 to 12 m)	All support members up to cooler	6.1.2.2, 6.1.3
Rotating equipment	20 to 40 ft (6 to 12 m) from the expected source of leakage	20 to 40 ft (6 to 12 m)	5.2.3
Tanks, spheres, and spheroids containing liquid flammable material other than LPG	The area shall extend to the dike wall, or 20 ft (6 m) from the storage vessel, whichever is greater.	20 to 40 ft (6 to 12 m) or as specified for equipment of concern	5.2.3
Marine docks where flammable materials are handled	100 ft (30 m) horizontally from the manifolds or loading connections	From the water surface up to and including the dock surface	

Table 2—Level of Fireproofing Protection in Fire-Scenario Envelope

Equipment	Protection Level[a]	Section in API 2218 or Other Reference
LPG vessels if not protected by fixed water spray systems.	Fireproofed equivalent to 1 ½ hours in UL 1709 (or functional equivalent).	API 2510 (1995) Section 8.7 Section 6.2.2
Pipe supports within 50 ft or in spill containment area of LPG vessels, whichever is greater.	Fireproofed equivalent to 1 ½ hours in UL 1709 (or functional equivalent).	Sections 6.2.2 and 6.2.3 API 2510 (1995) Section 8.8.5
Critical wiring and control systems.	15-to-30-minute protection in UL 1709 (or functional equivalent) temperature conditions.	Section 6.1.8.1 API 2510 (1995) Section 8.11

Note: [a]Some company standards require protection greater than that shown in column 2.

equipment might be exposed, the vulnerability of that equipment to heat exposure, and the resulting impacts of a scenario incident. These include social, environmental, and human impacts as well as the intrinsic and production value of that equipment. During the needs analysis, the effectiveness of other intervention and suppression resources is introduced into consideration. Finally, the needs analysis reviews the *probability* of a scenario incident.

The first phase of analysis considers potential severity and vulnerability:

a. The location and potential heat release of potential leaks.
   1. What equipment is potentially exposed?
   2. What is the nature and proximity of that exposure?

b. The severity of operating conditions in potentially exposed equipment.
   1. Process temperature and pressure.
   2. Whether process materials are above their autoignition points.
   3. Whether equipment contains liquid which can absorb heat or help cool the vessel walls upon vaporizing.

c. The Fire-Potential Category of equipment in the area (5.2.1.1 through 5.2.1.4).

d. Unit spacing, layout of equipment and potential fire exposure hazard to adjacent facilities.

e. The estimated duration of an unabated fire (from 5.2.2).

Further analysis considers intervention capability:

a. The effectiveness of the drainage system to remove a hydrocarbon spill.

b. Capability of isolation and deinventory systems.

c. Manual and automatic shutdown systems.

d. Active fire protection provided by fixed water spray systems or fixed monitors.
e. Response time and capabilities of fire brigades.
f. Unit spacing, equipment layout, and access for emergency response.

Finally, risk is evaluated:

a. The potential impact on employees, the public or the environment.
b. Scenario event probability (traditionally based on qualitative evaluations).
c. The fire-hazard rating of equipment (from Section 5.2.1).
d. The intrinsic value of potentially exposed plant or equipment.
e. The importance of unit equipment to continued plant operations and earnings.

The result of the needs analysis should include definition of which equipment to fireproof, and for what heat-exposure intensity and duration the fireproofing should provide protection. Where active protection systems are in place, the risk evaluation portion of the needs analysis judges whether potential incident impacts or equipment value justify fireproofing as an additional mode of protection.

Alternatives to experience-based proximity guidelines are now coming into use in some areas to assist the process of needs analysis. API RP 2510A, Section 2, discusses radiation from pool fires and provides a chart for estimating heat exposure from propane pool fires, assuming a specific set of conditions. Sophisticated computer *Hazard Consequence or Fire Effects* modeling can provide calculated heat flux exposure values for specific equipment and scenarios.

5.2.5 Fire-Resistance Rating Selection

Choosing a fire-resistance rating requires determining the length of time the fireproofing is intended to provide protection. The needs analysis in 5.2.4 identified risk factors related to severity and duration. For a few situations, industry standards have defined minimum requirements, as shown in Table 2. Review of these requirements should be included in the needs analysis to ensure that they are appropriately protective. For other equipment, the next step is to specifically define the desired protection time.

5.2.5.1 Time Aspects for Fire-Resistance Rating Selection

Evaluating the scenario incident, as defined in the needs analysis and refined during the selection process, should enable the person specifying fire protection to establish a duration for protection. The following considerations should aid in selecting the time desired for fireproofing protection:

a. The time required to block flows and backflows of fuel that may be released.
b. The availability and flow capacity of an uninterrupted water supply.
c. The time required to apply adequate, reliable cooling from fixed water spray systems or fixed monitors, including response time for personnel to operate them.
d. Response time and capability of plant or other fire brigades to apply portable or mobile fire response resources (including foam for suppression).
e. The time required for the area's drainage system to remove a hydrocarbon spill.

Typically, protection equivalent to 1.5 to 3 hours under UL 1709, or functionally equivalent test conditions is provided for most structural components.

5.2.5.2 Laboratory Fire-Resistance Ratings

Once the fire exposure time period has been estimated, the task of specifying the fireproofing fire-resistance rating can proceed for the various equipment and support systems within the fire-scenario envelope.

It is important to recognize that fire-resistance ratings are laboratory test results. The rating, expressed in hours, represents the time for a protected member (such as a steel column) to reach a specific temperature (1000°F end point for UL 1709 and ASTM E 1529) when a fireproofing system (precise assembly of structural member and fireproofing materials) is exposed to a strictly controlled fire in a specific test protocol. The amount of heat a steel member can absorb (its "thermal mass") is a primary factor in determining the fire protection required; and a fire resistance rating does not apply for fireproofing equipment or structural members other than those exactly represented by the assembly tested.

5.2.5.3 Using Laboratory Fire-Resistance Ratings

The fire-resistance rating is a useful relative measure for comparing fireproofing systems. However, fire-resistance ratings should be used with judgement, including some reasonable safety factor.

As an example, a steel column fireproofed to a 1½-hour laboratory rating may or may not withstand a "real-world" fire for 1½ hours without damage or failure, depending on the similarity of the field application to the laboratory assembly, and the scenario fire to the laboratory test conditions. And as discussed in 5.2.5.2, the rating is specific to a particular configuration. For example, if a certain fireproofing material applied to a W10 x 49 steel beam provides a 1½-hour-rated column, one cannot expect that the same thickness of material applied to a lightweight beam or to sheet steel would allow either to survive for 1½ hours with the same fire exposure.

In general, the number of hours of fire resistance selected would apply to most of the structural supports within the fire-scenario envelope. Increased fire resistance should be considered for supports on important equipment that could cause

extensive damage if collapsed. Certain large, important vessels such as reactors, regenerators, and vacuum towers may be mounted on high support structures. In these cases, fireproofing materials should be considered for the entire exposed support system, regardless of its height. In some other instances, particularly at higher elevations within the fire-scenario envelope, the fire-resistance rating may be reduced. Section 5 tables and Section 6 figures reflect common industry practice. These guidelines should be implemented using experienced fireproofing personnel.

For example, if the expected fire would only be a moderate exposure, with reasonable expectations that manual water cooling of exposed structure could effectively be in place within an hour or less, a 1½-hour UL 1709 (or functional equivalent) rating might be a reasonable choice. However, if responding emergency response personnel were 1½ hours away or exposure was more severe, a more protective rating (such as 3 hours) might be chosen. In service, the fireproofing goal is protection of equipment (such as structural supports) within a "real world" fire-scenario envelope. A fireproofing application should be designed for each fire-scenario envelope based on the best estimate of the duration and severity of a potential fire.

5.2.5.4 Additional Fire-Resistance Ratings Considerations

Many fire-scenario envelopes contain low-mass elements, such as pipe hangers and cable tray supports, which may need protection if their load-bearing capability needs to be maintained for the required length of time. If sufficient test data is available, a linear analysis can determine protection needs for these small elements. An alternative to fireproofing these small elements is using fireproofed "catch beams."

Interpolation between results for tested system assemblies (for instance, different thicknesses of the same material) should be done by personnel experienced in fireproofing analysis. Extrapolation to items of less-than-tested mass should be avoided.

There can be benefits from not fireproofing steel where the needs analysis determines fireproofing is not needed. The air-exposed surface can be a radiator of conducted heat to the atmosphere, which is one reason fireproofing is not specified for the top flange, if heat radiation will be from a fire below the beam.

5.2.6 Effect of Heat on Structural Steel

The effect of heat exposure on structural steel is of concern during and after the fire. Steel loses strength if exposed to increased temperatures. During a fire, if structural steel is hot enough for an adequate time period, it can weaken and lose its ability to support its load. Fireproofing tests simulating hydrocarbon fire conditions are designed to reach 2000°F in 5 minutes to represent fire exposure temperature. Some steels' internal structure can change when heated and cooled, resulting in the possibility of post-fire concerns. This concern normally involves alloy steels, but not mild steel used for structures.

5.2.6.1 Concerns during fire exposure increase as the temperature increases. Standardized tests use 1000°F (538°C) as the "failure" point.

5.2.6.2 Figure 2 shows the strength of a typical structural steel as it is heated; it loses about one-half of its strength at 1000°F (538°C).

5.2.6.3 Steel objects with smaller thermal mass will heat faster. Figure 3 shows the effect of steel plate thickness on the rate of temperature increase for plates of different thickness exposed to a gasoline fire of about 2000°F (1100°C).

6 Fireproofing Considerations for Equipment Within a Fire-Scenario Envelope

6.1 FIREPROOFING INSIDE PROCESSING AREAS

6.1.1 Multilevel Equipment Structures (Excluding Pipe Racks) Within a Fire-Scenario Envelope

6.1.1.1 When structures support equipment that has the potential to add fuel or escalate the fire, fireproofing should be considered for the vertical and horizontal steel support members from grade up to the highest level at which the equipment is supported (see Figure 4).

6.1.1.2 Elevated floors and platforms that could retain significant quantities of liquid hydrocarbons should be treated as though they were on the ground-floor level, for purposes of calculating vertical distances for fireproofing (see Figure 5).

6.1.1.3 Within a fire-scenario envelope, when the collapse of unprotected structures that support equipment could result in substantial damage to nearby fire-potential equipment, fireproofing should be considered for the vertical and horizontal steel members from grade level up to and including the level that is nearest to a 30-ft (9.1-m) elevation above grade (see Figure 6).

6.1.1.4 Fireproofing should be considered for knee and diagonal bracing that contributes to the support of vertical loads or to the horizontal stability of columns located within the fire-scenario envelope. Bracing that is exposed to the fire can conduct heat into the structure and negatively affect the fire rating of the fireproofing system. Fireproofing suppliers may be able to provide test-based recommendations for coverage of noncritical members. In many cases, knee and diagonal bracing that is used only for wind, earthquake, or surge loading, need not be fireproofed (see Figure 4).

6.1.1.5 When reactors, towers, or similar vessels are installed on protected steel or reinforced concrete structures,

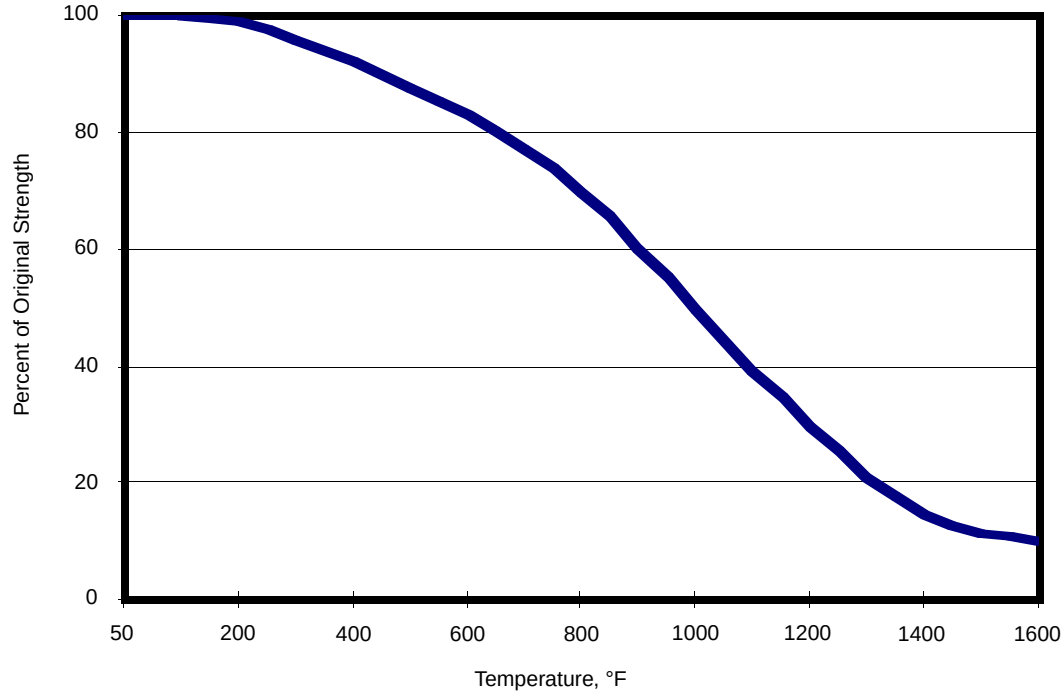

Figure 2—Example of Effect of Temperature on Strength of Structural Steel

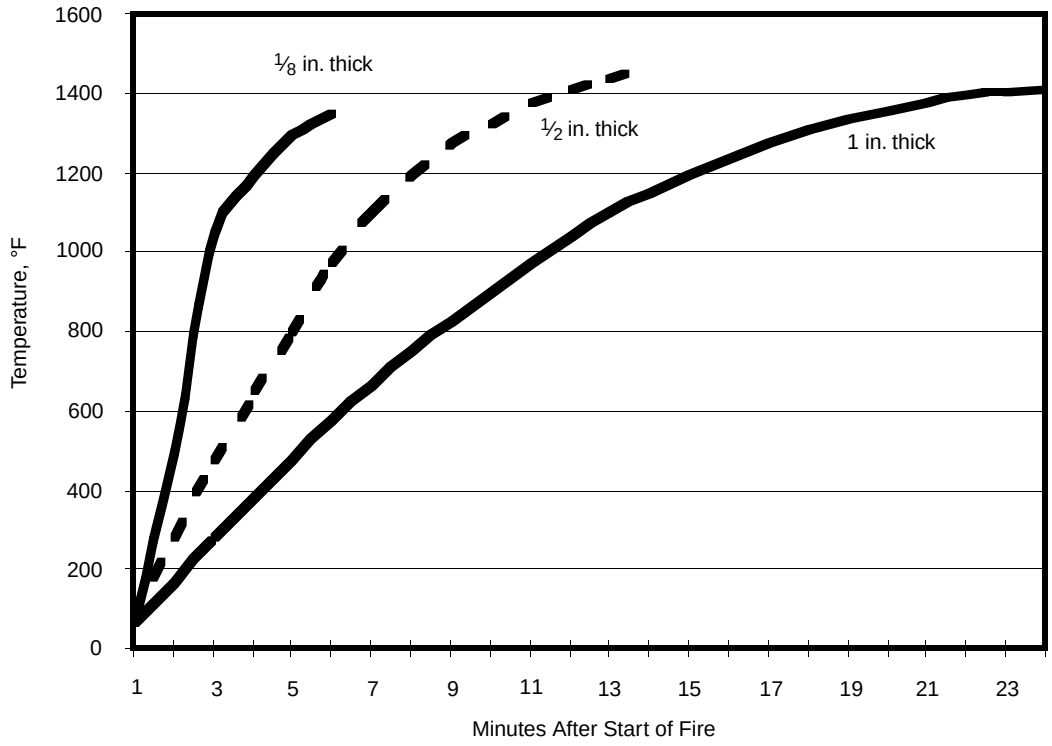

Figure 3—Heating of Unwetted Steel Plates Exposed to Gasoline Fire on One Side

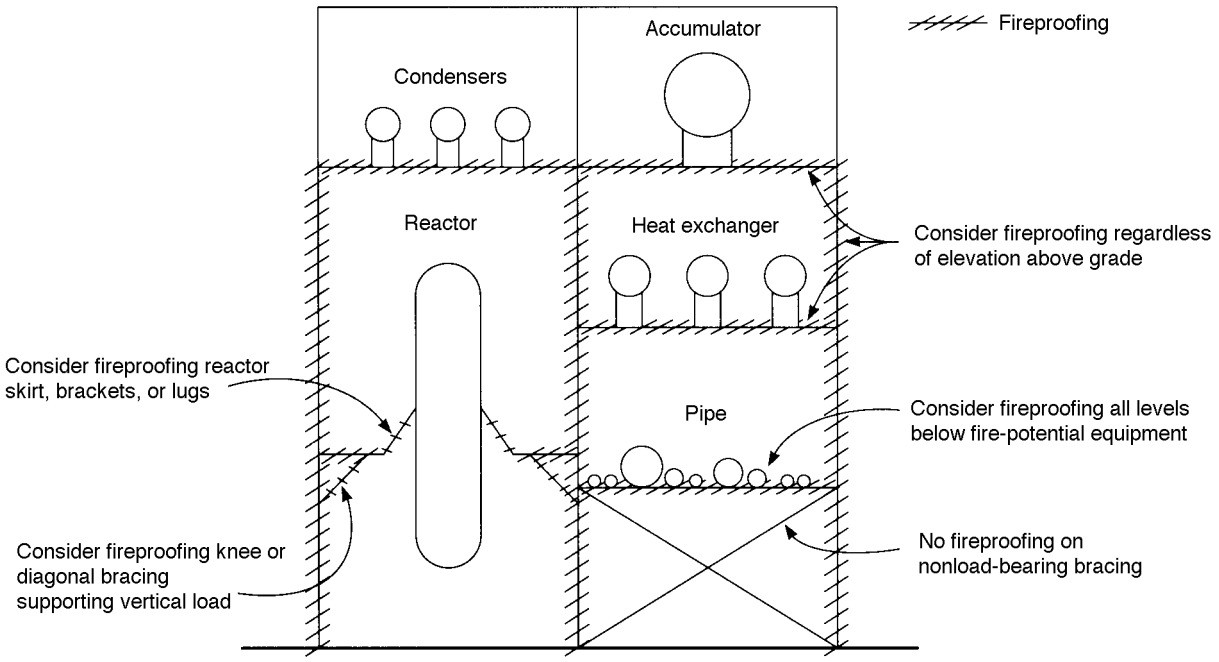

Figure 4 —Structure Supporting Fire-Potential and Nonfire-Potential Equipment in a Fire-Scenario Area

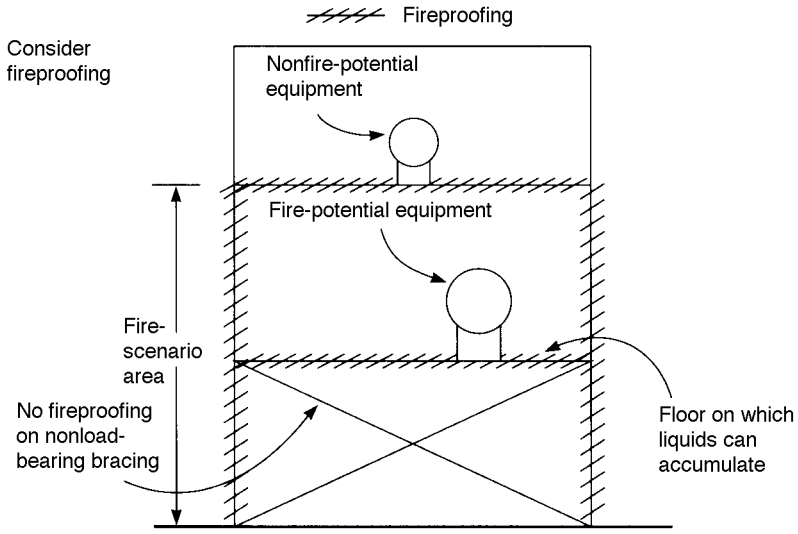

Figure 5—Structure Supporting Fire-Potential and Nonfire-Potential Equipment in a Fire-Scenario Area

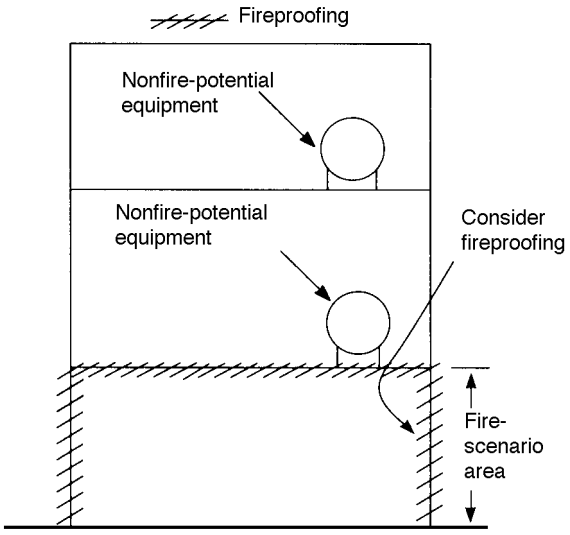

Figure 6—Structure Supporting Nonfire-Potential Equipment in a Fire-Scenario Area

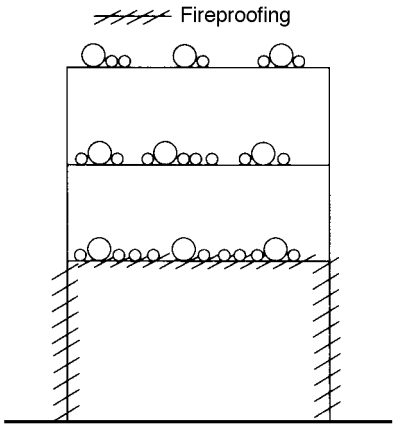

Figure 7—Pipe Rack Without Pumps in a Fire-Scenario Area

fireproofing should be considered for equivalent protection of supporting steel brackets, lugs, or skirts (see Figure 4). To maintain the structural integrity, it is very important to consider the insulating effect of the fireproofing material in the design of supports for vessels that operate at high temperatures.

6.1.1.6 For fireproofing that is required for horizontal beams that support equipment in fire-scenario areas, the upper surface of the beam need not be fireproofed.

6.1.2 Supports for Pipe Racks Within a Fire-Scenario Envelope

6.1.2.1 When a pipe rack is within a fire-scenario envelope, fireproofing should be considered for vertical and horizontal supports, up to and including the first level, especially if the supported piping contains flammable materials, combustible liquids or toxic materials. If a pipe rack carries piping with a diameter greater than 6 in., at levels above the first horizontal beam; or if large hydrocarbon pumps are installed beneath the rack, fireproofing should be considered up to and including the level that is nearest to a 30-ft (9-m) elevation (see Figures 7 and 8). Wind or earthquake bracing and non-load-bearing stringer beams that run parallel to piping need not be fireproofed (see Figure 9).

6.1.2.2 If air fin-fan coolers are installed on top of a pipe rack within a fire-scenario envelope, fireproofing should be considered for all vertical and horizontal support members on all levels of the pipe rack, including support members for the air fin-fan coolers, regardless of their elevation above grade (see Figure 9).

6.1.2.3 Fireproofing should be considered for knee and diagonal bracing that contributes to the support of vertical loads (see Figures 8 and 10). Bracing that is exposed to the fire condition should be reviewed for potential heat conductivity effects (see 6.1.1.4). Knee or diagonal bracing used only for wind or earthquake loading need not be fireproofed.

6.1.2.4 Frequently, the layout of piping requires that auxiliary pipe supports be placed outside the main pipe rack. These supports include small lateral pipe racks, independent stanchions, individual T columns, and columns with brackets. Whenever these members support piping with a diameter greater than 6 in., or important piping such as relief lines, blowdown lines, or pump suction lines from accumulators or towers, fireproofing should be considered (see Figure 11).

6.1.2.5 When piping containing flammable materials, combustible liquids, or toxic materials is hung by rod- or spring-type connections from a pipe-rack support member, and the rod or spring is in a fire-scenario envelope, a “catch beam” should be provided. The catch beam and its support members should be fireproofed. If the pipe that is hung by rod- or spring-type connections is the only line on the pipe rack that contains flammable or toxic material, the pipe-rack support members should be fireproofed to the extent they support the catch beam. Sufficient clearance should be provided between the bracket or beam and the pipe to permit free movement (see Figure 10).

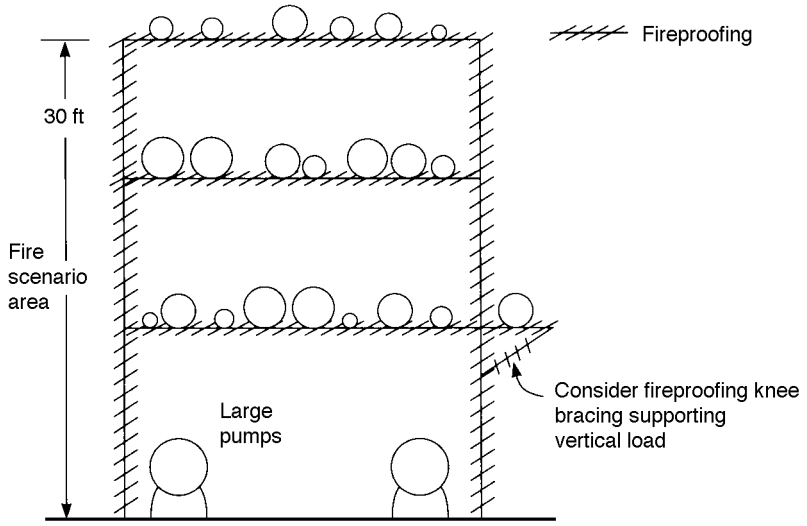

Figure 8—Pipe Rack With Large Fire-Potential Pumps Installed Below

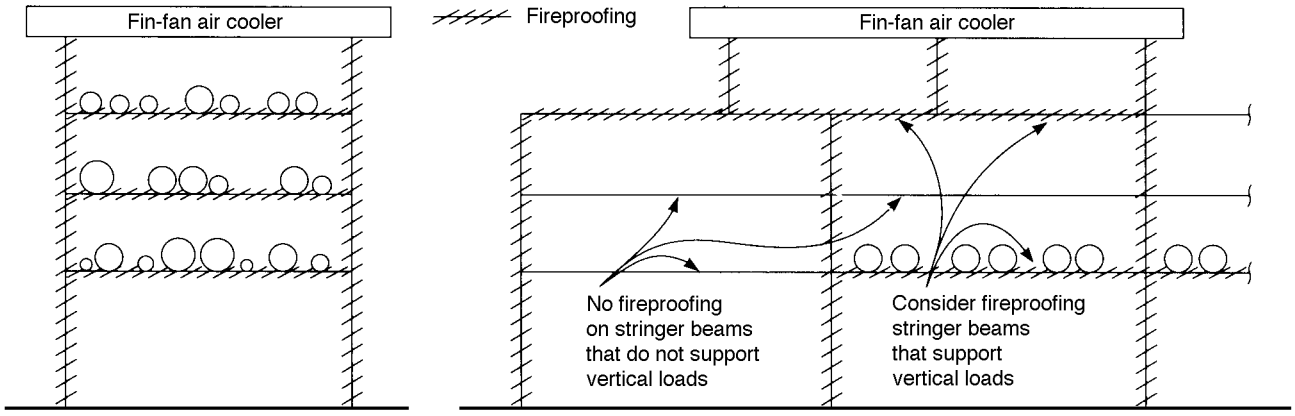

Figure 9—Pipe Rack Supporting Fin-Fan Air Coolers in a Fire Scenario Area

6.1.3 Air Coolers Within a Fire-Scenario Envelope

6.1.3.1 When air fin-fan coolers in liquid hydrocarbon service are located at grade level within a fire-scenario envelope, fireproofing should be considered for their supports.

6.1.3.2 Fireproofing should be considered for the structural supports of all air-cooled exchangers handling flammable or combustible liquids at an inlet temperature above their autoignition temperature, or above 600°F (315°C), whichever is lower.

6.1.3.3 When air-cooled exchangers are located above vessels or equipment that contain flammable materials, fireproofing should be considered for the structural supports located within a 20 ft–40 ft (6 m–12 m) horizontal radius of such vessels or equipment, regardless of height (see Figure 9).

6.1.3.4 Fireproofing for air-cooled exchangers located above pipe racks is covered in 6.1.2.2.

6.1.3.5 If air coolers are handling gas only, and are not exposed to a fire from other equipment at grade, fireproofing the support structure may not provide added value if, when the gas coolers fail (and if there is no liquid to spill), the fire will be above the coolers, and without the potential to jet downwards and cause flame impingement.

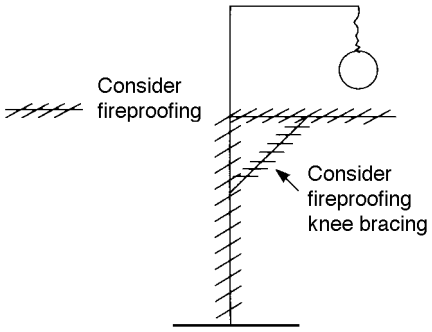

Figure 10—Transfer Line With Hanger Support and Catch Beam in a Fire-Scenario Area

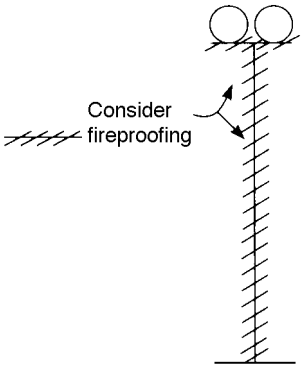

Figure 11—Transfer Line Support in a Fire-Scenario Area

6.1.4 Tower and Vessel Skirts Within a Fire-Scenario Envelope

6.1.4.1 Fireproofing should be considered for the exterior surfaces of skirts that support tower and vertical vessels. Consideration should also be given to fireproofing interior surfaces of skirts if there are flanges or valves inside the skirt, or if there are unsealed openings exceeding 24 in. (600 mm) equivalent diameter in the skirt.

Openings other than the single manway may be closed with removable steel plate at least ¼ in. (6 mm) thick. Consideration should be given to minimizing the effects of draft through vent openings and space that surround pipe penetrations in the skirt.

6.1.4.2 Fireproofing should be considered for brackets or lugs that are used to attach vertical reboilers or heat exchangers to towers or tower skirts. Specific requirements apply to LPG vessels (see 6.2.2 and 6.2.3).

6.1.5 Leg Supports for Towers and Vessels Within a Fire-Scenario Envelope

If towers or vessels are elevated on exposed steel legs, fireproofing the leg supports to their full-load-bearing height should be considered.

6.1.6 Supports for Horizontal Exchangers, Coolers, Condensers, Drums, Receivers, and Accumulators Within a Fire-Scenario Envelope

Fireproofing should be considered for steel saddles that support horizontal heat exchangers, coolers, condensers, drums, receivers, and accumulators that have diameters greater than 30 in. (750 mm), if the narrowest vertical distance between the concrete pier and the shell of the vessel exceeds 12 in. (300 mm).

6.1.7 Fired Heaters Within a Fire-Scenario Envelope

6.1.7.1 Structural members supporting fired heaters above grade should be fireproofed for heaters handling flammable or combustible liquids. Structural steel members supporting fired heaters in other services should be fireproofed if located within a fire-scenario area. These include fired heaters in other-than hydrocarbon service, such as steam superheaters or catalytic cracking-unit air heaters, if a collapse would result in damage to adjacent hydrocarbon-processing equipment or piping.

6.1.7.2 If structural support is provided by horizontal steel beams beneath the firebox of an elevated heater, fireproofing should be considered for the beams, unless at least one flange face is in continuous contact with the elevated firebox.

6.1.7.3 If common chimneys or stacks handle flue gas from several heaters, fireproofing should be considered for the structural supports for ducts, or breeching between heaters and stacks.

6.1.8 Power and Control Lines Within a Fire-Scenario Envelope

6.1.8.1 Electrical Power and Instrument Cable

Electrical, instrument, and control systems used to activate equipment needed to control a fire or mitigate its conse-

quences (such as emergency shut-down systems) should be protected from fire damage, unless they are designed to fail-safe during a fire exposure. The need to protect other electrical, instrument, or control systems not associated with control or mitigation of the fire should be based on a risk assessment. If the control wiring used to activate emergency shutdown devices (including depressurization or isolation systems) during a fire could be exposed to the fire, the wiring should be protected against a 15 minutes–30 minutes fire-exposure functionally equivalent to the conditions of UL 1709. If activation of these emergency systems would not be necessary during any fire to which it might be exposed, then protection of the wire is not required for emergency response purposes. Protection may be desirable if trays with cables servicing neighboring units run through the envelope. Loss control review may indicate need for a longer protection rating, as replacement of critical electrical feeder lines, and rewiring cable trays after a fire, can be very time consuming.

Power and instrument cable can quickly be destroyed in a fire, impeding the ability to safely shut down critical operating equipment and actuate loss-prevention devices.

The primary methods of avoiding early cable failure in a fire situation that could prevent the safe shutdown of a plant include the following:

a. Burying cable below grade.
b. Routing cable around areas that have a high-fire potential.
c. If neither of the above methods have been used, and continued cable service is advisable within a fire-exposed envelope, the following fireproofing designs may provide additional protection and extend operating time:

1. The use of cable rated for high temperatures (minimum 15 to 30 minutes in UL 1709, or functional equivalent fire conditions), such as stainless steel jacketed (MI/SI) mineral-insulated cable, protected by intumescent material fireproofing.
2. The use of foil-backed endothermic wrap insulating systems properly sealed to exclude moisture in accordance with the manufacturer's recommendations.
3. The use of cable tray systems designed to protect the cables from fire. Examples include:

   a. Specialist vendor-certified fireproofed cable tray systems.
   b. Completely enclosed cable trays made of galvanized sheet metal lined inside with insulating, fire-resistant fiber mats, or calcium silicate block.
   c. Cable trays encased with calcium silicate insulating panels with calcium silicate sleepers to hold cables away from bottom of the cable tray.
   d. Trays with exterior surfaces made of galvanized sheet metal coated with mastic fireproofing material.

4. The application of preformed pipe insulation rated for service at 1200°F (650°C), covered with stainless steel sheet metal held in place by stainless steel bands and screws.

The above items may or may not be listed and approved by national testing laboratories. However, two relevant tests are now available.

ASTM E 1725-95, *Standard Test Methods for Fire Tests of Fire-Resistive Barrier Systems for Electrical System Components*, is designed to measure and describe the response of electrical system materials, products, or assemblies to heat and flame under controlled conditions. It can be run using either ASTM E 119 or ASTM E 1529 temperature-curve conditions. For applicability to petroleum and petrochemical processing plants, the ASTM E 1529 pool fire conditions should be specified. The test measures the time for the electrical system component to reach an average temperature 250°F (139°C) above the initial temperature.

UL 2196, *Proposed First Edition of the Standard for Tests of Fire Resistive Cables*, had not yet been formally adopted in late 1998, but the draft protocol is being used. Like ASTM E 1725, there are two alternate temperature curves for testing: (a) the "normal temperature rise curve" is the same as UL 263 (ASTM E 119); and (b) the "rapid temperature rise curve" coincides with UL 1709. For use in petroleum and petrochemical processing plants, the rapid temperature rise curve should be specified.

The protection system selected should be proven by acceptable tests to keep the temperature of the cable within operating limits [usually below 300°F (150°C) for or-dinary polyvinyl chloride cable]. When exposed to UL 1709 hydrocarbon fire temperatures of 2000°F (1093°C), this protection should extend for the time necessary to actuate critical valves, and shut down equipment.

Experience indicates that fireproofing applied directly to thermo-plastic jacketed cables or conduit has a low probability of success. Because the plastic melts at a low temperature, the fireproofing is shed and the cable fails quickly, or the conduit becomes hot enough to melt the insulation of the wire inside. The system selected should be tested, or have manufacturer's evidence that it can protect the cable, to an appropriate temperature for the wire insulation for not less than 15 minutes–30 minutes (or longer if required).

Most fireproofing systems for cable result in cable operating temperatures that are higher than normal, so the electrical capacity of the cable may need to be derated.

6.1.8.2 Pneumatic and Hydraulic Instrument Lines

Pneumatic and hydraulic instrument lines are protected for the same reasons, and by the same methods, as those described in 6.1.8.1 for electrical cable. ASTM Types 304, 316, and 321 stainless steel tubing are highly resistant to failure during a hydrocarbon fire and do not have to be protected with insulating materials. Other types of control tubing could fail within a few minutes when exposed to fire; fireproofing

these types of tubing with preformed pipe insulation rated for service at 1200°F (650°C) or higher should be considered. The assembly should be weather-protected with stainless or galvanized steel sheeting held in place by stainless steel bands and screws.

6.1.9 Emergency Valves Within a Fire-Scenario Envelope

The operation of emergency valves and valve actuators in areas exposed to fire can be important to shutting down units safely, depressurizing equipment, or isolating fuel feeding a fire. Examples of important emergency isolation valves include suction valves in piping to pumps that are fed from large towers, accumulators, or feed surge drums.

To improve the probability that emergency isolation valves will operate properly, fireproofing should be considered for both the power and signal lines that are connected to the valve. The valve's motor operator should be sufficiently fire-protected to provide enough time for the valve to fully open or close. Valves that fail to the safe position need not be fireproofed.

Power and instrument lines can be protected as described in 6.1.8.1. Motor operators may be protected by various fire-rated systems that use preformed fire-resistant material, specially designed, lace-up fire-resistant blankets, assemblies that use mastic materials, or intumescent epoxy coatings permanently molded to the equipment. For each of the above options, it is important to confirm that the fireproofing material is suitable for the operating temperature of the equipment being protected. Some are limited to normal nonfire temperatures as low as 160°F (70°C), even though they can provide a 30-minute rating under UL 1709 (or functional equivalent) conditions.

The following items require special consideration:

a. Thermal-limit switches built into electric motors may cause the motors to fail before valves are fully closed or opened when exposed to fire. Deactivation of the thermal-limit switches should be considered; or the equipment supplier should be consulted about possible modifications to ensure that motor operation is of sufficient duration to obtain the desired valve operation.
b. The valve's handwheel and engaging lever should not be fireproofed to the extent that the valve is made inoperable.
c. It is important to ensure that the valve's position indicator remain visible after the valve is fireproofed.
d. The solenoid on solenoid-operated valves may be fireproofed with the materials described above. Because the insulating material retains heat and blocks ventilation, the design should be investigated to ensure satisfactory operation.
e. The diaphragm housing on diaphragm-operated valves should be fireproofed with the materials described above, unless the valve is designed to fail to the safe position.
f. It is important that the fireproofing system selected is rated for use at the operating temperature of the equipment being protected and its environment.

6.1.10 Special Hazard Fireproofing

Process units that use radioactive sources (as are frequently used in level indicators), or have toxic gas analyzers (such as for sulfur dioxide), should ensure that these are protected, to avoid potentially harmful releases. Enclosures made of fireproof materials can be used for this purpose.

6.2 FIREPROOFING OUTSIDE PROCESSING UNITS

6.2.1 Pipe Racks Within a Fire-Scenario Envelope

6.2.1.1 If pipe-rack supports outside processing units are located within a fire-scenario envelope they should be considered for fireproofing. Bracing for earthquakes, wind or surge protection, and stringer beams that run parallel to piping need not be fireproofed.

6.2.1.2 If important pipe racks run within 20 ft to 40 ft (6 m to 12 m) of open drainage ditches or channels that may contain oil waste or receive accidental spills, either fireproofing should be considered for the pipe rack supports, as described in 6.2.1.1, or the ditch should be covered.

6.2.1.3 Similar considerations to those in 6.2.1.2 should be evaluated if the piping that carries hydrocarbons uses accordion-style expansion joints.

6.2.2 LPG Storage Spheres Within a Fire-Scenario Envelope

API 2510 provides specific recommendations for fireproofing of LPG vessels. For the vessel itself, fireproofing should be considered for potentially impinged portions of the vessel identified in the fire-scenario, if there is no fixed fire-water protection. A fire-resistance rating of 1½ hours protection under UL 1709 conditions is cited. The fireproofing should be capable of withstanding exposure to direct fire impingement and shall be resistant to direct impact from fire-water streams, as outlined in NFPA 58, Appendix H.

Structural supports should be fireproofed to the same fire resistance for all above ground portions of the structure required to support the static load of the full vessel. Fireproofing should be provided on horizontal vessel saddles where the distance between the bottom of the vessel and the top of the support structure is more than 12 in. (300 mm). Where provided, it should extend from the support structure to the vessel, but not encase the points at which the saddles, or other structural supports, are welded to the vessel. When a vertical vessel is supported by a skirt, the exterior of the skirt should be fireproofed in accordance with 6.1.4.1. The interior should be fireproofed where there is more than one access opening in the skirt that is not covered with a plate (see API 2510A, 1996, Section 5.8.2).

6.2.3 Horizontal Pressurized Storage Tanks Within a Fire-Scenario Envelope

Horizontal pressurized storage tanks should preferably be installed on reinforced concrete saddles. All vessel support structures of concrete should meet the same fire-resistance rating (1½ hours in UL 1709) required for steel support fireproofing. Fireproofing should be used for exposed steel vessel supports that exceed 12 in. (300 mm) minimum distance at the narrowest point.

6.2.4 Flare Lines Within a Fire-Scenario Envelope

Fireproofing should be considered for supports for flare lines if they are within a fire-scenario envelope or if they are close to open ditches or drainage channels that may receive large accidental spills of hydrocarbons.

A more protective approach to the application of fireproofing is appropriate when the potential for structural failure or loss of process control from fire exposure could possibly result in the release of hazardous materials that could present a potentially serious exposure to employees and the community.

7 Fireproofing Materials

7.1 GENERAL

Each type of fireproofing system uses a different combination of materials with various physical and chemical properties. These properties should be taken into consideration so that the system selected will be appropriate for its intended application. Where fireproofing coatings are applied directly to steel, most manufacturers recommend the use of primers chosen for compatibility with the coating, and appropriate for corrosion control and the environmental conditions.

The following are important factors to consider when a fireproofing system is selected:

a. The weight limitations imposed by the strength of the steel supports for the assembly to be fireproofed. Design review should ensure that the assembly can support the additional weight of fireproofing at the temperature reached during fire exposure, while the metal strength is reduced (see 5.2.6).

b. The fire resistance rating (in hours) selected (see 5.2.5).

c. The material's adhesion strength and durability. Specific surface preparation (cleaning and priming, etc.) and/or support structures are specified for rated systems. Manufacturer's specifications should be followed exactly to assure the installed system is the equivalent of the tested system.

d. Whether the material is to be specified for equipment in the design stage or applied to existing equipment.

Note: Many systems that are cost effective on new construction may require dismantling and preparations that are costly or not feasible for existing facilities.

e. The material's ease of application and repair.

f. The corrosiveness of the atmosphere and of fireproofing materials to the substrate. (Stainless steel and aluminum can be especially susceptible to some conditions, especially chlorine exposure.)

g. Operating temperature limitations in nonfire conditions.

h. Expected or warranted lifetime of the fireproofing system.

i. Continuing maintenance requirements to ensure longevity of fireproofing system.

j. Risk associated with impaired fireproofing during maintenance.

k. Regulatory requirements.

l. Cost (including maintenance and surveillance expense).

7.2 CHARACTERISTICS OF FIREPROOFING MATERIALS

7.2.1 General

In selecting fireproofing materials, care should be taken to obtain the desired degree of protection during the system's service life. In addition to the system's degree of fire-resistance, a variety of other characteristics should be evaluated to ensure that its materials perform properly in the environment in which installed. Some of the standard tests used are listed in Appendix B. Some principal characteristics that govern the selection of fireproofing materials are discussed in 7.2.2 and 7.2.3.

7.2.2 Physical Properties

7.2.2.1 Resistance to Thermal Diffusivity

Fireproofing materials are generally designed to limit the temperature of steel supports to 1000°F (538°C) for a predetermined period. This temperature is at a point at which steel has lost about one-half of its strength (see 5.2.6), and is rapidly losing more strength. Different design temperatures are used for certain materials or equipment (such as electrical wiring).

Organizations, such as Underwriters Laboratories and Factory Mutual, test fireproofing materials, and publish ratings expressed in number of hours of protection. These are based on the time for enough heat to pass through the protective barrier to cause the substrate temperatures to reach 1000°F (538°C) when the materials are exposed to a given time-temperature environment. See Appendix B for discussion and comparison of various standard tests.

7.2.2.2 Specific Weight (Density)

The specific weight (sometimes called density) of fireproofing materials can be important, especially on pipe racks, since additional dead-weight loading is imposed. Different fireproofing materials should be compared, using the weight per square foot of protected surface required to provide a given degree of fire resistance, as the required thickness may

vary considerably. The specific weight of lightweight materials generally runs from 25 to 80 lb/ft^3 (400 to 1300 kg/m^3), which is substantially less than dense concrete at 140 to 150 lb/ft^3 (2240 to 2400 kg/m^3). Use of lightweight fireproofing systems may permit the specification of lighter steel in newly constructed pipe racks. The low density of lightweight materials may also be advantageous for retrofitting on existing racks where weight limitations exist.

Thermal conductivity tends to be inversely proportional to specific weight.

7.2.2.3 Bonding Strength

Bonding should be strong enough to ensure that fireproofing materials will withstand mechanical impact and protect the substrate against corrosion. Poor bonding can significantly reduce the service life of fireproofing materials, making them subject to total failure if they are exposed to a stress such as a fire-hose stream (see 7.2.3.2). A standard bonding test (ASTM E 736) is used for determining the "cohesion/adhesion" of spray-applied fire-resistive materials, either fibrous or cementitious.

7.2.2.4 Weatherability and Chemical Tolerance

A material's ability to withstand the effects of humidity, rain, sunlight, and ambient temperature can influence its insulating quality, the life expectancy of its coating, and possible corrosion of the substrate and its reinforcing material. Materials differ in their weatherability. Some require no surface protection; others require a sealer or top coat that may need periodic renewal during the service life of the fireproofing material.

Exposure to certain acids, bases, salts, or solvents can destroy fireproofing materials; for applications where there is potential for such exposure, the materials should be checked for chemical stability with respect to liquids and vapors that may be present.

UL 1709 tests of fireproofing system assemblies include a standard set of exposures for weatherability (accelerated aging, high humidity, cycling effects of water/freezing temperature/dryness) and chemical tolerance (salt spray, carbon dioxide, sulfur dioxide) as part of normal testing protocol; optional tests for exposures to solvents or acids can be added if required. As in UL 1709, ASTM E 1529 includes a recommended set of accelerated weathering and aging tests. Some manufacturers conduct accelerated weathering tests. The most common protocol is the Weather-Ometer test specified in ASTM G 26.

7.2.2.5 Protection From Corrosion

Depending on factors such as permeability, porosity, and pH, fireproofing materials may either inhibit or promote corrosion of the substrate and its steel reinforcements.

Vapors and liquids that might be present in some plant atmospheres could be highly corrosive if they are trapped between the fireproofing and the substrate, and corrosion can seriously weaken structural supports. When some types of fireproofing are penetrated by water, salts can leach out of the fireproofing and deposit on the substrate, resulting in corrosion. Chloride salts from some fireproofing materials, such as magnesium oxychloride, may leach through to a stainless steel substrate. If the substrate is subject to high temperatures, stress corrosion can rapidly lead to metal failure. With most materials, the substrate should be properly cleaned and primed, and the caulking and weather shields kept serviceable. With porous lightweight materials, a good top coat should be maintained to prevent contaminant or water intrusion and subsequent corrosion.

7.2.2.6 Hardness and Impact Resistance

Where rigging and maintenance operations may be necessary, fireproofing materials should be able to withstand a reasonable amount of mechanical impact and abrasion. If the integrity of the fireproofing system elements is impaired, the degree of fire resistance can be seriously compromised and the coating or fabricated structure may have to be repaired.

7.2.2.7 Vibration Resistance and Compressive, Tensile, and Flexural Strength

Vibration resistance and compressive, tensile, and flexural strength may be important to the life expectancy of fireproofing. In some applications, vibration can fracture fireproofing material and destroy bonding of rigid coatings to the substrate. Flexible epoxy intumescent fireproofing materials designed for elasticity and vibration tolerance are available, and flexible endothermic wrap systems perform well in such applications.

7.2.2.8 Coefficient of Expansion

The coefficient of expansion can be significant when fireproofing materials are used on substrates that are subject to expansion caused by changes in temperature or in the operating pressure of the equipment. Too rigid a material can lose its bond to the substrate and spall off the protected member. Flexible epoxy intumescent fireproofing materials designed for elasticity, thermal insulation designed for fire protection, and endothermic wrap systems are able to effectively contain such assemblies.

7.2.2.9 Vapor Permeability and Porosity

Vapor permeability and porosity mainly relate to corrosion prevention and are most important in moist environments or in the presence of chemicals that can penetrate the coating and attack the support members. Fireproofing that contains a significant amount of *free water* can readily spall

off when it is subjected to the high temperatures that are common to hydrocarbon fires. While free water inclusion or intrusion is potentially harmful, many endothermic, intumescent, or ablative fireproofing materials have *chemically bound water* that is released as an integral element of their fire protection mechanism.

7.2.2.10 Surface Temperature of Substrate

Some fireproofing materials have definite limitations on their operating temperatures. Some classes of material used for thermal insulation of process vessels or piping may provide some fire protection (if properly installed and protected). However, as a general rule, fireproofing materials should not be considered for thermal insulation. Specifically, some fireproofing materials may be limited to operating (nonfire) temperatures as low as 160°F (70°C). Material that is suitable for the substrate's normal range of operating temperatures should be selected by carefully reviewing the vendor data sheets for possible thermal restrictions.

7.2.3 Behavior During Exposure to Fire

7.2.3.1 Combustibility

Some fireproofing materials, particularly organic systems (including some intumescent fireproofing), have levels of combustibility that can be assigned values, according to ASTM E 84 (NFPA 255), for flame spread, and smoke developed.

When fireproofing materials are used in enclosed structures, combustibility should be limited as follows:

Flame spread index: 0 – 25
Smoke developed: 0 – 450

Note: The limits above conform to NFPA 101, Class A interior finish.

When fireproofing materials are used in the open, combustibility should be limited as follows:

Flame spread: 26–75
Smoke developed: (No limit)

Note: The limits above conform to NFPA 101, Class B.

While there is no smoke limit, the toxicity of heat-exposed, fireproofing off-gases should be evaluated, if used in areas where employee or responder exposure is a concern. See Appendix B.4.2 for explanation of ratings.

7.2.3.2 Resistance to Hydraulic Erosion and Thermal Shock

Where fireproofing materials must remain in place when water cooling streams are applied, a hose-stream test should be conducted to compare the ability of different materials to withstand hydraulic erosion and thermal shock. Firehose-stream tests are described in NFPA 251, Section 4-2, and NFPA 58, Appendix H.

7.3 TYPES OF FIREPROOFING MATERIALS

7.3.1 Dense Concretes

Concretes made with Portland cement have a specific weight of 140 to 150 lbs/ft^3 (2200 to 2400 kg/m^3). Dense concretes can be formed in place, or pneumatically sprayed to the required thickness using steel reinforcement. The corrosive effect of chlorides on the steel surface in moist environments dictates the use of protective primers and topcoat sealers.

Major advantages of dense concrete are:

a. Durability; can withstand thermal shock and direct hose streams.
b. Can withstand direct flame impingement up to 2000°F (1100°C).
c. Ability for most contractors to satisfactorily apply (no specialty contractors required).
d. Extensive proven performance; can provide 4 or more hours of protection.

Disadvantages of dense concrete include:

a. Relatively high weight.
b. Relatively high thermal conductivity.
c. Need for steel reinforcement.
d. The installation cost and time involved in forming in-place, especially when applied to existing facilities.

Concrete absorbs heat through an endothermic heat of reaction when chemically bound water is released from the crystalline structure and is reduced to lime by high heats. This adds to the fire barrier effect, which directionally compensates for its relatively high thermal conductivity.

7.3.2 Lightweight Concrete

Lightweight concrete uses very light aggregate, such as vermiculite or perlite (instead of gravel), with cements that are resistant to high temperatures. Dry densities range from 25 to 80 lbs/ft^3 (400 to 1300 kg/m^3).

Lightweight concrete is usually sprayed on, but may be troweled or formed in-place using reinforcing mesh. Pneumatically applied material is about 20% heavier than poured-in-place lightweight concrete. As with all concretes, moisture creates a corrosive condition at the surface of the steel. Protective coating of the substrate surface is needed to protect against corrosion.

Advantages of lightweight concrete materials are:

a. Lightweight concrete materials have better fire-protection properties than dense concrete (for equivalent coating thickness; and much better on a weight basis).
b. They are fairly durable and have limited maintenance requirements.
c. They are capable of withstanding direct flame impingement up to 2000°F (1100°C).

d. They can withstand thermal shock and high-pressure hose streams.
e. They can be satisfactorily applied by most contractors.

Disadvantages of lightweight concrete materials include:

a. Porosity, which can allow penetration by water or leaked hydrocarbons.
b. Moisture absorption can lead to cracking and spalling in freezing climates.
c. The need to maintain a top coating (and possible shielding or caulking) to prevent moisture or hydrocarbons from penetrating.
d. Lightweight concrete is more susceptible to mechanical damage than dense concrete materials (but can be shielded if mechanical damage is a threat).

7.3.3 Spray-Applied Fire-Resistive Materials (SFRM)

7.3.3.1 Subliming, Intumescent, and Ablative Mastics

Mastics provide heat barriers through one or more of the following mechanisms:

a. Subliming mastics absorb large amounts of heat as they change directly from a solid to a gaseous state.
b. Intumescent mastics expand to several times their volume when exposed to heat, and form a protective insulating ash or char at the barrier that faces the fire.
c. Ablative mastics absorb heat as they lose mass through oxidative erosion.

Mastics are sprayed on a substrate in one or more coats, depending on the desired degree of fire resistance. Reinforcing fabric or wire (which may be rigidly specified) is usually needed for fire-resistance ratings of 1 hour or more. Mastics may also be hand troweled, if permitted in the manufacturer's specifications. Substrate preparation is important to achieve adequate bonding in applying coatings; a specific primer may be required. After applying the mastic coat, some materials require a top-finish coat on the surface to prevent moisture from penetrating. The surface coating should be inspected and renewed according to the vendor's recommendations (see Section 9).

Advantages of mastics are:

a. They can be quickly applied.
b. They are lightweight.
c. They are suitable for use on existing equipment supports that may not be able to handle additional weight.

Disadvantages of mastics include:

a. Because coat thickness and proper bonding to the substrate are important to satisfactory performance, application techniques specified by the manufacturer should be rigorously followed to ensure good long-term performance.
b. In all cases it is preferable to use experienced appliers.
c. For some materials, only vendor-approved or trained appliers experienced with the specific material should be used.
d. Some mastics tend to shrink while drying. Specifications should indicate the wet thickness that will yield the required dry thickness.
e. Materials rated for protection with thin coats should be applied skillfully to maintain adequate thickness. To ensure proper thickness, a qualified person should frequently check the applier's work (see 9.4).
f. Some materials may have to be repaired or replaced after a brief flash fire. (Consultation with the supplier is advisable as some materials are intended only for new construction, and require special post-fire repair techniques.)
g. Using hose streams on some mastics during a fire can wash away part of the material itself, or a protective char, thereby reducing the overall effectiveness.
h. Some mastics use a flammable solvent requiring appropriate precautions during application to avoid sources of ignition, such as operating fired heaters and boilers.
i. Some mastics are less durable than more traditional concrete materials when subjected to mechanical impact and abrasion.

Certain intumescent mastic materials may not be affected by small scratches or chips, because the coating can perform some degree of "self-healing" when the coating swells under the heat of a fire. However, the ability of materials to change in volume and density when exposed to heat may also lead to cracking, as a result of swelling and shrinking, exposing the protected assembly to fire on edges, sharp curves, or intricate shapes. Fire performance should not be extrapolated from flat surfaces to such shapes. Documented ratings should be obtained for shapes or assemblies similar to the application being specified.

7.3.3.2 Intumescent Epoxy Coatings

A wide range of intumescent epoxy coatings are available. These can be described as a mix of thermally reactive chemicals in a specific epoxy matrix formulated for fireproofing applications. Under fire conditions they react to emit gases, which cool the surface while a low density carbonaceous char is formed. This char then serves as a thermal barrier.

Advantages of intumescent epoxy coatings are:

a. Properly applied, these coatings have excellent bonding and corrosion protection.
b. They are typically lightweight and durable under nonfire conditions.
c. Product is available that is flexible and tolerates vibration.
d. Certain materials have demonstrated exceptional durability in severe jet-fire tests.

e. Because they are based on an organic system, special characteristics can be designed into the coating.
f. Coatings are available that provide an attractive finish appearance.

Disadvantages of intumescent epoxy coatings are:

a. There is a possibility of damage to a char coating during a fire, if subjected to impingement by firehose streams.
b. They require expertise in application, and may require multiple coats or special equipment which can apply dual components simultaneously.
c. Some manufacturers require factory-certified applier personnel.
d. Some concerns have been raised regarding potential toxicity of gases generated during fire conditions.

7.3.3.3 Lightweight Cementitious Fireproofing

A sprayed (or troweled) coating formulated from Portland cement and lightweight aggregate or perlite provides excellent fireproofing insulation (up to 4 hours in UL 1709 or functional equivalent tests) with durability in exterior applications. The properties of the vermiculite allow it to dent rather than crack or shatter on impact. The material is relatively lightweight at 45 to 50 lbs/ft^3 (700 to 800 kg/m^3) and may not need a top-sealing coat.

7.3.4 PREFORMED INORGANIC UNITS OR MASONRY

7.3.4.1 Preformed Inorganic Panels

Preformed fire-resistant inorganic panels can be cast or compressed from lightweight aggregate and a cement binder, or from compressed inorganic insulating material, such as calcium silicate. The panels are attached to the substrate by mechanical fasteners designed to withstand fire exposure without appreciable loss of strength. When panels are used outdoors, an external weatherproofing system to prevent moisture penetration is typically required. All joints or penetrations through fireproofing (such as clips or attachments) should be rigorously caulked or sealed.

Preformed materials are advantageous because:

a. They can be applied cleanly.
b. They have no curing time.
c. They have low conductivity.

Disadvantages of preformed materials are:

a. Labor-intensive application when unit instruments and appurtenances are attached to columns.
b. Preformed materials are more susceptible to damage from impact than concretes.

Unless specified for fireproofing use, materials sold as pipe insulation might not survive the high temperatures generated in tests such as UL 1709 or ASTM E 1529. The user should ensure the fireproofing system components are fire-rated before they are specified.

7.3.4.2 Masonry Blocks and Bricks

Masonry blocks of lightweight blast-furnace slag (used as coarse aggregate) are sometimes used. These units are laid up with thin staggered joints not more than 1⁄3 in. (8 mm) thick. Joints should use only fire-resistant mortar.

Brick and block are no longer commonly used because of their high installation cost and fairly extensive maintenance requirements. Brick-and-block assemblies tend to crack and admit moisture, which can lead to serious corrosion and spalling.

7.3.5 Endothermic Wrap Fireproofing

Endothermic materials absorb heat chemically, generally with the concurrent release of water, and physically through heat absorption by the released water. This flexible, tough, inorganic sheet material with a bonded aluminum foil outer layer is formed from a maximum of inorganic, highly endothermic filler, and a minimum of organic binder and fiber. It can be wrapped around a wide variety of potentially exposed vulnerable equipment. Electrical cable trays are particularly suited for this type of protection, providing rated performance under UL 1709 (or functionally equivalent) conditions. In most applications, the wrap is held in place by stainless steel bands with foil tape and/or fireproofing caulk on seams, gaps and termination points. For structural steel in new construction, surface preparation of the substrate should include fresh prime paint to provide corrosion protection.

Advantages are:

a. Fire-rated wrap systems are easily reentered and repaired, allowing retrofitting over steel without dissembling wiring and other attached items.
b. The wrap material does not catalyze corrosion (nor protect against corrosion).
c. Endothermic wrap systems can be applied directly over existing cement or block where additional protection is required.
d. These systems can be applied directly over other fireproofing, although a reduction in rated system requirements may not be allowed for the existing materials.
e. Flexible endothermic wrap systems are explosion-rated.

A disadvantage is that when used outdoors, the fire protection system must be weatherproofed. Stainless steel jacketing, or wrapping with the manufacturer's specified environmental protection tape, provide the recommended protection.

8 Testing and Rating Fireproofing Materials

8.1 GENERAL

Fire-resistant materials used in petroleum or petrochemical facilities should be tested and rated in compliance with industry-accepted procedures that indicate how those materials will perform subjected to conditions representative of petroleum or petrochemical fires. Hydrocarbon fires can reach 2000°F (1100°C) shortly after ignition. This publication recommends UL 1709 (or a functional equivalent) as the primary standard representing such a test.

ASTM E 119 is no longer recommended as a test procedure for petroleum and petrochemical processing plant applications.

Tests procedures are compared and discussed in Appendix B.

8.2 STANDARD TESTING OF FIREPROOFING SYSTEMS FOR STRUCTURAL SUPPORTS

8.2.1 UL 1709

UL 1709 simulates hydrocarbon pool fire conditions. It subjects a protected steel column to a heat flux that produces a temperature of 2000°F (1093°C) in 5 minutes. After that time, the furnace temperature is held constant for the remainder of the test, subjecting the test fireproofing system assembly to a heat flux of 65,000 BTU/ft^2-hr. The test is terminated when the average temperature of the steel substrate reaches 1000°F (538°C). This standardized test, developed in conjunction with the oil industry, uses a severe test regime with faster temperature rise than prior tests. This is significant, not only because thicker protective coatings may be necessary, but also because the behavior of some materials may be significantly poorer under the hydrocarbon fire conditions that subject the test material to substantially higher heat flux. UL 1709 (or a functional equivalent) is recommended as a standard test for evaluating fireproofing systems for petroleum and petrochemical processing plants.

8.2.2 ASTM E 1529

ASTM E 1529 simulates hydrocarbon pool fire conditions with temperatures and rate of temperature rise essentially the same as UL 1709, but with the test specimen exposed to a lower heat flux of 50,000 BTU/hr-ft^2 (158 kW/m^2). The rationale for using this heat flux level is explained in ASTM E 1529, Appendix X1, in which it is supported by measured heat flux data from hydrocarbon pool fires. On this basis, subject to approval by the Purchaser, ASTM E 1529 may be considered as functionally equivalent to UL 1709 as an alternative criterion for the acceptance of fireproofing methods and materials. As in UL 1709, ASTM E 1529 evaluates materials intended for outdoor use, and includes a recommended set of accelerated weathering and aging tests.

8.2.3 Comparing Test Results

In comparing fireproofing material test results, the reviewer should be aware that differences in test specimen assembly mass can significantly affect results conducted using the same standard test. The test columns and beams should be the same size for valid comparisons of structural members; a smaller column with less heat sink will reach a failing temperature sooner if the thickness of the fireproofing material is the same. A 10-in. structural steel column that weighs 49 pounds per lineal foot (W10 x 49) is frequently used by testing organizations as the de facto standard for structural steel. It can be assumed a system that provides rated protection on a W10 x 49 will also provide protection to beams with a similar or greater mass per unit of beam cross-section perimeter. However, extrapolations to beams of a lesser mass-to-perimeter ratio cannot be made with any confidence.

8.2.4 Other Tests Used to Evaluate Fireproofing Systems

Tests other than those used to measure resistance to heat penetration can be important to evaluate the satisfactory performance of fireproofing materials during their anticipated life span (see 7.2 for a list of other properties of fireproofing materials). Test results for these properties may be important to the satisfactory performance of the material. Appendix B includes a reference list of nonfire tests that are used in manufacturers' technical literature to help define performance characteristics.

9 Installation and Quality Assurance

9.1 GENERAL

Fireproofing systems must be applied properly to be successful. A variety of factors are involved: the availability of the proper on-specification material; the proper equipment; and qualified personnel to complete the task in accordance with the manufacturer's specifications. For a majority of fireproofing systems, the long-term success depends on attention to detail during installation.

9.2 EASE OF APPLICATION

If the ease of application reduces the potential for error, it will ultimately benefit the cost, durability, and effectiveness of the installed fireproofing system.

The following factors impact the ease of installing fireproofing systems:

a. Whether required surface preparation can safely be performed in the area.

b. Availability of experienced appliers to do the job properly and efficiently.

c. Shelf life and handling requirements of the raw materials.

d. Pot life of mixed materials.

e. The ability to use low-velocity spray guns that minimize overspray.

f. The type of thinners, if used (water-based or containing solvents that could be hazardous, or may require special ventilation).

g. Weather conditions (temperature and humidity) required during application and curing.

h. The need and complexity of embedded reinforcement in thick coatings.

i. The need for application of a sealer or top coat to protect fireproofing materials from the weather or plant environment.

j. Cleanup time and cost.

k. Disposal of solvents requiring special handling.

l. Downtime required for installation on existing facilities.

9.3 FIREPROOFING INSTALLATION CONSIDERATIONS

All rated fireproofing systems should be carefully installed to specification and manufacturer's requirements. Factors discussed in 9.1, regarding ease of application, are the first part of an overall set of installation considerations.

Substrate surfaces should be cleaned so they are free from oil, grease, liquid contaminants, rust, scale, and dust. If a primer is required, it should be compatible with the fireproofing. Specifications to be followed include the specified thickness or number of layers, adequate attachment, and proper caulking, sealing, or top-coating of the systems.

Installation of dense concrete can be applied satisfactorily by facility personnel or fireproofing contractors familiar with fireproofing work. To apply lightweight concrete, mastics, and magnesium oxychloride plasters, however, the appliers must understand and have experience with the specific materials and their use. If improperly applied, the application may lose its bond, deteriorate, or fail to perform as expected during a fire.

The following installation considerations apply to fireproofing coatings and wet cementitious materials:

a. Shelf life should be determined and maintained.

b. Materials should be stored on site in accordance with the manufacturer's recommendations. (Some materials must remain upright in their containers for proper sealing; refer to manufacturer's specifications.)

c. Some materials are temperature-sensitive and cannot tolerate extremes during storage and shipping.

d. Fireproofing materials should be applied directly from their original sealed containers to avoid possible additions to, or changes in, their formulation.

e. Some materials require a controlled curing period to develop full strength and prevent serious cracking in the future.

f. Materials that contain free water require a drying period during above-freezing temperatures.

g. Appliers should understand that the specified thickness is a dry thickness, not the wet thickness. Some mastic coatings shrink as much as 30% when cured.

9.4 QUALITY CONTROL IN APPLICATION

Fireproofing practices continue to evolve and utilize high technology methods (intumescent rigid and flexible epoxies, flexible endothermic wraps, etc.), while traditional lower tech methods (dense and lightweight concrete) continue to be used as well.

Satisfactory performance of the fireproofing material over its expected lifetime depends on the user's and the applier's knowledge of materials and application techniques, and on continuing inspection by qualified personnel. Specifically, once a fireproofing system has been chosen, it is imperative that personnel involved in each phase of the project be familiar with the relevant aspects of the manufacturer's requirements and specifications for that phase.

Attention to the following points will help ensure a quality job:

a. Both the user and the applier should have detailed knowledge of fireproofing material characteristics along with the application and maintenance techniques that are necessary to achieve the desired degree of fire resistance. Most of this information can be found by reviewing data sheets and manuals provided by the manufacturer, visiting sites where the fireproofing material has been applied, or consulting with previous users of the fireproofing material.

b. Coatings require the following special considerations:

1. The applier may be required to provide a sample of the finished work so that there is no misunderstanding about the desired texture and smoothness of the finished surface. (This is sometimes done on a piece of representative on-site equipment or structure.)

2. Qualified personnel familiar with job specifications should monitor items such as mixing, density, substrate preparation, application thickness, installation of imbedded reinforcement, and surface finishing in accordance with the demonstration sample, and surface top-coating (if required).

3. The materials must be applied in compliance with the manufacturer's recommendations for dry thickness. Small variations are significant to the fire-resistance of the finished coating when using thin mastic coatings, and are most often found in parts of the structure that are congested, or difficult to reach.

4. The user and the applier should agree concerning the extent of random core sampling necessary to verify coat thickness, proper bonding, and lack of voids, and the specific procedures to be used for these evaluations.

The UL Fire Resistance Directory quotes the following ASTM E 605 quality assurance requirements for thickness of sprayed coatings:

ASTM E 605 Spray-Applied Coating QA Requirements	
Coating Design Thickness	Minimum Thickness Tolerance
1 inch or less	Design thickness less 25%
Over 1 inch	Design thickness less ¼ inch

Note: Average thickness must be no less than design thickness.

ASTM E 605 states the thickness of the spray-applied material shall be corrected by applying additional material at any location where: (a) the calculated average thickness of the material is less than that required by the design; or, (b) an individual measured thickness is more than ¼ in. less than design (for thicknesses over 1 in.), or design minus 25% for design thicknesses less than 1 in.

10 Inspection and Maintenance

10.1 EFFECTS OF LONG-TERM EXPOSURE

As fireproofing materials age, problems can develop that affect the function of the system or coating and possibly weaken the protected structural supports. Inspection seeks to discover problems in physical property areas discussed in 7.2.2 while maintenance should correct identified problems and maintain scheduled preventive maintenance programs (e.g., periodic renewal of top-coat sealers).

Any fireproofing material is subject to degradation over time; however, some applications have been known to fail at a rapid rate. While failure may be caused by materials that are improperly selected, experience shows that in many cases failure resulted from poor application (this reinforces the significance of quality assurance, Section 9).

Cracking or bulging of the surface of the material is an early sign of a problem. If the problem is not corrected, moisture, chemicals, corrosive vapor, or marine condensation could enter and lead to corrosion of both the substrate and the reinforcement materials.

Weathering or the use of the wrong top coat can cause fireproofing to become permeable to moisture and vapor. This permeability can lead to corrosion and deterioration. The weathering effects of sunlight and chemical atmospheres have been known to affect some coating materials to the extent that they lose a significant amount of their ability to protect.

Loss of bonding to the substrate seriously affects the material's performance, and may be caused by moisture penetration, corrosion, the use of an improper primer on the substrate, or poor preparation of the substrate before the fireproofing is applied.

Fireproofing is sometimes scraped or knocked off equipment during construction or maintenance.

10.2 INSPECTION

Periodic inspection and testing maximizes the useful life of the fireproofing system. The manufacturer or applier may be invited to participate in the inspection. An inspection and testing program should include the following steps:

a. Survey coatings for surface cracking, delamination, rust staining, or bulging.

b. Survey coatings for signs of weathering (color change, powdering, thinning of coat).

c. Selectively remove small sections of fireproofing to examine conditions at the face of the substrate and the surface of reinforcing wire. Repair the inspection area.

d. Visually check for the loss of fireproofing materials as a result of mechanical abuse.

e. When the fireproofing material is applied, coat and set aside several pieces of structural steel for periodic fire-testing over the expected life of the coating. (This is not necessary with rigid box or flexible containment systems.)

f. Inspect to make sure that the fireproofing hasn't been removed for maintenance and not replaced.

10.3 MAINTENANCE

Timely and consistent maintenance provides assurance that the system is physically in the condition intended.

10.3.1 Hairline Cracking

When more than hairline cracking appears, the openings should be cleaned out and filled with new material according to the manufacturer's instructions.

10.3.2 Substrate Bonding

Loss of bonding to the substrate may be determined by surface bulges or an abnormal sound when the surface is tapped with a light hammer.

10.3.3 Bond Failure

In evident areas of bond failure, fireproofing should be removed and the substrate should be thoroughly cleaned and properly primed before new material is applied.

10.3.4 Surface Coating

If surface coating is required to prevent moisture from penetrating, it should be renewed at intervals recommended by the manufacturer. The previously listed inspections should be completed prior to renewal of coating so that defects are not hidden by the coating.

APPENDIX A—DEFINITION OF TERMS USED IN THIS STANDARD WHICH ARE IN GENERAL USE IN THE PETROLEUM INDUSTRY

A.1 autoignition temperature: Minimum temperature to which a fuel in air must be heated to start self-sustained combustion without a separate ignition source. This means that, should a leak occur on a line containing a petroleum product above its ignition temperature, ignition can occur independent of an ignition source.

A.2 boiling point: The temperature at which the vapor pressure of a liquid equals the surrounding atmospheric pressure. For purposes of defining the boiling point, atmospheric pressure shall be considered to be 14.7 psia (760 mm Hg). For mixtures that do not have a constant boiling point, the 20% evaporated point of a distillation performed in accordance with ASTM D86 shall be considered to be the boiling point.

A.3 combustible liquids: Have flash points at or above 100°F (37.8°C)

a. Class II—Flash point at or above 100°F (37.8°C) and below 140°F (60°C).
b. Class IIIA—Flash point at or above 140°F (60°C) and below 200°F (93°C).
c. Class IIIB—flash point at or above 200°F (93°C).

Note: OSHA uses NFPA definitions for flammable and combustible. Alternate systems using 140°F (60°C) as the dividing point between flammable and combustible appear in ANSI/CMA Z129.1-1994 and the regulations of the U.S. Department of Transportation and the United Nations. The NFPA classification system is used in this document, and is widely used for facility-based fire protection purposes in the USA. For regulatory compliance purposes (such as labeling for off-site transportation), reference should be made to the specific regulations or codes governing the activity of concern.

A.4 fire point: The temperature (usually a few degrees above the flash point) at which a liquid produces enough vapors to sustain combustion.

A.5 flammable liquids: Have flash points below 100°F (37.8°C), and vapor pressures not exceeding 40 psia (2068.6 mm Hg) at 100°F (37.8°C). Liquids with vapor pressures above 40 psia (276 kPa) at 100°F (37.8°C) are considered gases by NFPA.

a. Class IA—Flash point below 73°F (22.8°C) and boiling point below 100°F (37.8°C).
b. Class IB—Flash point below 73°F (22.8°C) and boiling point above 100°F (37.8°C).
c. Class IC—Flash point at or above 73°F (22.8°C) and below 100°F (37.8°C).

Note: See note under *combustible liquids*.

A.6 flammable materials: Flammable liquids, hydrocarbon vapors, gases (such as LPG or hydrogen), and other vapors (such as carbon disulfide), with a flash point below 100°F (37.8°C).

A.7 flammable range: A range of vapor-to-air ratios within which ignition can occur. The lower flammable limit (LFL) is the minimum vapor-to-air concentration below which ignition cannot occur. Atmospheres below the LFL are referred to as too lean to burn. The upper flammable limit (UFL) is the maximum vapor-to-air concentration above which ignition cannot occur. Atmospheres above the UFL are referred to as too rich to burn. Flammable ranges can vary widely, as illustrated by flammable vapor-to-air ranges for gasoline (1.4 to 7.6%) and acetylene (2.5 to 100%).

A.8 flash point: The lowest temperature at which a liquid gives off enough vapor to produce a flammable mixture with air immediately above the surface. A source of ignition is needed for flash to occur. When this temperature is above ambient, vapors will ignite but will not continue to burn until heated to the "fire point". The flash point temperature can be very low for volatile petroleum products; for instance, the flash point for gasoline is typically quoted as about -45°F (-43°C).

A.9 jet fire: A leak from a pressurized system which ignites and forms a burning jet which might impinge on other equipment causing damage. [See AIChE (CCPS) *Guidelines for Safe Automation of Chemical Processes*, Section 7.2.4. For vinyl chloride monomer, the jet length in rough terms is about 150 times the jet orifice diameter—a jet from a 2-in. hole could produce a burning jet about 30-ft long.]

A.10 pool fire: Fuel from a release that forms a pool when ignited can burn with a flame height two or three times the pool diameter. (See AIChE *Guidelines for Safe Automation of Chemical Processes*, Section 7.2.4.)

APPENDIX B— TESTING AND RATING FIREPROOFING MATERIALS

B.1 General

Fire-resistant materials should be tested and rated according to industry-accepted procedures that indicate how the material will perform when it is subjected to a realistic petroleum or petrochemical fire. API Publ 2218 recommends the use of UL 1709 (or functional equivalent) as the primary standard for fireproofing in petroleum and petrochemical plants.

B.2 Rapid-Rise Hydrocarbon Pool Fire Tests

Two test procedures designed to simulate hydrocarbon fires have been developed to represent pool-fire test conditions. UL 1709 was introduced in 1984 and was approved as an ANSI/UL standard on February 27, 1991. ASTM E 1529 was published in July 1993. Both reach 2000°F within 5 minutes, and maintain that temperature for the duration of the test. The primary difference is that UL 1709 subjects the test fireproofing system assembly to a heat flux of 65,000 BTU/ft^2-hr vs. 50,000 BTU/ft^2-hr for ASTM E 1529. It is clear from Table B that both tests are substantially more severe than the historically used ASTM E 119; and that UL 1709 places 30% higher heat load on the test specimen than does ASTM E 1529. Because of the established acceptance of UL 1709 and the availability of fireproofing performance test data, it was chosen as the primary reference. Published results for ASTM E 1529 are uncommon at this time. It is recognized that for some purposes the less severe ASTM E 1529 test may provide results that are functionally equivalent to those from UL 1709. Determination of that equivalency rests with the user, in dialogue with the fireproofing system supplier.

Tests are discussed in subsequent parts of this section and are compared in Table B-1.

B.3 Standard Testing for Fireproofing of Structural Supports

In the past, most ratings for fireproofing of structural supports were based on a standard time-temperature curve developed in 1918 to simulate interior structural building fires. This does not correlate well with the actual time-temperature and heat flux experienced during a hydrocarbon-spill fire, which can rapidly produce a temperature of 2000°F (1100°C) shortly after ignition. UL 1709 (or functional equivalent) is the recommended standard fireproofing reference test for petroleum and petrochemical processing plants. As discussed above, the less severe ASTM E 1529 test may provide results which are functionally equivalent to those from UL 1709, based on the application and judgement of the user and fireproofing system supplier.

ASTM E 119 is not recommended as a test procedure for petroleum and petrochemical processing plant applications.

Table B-1—Comparison of Standardized Fireproofing Test Procedures

Fireproofing test standards	UL 1709 ANSI/UL 1709	ASTM E 1529	ASTM E 119 ANSI A2.1 NFPA 251 UL 263
Environment which test intends to simulate	Rapid rise fires Exterior Petrochemical	Effects of large hydrocarbon pool fires on exterior structural members	Structural materials for building interiors
Heat flux BTU/ft^2-hr after			
5 minutes	65,000 (± 5,000)	50,000 (± 2,500)	(11,000)[a]
1 hour			(37,400)[a]
Temperature after:			
3 minutes		> 1500°F	
5 minutes	2,000 ± 200°F	2,000 ± 150°F	1000°F
30 minutes	2,000 ± 200°F	2,000 ± 150°F	1550°F
1 hour	2,000 ± 200°F	2,000 ± 150°F	1850°F
4 hours	2,000 ± 200°F	2,000 ± 150°F	2000°F
8 hours	2,000 ± 200°F	2,000 ± 150°F	2300°F
Environmental exposure tests	*Standard* Aging High Humidity Salt Spray CO_2/SO_2 Wet/freeze/dry	*Recommended* Aging Weathering Wet/freeze/thaw High Humidity CO_2/SO_2	*ANSI/UL 263* Optional for exterior use rating
Firehose stream test	Optional	Optional	Optional

Note: [a]Heat flux is not specified nor measured in ASTM E 119. Data listed are from a "Major Test Methods E 119 furnace," as reported in the Appendix of ASTM E 1529-93, Section X1.2.2.

B.3.1 UL 1709

In 1984, Underwriters Laboratories adopted the first high temperature rise test that simulated hydrocarbon pool fire conditions. It subjects a protected steel column to a heat flux that produces a temperature of 2000°F (1093°C) in 5 minutes. After that time, the furnace temperature is held constant for the remainder of the test. The test is terminated once the average temperature of the steel substrate reaches 1000°F (538°C). This standardized test was developed in conjunction with the oil industry. The more severe regime is considered significant not only because thicker protective coatings may be necessary, but also because the behavior of some materials may be significantly poorer under the hydrocarbon fire conditions that subject the test material to substantially higher heat flux. UL 1709 (or functional equivalent) is recommended as a standard test for evaluating fireproofing systems for petroleum and petrochemical processing plants.

B.3.2 ASTM E 1529

This test method is used to determine the response of structural components and assemblies used in the hydrocarbon processing industries when exposed to conditions representative of large, free-burning exterior liquid hydrocarbon pool fires. Temperatures and rate of temperature rise are higher than ASTM E 119 and essentially the same as UL 1709. The heat flux is higher than ASTM E 119 with UL 1709 heat flux being about 30% higher than ASTM E 1529. This test procedure evaluates materials intended for outdoor use, and recommends an included set of accelerated weathering and aging tests. The appendices to ASTM E 1529 provide an informative commentary on test methods, heat fluxes, and pool fires. The analysis of "reasonably worst case" describes the history and rationale for choosing 50,000 BTU/ft^2-hr (158 kW/m^2). Some companies judge test results from ASTM E 1529 to be functionally equivalent to those from UL 1709.

B.3.3 E 1725

ASTM E 1725-95 is designed to measure and describe the response of materials, products or assemblies to heat and flame under controlled conditions. It can be run using either ASTM E 119 or ASTM E 1529 temperature curve conditions. For use in petroleum and petrochemical processing plants, the ASTM E 1529 pool fire conditions should be specified. The test measures the time for the electrical system component to reach an average temperature 250°F above the initial temperature.

B.3.4 UL 2196

UL 2196 had not yet been formally adopted in late 1998. Like ASTM E 1725, there are two alternate temperature curves for testing: "normal temperature rise" uses the same temperature curve as UL 263 (ASTM E 119); the "rapid temperature rise curve" coincides with UL 1709 (and ASTM E 1529). For use in petroleum and petrochemical processing plants, the rapid temperature rise curve should be specified. While not yet adopted, use of this test protocol was proposed for inclusion in the 1999 National Electric Code for Fire Alarm circuit integrity (CI) cable.

B.3.5 ASTM E 119

ASTM E 119 describes procedures for testing structural components, including walls, partitions, floor and roof assemblies, and individual load-bearing components such as beams and columns. It uses a standard time-temperature curve developed in 1918 to simulate interior structural building fires. Its purpose was to represent conditions relevant to buildings or combustible structures where the primary fuel was solid in nature. This does not correlate well with either the actual time-temperature or the heat flux experienced during a hydrocarbon-spill fire. ASTM E 119 is not recommended as a primary standard test procedure for petroleum and petrochemical processing plants: (ANSI A2.1, NFPA 251, and UL 263 are essentially the same tests.)

B.3.6 AVAILABILITY OF TEST DATA

Standardized fire testing is time consuming and expensive. Because of this, and the substantial market for fireproofing materials used in construction of buildings, the extensive body of data which exists using less severe building-oriented tests, such as ASTM E 119, will continue to be available and may be of value as secondary reference material. The UL Fire Resistance Directory, classifying fire protection for beams and related structures (Volume 1), has 90% of classification test results for UL 653 (equivalent to ASTM E 119), with about 10% for UL 1709.

B.4 Summary of Other Tests Related to Fireproofing

Performance characteristics other than resistance to heat penetration can be important to the satisfactory performance of fireproofing materials during their anticipated life span. Section 7.2 lists properties of fireproofing materials. The following list references tests used in manufacturer's technical literature to characterize nonfire performance.

B.4.1 REFERENCE TESTS

ASTM

E 605	*Standard Test Methods for Thickness and Density of Sprayed Fire Resistive Material Applied to Structural Members*
E 736	*Standard Test Methods for Cohesion/Adhesion of Sprayed Fire Resistive Material Applied to Structural Members*

E759 *Effect of Deflection on Sprayed-on Fire Resistive Material Applied to Structural Members*

E760 *Effect of Impact on Bonding of Sprayed-on Fire Resistive Material Applied to Structural Members*

E761 *Compressive Strength of Sprayed-on Fire Resistive Material Applied to Structural Members*

E859 *Air-Erosion of Sprayed-on Fire Resistive Material Applied to Structural Members*

E937 *Corrosion of Steel by Sprayed Fire Resistive Material Applied to Structural Members*

G21 *Standard Practice for Determining Resistance of Synthetic Polymeric Materials to Fungi*

G 26 *Recommended Practice for Operating Light-Exposure Apparatus (Xenon-Arc Type) With and Without Water for Exposure of Nonmetallic Materials*

B.4.2 INTERPRETING RESULTS FROM ASTM E 84 METHOD OF TEST FOR SURFACE BURNING CHARACTERISTICS OF BUILDING MATERIALS

The ratings from ASTM E 84 are indices based on the flame spread or smoke development in a 10-minute "Steiner Tunnel" test. Both tests originally were based on the performance of red oak, with an index of 100, and the ratings as percent of red oak performance. The Flame Spread Index is now an arbitrary rating; while the "smoke developed" test is still based on percent of red oak as the standard, with a rating of 100.

APPENDIX C—FIREPROOFING QUESTIONS AND ANSWERS

The material included in this section is provided as a service to the user of this document. While believed to be useful, it has not been subjected to rigorous technical review. It contains generalizations, "rules of thumb," historical sharing of individual experience, and suggestions for further research on the subject of fireproofing. The reader is advised to ensure that the information is accurate and appropriate to the intended application prior to use. It is organized in sections to parallel the main text of this recommended practice.

C.1 INTRODUCTION

Q: Are there forms of passive fire protection other than fireproofing?

A: Any form of fire protection is passive if it functions without intervention, which requires energy (human or mechanical). Separation distances, spacing, drainage and spill control systems (e.g., as described in NFPA 30), fire-resistant construction, thermal insulation, and fire barriers all can be forms of passive fire protection.

Q: Why is fireproofing research so active in the European Community?

A: On July 6, 1988, a fire on the Piper Alpha offshore North Sea oil platform resulted in 167 fatalities. Fireproofing was cited as an area of concern and potential contributing cause of escalation (although not a primary cause of the incident). Government regulation followed, accompanied by joint industry and government research, which included fireproofing.

Q: What is the allowable heat flux exposure for humans?

A: Radiant heat levels up to 2500 BTU/hr-ft^2 (7.9 kW/m^2) may be tolerated for 5 to 15 seconds if the only concern is short-time exposure of personnel to permit escape from the area under emergency release conditions.

Source: CCPS *Guidelines for Evaluating the Characteristics of Vapor Cloud Explosions, Flash Fires and Bleves*—p. 181, Tables 6.5, 6.6, and Figure 6.10. The EPA in *RMP Offsite Consequence Analysis Guidance* for worst case scenarios uses 5 kW/m^2 (1582 BTU/hr-ft^2) for 40 seconds as a level of exposure which will cause second-degree burns.

C.2 GENERAL

Q: What is the general goal of fireproofing?

A: The goal is to prevent structures or equipment from collapsing or failing. Typically, fireproofing is designed to protect structural steel supporting high risk or valuable equipment from reaching 1000°F for a 2–4-hour period (depending on the fire scenario). Allowable temperature for other equipment may be lower (e.g., wiring).

Q: Is 1000°F a satisfactory operating temperature for steel?

A: 1000°F is used as the failure point in standard tests, not a "safe" operating temperature. Section 5.2.6 discusses the effects of extreme temperatures on strength of steel structures. Figure 2 shows that a typical structural steel drops to one-half of its strength by 1000°F. Significant losses of strength occur as low as 410° to 440°C (770° to 824°F). The significance of temperature in real fire exposure situations relates to many factors, including the safety margins built into the structure during the design phase.

Q: What is the most important aspect in planning for fireproofing?

A: Understanding potential fire exposures in developing a fire-scenario envelope.

Q: What is the difference in heating value among hydrocarbon fuels?

A: For pure hydrocarbons, the heating values per pound is within a relatively small range for materials from methane (23,850 BTU/lb), to dodecane (21,300 BTU/lb). Alcohols are substantially lower in heat content. Other significant properties are specific heat, latent heat of evaporation, specific gravity, and volatility, which combine to determine the rate at which fuels will evaporate and be available to burn.

Q: How hot are flames from a liquid hydrocarbon pool fire?

A: Underwriters Laboratories and ASTM both chose 2000°F (1093°C) as representative of hydrocarbon fire exposure. The commentary on pool fires in appendices to ASTM E 1529 cites core temperatures from a variety of reports in the range from 1600°F to 2000°F (870°C to 1100°C). Other studies of 30- and 50-meter pan tests of kerosene measured maximum flame temperatures of 1380°C (2520°F).

Q: How rapidly will a pool fire burn?

A: Historically used values based on experience use a burning rate of 6 to 12 in./hr for gasoline, and 5 to 8 in./hr for kerosene, from pool fires, in depth. Thin layers of fuel burn faster because the radiant heat from the flames evaporates fuel from the pool faster.

Q: How big a pool will a given spill make?

A1: For burning pools, a Bureau of Mines study cited in the NFPA *Fire Protection Handbook*, 17th Edition, pp. 3–51, concludes that a spill fire will reach an equilibrium area of about 8 ft^2/gpm for liquid petroleum burning at the rate of 1 ft/hr. For example, a 100 gpm spill would have an equilibrium pool fire area of about 800 ft^2. Faster burning materials will cover smaller areas and slower materials will cover larger areas.

A2: For nonburning situations, the EPA, in *RMP Offsite Consequence Analysis Guidance* for worst case scenarios, assumes that an unconstrained liquid spill onto a nonabsorbing surface will form a pool 1-cm (0.39-in.) deep; based on this

assumption, each gallon (231 $in.^3$) of spilled material would cover about 4 ft^2.

Q: How high will a pool fire burn?

A: The CCPS *Guidelines for Safe Automation of Chemical Processes* provides the following estimate for VCM (which has physical properties similar to propane or butane): residual liquid from a flashing release forms a pool that may ignite and burn with a flame height that is two or three times the width of the pool.

Q: How far will a jet fire reach?

A: The CCPS book cited above suggests that for VCM, in "rough terms," the jet length is about 150 times the jet orifice diameter; thus a jet from a 2-in. hole could produce a burning jet about 30-ft long. This estimate is for material for which two-phase flow would be expected. A single-phase jet composed of only liquid would be expected to reach further and release material at a higher rate.

Q: Are U.S. government resources available for hazard analysis?

A: Yes—with the caveat that since these programs are intended for environmental planning, they treat all assumptions at the most conservative (protective) end of a range. They intentionally err toward overestimating consequences in making a "worst case" analysis.

The U.S. Federal Government has made a number of resources available to assist in hazard analysis. At 1998 year-end, these were available free from the Internet. Among these are:

Automated Resource for Chemical Hazard Incident Evaluation (ARCHIE): ARCHIE is described as: performing release rate, pool evaporation, neutral and dense gas dispersion, pool fire, jet fire, fireball, BLEVE, and vapor cloud explosion calculations. ARCHIE uses simple methods. The user must provide chemical data (no chemical database); but little or no modeling experience is required.

http://www.epa.gov/rgytgrnj/programs/artd/toxics/arpp/archie.htm

The following documents are provided in support of the Clean Air Act (CAA) Risk Management Program Rule (RMP). http://www.epa.gov/swercepp/tech.html

General Guidance for Risk Management Programs (July 1998)

General Guidance addressing: Five-Year Accident History; Offsite Consequence Analysis; Management System; Prevention & Emergency Response Programs; Risk Management Plan; Updated Data Elements and Instructions for Risk Management Plans and Off-site Consequence Analysis.

Off-Site Consequence Model

U.S. Federal EPA/NOAA RMP*Comp Computer Program

RMP*Comp is a free computer program used to complete the consequence analyses required under the Risk Management Planning Rule, which implements §112(r) of the 1990 Clean Air Act. In 1998, EPA made RMP*Comp available in draft form to help facility owners with initial risk management program planning and evaluation.

http://response.restoration.noaa.gov/chemaids/rmp/rmp.html

RMP*Comp is intended to (a) eliminate making calculations by hand, and (b) to have the program guide the user through the analysis process. RMP*Comp makes the same calculations made manually, using procedures described in EPA's draft guidance document, RMP *Offsite Consequence Analysis Guidance* (May 24, 1996).

C.3 Fireproofing Considerations for Equipment

Q: What is the allowable heat flux exposure for equipment?

A: While no single number can be used for all equipment, one company uses a value of 300°C (572°F) as a safe operating maximum for steel structures and process equipment. They then calculate acceptable radiation guidelines. Computer modeling equates 300°C to an exposure of approximately 12.5 kW/m^2 (4000 $BTU/hr\text{-}ft^2$) for exposure without fireproofing or water spray; for vulnerable structures they lower this to as little as 8 kW/m^2 (2500 $BTU/hr\text{-}ft^2$). They require fireproofing for any case where the fire scenario envisions direct fire impingement.

C.4 FIREPROOFING MATERIALS

Q: What is the most important aspect in choice of fireproofing?

A: Matching the fireproofing product or system to the needs analysis.

Q: What is an example of "functionally equivalent performance" for fireproofing materials?

A: For fireproofing materials, "functionally equivalent performance" could be the ability to perform the fire protection function (of preventing substrate failure) under the specific fire-scenario conditions in a manner equivalent to alternatives under those same conditions. For instance, under lower heat flux or shorter times exposures, a thick and thin coatings may both provide sufficient protection to prevent failure, even though the substrate temperatures may differ.

Q: What is a typical composition for dense concrete?

A: The following mixes are commonly used for dense concrete:

Formed concrete, made of 1 part cement, 2½ parts sand, and 2½ parts gravel that passes through a ⅜-in. (9.5-mm) sieve. Water should not exceed 6 gal/ft^3 of cement (802 l/m^3 o*f cement).*

Pneumatically applied concrete, made of 1 part cement and 4 parts sand. Water should not exceed 6 gal/ft^3 of cement (800 l/m^3 of cement).

Q: What is typical reinforcement for dense concrete?

A: Dense concrete can be formed in place or pneumatically sprayed to the required thickness using steel reinforcement, such as galvanized, electrically-welded 14 U.S. gauge steel mesh with openings of 2 in. x 2 in. (50 mm x 50 mm), usually spaced to be at the midpoint of the concrete layer.

Q: What types of reinforcement are needed for other fireproofing?

A: Because fireproofing is considered a "system," the reinforcement required depends on the fireproofing material being used and the manufacturer's specifications. Examples are: galvanized metal lath, wire mesh, specially coated wire mesh, glass fiber ribbon, and proprietary hexagonal mesh.

Q: What level of protection can be expected from dense concrete?

*A:*API 2510A, 5.8.3.2, cites 2 in. of reinforced or poured-in-place concrete as being satisfactory for steel supports of LPG vessels and piping.

One company uses the following "rules of thumb" for level of protection:

a. 2 in. of dense concrete = 3-hr ASTM E119 rating, or 2-hr UL 1709 protection.
b. 2½ in. of dense concrete is approx. a 3-hr UL 1709 rating.
c. 3 in. of dense concrete is approx. a 4-hr UL 1709 rating.

Q: Do reinforced high-strength concrete structures need fireproofing?

A: Work evaluating the effect of hydrocarbon fires on high-strength concrete (NIST Special Publication 919) indicated that (relative to low and medium strength concrete) high strength concrete is more vulnerable to loss of compressive strength as a result of fire exposure. Results showed that even when post-fire spalling was minor, that reduction in strength could be severe. Beams with a specific passive fire protection (Light-Cem LC5) showed no loss of strength and no spalling.

Q: What is a typical composition for lightweight concrete?

A: The following range of mixes of cement and lightweight aggregate is cited for lightweight concrete: 1 part volume cement with 4 to 8 parts by volume of vermiculite.

Q: What is a typical composition for fire-resistant mortar?

A: Fire-resistant mortar might be made of a mixture such as 1 part lime, 4 parts Portland cement, and 12 parts perlite.

C.5 Testing and Rating Fireproofing Materials

Q: Why is heat flux used as a fireproofing test parameter when the temperature regime is specified?

A: Heat flux more accurately defines the amount of heat stress being placed on a fireproofing system. As the quantity of material burning increases, heat transfer to the receiver goes up because the size of the emitter increases, even though the temperature differential remains the same. Temperature is comparable to pressure while heat flux relates to flow.

Q: How do I convert between conventional and SI heat flux units?

A: 1.00 kW/m^2 = 317 BTU/hr/ft^2;
1000 BTU/hr/ft^2 = 3.16 kW/m^2.

Q: What is the difference in performance of the same fireproofing system in different tests?

A: Standardized fire testing is time consuming and expensive. Published data comparing various tests is hard to find. An extensive body of data exists using building-oriented tests (such as ASTM E 119). The 1998 UL *Fire Resistance Directory* of fire protection for beams and related structures (Volume 1) lists 90% of its classification tests for UL 653 (equivalent to ASTM E 119), with about 10% for UL 1709.

Fire ratings for the same fireproofing system tested in ASTM E 119 typically show more hours of protection than in UL 1709. One UL listed mastic required a 25% thicker coating in UL 1709 to reach the same fire-resistance rating as in UL 263 (ASTM 119); literature from the supplier of this material equates a 3-hr ASTM E 119 rating to a 2½-hr UL 1709 rating.

One petroleum company uses a "rule of thumb" equivalence that an ASTM E119 4-hr rating roughly equals a UL 1709 3-hr rating.

Based on another petroleum company's testing for North Sea platforms, there was a very wide range of difference in comparative test results depending on the fireproofing material, the actual member being protected, and the time rating desired. In general, the UL 1709 rating for the same identical configuration was from 85% to 50% of the ASTM E 119 rating. They chose a rule of thumb that, if only ASTM E 119 data were available, they would consider that it would only last half as long under hydrocarbon fire exposure. While it is a frequent practice, it is not recommended to extrapolate pool fire performance from E 119 ratings.

Q: Why did ASTM E 1529 choose a lower heat flux than UL 1709?

A: The appendices to ASTM E 1529 provide an informative commentary on test methods, heat flux, and pool fires. Their analysis of "reasonably worst case" describes the history and rationale for choosing 50,000 BTU/ft^2-hr (158 kW/m^2). It is reported that an earlier industry test called the "pit test" provided background for development of ASTM E 1529.

Q: How is heat flux measured and controlled?

A: Section 4 of UL 1709 specifies furnace calibration using a test assembly fitted with 100,000 BTU/ft^2-hr, 180° view angle, water-cooled calorimeters. Test conditions, including combustion gas oxygen content, are established and maintained during tests (without calorimeters being used).

Q: What is an example of "functionally equivalent performance" for fireproofing test procedures?

A: For fireproofing test procedures, functionally equivalent performance could be the ability to predict the "real world" fire protection function (preventing substrate failure) under specific fire-scenario conditions in a manner equivalent to results from an alternative test procedure. For instance, for a given fireproofing system (same material, thickness etc.), tests that use comparable temperature rise and exposure with different heat flux may both predict functionally equivalent field performance (preventing failure), depending on the scenario conditions, time of exposure, and relevance of the test conditions to the "real world."

Q: What fireproofing test procedures are used for "jet fires?"

A: There appear to be no standard UL, ASTM, or ISO fireproofing test procedures for jet fires. European test laboratories do jet fire tests following the standard OTI 95635, issued by the British Health & Safety Executive. OTI 95634 tests 3-m long straight tubular sections of pipe. Other proprietary tests are conducted on flat panels, corrugated wall elements, simulated valve tubular, penetration seal panel, and GRE pipe spools with flowing water. In many cases, these tests do not yet have a formal nonproprietary standard, but are tested "as is" and witnessed by an "approving authority."

Q: How severe are "jet fires" fireproofing test procedures?

A: Results from proprietary tests show exposure of the test specimen to a jet flow emanating at sonic velocity from a nozzle with impingement velocity of about 130 ft/sec. Flame temperatures are approximately 1100°C (2000°F). Heat flux is about 320 kW/m^2 (100,000 BTU/hr/ft^2). Other tests may use different conditions. In all cases, the tests challenge both the ability of the test specimen to withstand high speed gas flow, as well as the heat flux.

C.6 Installation and Quality Assurance

Q: What is the most important aspect in installing fireproofing?

A: Fully understanding and following all of detailed requirements in the manufacturer's instructions for handling the received fireproofing material, surface preparation, proper mixing in the proper equipment, application exactly as specified using manufacturer approved equipment, and approved or trained applier personnel, if specified.

Q: Does the entire surface of horizontal beams need to be fireproofed to protect against a ground fire?

A: No. The top surface of the beam does not normally need to be fireproofed if the fire is below, since the major source of heat input is radiant. The interface of the fireproofing and the beam must be rigorously sealed to prevent water incursion. There can be benefits from not fireproofing steel if the needs analysis determines part of a structure doesn't need fireproofing protection. If connected structure has fire-related heat exposure, the air-exposed surface can be a radiator of conducted heat to the atmosphere. This can reduce the rate of temperature rise, and is one reason fireproofing is not specified for the top flange of beams where a fire-scenario exposure is heat radiation from a fire below the beam.

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