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Evaluating Shipboard Paint and Flammable Liquid Storage Lockers

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Harold E. Nelson
Edward K. Budnick
Richard G. Gewain
Charles W. Siegmann

Hughes Associates, Inc.
Columbia, MD 21045

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D. L. Motherway
Technical Director, Acting
United States Coast Guard
Research & Development Center
1082 Shennecossett Road
Groton, CT 06340-6096

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16. Abstract

This report provides an evaluation of the hazards associated with shipboard paint and flammable liquid storage lockers on merchant ships. The report also analyzes proposed modifications of the SOLAS regulations addressing fire suppression requirements for paint lockers. Finally, conclusions and recommendations are made for improvement in the regulations for fire and explosion protection of paint locker spaces.

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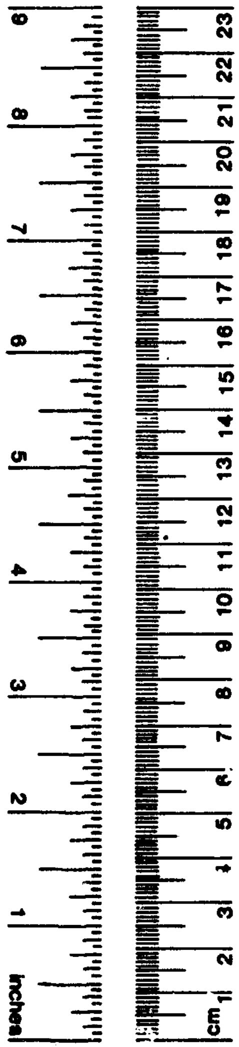
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

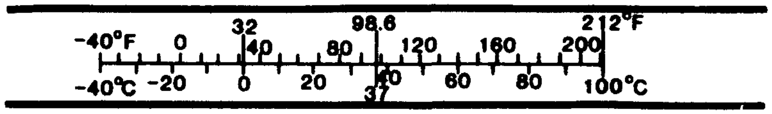
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly).



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1.0 SCOPE

This report provides an evaluation of the hazards associated with shipboard paint and flammable liquid storage lockers installed on merchant ships. The report also analyzes the proposed modifications to the Safety of Life at Sea (SOLAS) (Reference 1) regulations addressing fire suppression device requirements for paint lockers submitted by the International Association of Classification Societies (IACS). Finally, conclusions and recommendations are made for further improvement in the regulations (requirements) for fire/explosion protection of paint locker spaces.

2.0 BACKGROUND

Both the SOLAS and the U.S. Coast Guard regulations as published in the Code of Federal Regulations (CFR) (Reference 2) include requirements for paint lockers. Both sets of requirements specify explosion-proof electrical equipment within the paint locker. Both requirements also specify A Class bulkheads. A Class bulkheads are made of steel and have sufficient structural integrity to prevent the passage of flame if exposed to a fire meeting the standard time-temperature curve for one hour. For the most part, the bulkheads are not required to have any thermal fire resistance; the principle exception being requirements for 30-60 minute thermal fire resistance on passenger vessels when the paint locker is adjacent to control stations, stairway and elevator enclosures, staterooms and public spaces, and isolated storerooms. The principle difference between the current SOLAS requirements and CFR requirements lies in the requirements for fixed fire protection systems. The current situation is outlined in Table 1.

Table 1. Fixed Fire Protection System Requirements

	U.S. CFR	IMO SOLAS	Proposed IACS	Proposed Denmark
Passenger Vessels	Smoke Det. CFR 46-67.33 & Manual CO_2 CFR 46-75.15	Appropriate & Approved	None if: < 4 sq m Or If:	Smoke Detector &
Tank Vessels	Manual CO_2 or Water Spray CFR 46-34.05 (a)(3)		< 10 sq m and outside main superstructure	Manual Gas Foam System Pressure Water System or Spray Water System
Cargo & Misc. Vessels	Manual CO_2 or other Appr. CFR 45-95.05-10		Else: Dry Chem. Water Spray or other	

2.1 SOLAS

The current SOLAS requirement is included in Regulation 18, Chapter II-2, Paragraph 7 which reads as follows: "Paint lockers and flammable liquid lockers shall be protected by an appropriate fire extinguishment arrangement approved by the administration." The CFR requirements for fixed fire protection systems vary by type of vessel. Specific requirements are as follows:

a. Passenger Vessels. Smoke detection (CFR 46-67.33) and fixed manual Carbon Dioxide (CFR 46-75.15);

b. Tank Vessels. Fixed manual carbon dioxide or water spray (CFR 46-34.05(a)(3); and

c. Cargo and Miscellaneous Vessels. Fixed manual carbon dioxide or other approved system (CFR 45-95.05-10).

2.2 IACS Proposal

The IACS has issued an interpretation entitled, "Uniform Interpretation of SOLAS 1989 AMS. Chapter II-2, Reg. 18.7." This interpretation covers fire extinguishing arrangements for paint lockers as follows:

"(1) Paint lockers and flammable liquid lockers of deck areas 4 m^2 and more shall be provided with a fire extinguishing system enabling the crew to extinguish a fire without entering the space. Fixed arrangements as specified belo.. may be provided.

- CO_2 systems designed for 40 percent of the gross volume of the space.
- Dry powder systems designed for at least 0.5 kg powder/m^3.
- Water spraying systems designed for 5 L/m^2, min.

(2) Water spraying systems may be connected to the ship's main system.

(3) Other systems than those mentioned above may be accepted.

(4) For lockers of deck areas less than 4 m^2, CO_2 or dry powder fire extinguishers may be accepted."

The IACS has submitted this interpretation with an additional paragraph stating the following:

"Portable fire extinguishing equipment stowed near the entrance may be accepted for paint lockers of deck area less than 10 m^2 (108 ft^2) located outside the main superstructure block and having no contiguous boundary with accommodation machinery spaces of Category A, or gas danger spaces."

2.3 Review of Denmark Representation Remarks

Subsequent to the IACS submission, the Denmark representation on the Subcommittee for Fire Protection has offered general remarks for such unified interpretation as follows:

(a) The appropriate fire extinguishing system should be of a fixed type.
  - Only gaseous firefighting foam or pressure-water systems should be used.
  - Spray water systems may be supplied from the ship's fresh water supply.

(b) The release arrangement for the fixed fire extinguishing system should be manually operated and located outside the space concerned.

(c) One or more smoke detectors should be installed in the space concerned.
  - An early fire warning is especially important in such spaces since paint and similar substances can be spontaneously ignited.

2.4 Study Objectives

Given the above, Hughes Associates, Inc. (HAI) was charged with conducting a hazard analysis of the fire and explosion potential of paint lockers. Upon completion of the hazard analysis, HAI was to compare the proposed SOLAS requirements for paint locker fire protection systems against both the comparable requirements for shoreside flammable liquid storage rooms and the hazard analysis. The assigned tasks have been completed, and the results are reported herein.

3.0 APPROACH

3.1 Data Gathering

Data was gathered by the following:

(a) Visits to several ships available for inspection in Baltimore Harbor;

(b) Interviews with Coast Guard and American Bureau of Shipping (ABS) inspectors serving the Port of Baltimore;

(c) A review of fire incidents in shipboard paint lockers, an analysis of the data on flammable liquid fires contained in the National Fire Incident Reporting System (NFIRS) (this survey proved unfruitful as no comparisons were available within the depth of the data provided); and

(d) A detailed analysis of important U.S. codes and standards for the handling of flammable liquids in shoreside buildings.

3.2 Hazard Analysis

Analysis of the potential for fire or an explosion in a paint locker has been conducted. The analysis is based on: (1) fire test data from research investigations of fire development in similar shipboard spaces, and (2) analytical analysis using compartment fire models and other computational approaches based on fire dynamics and physics.

3.3 Consequence Analysis

An analysis was made of the potential consequence as a function of the location of the paint locker, the position of the door (and vents) during the course of the fire, and exposures outside of the paint locker if no fixed suppression system was present (or used). This was then compared to the impact of the various manual and automatic suppression systems under consideration. The potential consequences of deflagration-type explosions of a mixture of combustible vapors was also considered on the basis of both potential overpressure as a function of the tightness of the enclosure and the amount of vent opening, and as a potential source for an ensuing fire.

3.4 Conclusions and Recommendations

Conclusions and recommendations made are provided.

4.0 SHIP VISITS AND SIMILAR CONTACTS

4.1 Contacts

While a number of contacts were made, the most informative were those with Coast Guard and ABS inspectors in the Port of Baltimore, and visits to five paint lockers on three ships in the port. The interviews brought out the following points:

(a) Most of the newer installations of suppression systems in paint lockers are automatic carbon dioxide systems operated by heat detection devices.

(b) Many of the retrofits of lockers on older, foreign flag ships consist of manually operated water systems. In some cases, these systems are connected directly to the fresh water system; in others, they are open pipe, and water is supplied by a hose connection from the fire main when needed.

(c) Main paint lockers will normally contain materials directly related to paints such as paints, thinners, brushes, paint rollers, and other materials. Since the paint lockers are the only spaces on most ships designed to handle flammable liquids, flammable liquids for purposes other than painting are frequently stored in these lockers. For example, on one of the ships visited, the gasoline for operating the ship's boats was stored in the paint locker.

(d) Many ships have a second paint locker, often referred to as the engineer's locker, located in the machinery portions of the ship. The engineer's locker will frequently contain both paint and other materials related to maintenance of the mechanical equipment. The one observed during this project included paints, thinners, greases, chain falls, saws, ropes, and similar equipment. Normally, these lockers are smaller in size than a typical paint locker. The one observed during the visit to one of the ships was approximately 6 m^2 in size.

4.2 Shipboard Visits

The following pertinent observations, summarized in Table 2, were made as a result of the visits to actual paint lockers:

(a) The capacity of the paint locker seen was approximately 400 L/m^2 (10 gal/ft^2). The exception to this general rule was the engineer's paint locker where only half the locker was used for paint storage. Of the other four lockers observed, three actually had approximately the maximum capacity on hand. One was in less than full use but if fully loaded would have held approximately 400 L/m^2 (10 gal/ft^2).

Table 2. Data on Paint Lockers Visited

	Ship 1 RO-RO		Ship 2 Trans./ Cargo	Ship 3 Cable Laying	
	Main Locker	Engineers Locker	Paint Locker	Fore	Aft
Approx. Size	11 sq m 128 sq ft	4 sq m 43 sq ft	15 sq m 160 sq ft	13 sq m 145 sq ft	8 sq m 85 sq ft
Location	Inside opens to Cargo Bay	Inside below water line. Opens to steering motors	Inside below water line. Opens to steering motors	In main super-structure opens to weather deck	In main super-structure opens to weather deck
Enclosure	A Class Bulkheads 0 Thermal Fire Resistance				
Vent	Gravity (high)	None	Power	Gravity & Power	Gravity & Power
Fuel Loading	400 L/sq m 10 gal/sq ft	200 L/sq m 5 gal/sq ft	400 L/sq m 10 gal/sq ft	400 L/sq m 10 gal/sq ft	400 L/sq m 10 gal/sq ft
Detection	Heat Detection				
Suppression	Manual Carbon Dioxide		Automatic Carbon Dioxide		

(b) Of the five paint lockers observed, one was in active use for ongoing painting operations, and four were unlocked and unsecured.

(c) Each of the doors had a method of holding the door open. In four of the cases, this consisted of a large hook and eye (similar to an oversize screen door hook). In the fifth case, the door was held open with a rope tied to an external station. In one case (the engineer's paint locker), it was necessary to actually step into the paint locker and extend a stick behind the door to reach and unhook the latch.

(d) Three of the five paint lockers were actually inside the vessel superstructure with their doors opening to an internal space. In one case, this was into a cargo space. In the other two, the door opened into an area containing the steering motors. This arrangement is contrary to the information obtained by interviewing inspectors. The general consensus of inspectors was that the majority of the paint lockers open onto weather decks. It is therefore assumed that the distribution of the paint lockers locations observed was not typical of vessels in general.

(e) The two paint lockers that opened onto the weather deck were located in the main superstructure of the vessel. This is also contrary to the general view held by the interviewed inspectors who felt that the majority of the paint lockers were located in the focsle outside the main superstructure.

(f) None of the paint lockers viewed had any insulation in their bulkheads. All of the bulkheads were of heavy steel construction and are presumed to be A Class with no thermal fire resistance.

(g) One of the paint lockers opening to the weather deck internally exposed critical cabling immediately below its deck and a critical computer mounted almost in contact with one of its uninsulated vertical bulkheads.

(h) All of the paint lockers observed were protected with carbon dioxide systems. Three were automatic; two were manual.

(i) All of the paint lockers observed had heat detection devices. Where the system was automatic, the device both operated the system and sounded an alarm. Where the system was manual, it sounded an alarm. In each case, the heat detectors appeared to be explosion proof.

(j) In each case where there was an automatic system, the system automatically closed the vents. In one case, the vents were ducted and fan operated. In the other two cases having automatic carbon dioxide systems, the vents were both dampered openings near the top of the paint locker and a powered exhaust fan near the top of the paint locker. In each of these cases, operation of the carbon dioxide system shut down the dampers closing each of the vents and shut off the fan.

(k) In the paint lockers where the carbon dioxide system was manually operated, one was vented, and the other (the smaller engineer's locker) was not vented. The vent in the larger paint locker consisted of an opening of approximately 0.1 m^2 (15 $in.^2$). A sign was mounted under the vent advising the crew to close the vent before operating the carbon dioxide system. The carbon dioxide system controls were located close by on the same wall.

(l) In four of the five paint lockers, a low flash point flammable liquid (acetone-based thinner or gasoline) was found. In one case, the acetone thinner was in two five-gallon shipping containers of the screwon cap type. At the time they were found, one was open; the other was closed. The gasoline storage consisted of five five-gallon containers, three of metal and two of plastic construction type typical of containers used for domestic purposes.

(m) In one case, an ordinary type electrical outlet had been installed outside of, but immediately adjacent to, the opening of the paint locker. Inside the paint locker, an open sparking industrial drill with a paint mixing attachment was found. We were told that the mixing operation was always conducted on the open deck outside of the paint locker.

5.0 REVIEW OF INCIDENTS

An attempt was made to identify incidents in paint lockers and shoreside incidents in similar facilities. Unsuccessful inquiries for data were made to a number of sources including the American Bureau of Shipping, Lloyds of London, American Institute of Merchant Shipping, and the National Transportation Safety Board. An analysis run on the NFIRS data showed reports of approximately 400 flammable liquid fires in a single year; however, the data breakdown was not sufficient to derive any useful information covering fires in small paint storage locations similar to those found shipboard.

The only successful inquiry involved incident data collected by the Navy Safety Center. Data were obtained from that source on eight paint locker fires on U.S. Navy ships between the years, 1981 and 1992. There were no reported injuries in any of these fires. None involved material beyond the paint locker. Two appeared to have the potential for a serious fire, but were handled by, in one case, closing the door followed by fire suppression, and in the other case, by handheld fire suppression equipment. The sources of ignition included welding on the exterior of a bulkhead, arson, playful use of a cigarette lighter inside the paint locker, use of the space as a place for smoking marijuana, spontaneous heating, and an electrical spark in a nonexplosion proof electrical panel mounted inside a locker that had been converted to flammable liquid storage. Suppression methods used included handheld carbon dioxide extinguishers, hand-held water hose streams, installed manually operated carbon dioxide systems, installed automatic operated carbon dioxide systems, installed halon systems, manually operated AFFF foam, PKP dry chemical, and closing of the door. A tabular summary of the Navy incident data is shown in Table 3.

6.0 COMPARISON OF SHORESIDE AND SHIPBOARD HANDLING OF FLAMMABLE LIQUIDS

A detailed analysis of the major code requirements for shoreside handling of flammable liquids other than large warehouses or bulk storage was performed and included as Appendix A to this report. A comparison of the requirements and practices for shipboard paint lockers versus that prescribed for shoreside storage of flammable liquids was made. Table 4 is a side-by-side comparison of the essential fire protection features. There are many points where the shipboard approach is entirely different than the shoreside approach. A major factor comparison follows.

6.1 Enclosure

A shipboard paint locker provides a tight, normally welded enclosure structurally strong enough to resist a fire for approximately one hour. However, thermal fire resistance per se is not required unless there is a serious exposure to people or property. Conversely, in the shoreside installations, there is no attempt at tightness, there is no expectation that the development of the fire will be retarded by any resulting limitation on available oxygen. The fire resistance of the enclosure is between one and two hours and expected to have both structural and fire resistive capabilities.

Table 3. Summary of Paint Locker Fires on U.S. Navy Ships

Year	Cause	Fuel	Size	Suppression	Door
1981	Welding Bulkhead	Class A to Paints	Moderate flashed several times	Hand CO_2 and Hose Streams	Closed
1983	Arson	Rags	Small	None	Closed
1985	Cigarette Lighter	Paint Thinner	Small Brushes	Closed Door - Man. CO_2	Open
1985	Smoking Marijuana	Class A	Small	Installed CO_2	
1986	Spont. Heating	Rags	Small	Hand CO_2	
1991	Spont. Heating	Class A	Small	Installed Halon & Man. AFFF	Closed
1991	Electrical Panel	Electrical Insulation	Small	Hand CO_2	
1992	Auto Ignition	Low Flash, F.L.	Large Flame - No Flashover	PKP and Hand Hose	Open

Table 4. A Comparison of Basic Shipboard and Shoreside Fire Protection Requirements

Protection Element	Shipboard	Shoreside
Room Enclosure	Tight One-Hour Structural F.R. 0 to 1 Hour Thermal F.R.	No Attempt At Tightness 1 to 2 Hour Structural F.R. 1 to 2 Hour Thermal F.R.
Door	Steel - No Rating (Usually A Class) Manual Closing, Manual Latching	Listed Fire Door (1-1/2 Hr.) Self Or Automatic Closing Automatic Latching
Vents	Expected Must be Closeable, Can Be To Inside	Can Be Vented To Outside. Closing Of Vents Not To Be Expected Or Desired. May Have Explosion Venting. (SSBC REQ.)
Location	Often In Focsle, Often Open To Weather Deck, Some Inside Vessel	Often Opens Into Building. Some On Docks Or In Out Buildings.
Installed Fire Protection	CO_2 Favored. Often Manual Auto. Often On New. Other Systems Accept.	Almost Always Automatic Sprinklers (Other systems Usually Subject To AHJ).

6.2 Doors

Shipboard requirements specify a steel door, but no particular fire rating. The door is normally a watertight door which would be expected to meet the A Class rating. The doors on shipboard paint lockers are heavy, manually operated doors with no closing mechanisms. The doors are normally held closed by the classic six dogs, handling watertight doors. Conversely, shoreside storage calls for UL listed fire doors (normally 1.5 hour fire resistance rating). The doors are also required to be self or automatic closing and automatic latching.

6.3 Vents

On shipboard paint lockers, venting is expected (though not specifically mentioned in the requirements except by references that venting shall be closable). In some cases, the vent opening is directly to the inside of the vessel. For shoreside requirements, there is normally no specific venting requirement though some codes do specify an air-sweeping arrangement in an attempt to remove flammable vapors from the floor level. Explosion venting however can be and is often provided. Closing of vents where they exist is not expected, nor desired. Some shoreside facilities may be explosion vented. Such venting is required by the Southern Standard Building Code.

6.4 Location

Shipboard paint lockers are often located in the focsle, often open to the weather deck, but sometimes located inside the vessel. Shoreside facilities most often open into buildings. Sometimes they are located in docks or in outbuildings. The requirements however are based on doors that open into occupied areas.

6.5 Installed Fire Protection

In shipboard installations, carbon dioxide appears to be the most favored and common. It is also understood that water spray systems have been frequently used on retrofit systems on older ships. The systems are often manually operated. The CFR requirements specify manual operation on passenger vessels. However, automatic systems are increasingly appearing in new installations. Shoreside installations are almost always automatic sprinklers. Other systems are legally permitted if acceptable to the authority having jurisdiction (AHJ), but they are seldom used.

6.6 Overall Comparisons

Under typical shipboard paint and flammable liquids locker system arrangements, a closed locker will restrict the development of a fire to a level that will not endanger the ship, its cargo, or its passengers. With a closed door, the prime purpose of the suppression system is to terminate an already controlled fire situation. The principle weakness of the shipboard arrangement is the possibility that the paint locker door will be open at the time of fire and that fire will either extend beyond the paint locker or present a condition that prevents door closing. This could allow a fire to develop into a fully involved (flashed over) condition that the installed suppression system fails to handle (possibly due to loss of agent through the open door) in a situation where the door cannot be closed due to the intensity of the fire or other cause, and the emitting flame and gases impinge upon or fill a space where they cause serious harm.

Shoreside arrangements fundamentally expect and are designed for the burnout of a fire of significant size. The self-closing door and fire partition are intended to confine the fire effects to the storage room. The use of automatic sprinklers is recognized as incapable of extinguishing a flammable liquid pool fire. Systems prescribed however are of high water discharge density and tend to perform the function of either extinguishing the fire before a pool fire develops and/or preventing the rupture of uninvolved flammable liquids containers thereby keeping fuel from the fire.

7.0 FIRE HAZARD POTENTIAL

7.1 Selection of Critical Fire Scenario

The following is a copy of the instructions for attacking a paint locker fire abstracted from a manual entitled, "Marine Fire Prevention, Firefighting, and Fire Safety" (Reference 3), published by the Maritime Administration of the Department of Commerce (undated).

"Paint Locker Fire

The Fire. Smoke is discovered issuing from a paint locker in the machinery spaces, through a partially opened door. This paint locker has a manual CO_2 system.

Size-up. If there is not much smoke, the fire is in the early stages. Large volumes of dense smoke indicate that the fire has been burning for some time.

Attack 1 (Light Smoke). The alarm is sounded. The door is opened further, and the locker is visually examined to determine what is burning. A smoldering Class A fire (rags, rope, paint brushes) is extinguished with a multipurpose portable dry chemical or water extinguisher.

Backup. A hoseline is run out and charged with water, to be used to wet down any smoldering material.

Attack 2 (Heavy Smoke). The door and vents are closed, and the manual CO_2 system is activated.

Confining the Fire. The fire was isolated when the door was closed.

Protecting Exposures. All sides of the paint locker are continuously examined to ensure that the fire is not extending.

Ventilation. The locker is not opened or ventilated until all bulkheads, decks, and overheads are cool to the touch. Then, with a charged hoseline in position, the door is opened and the compartment is allowed to ventilate long enough for a normal level of oxygen to return a small space. Test for a safe oxygen level.

Overhaul. Fire-damaged material is removed from the locker. Expended CO_2 protection is restored.

The fire attack procedure described assumes two scenarios. The first is a small fire with the door partially opened. The second a more significant fire but with the door closed. These two scenarios may represent the majority of the incidents. Certainly, the lack of a record of serious incidents would lend support to these scenarios or other nondamaging scenarios as being the majority of cases. However, the analysis here is based on a worst case appraisal involving identification of potential scenarios that can result in significant damage or other harm outside of the paint locker. In this analysis, an assumption has been made that fire must have or be capable of producing a rate of heat release that would raise the temperature and conditions in the paint locker to a level capable of producing a flashover or similar high temperature condition, emitting flames, gases, and probably excess unburned hydrocarbons. For this to occur, it would require a pool fire or an equivalent cascading fire involving about 5 L/min (1.3 gal/min) of flammable liquid supply to the fire producing a total burning surface area of about 1 m^2 (10 ft^2) (Reference 4). Continuation of the fire would require breakage or rupture of additional containers to continue to provide fuel. These secondary fuels could be either combustible or flammable liquids.

While the incident investigation did not demonstrate that such a fire has ever occurred, it is accepted as a potential. And, the potential for such a scenario may increase if more plastic containers are brought on board (Reference 5). Fire tests of such containers have demonstrated rapid involvement in any exposure fire and difficulty in controlling such fires with conventional suppression systems. Therefore, for the most severe case used in this analysis, it is assumed that a flammable liquid pool of at least one meter diameter exist at the moment of ignition and is continually fed to maintain that pool or a flaming fire at the rate of 5 L (1.3 gal) per minute.

7.2 Relevant Test Work

Recent shipboard fire tests conducted for the U.S. Navy's Navy Technology Center for Safety and Survivability (Reference 6) involved an open door to a 6 m^2 compartment, similar in geometry and arrangement to many paint lockers. In these tests, an oil burner was used to produce the fuel. The flow rate to that burner ranged from 2.6 to 4.5 L (0.7 to 1.2 gal) per minute. While this is a more controlled fuel rate than would likely occur in a paint locker, there is sufficient similarity, so that the data are of value. Fuel rates were controlled to produce three different types of burning: (1) fuel controlled (2.7 L/min), (2) stoichiometric (3.8 L/min), and (3) vent controlled (3.8 L/min). In the fuel controlled situation, all burning took place within the space even though temperature conditions reached levels indicative of flashover. In the stoichiometric situation, the air supply and fuel supply were tuned to be perfectly matched so that the fuel essentially burned within the room with some incandescent flame extension beyond. In the vent controlled situation, the rate of fuel release exceeded the rate of available air resulting in extensive emission of unburned fuel demonstrating itself as a flame emitting from the burning room. Table 5 is extracted from Reference 6. It provides a summary of the fuel flow rates, energy produced, and resulting conditions.

Table 5. Summary Data Sheet for Test Series #1 - Spray Pan Fires 1 Door Tests (Opening Factor $A_T/A\sqrt{H} = 20.1\ m^{-1/2}$)(Reference 7)

	Case 1 (Fuel Controls)	Case 2 (Stoichiometric)	Case 3 (Vent controlled)
Test Number	11	12	16
JP-5 Flow Rate, lpm (gpm)	2.7 (0.7)	3.8 (1.0)	4.5 (1.2)
Equivalent Energy Release Rate of Fuel, MW (Btu/hr x 10^6)	1.6 (5.5)	2.2 (7.5)	2.7 (9.2)
Fire Compartment Upper Layer Temp., °C (°F) Com. Temp., °C (°F)	 725 (1337) 675 (1247)	 900 (1652) 800 (1472)	 700 (1292) 650 (1202)
Peak Upper Comp. Temp., °C (°F)	325 (617)	350 (662)	250 (482)
Upper Comp. Temp., °C (°F)	275 (527)	300 (572)	200 (482)
Adj. Comp. Temp., °C (east) (°F)	200 (392)	250 (482)	150 (302)
Max. Wall Temps. Interior, °C (°F) Exterior, °C (°F)	 650 (1202) 600 (1112)	 700 (1292) 675 (1247)	 600 (1112) 525 (977)
Max. Ceiling Temps. Interior, °C (°F) Exterior, °C (°F)	 -- -- -- --	 -- -- -- --	 650 (1202) 575 (1067)
O_2 Content, % vol (dry)	6	2	0
CO Content, % vol (dry)	0	1	4
CO_2 Content, % vol (dry)	8	10	9

For purposes of this analysis, the conditions represented by the data in the third column (Case 3), i.e., vent controlled situation, were used as the model exposure. While this represents an extreme exposure, it is within the potential range and is felt to represent the reasonable worst or design case upon which to base fire protection systems. Situations of less severity will of course be simpler to handle and less taxing on the fire protection systems provided.

7.3 Use of Modeling to Extend Test Case to Other Situations

7.3.1 Model Used (CFAST 1.6.4)

In order to extend the comparison from the single case tested (door wide open, very rapidly developing fire) to other cases and situations, the compartment fire model, CFAST (Version 1.6.4) (Reference 7) was used. The model was used to simulate other fire growth rates, different compartment sizes, and conditions that could occur with the door open, door closed, vent open, and door and vent closed.

7.3.2 Model Accuracy

An important limitation associated with the use of the CFAST model is its inability to accurately simulate the temperatures of a thermally thin wall. Test cases from the model versus the full-scale test results demonstrated reasonable agreement for room temperature conditions, but unreasonable results for the wall temperature and the drop in wall temperature from the inside to the outside. Therefore, the temperature values used in assessing transfer of energy through the steel walls and the resulting consequences were based on the test results reported in Reference 6. These tests demonstrated a temperature drop of between 25 and 75°C across the steel bulkhead and a bulkhead temperature of approximately 100°C less than the average fire compartment temperature.

7.3.3 Post-flashover Adjustment

A second limitation of the CFAST model occurs in estimating post-flashover mass loss rates. The model requires the user to input a mass burning rate. If that mass burning rate is too high, the model will falsely report low temperatures and high pressures. To avoid this complication, the post-flashover entries were limited to a mass burning rate of twice the mass that would produce the rate of heat release available as a result of the air drawn in through the opening (i.e., twice stoichiometric). This adjustment eliminated the apparent false results.

7.3.4 Comparison of Test Results and CFAST Results

Figure 1 provides a comparison between the predicted average upper level room temperature by CFAST and that recorded during the test. The model reasonably predicts the measured temperatures, although the predictions are about 50°C higher than the test measurements.

7.3.5 Use of CFAST to Extend Analysis to Other Cases

Since the proposals to SOLAS mention both 4 m^2 and 10 m^2 as potential dividing lines for paint locker fire protection requirements, calculation runs were made with paint lockers having those two areas. In addition, calculations were made for a paint locker having a 2 m^2 area to examine the apparent trend indicating the smaller the locker, the higher the resulting temperature (presumably as a result of less surface area for heat transfer). For each of these three sizes, calculations were made with a vent size simulating a full, open door of approximately 1.6 m^2 (17.2 ft^2), 0.1 m^2 (16 $in.^2$) representing a typical open vent, and 0.01 m^2 (1.5 $in.^2$). The 0.01 m^2 vent was intended to represent the leakage that would be expected to occur around closed dampers in the vents, at any point where the watertight door is not completely closed, or where the joints of the bulkhead are not complete. Figures 2 and 3 show the results of these analyses.

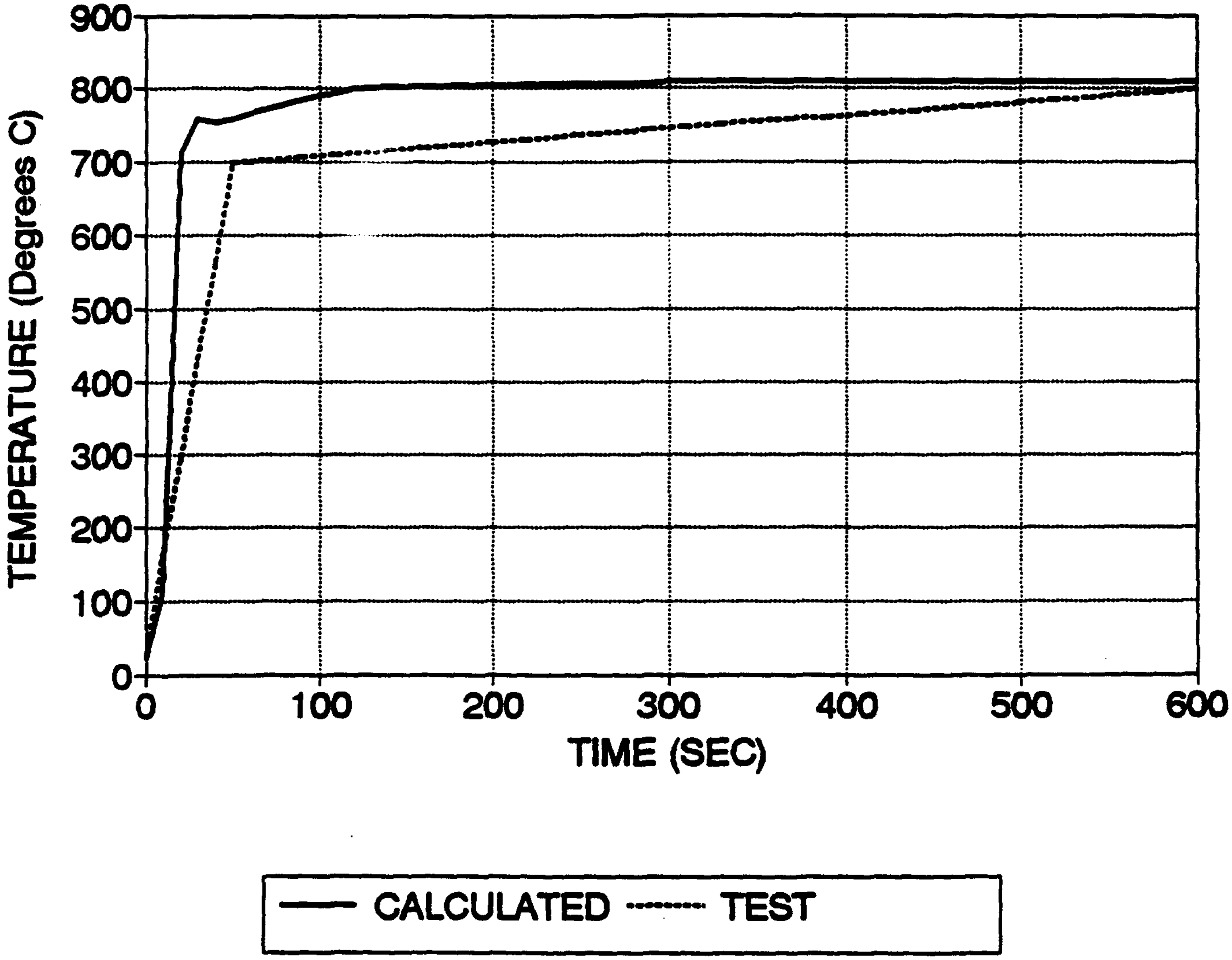

Figure 1. Comparison of Test Results and CFAST Model Results

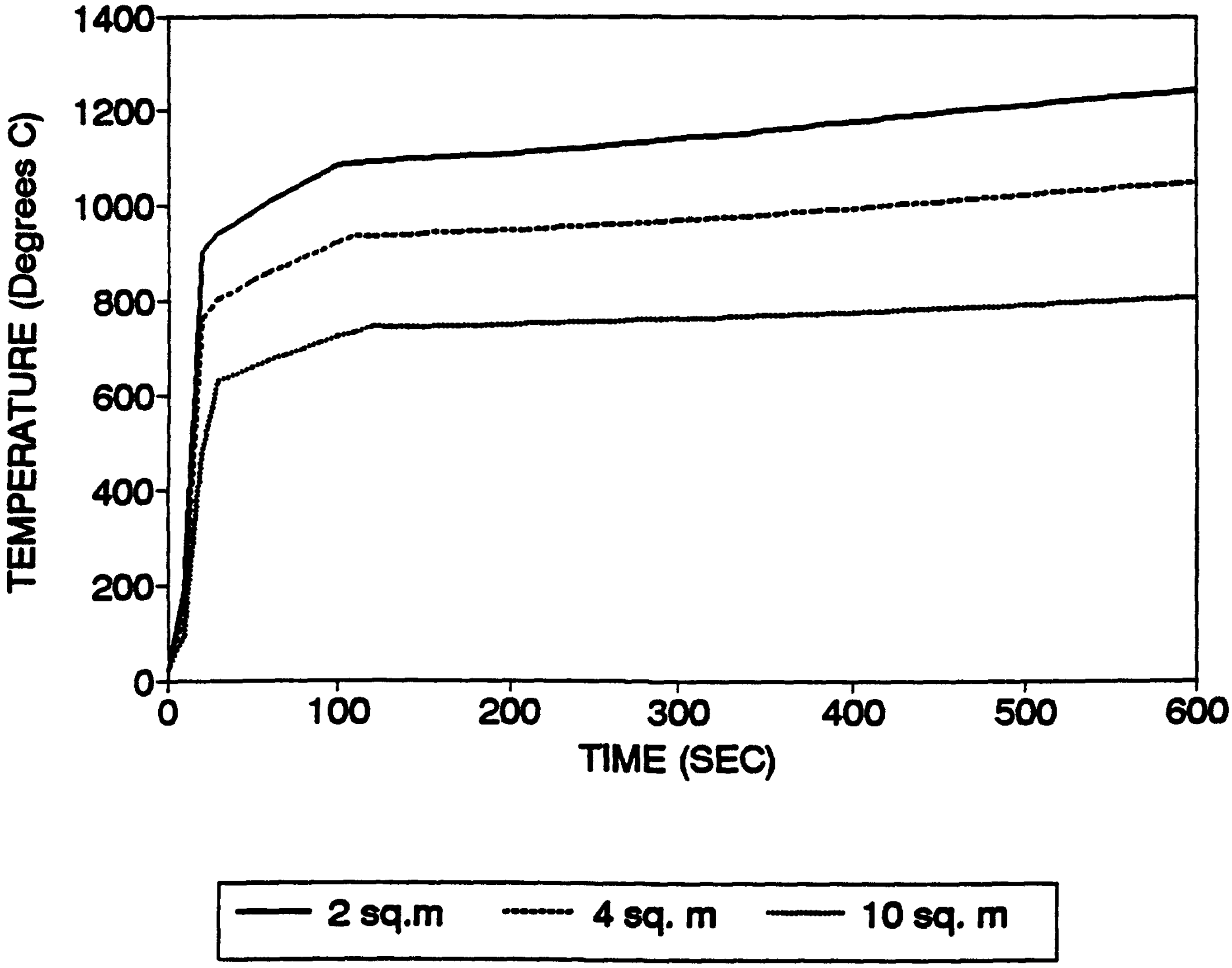

Figure 2. Calculated Smoke Layer Temperature in a Paint Locker with Open Door Given a Serious Pool Fire

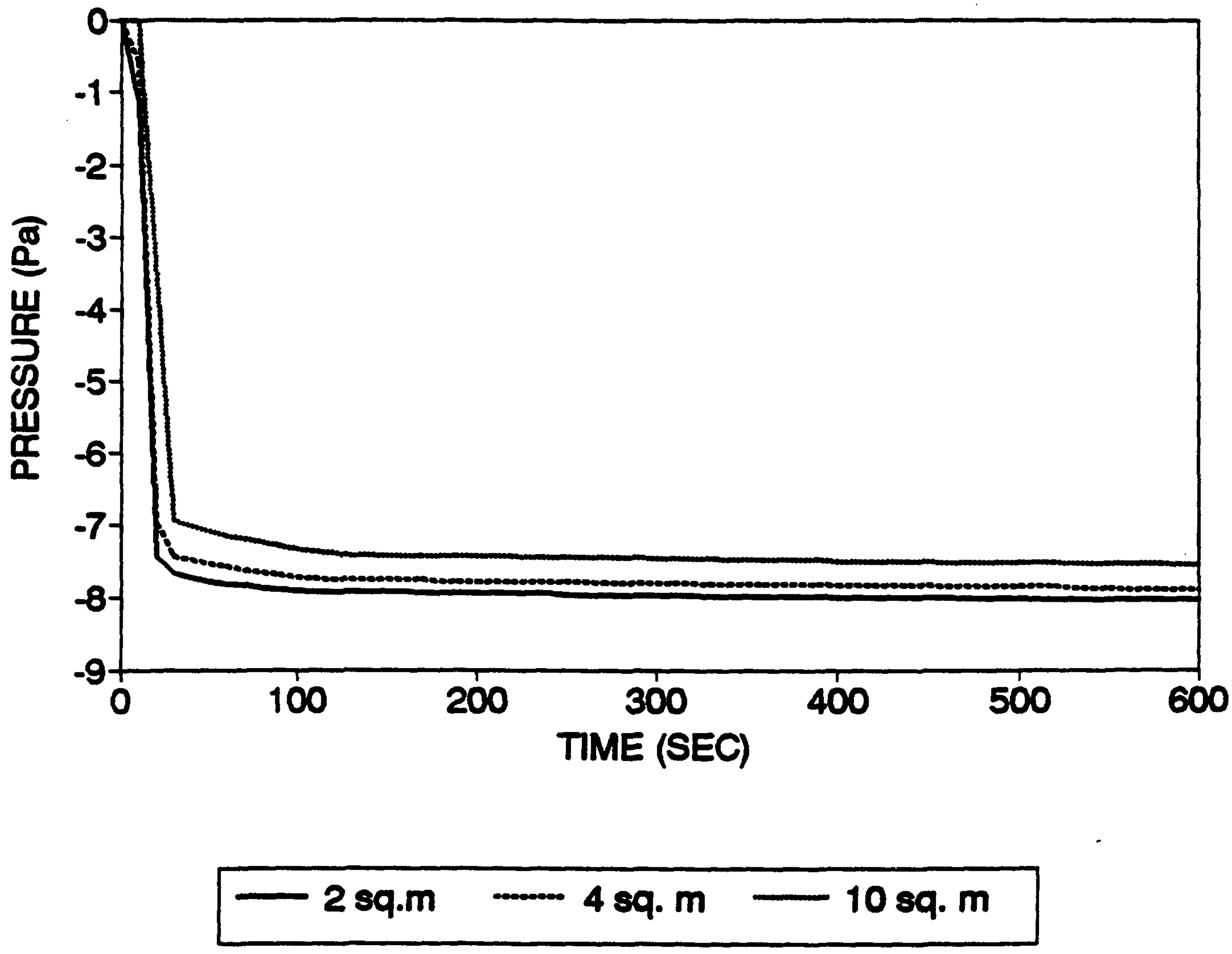

Figure 3. Calculated Pressure Conditions in a Paint Locker with Open Door Given a Serious Pool Fire

7.3.6 Door Open Conditions

Figure 2 demonstrates that flashover temperatures are potentially achievable in paint lockers for all three of the sizes evaluated. The trend of the calculated temperature curves indicates that at some very large area, the fire may lose enough energy to the partition to drop temperatures near or below the flashover level. In such a large space, however, the validity of a zone-type compartment fire model becomes a factor. It is quite conceivable that in such large spaces, a portion of the space could exceed flashover temperatures while another portion does not.

The model results also predicted a net negative pressure across the open door (see Figure 3). There will of course be a positive pressure of low order in the top of the compartment driving the combustion gases from the compartment and drawing air into it. However, the maximum ΔP is however only 8 Pa (0.001 psi) and of an insignificant value in terms of structural stress on the paint locker structure.

7.3.7 Door Closed, Vent Open Conditions

The second set of simulations represents situations where the door is closed and a vent is open. With the rapid developing fire simulated, flashover can briefly occur based on the oxygen available in the room and the small amount drawn in from the vent. However, the temperatures (see Figure 4) will drop rapidly and stabilize at an elevated but sub-flashover temperature. For the model cases examined here, the vent opening was assumed to be a long, narrow crack running from the overhead to the deck of the paint locker. For actual cases where the vent is located near the top of the paint locker, the available air would likely be less and the temperature would be expected to be lower than that predicted for the prescribed vent condition.

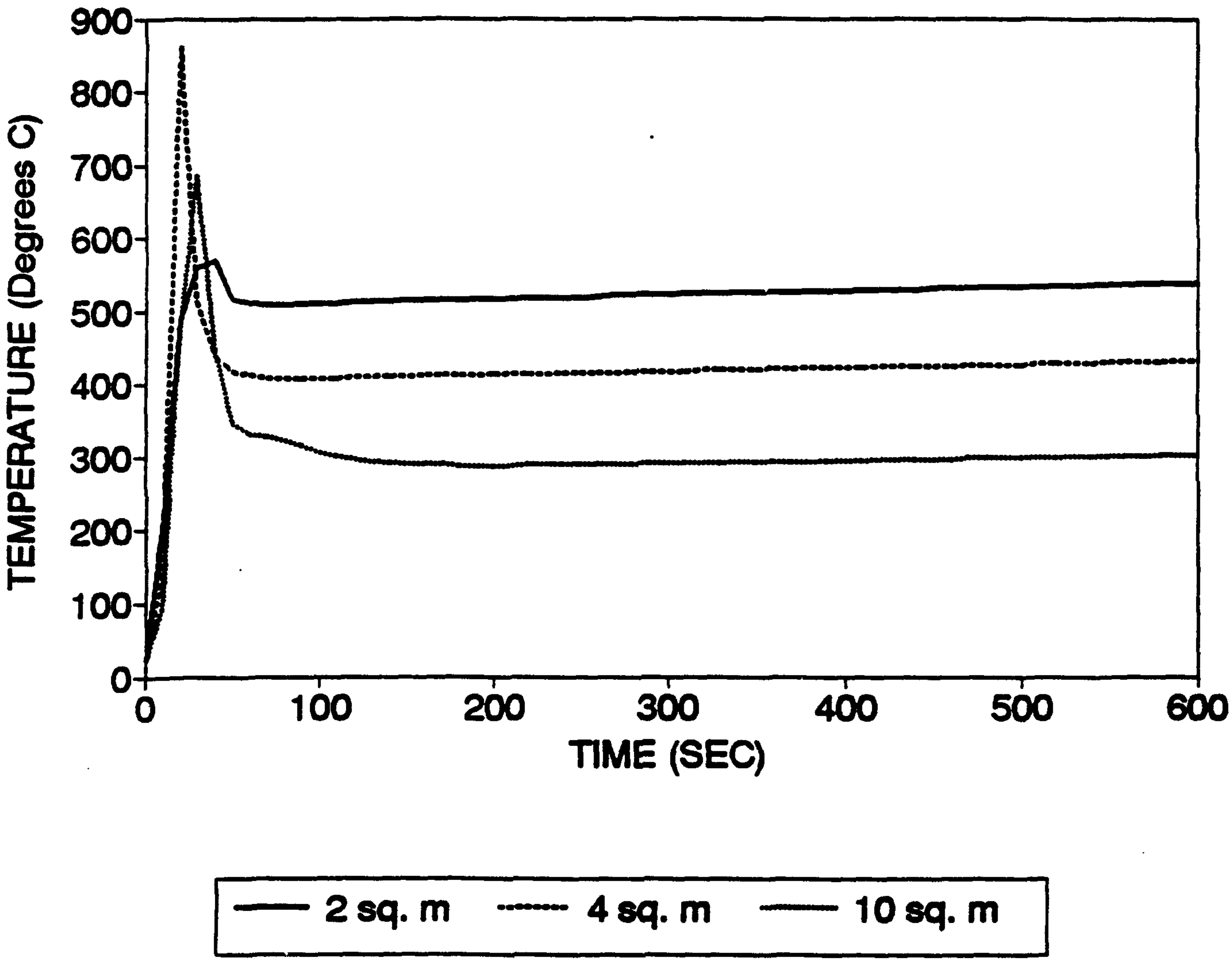

Figure 4. Calculated Smoke Layer Temperature in a Paint Locker with Closed Door but Open 0.1 m^2 Vent Given a Serious Pool Fire

The prediction of pressure rise (Figure 5) indicates a brief pulse reaching approximately 425 Pa or 0.005 atm (0.06 psi or 1.7 in.H_2O) should this very rapid fire occur in a paint locker as large as 10 m^2. In the smaller paint lockers, the brief pulse or peak is not apparent. This peak is the combined function of the larger amount of air available for combustion and the restriction of the gas flow through the vent.

7.3.8 Door Closed, Vent Closed Conditions

The last set of calculations simulate conditions with the paint locker door and vents closed. An assumed leakage of 0.01 m^2 (1.5 $in.^2$) was prescribed to simulate leakage around damper blades and any other cracks or openings in the locker. This was simulated as a crack that ran the height of the locker. As with the larger opening representing the 0.1 m^2 area for vents, an initial temperature peak (Figure 6), in most cases exceeding flashover conditions, occurred as a very rapid fire found sufficient oxygen in the room to briefly burn at intense levels. However, the duration of this peak was very short, due to rapid consumption of the oxygen in the room. The fire is then predicted to result in lower temperatures between 100 and 200°C depending on the size of the room. Again, as would be expected, the smallest room resulted in the hottest temperature, while the larger room was somewhat lower.

As shown in Figure 7, the model predicts a pressure pulse in the 10 m^2 locker of approximately 20,000 Pa or 0.2 atm (2.9 psi or 80 in.H_2O) overpressure. Whether this overpressure would actually occur in an actual fire condition is doubtful, and subject to the exact rate of rise of temperature in the space and the size of the opening. However, it is useful to compare this predicted maximum to the predicted overtemperatures in case of explosive deflagration of combustible vapors inside a paint locker.

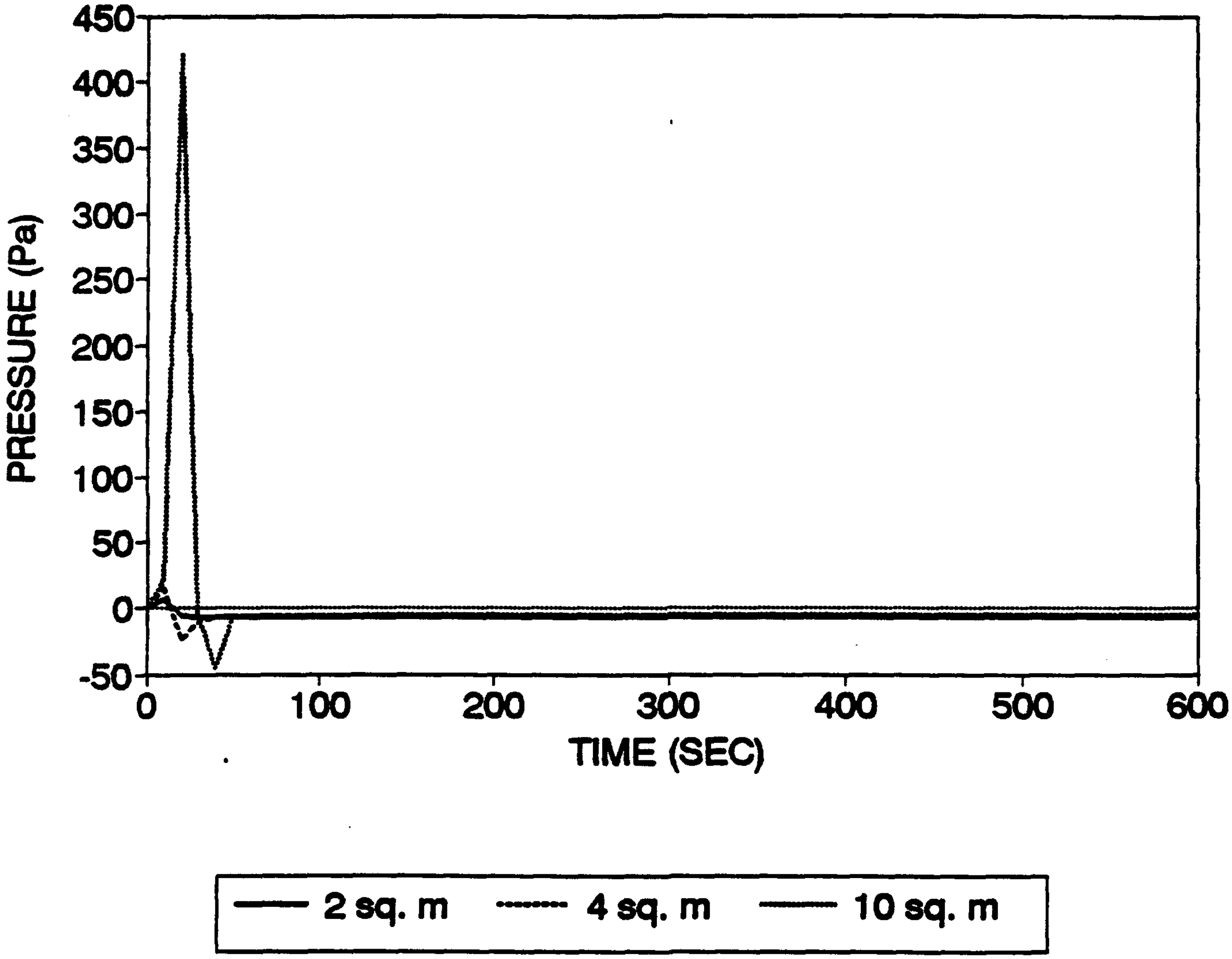

Figure 5. Calculated Pressure Conditions in a Paint Locker with Closed Door but Open 0.1 m^2 Vent Given a Serious Pool Fire

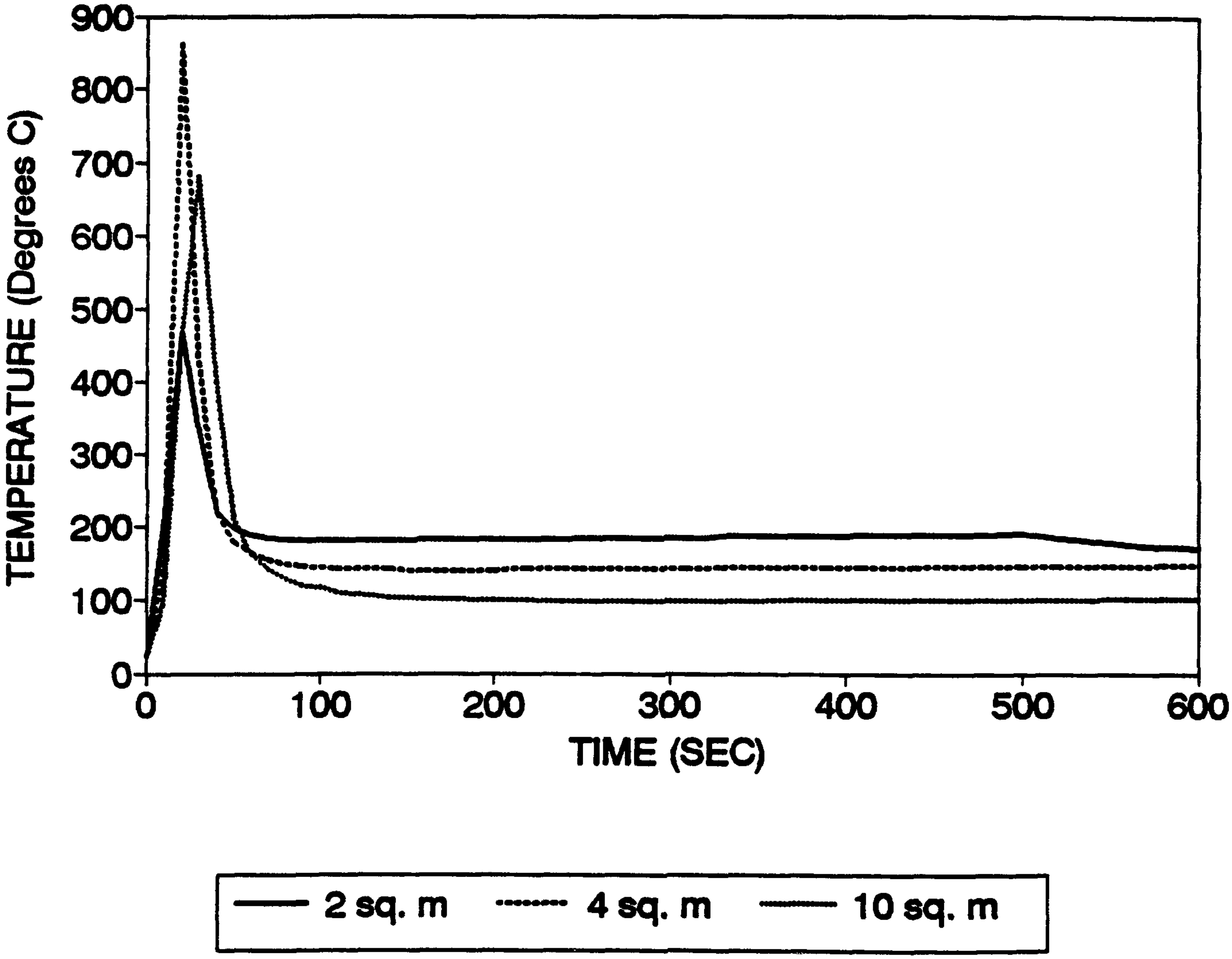

Figure 6. Calculated Smoke Layer Temperature in a Paint Locker with Closed Door but Open 0.1 m^2 Leakage Area Given a Serious Pool Fire

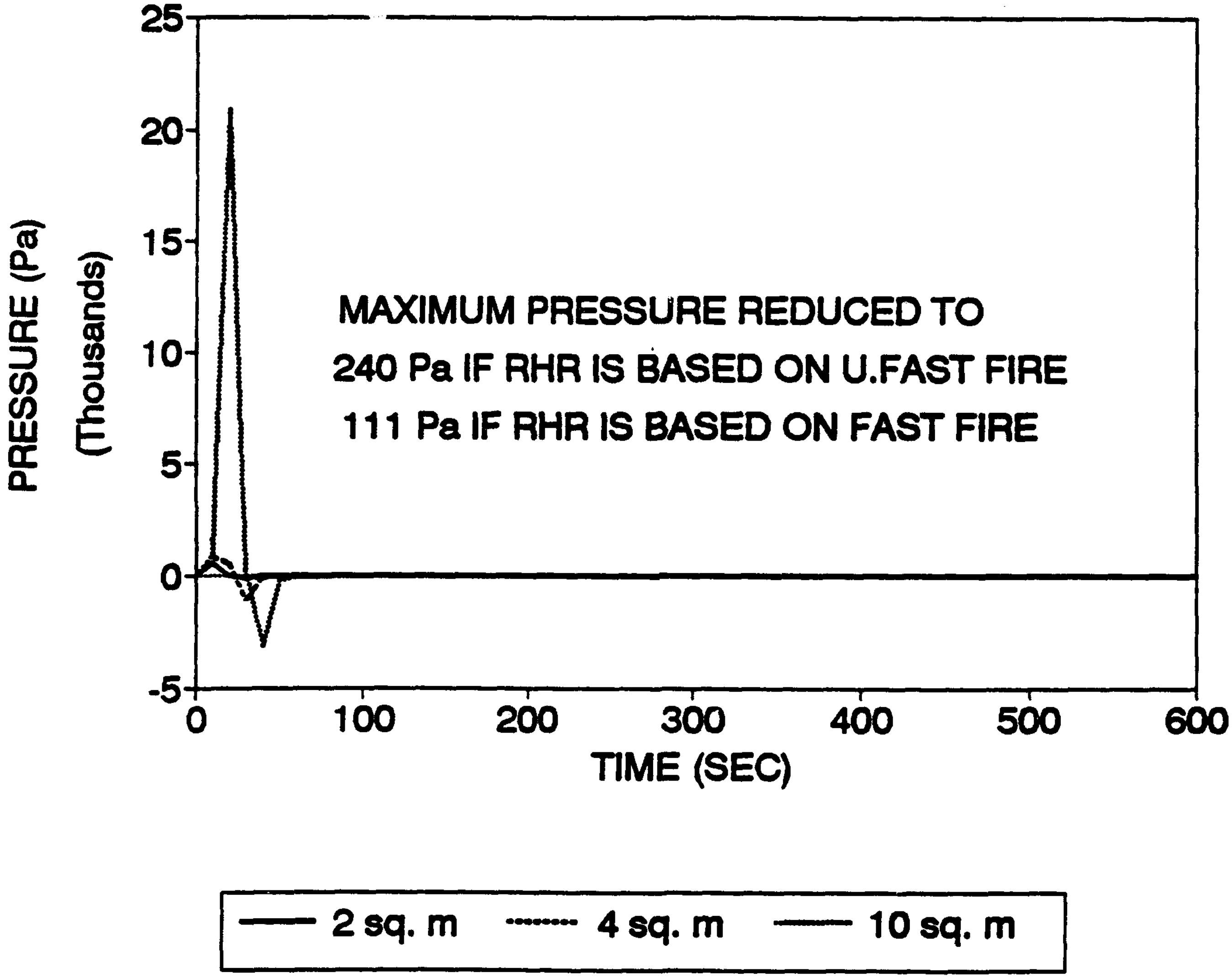

Figure 7. Calculated Pressure Conditions in a Paint Locker with Closed Door but Open 0.01 m^2 Leakage Area Given a Serious Pool Fire

The size of the pressure pulse is very sensitive to the rate of growth of the fire. If the rate of fire growth is reduced from the very rapid fire selected for this analysis to one that increases with the square of time at a rate that would produce 100 kW in 75 seconds (often referred to as an "ultra-fast" t-squared fire), the pressure peak would reduce 80 fold to approximately 240 Pa (0.03 psig). The relative growth rates involved are the Case 1, and U. Fast curves are shown in Figure 8.

7.4 Use of Modeling to Estimate Activation Time of Detection Devices in Paint Lockers

7.4.1 Model Used (Fire Simulator from FPETOOL)

The model Fire Simulator for the FPETOOL collection (Reference 8) was used to develop estimates of the time to activation and the fire conditions likely to be present at the time of detection or activation of an automatic suppression system. This model was used since it contains the features necessary to make the desired estimates.

7.4.2 Conditions Simulated

Since the response of detection devices is very sensitive to the specific characteristics of the early stages of fire development a series of fire descriptions were used. The base fire was the same as that discussed in paragraph 7.3.4 and shown in Figure 1. This is identified as Case 1 in Figure 2. In addition, two fire descriptions were developed based on the Case 1 fire differing only in time to reach peak level of 2700 kW. These are shown as Cases 2 and 3 in Figure 8. Finally, three fires varying in rate of energy release with the square of time (commonly referred to as "t-squared fires") were simulated. The three t-squared fires were based on fire curves that reached 1000 kW in 75, 300, and 600 seconds, respectively. These fires are often referred to as ultra fast, moderate, and slow fires. The plots of all six of these curves are shown in Figure 8.

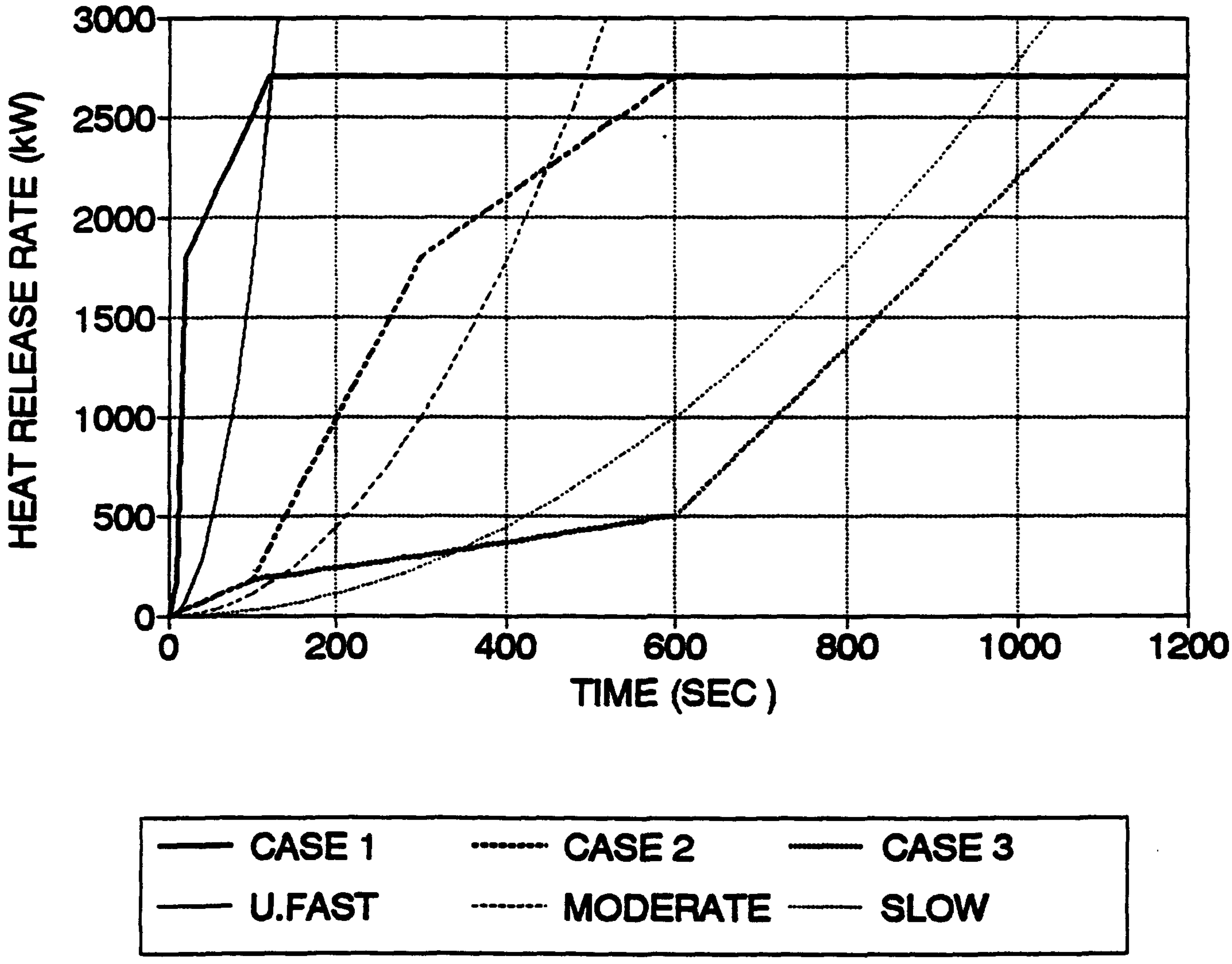

Figure 8. Comparison of the Rates of Heat Release of Various Fire Descriptions Used to Calculate Detector Response

7.4.3 Data Used to Describe Detectors

Fire Simulator was run to simulate both a 4 m^2 and 10 m^2 paint locker. In each instance, the heat detector was located 1.5 m (5 ft) laterally from the center of the fire. In the 4 m^2 locker, the smoke detector was located [illegible] (10 ft) laterally from the center of the fire. In the 10 m^2 locker, the smoke detector was located 4.2 m (14 ft) from the center of the fire. The heat detector was described as having a Response Time Index (RTI) of 28 $(m\text{-}s)^{.5}$ (50 $(ft\text{-}s)^{.5}$). This response is equivalent to modern quick response sprinkler heads. The smoke detector was simulated as a heat detector set to operate at 13°C (23°F) above ambient and having a RTI of zero. The results are shown in Table 6.

Table 6. Fire Simulator Evaluation of Detector Response

Response of smoke detectors located 3 m (10 ft) laterally from fire source and response of heat detectors located 1.5 m (5 ft) laterally from fire source in a 4 sq m steel locker with the door open. Heat detectors rated at 74°C with an RTI of 28 $(m\text{-}s)^{.5}$.

Fire Curve	Smoke Detection Time (sec)	Heat Detection Time (sec)	kW @ Heat Detection	kW 30s After Heat Detection	Flashover Time (sec)	kW @ Flashover
Case 1	13	15	940	>1400	18	1400
U. Fast	30	39	270	800	96	1650
Case 2	40	66	110	170	288	1620
Mod.	71	101	110	190	383	1630
Slow	122	167	80	110	676	1270
Case 3	40	66	110	170	895	1500

Table 6. Fire Simulator Evaluation of Detector Response (Continued)

Response of smoke detectors located 4.6 m (15 ft) laterally from fire source and response of heat detectors located 1.5 m (5 ft) laterally from fire source in a 10 sq m steel locker with the door open. Heat detectors rated at 74°C with an RTI of 28 $(m\text{-}s)^{.5}$.

Fire Curve	Smoke Detection Time (sec)	Heat Detection Time (sec)	kW @ Heat Detection	kW 30s After Heat Detection	Flashover Time (sec)	kW @ Flashover
Case 1	15	19	1640	>1700	25	1700
U. Fast	35	49	450	1150	116	2400
Case 2	50	91	160	350	449	2250
Mod.	84	125	180	300	449	2350
Slow	132	207	125	170	898	2400
Case 3	50	91	165	200	1078	2250

8.0 RADIATION FROM HOT BULKHEADS

8.1 Test Data

In the previously referenced Navy shipboard compartment tests (Reference 6), the effective radiation on targets was found to be approximately 0.6 times the blackbody radiation. This value accounts for both the emissivity of the hot wall and the absorption of radiation by smoke from burning paint and/or other factors.

8.2 Heat Transfer

To estimate the impact of the radiation initially, the configuration factor was developed based on the distance from the radiator and the length of the radiating wall. In all cases, the radiating wall was assumed to be 2.44 m (8 ft) high. The configuration factor was calculated using the equation in Appendix A of NFPA Standard 80A (Reference 9).

$$\phi = \frac{2}{\pi}\left[\frac{X}{\sqrt{X^2+Y^2}}\arctan\left(\frac{Z}{\sqrt{X^2+Y^2}}\right)+\frac{Z}{\sqrt{Y^2+Z^2}}\arctan\left(\frac{X}{\sqrt{Y^2+Z^2}}\right)\right] \quad (1)$$

where ϕ = Configuration Factor
X = half-length of rectangular radiating surface,
Y = half-height of rectangular radiating surface, and
Z = separation distance between radiator and receiving surface.

The temperature of the heated bulkhead was assumed to be 525°C as reported in the Navy tests (Reference 7). A blackbody having a temperature of 525°C radiates approximately 22.5 kW/m^2. Assuming an efficiency factor of 0.6 reduces the apparent radiant energy to 13.5 kW/m^2.

8.3 Impact

Most materials require an incident flux of at least 10 kW/m^2 for ignition, regardless of the time of exposure. This is usually referred to as the critical flux. Below that level, most materials will not ignite. The time it takes to ignite is also a function of the incident flux (Reference 10). For relatively dense materials such as wood planks, prompt ignition would normally require an incident flux of about 40 kW/m^2 (see Figure 9). Ordinary upholstered material is expected to promptly ignite at an incident flux of about 20 kW/m^2. Light materials such as curtaining will promptly ignite if the flux exceeds 10 kW/m^2.

For a 2.44 m (8 ft) high radiator, a critical ignition flux of 10 kW/m^2 would impact on exposed materials located within a distance of 0.2 and 0.5 m to the radiator, depending on the length of the radiator. The pain threshold (Reference 11) on bare human skin is reached at a radiant flux level of approximately 1.7 kW/m^2. Persons attempting to evacuate past a heated bulkhead or attempting to approach or

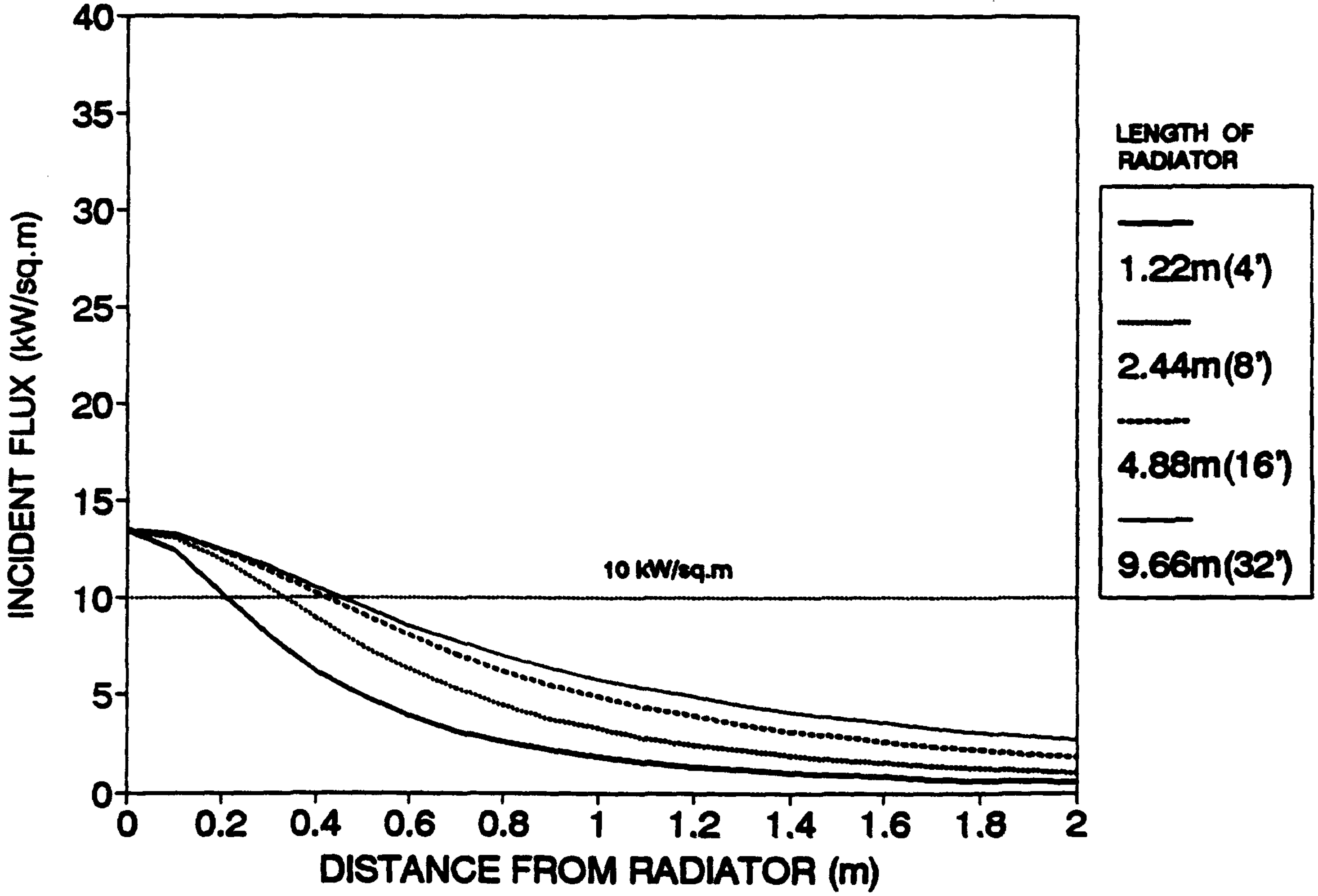

Figure 9. Ignition Level Radiation on Targets (Bulkhead Temperature = 525°C)

pass it for firefighting purposes would receive pain levels forcing their withdrawal if they were within 1-3 m of the wall depending on the length (see Figure 10). This could be a serious detriment to an exit path immediately adjacent to an uninsulated paint locker wall or if the arrangement was such that it was necessary to come in close proximity with such a wall in order to activate the suppression system, close the vents, or perform direct firefighting actions.

The level of radiation is directly affected by the temperature of the exposing wall. Radiation intensity increases to the 4th power of the increase in absolute temperature. If the assumed temperature of the exposing wall is raised to 675°C (the maximum observed in Reference 6), the minimum distances required to avoid dangerous flux levels will increase. Figures 11 and 12 illustrate the resulting affect of assuming the higher bulkhead temperature.

9.0 EXPLOSIVE DEFLAGRATION

9.1 Potential Pressure Rise

In order to create a deflagration, both an explosive atmosphere and an ignition source must be present, concurrently. The possibility of developing such a condition inside a paint locker is felt to be extremely low, but not impossible. In order to appraise the impact of such an occurrence, the equation proposed for low strength enclosures as presented by Zalosh (Reference 12) was used to gain an order of magnitude estimate of the potential impact of a deflagration of a combustible vapor mixture. For purposes of the analysis it was assumed that the optimum vapor concentration exists within the explosive limits and was distributed, e.g., well mixed, filling the entire paint locker.

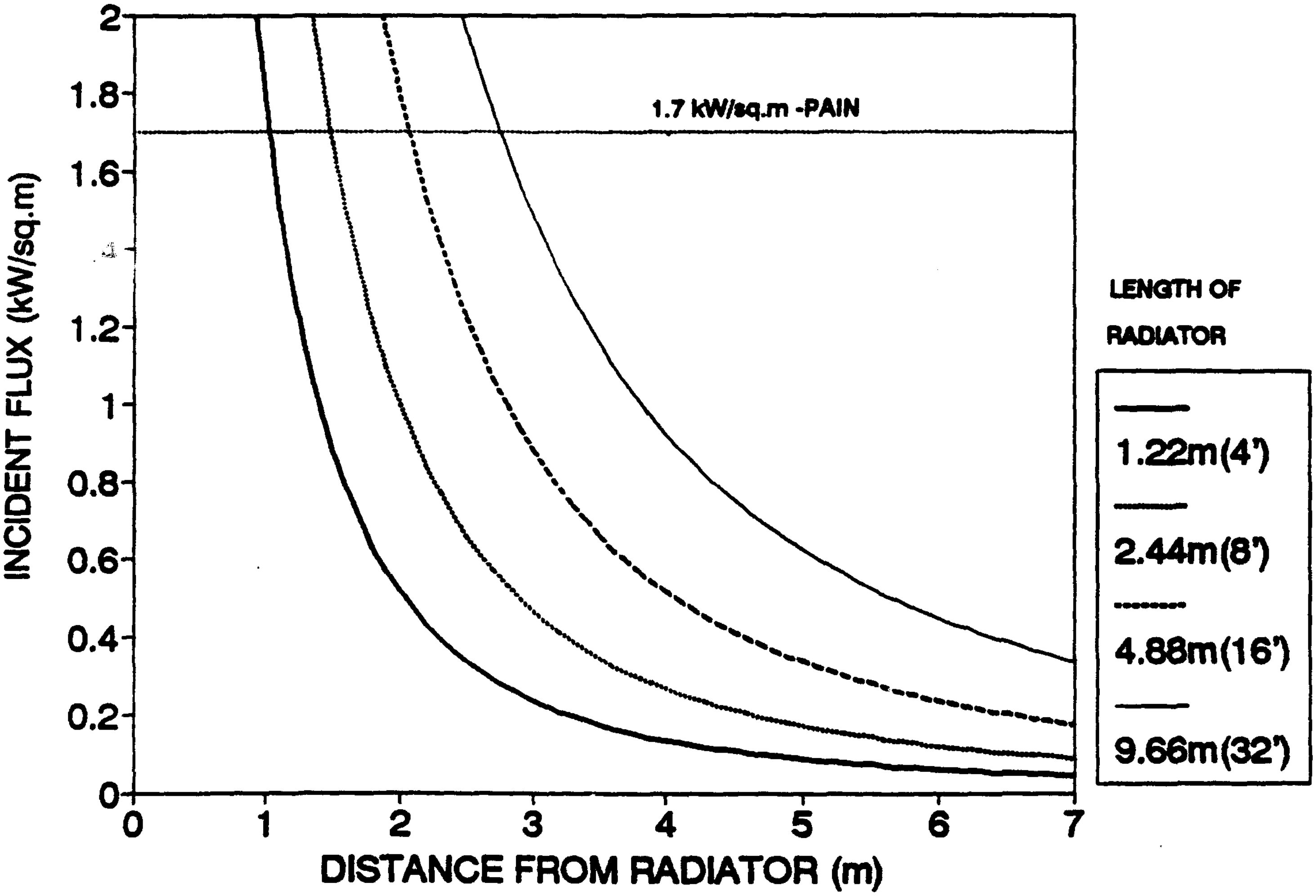

Figure 10. Painful Radiation Range (Bulkhead Temperature = 525°C)

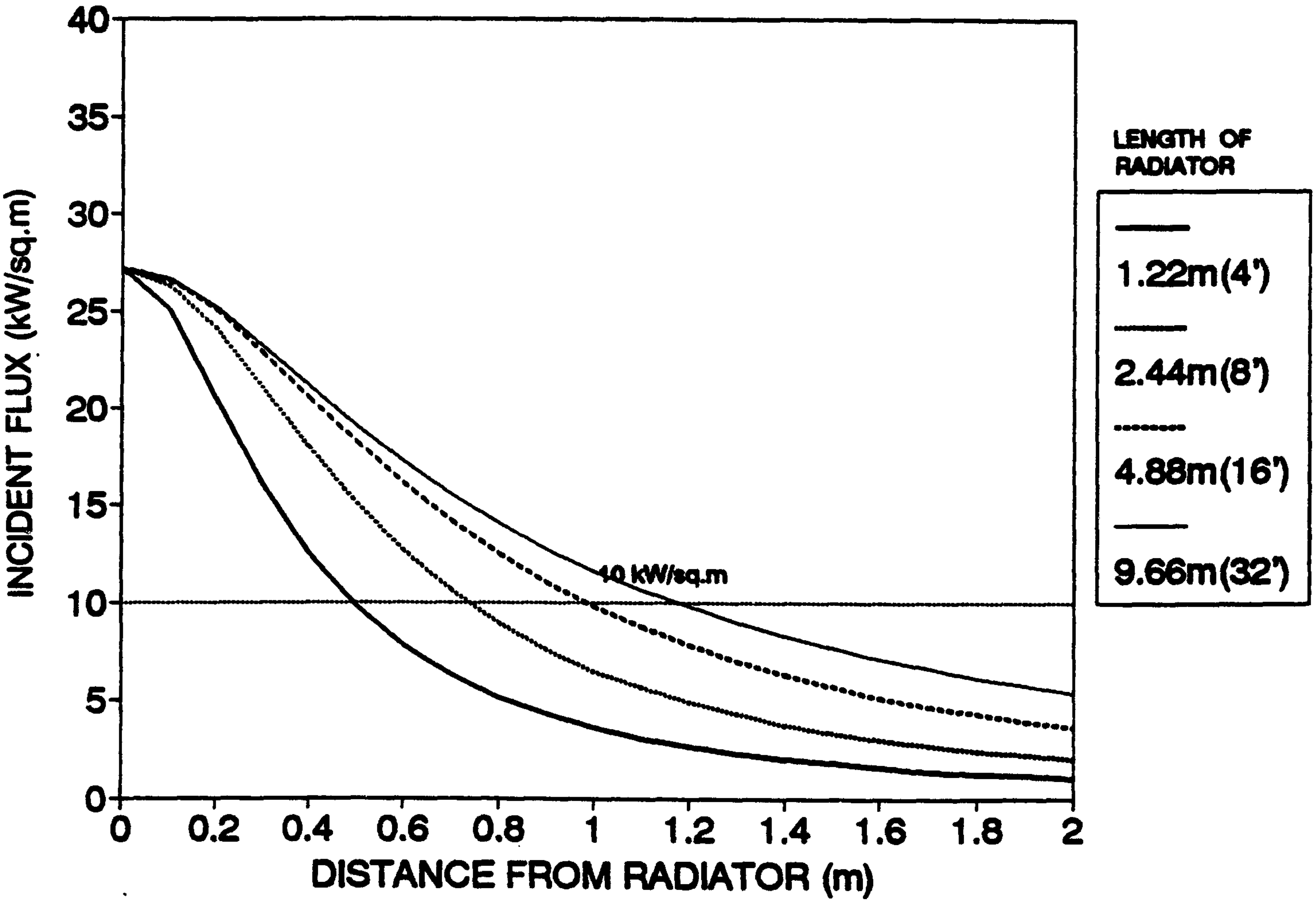

Figure 11. Ignition Level Radiation on Targets (Bulkhead Temperature = 675°C)

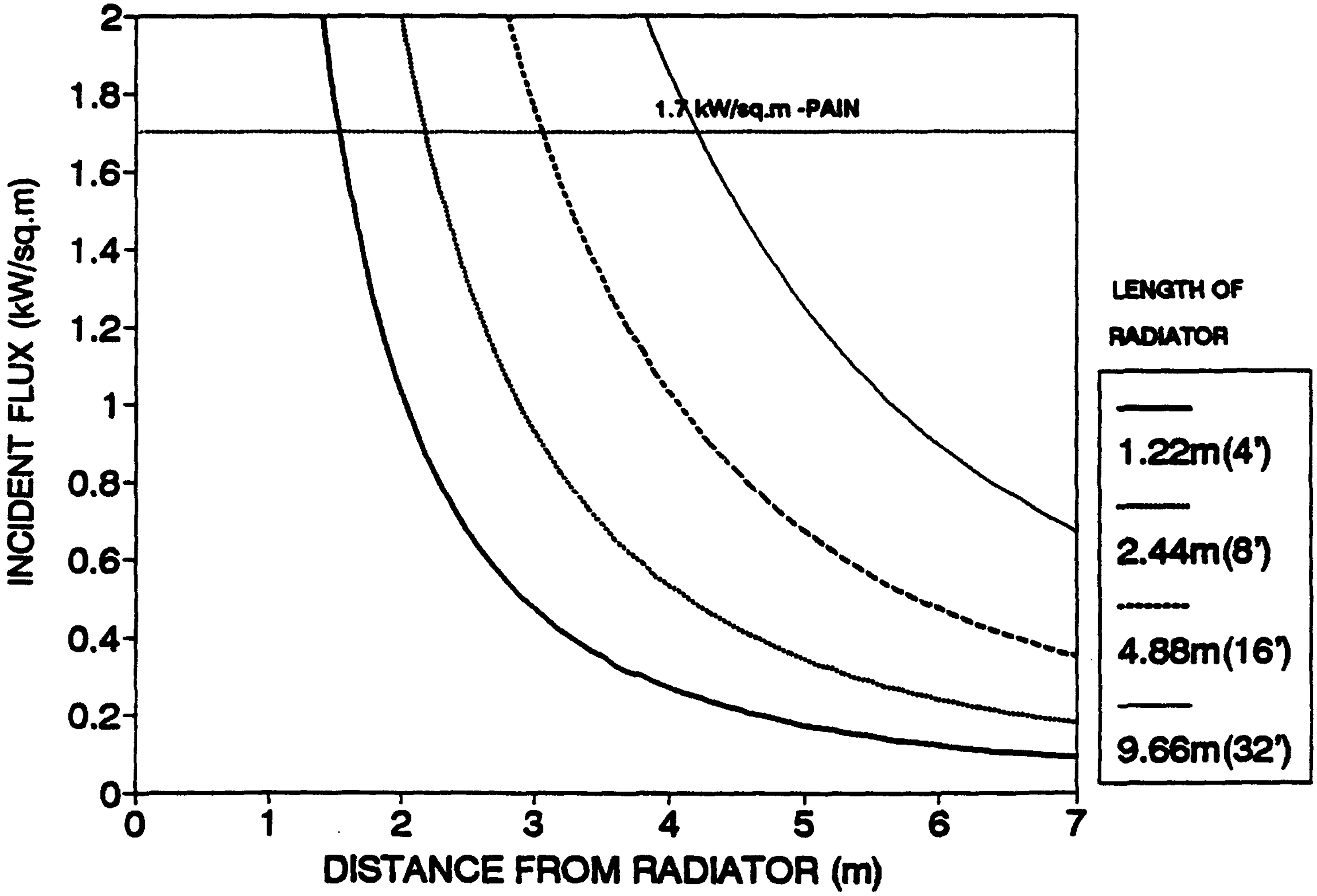

Figure 12. Painful Radiation Range (Bulkhead Temperature = 675°C)

The equation is as follows:

$$A_V = \frac{C\,A_S}{P_{RED}^{\,½}}\ ; \quad P_{RED} = \left[\frac{C\,A_S}{A_V}\right]^2 \qquad (2)$$

where A_V = vent area,
C = fuel characteristic constant,
A_S = internal surface of enclosure, and
P_{RED} = overpressure damage threshold.

For these calculations, the value of C was taken as 0.4 $kPa^{½}$. It was also assumed that the peak temperature (adiabatic constant-pressure explosion temperature) would be a maximum of 2400 K. Since this value is approximately eight times the room temperature, all of the calculations were assumed to have peaked if they indicated a rise in pressure of 8 atm or more.

Zalosh limits the application of this equation to pressures less than approximately 3.6 kPa (12.5 psig), i.e., slightly less than 1 atm. As shown in Figure 13, the pressure developed increases as the paint locker size increases. This reflects the assumption inherent in equation (2) that the entire volume of the locker is in the explosive range and therefore increased paint locker size increases the amount of fuel vapor that deflagrates, releasing energy.

9.2 Explosion Vent Area Needed to Minimize Pressure to 8 kPa (1 psig)

Since it is doubtful that the construction of most paint lockers could sustain a pressure over about 8 kPa (1 psig), a second evaluation was made of the minimum vent area size that would be necessary to maintain the pressure below the 8 kPa level. For the three sizes of the paint lockers considered in the previous analysis (2, 4, and 10 m^2), the vent areas that would be needed to maintain the pressure below 8 kPa would be 2.6 m^2, 4 m^2, and 7.7 m^2 respectively. These all assume a paint locker

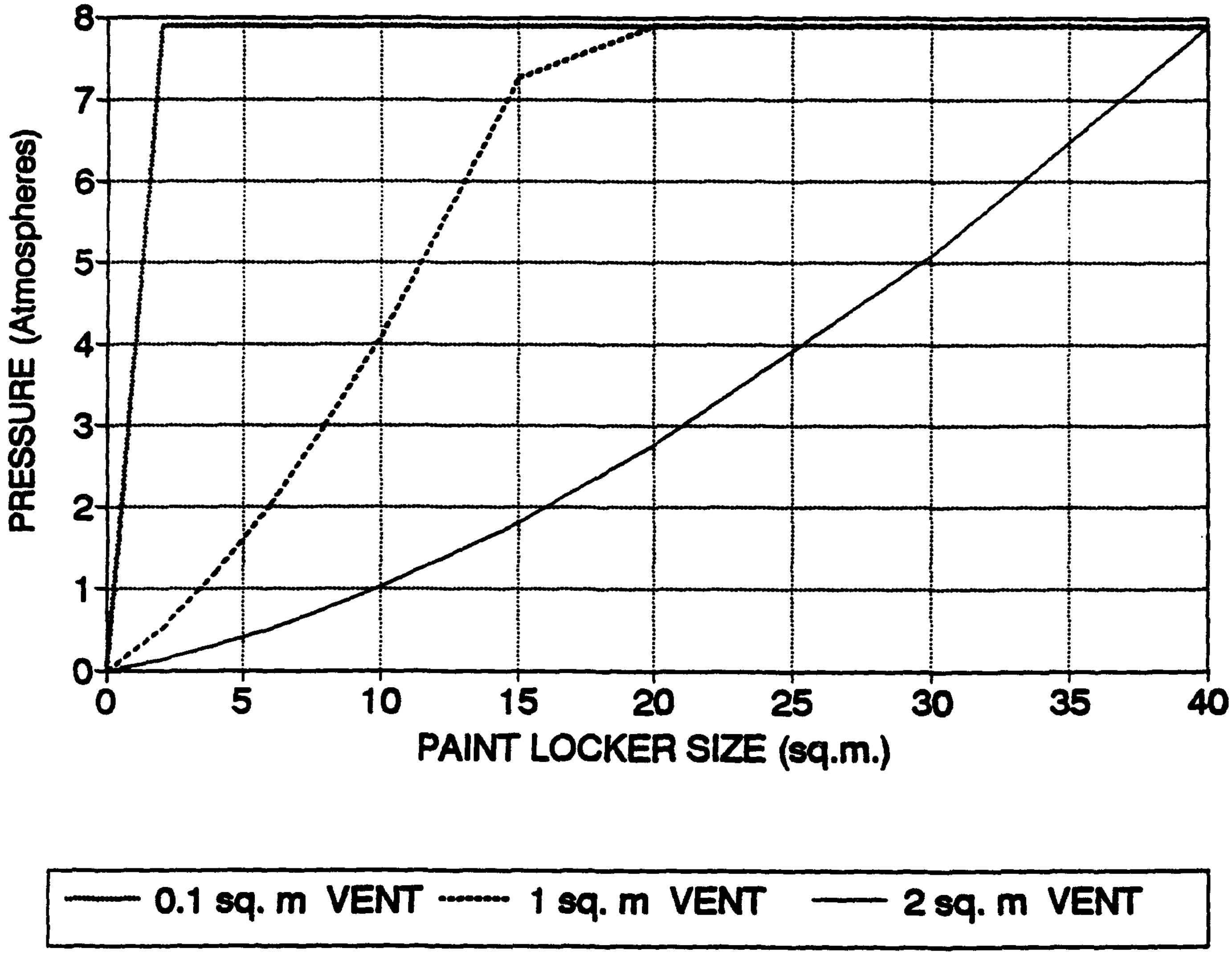

Figure 13. Deflagration of Combustible Vapors (Assumes Entire Space is within Explosive Limits)

2.4 m high and square in shape. The practicality of being able to provide such vent areas is remote. However, the potential of developing such pressures, even under remote circumstances, emphasizes the importance of maintaining explosion proof equipment, thereby avoiding the primary source of a potential ignition in a closed paint locker.

10.0 CONSEQUENCE ANALYSIS

10.1 Flashover Assumption

A basic assumption in this analysis is that there are no unacceptable consequences from a fire unless that fire produces flashover in the paint locker.

An initial consequence analysis was made to estimate the potential impact if the fire is not suppressed by either fixed or manual equipment and flashover occurs. Figure 14 is a pictorial representation of the configurations paint locker considered for this analysis. Table 7 is a matrix depicting the probable consequences given flashover under the four different configurations.

10.2 Situations of Concern

(a) Situation 1 is a paint locker that opens onto a weather deck, and there are no internal exposures that could be damaged or ignited due to the temperature rise of the paint locker bulkheads.

(b) Situation 2 is a paint locker that opens onto a weather deck and has thermally resistant bulkheads capable of preventing the rise in temperature to ignition levels through the course of any fire.

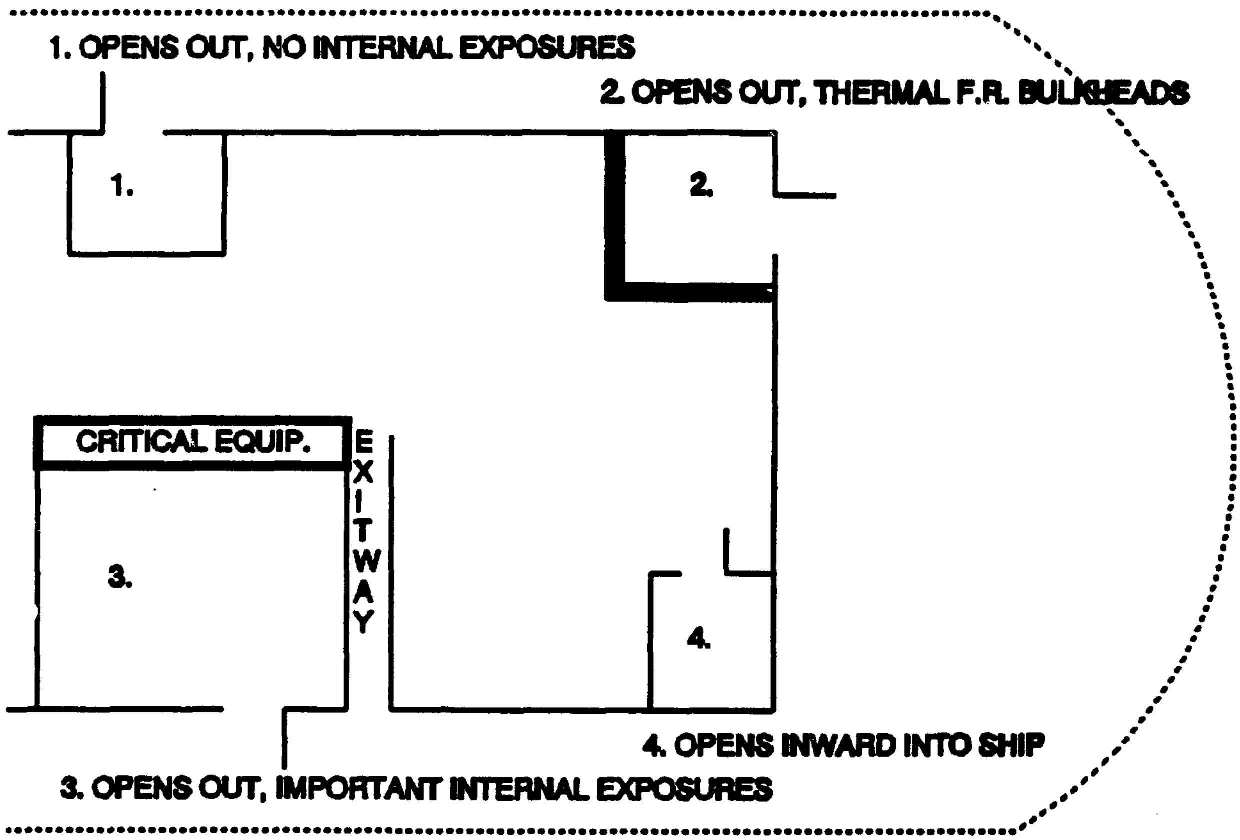

Figure 14. Paint Locker Fire Consequence Situations

Table 7. Analysis of Situation Versus Consequences - Given Flashover

		1. Opens Out No Internal Exposures	2. Opens Out Thermal Fire Resit. Bulkheads	3. Opens Out Important Internal Exposures	4. Opens Inward Into Ship
Consequences	A. Mass of High Temp. Flame &/Or Toxic Gases Vent Into Vessel				X
	B. High Temp. Bulkheads Burns Paint Off Walls. Radiation Can Ignite Combustibles Or Harm Humans.			X	X' ' Harm Limited To Extent That Bulkheads Transmit Heat and Items Are In Position To Be Harmed.
	C. Flame Vented Through Door and Radiation From Flame Impacts on Deck Items.	X^ ^ Impacts Only To Extent That Deck Items Are Vulnerable And In The Zone Of Flame Or Radiation Impact	X^ ^ Impacts Only To Extent That Deck Items Are Vulnerable And In The Zone Of Flame Or Radiation Impact	X^ ^ Impacts Only To Extent That Deck Items Are Vulnerable And In The Zone Of Flame Or Radiation Impact	

(c) Situation 3 is a paint locker that opens externally onto a weather deck but where there is no thermal insulation in the bulkheads and there are important exposures to critical equipment, dangerous storage, or emergency exit passageways close enough to be ignited or otherwise detrimentally affected by temperature rise in the bulkheads.

(d) Situation 4 is a paint locker whose door opens inward into the vessel and any flashover flame would be expelled into the vessel itself.

10.3 Expected Consequences

The classes of consequences were then postulated as follows:

(a) Consequence A – A mass of high temperature flame and/or highly toxic gases vent into the vessel. This consequence would be expected under condition 4 and is potentially the most serious of the fire consequences.

(b) Consequence B – The temperature of the bulkheads rises to a range as high as 500-650°C. Any paint on the bulkheads is burned off causing smoke and other problems on the vessel side of the bulkhead. Material in contact with the bulkhead or close enough to be ignited by radiation can ignite. Painful levels of radiation can also occur that can prevent passage close to the hot bulkhead, restrict approaching the bulkhead in the process of firefighting attempts, or produce harm to persons who cannot escape the radiation.

(c) Consequence C – Flames vented from the door of a flashed over space and radiation from that flame impacts on deck items. This consequence applies to situations 1, 2, and 3 where the venting is external and the impact is only to the extent that the deck items are vulnerable and in the zone of flame or radiation impact.

10.4 Explosion Consequences

If a vapor deflagration type of explosion occurs in a paint locker and produces sufficient force to disrupt that locker, physical damage to the area of the ship, disruption and disablement of any suppression system, and an ensuing fire are likely. If an explosion occurs and is successfully vented without serious disruption, as through an open door, it is likely that a fire will ensue and, depending on the fuels, will probably reach flashover conditions. In this case, the situation becomes the same as if flashover were reached in some other course. The consequences are the same as those from any other flashed over fire.

If the explosion is of a sufficiently low pressure that the paint locker contains the explosion and no large vent area is opened, it is probable that the fire will decrease as described under the fire analysis for limited vent opening situations.

11.0 SUPPRESSION SYSTEM INTERVENTION TO PREVENT OR SUPPRESS FLASHOVER

11.1 Concept

An analysis was made of the potential for installed extinguishing systems to prevent flashover. It was concluded that the ability of an installed fire suppression system is a function not only of the suppression system itself, but of the position of the door at the time of fire initiation, any detection and alarm equipment installed in the paint locker, any activity to change the position of the door (open a closed door or close an opened door), and the installed system itself.

11.2 Fire Input Analysis

A decision tree titled, *Fire Impact Analysis Tree*, presenting all of the options and relating it to 11 different arrangements of suppression systems covering the scope of all of the elements in the proposals to be presented to SOLAS was developed. Figure 15 shows the layout of the tree. The complete tree is included as Appendix B. The elements of the decision tree are individually discussed in the following paragraphs. The abbreviations in parenthesis in the title lines of the following paragraphs match those in Figure 15 and Appendix B.

11.2.1 Fire Growth Rate

The decision tree addresses smoldering or flaming fires. It does not address explosive deflagrations (explosive deflagration is separately analyzed in Section 9.0 and paragraph 10.4). With this limitation, the Fire Growth Rate branch opens the tree by dividing the analysis into two components:

a. No Flashover Potential. Many fire incidents are so restricted in potential energy release that flashover will not happen even if the incident occurs with the paint locker door open, is undiscovered and no suppression action occurs. Examples range from smoldering rags remote from any other fuel to fire in open containers of flammable liquids that do not in themselves produce enough energy to generate flashover and are in positions where the flame and heat produced does not cause the involvement of other materials in the fire. Since all such cases are by definition incapable of causing flashover. This branch of the tree is not further developed and all courses through this branch are assigned a flashover potential of zero (0).

b. Flashover Potential. A portion of fire incidents will by the nature of the fuel condition (e.g., spill, cascading fluid from a leak or rupture) and the

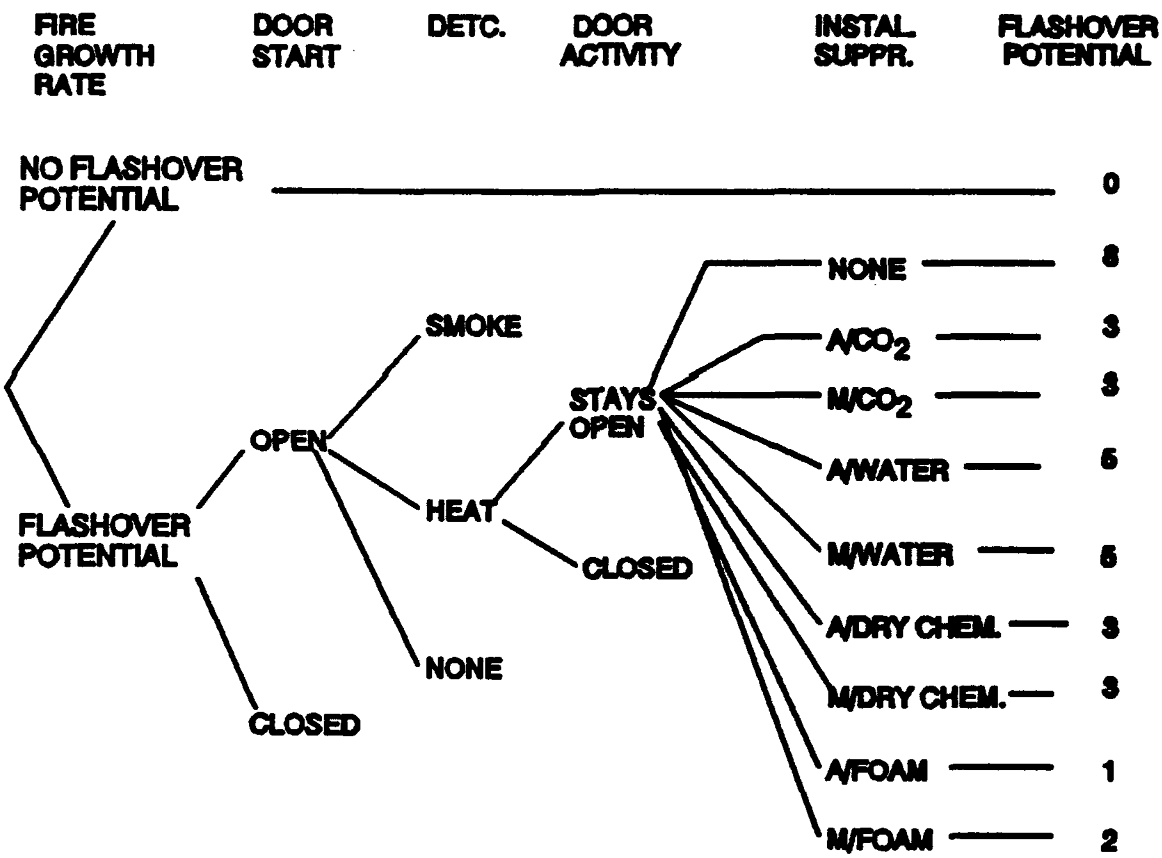

Figure 15. Fire Impact Analysis Tree

amount have the potential of flashover unless the process is constrained by oxygen limitation or suppressed using either a system installed in the paint locker or manual use of the ship's fire suppression capabilities (e.g., fire extinguishes, water hose streams, manually applied foam). It is these incidents that are further analyzed in the decision tree.

11.2.2 Position of Paint Locker Door at Start of Fire Incident (DOOR START)

As discussed in Section 7.0, the position of the door (open or closed) has a critical impact on the development of fire in a paint locker. The tree divides the door position into two factors. This factor addresses the position at the moment of fire initiation. A latter element (see 11.2.4, below) addresses the potential that the door position will change during the course of the fire and fire attack efforts; the analysis considers only the two cases of open or closed. It does not address the situation of a door partially open or ajar. For purposes of analysis, it is assumed that door is either tightly closed or it sufficiently open to allow enough air flow into the paint locker to permit and sustain flashover.

11.2.3 Detection System Within The Paint Locker (DETC)

The impact c letection is analyzed in this element in terms of giving warning that can result in faster response of the crew to take emergency actions such as closing the paint locker door, actuating manually initiated fixed suppression systems, or attacking the fire with fire extinguishes, hose steams or other available fire attack. The impact of detection as an activator of any automatic installed fire suppression system is separately considered as discussed in 11.2.5.

11.2.4 Opening or Closing of the Paint Locker Door during the Course of the Fire (DOOR ACTIVITY)

The opening of a closed paint locker door during the course of a fire may be done to facilitate fire attack, to investigate the condition or for other reasons. If the fire has flashover potentials and is not fully extinguished at the time the door is opened, it can rapidly grow to conditions similar to that which would have occurred if the door had been open at the start of the fire. Whether or not such rapid growth occurs is a function of the availability of exposed flammable or heated combustible liquids in the locker and the presence of absence of a flame or other hot source, such as embers, to ignite the available fuel.

Conversely, the closing of an open paint locker door after ignition, or even flashover, will close off the prime source of air for combustion and confine the source paint locker fire to the paint locker. The closing of the door will also reduce the resulting temperature in the paint locker to levels in the range of those discussed for closed door situations in Section 7.0. If the paint locker has flashed over prior to the closing of the door, there may be ignitions in the area external to the paint locker which will have to be separately suppressed and may be minor or serious as a function of the type, location, and amount of fuel then available in the involved area.

11.2.5 Fixed (Installed) Fire Suppression System in the Paint Locker (INSTAL.SUPPR)

The final branch of the tree divides the analysis by the type of installed suppression system in the paint locker. The suppression systems considered are as follows:

a. None. The paint locker is evaluated by this branch if there is no installed suppression system in the locker. Fire extinguishers or fire hose stations are not considered as fixed fire suppression systems but are expected to be reasonably available for attacking a fire in the paint locker.

b. Automatic Carbon Dioxide Suppression System (A/CO_2). Automatic carbon dioxide systems are systems that have sufficient carbon dioxide to result in a 40% carbon dioxide concentration in the paint locker assuming no leakage from the paint locker. The system is actuated by a heat detection system in the paint locker. It is expected that the activation of the system will automatically shut off any exhaust fans for the paint locker and close dampers in any powered or gravity vents. It is not expected in this analysis that the operation of the system will close the paint locker door, should it be open. It is expected that the activation of the system will involve a safety delay of at least 30 seconds between the detection of fire and the initiation of carbon dioxide discharge. Automatic systems also have facilities for manual activation of the system.

c. Manual Carbon Dioxide Suppression System (M/CO_2). Manual carbon dioxide systems have the same carbon dioxide flooding capabilities as automatic systems but are without automatic operation features. The shutting down of vent fans and closing of gravity vents as well as closing of the paint locker door may also depend on manual actions by the responding members of the crew.

d. Automatic Water System (A/WATER). Automatic water systems include automatic sprinkler systems, deluge sprinkler systems, or other similar systems that upon heat detection will discharge water delivering 5 L/m^2-min. (0.12 gpm/ft^2). The design and water capacity being sufficient to deliver the required density over the entire paint locker. The heat detector may be in the form of an automatic sprinkler head or (for a deluge system) separate heat detectors arranged to trip the deluge valve.

e. Manual Water System (M/WATER). Manual water systems are normally open head (deluge) systems that may be attached to a water supply system and operated by opening a valve or may depend on connection of a hose from the ship's fire main system to an inlet fitting on the water system to provide the suppression system with a water supply. For the purposes of this analysis, it is assumed that the system, when activated, will deliver 5 L/m^2-min. (0.12 gpm/ft^2) over the entire area of the paint locker.

f. Automatic Dry Chemical System (A/DRY CHEM.). Automatic dry chemical systems dispense fire suppressing dry chemical at concentration of 0.5 kg/m^3 (0.03 lb/ft^3) inside the paint locker. The system is activated by a heat detection system within the paint locker.

g. Manual Dry Chemical System (M/DRY CHEM.). Manual dry chemical systems dispense dry chemicals at the same rate as automatic dry chemical systems but are actuated by manual action.

h. Automatic Foam System (A/FOAM). Automatic foam system is a broad class including both AFFF and protein based foam systems. The means of activation is a heat detection system, and there is an automatic system to generate and discharge the foam.

i. Manual Foam System (M/FOAM). Manual foam systems include both preset systems similar to automatic foam systems except that the system is initiated by manual means and systems where the set-up and feeding of foam components to the generator is by manual means.

11.2.6 Relative Likelihood of Flashover (FLASHOVER POTENTIAL)

The values entered for those branches of the tree that start with "FLASHOVER POTENTIAL" represent the judgement of the authors of the relative likelihood that the intervention potential in the factors related to compartmentation and oxygen starvation, early detection, and suppression will not prevent flashover. In this analysis, flashover potential was rated on a scale of zero to ten, with zero rated as virtually no possibility of flashover and ten as a virtual certainty of flashover.

11.3 Impact of Paint Locker Door that is Closed through the Course of a Fire

Based on the prior analysis, all of those situations where the door is closed at the start of the fire and kept closed through its course or until such time that it is clear that the fire is suppressed are assigned a value of zero (virtually no potential of flashover).

If the door to a paint locker is equipped with an automatic closing device operated by a smoke or heat detector (including a fusible link) or by the operation of an installed automatic suppression system in the paint locker, that paint locker can be considered as virtually equivalent to a paint locker where the door is closed throughout the fire, subject to the reliability of the closing device system.

11.4 Impact of Closing the Paint Locker Door during the Course of a Fire

In those situations where the door is open at the start of the fire but later closed, flashover potential is indicated. In this case, however, once the door is closed, it is expected that further damage will be confined to the inside of the paint locker. Ignitions that occurred outside the paint locker prior to the closing of the door will however continue.

11.5 Impact of Opening Closed Paint Locker Door during a Fire

When a paint locker door is closed at the start of a fire but later opened, the resulting potential of flashover is a consideration of the potential of the fire to rekindle or for accumulated unburned hydrocarbons to produce a flare-up or backdraft explosion. In this case, the potential for flashover is a function of how long the crew keeps the door closed. The assigned values are indicative of situations were the door is open for investigation as soon as the crew or firefighting team arrives.

11.6 Impact in Case of No Installed Protection Devices

There are no cases where flashover was assumed to be a virtual certainty. Even where there are no fire protection systems and no detection, there is a potential that the fire will occur in the presence of a member of the crew and be extinguished with fire extinguishers or hose streams. This potential is more than casual due to the likelihood that the person discovering the fire will in some manner be intently involved in its ignition. For this reason, the highest relative value for flashover potential assigned was eight.

11.7 Rational for Rankings Assigned to Different Types of Suppression Systems

(a) Foam Systems, based on the literature (Reference 13), were ranked as having the highest potential in preventing flashover. This is based on the ability of foam systems to attack both an incipient and an advanced fire, and the lack of potential loss of agent through an open door. A key limitation of foam systems is that while the foam agent is excellent for a pool fire on the deck, it will have little effect on fire cascading towards the deck from ruptured containers. This evaluation however does not include an appraisal of any problems of installing or maintaining such a system.

(b) Carbon dioxide and dry chemical systems, manual and automatic carbon dioxide and manual and automatic dry chemical systems, are for the most part given relatively high ratings. Each however has a failure mode. In the case of the automatic system (except in the situation where the door is closed at the time of operation), it is possible for the system to expend the agent without extinguishing the fire. In the case of a carbon dioxide system, it is possible that some carbon dioxide will collect in the bottom of the paint locker due to the existence of lower door. The potential for this, and its impact on fire control, is not realistically known and can be evaluated only with tests.

In the case of the manual system, failure would occur if the system were operated with the door open. This may occur if the system is operated with the door open by a responding crew member or because fire conditions make it impossible to close the paint locker door. If the agent is discharged and the fire is not extinguished, its potential effect is lost.

(c) Water systems are given the poorest rating of all the suppression systems; however, they are still given a reasonable potential of preventing flashover. While such systems will not extinguish a pool fire, they do provide cooling and can extinguish the many exposure fires that can lead to pool fires, cool the temperatures sufficiently in some cases to prevent flashover, and often cool containers sufficiently to prevent their rupture and entry of their contents into the fire. If a water system can cool a situation sufficiently to allow the paint locker door to be closed, this will result in a rapid reduction in temperature and the potential for further harm will be significantly reduced.

The results of this analysis are summarized and grouped by the position of the door at the start of the incident and any changes in that position during the fire in Tables 8 through 11.

12.0 CONCLUSIONS

1. Fires in paint lockers that do not produce flashover or a vapor gas explosion will most likely be controllable by the crew. Such fires are not expected to endanger the ship, its cargo, or its passengers.

Table 8. Flashover Potential with Door Open Throughout Fire

Installed Suppression System	Installed Detection System Smoke	 Heat	 None
Automatic or Manual Foam	1	1-Auto 2-Manual	1-Auto 2-Manual
Automatic of Manual CO_2 or Dry Chemical	2	3	3
Automatic or Manual Water Sprinkler or Spray Systems	4	3	3
None	7	8	8

Table 9. Flashover Potential with Door Opened at the Start of Fire but Later Closed

Installed Suppression System	Installed Detection System Smoke	 Heat	 None
Automatic or Manual Foam	1	1	1
Automatic of Manual CO_2 or Dry Chemical	2	3-Auto 2-Manual	3-Auto 2-Manual
Automatic or Manual Water Sprinkler or Spray Systems	4	4	4
None	5	6	6

Table 10. Flashover Potential with Door Closed at the Start of Fire but Later Opened

Installed Suppression System	Installed Detection System Smoke	 Heat	 None
Automatic or Manual Foam	1	2	2
Automatic of Manual CO_2	1-Auto 2-Manual	2-Auto 3-Manual	2-Auto 3-Manual
Automatic or Manual Water Sprinkler or Spray Systems	2	3	3
None	3	4	4

Table 11. Flashover Potential with Door Closed Throughout Fire

Installed Suppression Systems	Installed Detection System		
	Smoke	Heat	None
Automatic or Manual Foam	0	0	0
Automatic or Manual CO_2 or Dry Chemical	0	0	0
Automatic or Manual Water Sprinkler or Spray Systems	0	0	0
None	0	0	0

2. While the likelihood of flashover is low, the potential exists in many paint lockers. The primary sources of fuel capable of initiating a fire that progresses to flashover are low flash point thinners, gasoline, or other highly volatile materials stored within the paint locker. Normally, this is a small percentage of the material in the paint locker, but often sufficient to provide the energy source to involve the higher flash point combustible liquids into the fire.

3. To a modest degree, it is reasonable to assume that the smaller the size of a paint locker the higher the probability of reaching flashover from a fire.

4. Any fire in a paint locker that starts with the door closed can reach major proportions (flashover) only if the door to the paint locker is opened and the fire then rapidly grows to major proportions that prevent both manual extinguishment and reclosing of the door. The critical element in the scenario is the condition in the paint locker when the door is open. If the door is kept closed until the paint locker cools, the possibility of re-ignition or regrowth of an ongoing fire is extremely low.

5. Items exposed to flashover generated flames and gases that vent from the open door of a paint locker door are appropriate determinants of potential danger and damage that can remain after a previously open paint locker door is closed.

6. The greatest danger potential exists with lockers where the paint locker door opens to the interior of the ship, the specific level of danger depending on the exact location and exposures involved.

7. All suppression systems have failure modes that can allow flashover even if the system operates exactly as intended and designed.

8. Paint lockers are not designed to handle the pressure build-up potential in the worst case deflagration explosion of a paint locker filled with combustible vapors in the explosive range.

9. The presence of smoke detection increases the potential for detection of fire at the earliest stages of development, allowing manual attack prior to the development of serious conditions. The ability to prevent flashover where the locker door is open, however, depends upon the speed of fire development and the speed of response and the actions taken upon response to the fire. If smoke detectors are used, it is necessary that the installation meet the electrical explosion prevention requirements.

10. If a flashed over fire persists, the interior surface of the bulkhead will become very hot. If the bulkhead is not thermally insulated, the temperature of the exterior, unexposed surface will lag the temperature of the interior surface by only 50-100°C. The temperature in such cases is expected to be high enough to burn the paint on the bulkhead and ignite materials in close proximity to that bulkhead. The radiation can present a serious problem, preventing passage within 2-3 m of the

bulkhead depending on size of the bulkhead and the actual fire temperature.

13.0 RECOMMENDATIONS

1. Analysis of relatively severe fire potentials in paint lockers which are not opened or vented indicates that limited damage or risk to life safety exists if the lockers remain closed. However, this inherent level of safety is lessened significantly due to the use of manual closing doors that do not automatically latch when closed. Consideration should be given to requiring automatic closing doors, triggered to close prior to flashover and/or with the operation of the installed fire protection system. Triggering devices separated from installed fire protection systems could be smoke or heat activated.

2. If automatic doors are provided, installed fire protection systems should be automatic in operation.

3. A study should be made to develop the best means of ventilating paint lockers to avoid the accumulation of a flammable vapor mixture capable of a deflagration type of explosion.

4. The IACS proposal to exempt all paint lockers, regardless of location or door position, that are less than 4 m^2 from requirements for an installed suppression system cannot be supported based on the analysis performed in this study, and therefore should not be accepted. Such small paint lockers have the potential of flashover and enough fuel to sustain the post-flashover conditions for sufficient time to cause serious damage or injury if the locker door vents into the ship or the locker otherwise exposes critical spaces or exit routes.

5. Conversely, while it is desirable to provide suppression systems in all paint lockers, the IACS proposal to exempt paint lockers less than 10 m^2 under

certain conditions is reasonable provided it is clear that such lockers open onto a weather deck and the potential vented flame and heated walls will present no serious harm to passengers, crew, equipment, or cargo and will not initiate a serious fire external to the paint locker.

6. All of the suppression systems proposed have merit as well as limitations. It is recommended that the SOLAS requirements remain flexible to permit alternative systems.

7. The proposed water application rate (IACS Proposal) of 5 L/m^2 (0.12 gpm/ft^2) is much less than the rates required for shoreside facilities. With the advent of plastic containers for flammable and combustible liquids, the challenge to water type suppression will be greater. A program of tests and investigations should be undertaken to develop the proper required discharge density for paint lockers.

14.0 REFERENCES

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Appendix A

SUMMARY OF CODES AND STANDARDS' QUANTITIES (GALLONS) OF FLAMMABLE AND COMBUSTIBLE LIQUIDS IN INSIDE STORAGE ROOMS

Code	Class of Liquid IA	IB	IC	II	III
• NFPA 30 (4-4.1.4)					
500SF; Sprinklers; 2 hr. Construction	<—— 5000 ——> (all classes)				
500SF; No Sprinklers; 2 hr. Construction	(660)**	(1375)**			
	<—— 2000 ——> (all classes)				
150SF; Sprinklers; 1 hr. Construction	<—— 750 ——> (all classes)				
150SF; No Sprinklers; 1 hr. Construction	<—— 300 ——> (all classes)				
• BOCA National Fire Prevention Code (F3201.1)	References NFPA 30 for matters not covered in the code				
• SBCCI Standard Fire Prevention Code (Table 904.6)	Quantities same as NFPA 30 without the footnote				
• ICBO Uniform Fire Code (79.203)+					
Ground Floor Pallets or solid pile, sprinklers	12,000	15,000	15,000	25,000	50,000
Ground Floor Racks Sprinklers	7,500	15,000	15,000	24,000	48,000

Notes: ** 4-4.2.10 Where two or more classes of liquids are stored in a single pile or rack section, the maximum quantities and height of storage permitted in that pile or rack section shall be the smallest of the two or more separate quantities and heights. The maximum total quantities permitted shall be limited to a sum of proportional amounts that each class of liquid present bears to the maximum total permitted for its respective class; sum of proportional amounts not to exceed 100 percent.

+ **2.207 Mixed storage.** When two or more classes of liquids are stored in a single pile or single rack section, the quantity in the pile or rack section shall not exceed the smallest of the maximum quantities for the classes of liquids stored.

The section numbers in this table and the following report correspond to the Section numbers in each code cited.

SUBJECT OF THIS REPORT:
TASK 2 COMPARISON OF IACS PROPOSAL TO SHORESIDE REQUIREMENTS

Review of fire protection requirements in NFPA and Model Building and Fire Codes for flammable and combustible liquid storage in inside storage rooms and in hazardous material storage cabinets.

1.0 BUILDING OFFICIALS AND CODE ADMINISTRATORS (BOCA)

- National Fire Prevention Code, 1993 Edition.
  The building code and fire prevention code provide for fire protection for storage exceeding the exempt amounts of flammable and combustible liquids (H2 Use Group). Amounts less than the exempt amounts are regulated under NFPA 30 or by the code for the Use Group they more nearly represent. Section numbers refer to the model code sections.

SECTION F-2306.0 HAZARDOUS MATERIAL STORAGE CABINETS

F-2306.1 General: Where storage cabinets are utilized to establish the allowable exempt amounts in accordance with the provisions of Chapters 24 through 43, such cabinets shall comply with Sections F-2306.2 through F-2306.4.

F-2306.2 Warning labels: Cabinets shall be conspicuously labeled in red letters on a contrasting background to read as: "HAZARDOUS – KEEP FIRE AWAY."

F-2306.3 Approval: Cabinets shall be approved as suitable for the intended storage or shall be constructed in accordance with Section F-2306.3.1 through F-2306.3.2.

F-2306.3.1 Construction: Cabinets shall be of steel with a thickness of not less than 0.0478 inches (No. 18 Gage). The cabinet, including the door, shall be double-walled with a 1-1/2 inch (38 mm) airspace between the walls. Joints shall be riveted or welded and tight fitting. Doors shall be well-fitted, self-closing and equipped with a self-latching device.

F-2306.3.2 Bottom: The bottoms of cabinets utilized for the storage of liquids shall be recessed and liquid tight to a minimum height of 2 inches (50 mm).

F-2306.4 Interior surfaces: The interior of cabinets shall be treated, coated or constructed of materials that are nonreactive with the ***hazardous material*** stored. Such treatment, coating or construction shall include the entire interior of the cabinet.

F-3201.4 Use group classification: The storage of ***flammable and combustible liquids*** exceeding the exempt amounts per *control area* indicated in Table F-3201.4 shall be classified as Use Group H2.

Exception: The storage of Class III B liquids shall be classified as Use Group H-3 materials.

Table F-3201.4
EXEMPT AMOUNTS OF FLAMMABLE AND COMBUSTIBLE LIQUIDS

Condition	Class	Exempt amounts (gallons)[b]
Inside storage Unprotected by sprinklers, approved cabinets or safety containers	IA	30
	IB	60
	IC	90
	Combination (IA, IB, IC)	120[a]
	II	120
	IIIA	330
	IIIB	13,200
In sprinklered structure, not in approved cabinet or safety containers	IA	60
	IB	120
	IC	180
	Combination (IA, IB, IC)	240[a]
	II	240
	IIIA	660
	IIIB	Unlimited
In sprinklered structure, within approved cabinet or safety containers	IA	120
	IB	240
	IC	360
	Combination (IA, IB, IC)	480[a]
	II	1,480
	IIIA	1,320
	IIIB	Unlimited

Note a. Containing not more than the exempt amounts of Class IA, IB or IC flammable liquids.

Note b. 1 gallon = 0.00379 m^3.

SECTION F-2305.0 CONTROL AREAS

F-2305.1 General: *Control areas* shall be those spaces located within a structure where quantities of *hazardous materials* not exceeding the allowable exempt amounts are stored, *dispensed*, used or handled. *Control areas* shall be separated assemblies in accordance with the building code listed in Chapter 44.

F-2305.2 Number and separation: The number of permitted *control areas* and degree of fire separation shall comply with Table F-2305.2. The floor construction and supporting structure for all floors located within the *control area* shall have a minimum two-hour fire resistance rating.

Table F-2305.2
PERMITTED CONTROL AREAS[a]

Floor level	Percentage of allowable exempt quantities per control area	Number of control areas per floor[b]	Fire resistance rating of fire separation wall(s) (hours)
1	100	4	1
2	75	3	1
3	50	2	1
4	12.5	2	2
5	12.5	2	2
6	12.5	2	2
7-9	5	2	2
Higher than 9	5	1	2

Note a. See Section F-2305.3 for permitted control area locations.

Note b. In mercantile occupancies, a maximum of two control areas per floor shall be permitted in retail sales rooms.

F-2305.3 Location of floor levels: Floor levels below grade shall not exceed two. The first floor level located below grade shall be limited to 75 percent of the maximum allowable exempt quantity per control area with a maximum of three control areas. The second floor level located below grade shall be limited to 50 percent of the maximum allowable exempt quantity per control area with a maximum of two control areas.

- National Building Code

The area of an unprotected noncombustible building for Use Group H2 (i.e., flammable and combustible liquid storage) may be 25% x 4800 sq ft or 1200 sq ft when located within the structure or 4800 sq ft if the storage is located at the perimeter of the building. Fire separation from the interior of the building shall comply with Table 313.1.2.

The building code references the fire code.

AEROSOL PAINT STORAGE

F-2403.5 Storage in inside flammable liquid storage rooms: Inside flammable liquid storage rooms shall comply with NFPA 30 listed in Chapter 44. The maximum quantities of *aerosol* products shall comply with Section F-2403.5.1. or F-2403.5.2.

F-2403.5.1 **Storage rooms of 500 square feet or less:** The storage of *aerosol* products in flammable liquid storage rooms less than or equal to 500 square feet (46.5 m^2) in area shall not exceed the following quantities:

1. A net weight of 1,000 pounds (454 kg) of Level 2 *aerosol* products;

2. A net weight of 500 pounds (227 kg) of Level 3 *aerosol* products; and

3. A combined net weight of 1,000 pounds (454 kg) of Levels 2 and 3 *aerosol* products.

F-2403.5.2 Storage rooms greater than 500 square feet: The storage of *aerosol* products in flammable liquid storage rooms greater than 500 square feet (46.5 m^2) in area shall not exceed the following quantities:

1. A net weight of 2,500 pounds (1135 kg) of Level 2 *aerosol* products;

2. A net weight of 1,000 pounds (454 kg) of Level 3 *aerosol* products; and

3. A combined net weight of 2,500 pounds (1135 kg) of Levels 2 and 3 *aerosol* products.

Exception: An aggregate storage limit of 5,000 pounds (2270 kg) of Levels 2 and 3 *aerosol* products shall be permitted in separate inside storage rooms protected by an approved *automatic sprinkler system* in accordance with NFPA 30 (NFPA 30B) listed in Chapter 44.

2.0 SOUTHERN BUILDING CODE CONGRESS, INT., INC. (SBCCI)

- Standard Fire Prevention Code, 1991 Edition.

2203.1.14 Hazardous Materials Storage Cabinets. When storage cabinets are used to comply with the provisions of this chapter, such cabinets shall be in accordance with this section.

2203.1.14.1 General. Cabinets shall be conspicuously labeled HAZARDOUS – KEEP FIRE AWAY in red letters on contrasting background.

2203.1.14.2 Construction. Cabinets shall be constructed of metal. The interior of cabinets shall be treated, coated or constructed of materials that are non-reactive with the hazardous material stored. Such treatment, coating or construction shall include the entire interior of the cabinet. Cabinets shall either be listed as suitable for the intended storage or constructed in accordance with the following:

1. Cabinets shall be of steel having a thickness of not less than 0.0478 inches. The cabinet including the door, shall be double-walled with 1-1/2 inch airspace between the walls. Joints shall be riveted or welded and shall be tight fitting. Doors shall be well-fitted, self-closing and equipped with a self-latching device.

2. The bottoms of cabinets utilized for the storage of liquids shall be liquid tight to a minimum height of two inches.

2203.4 Flammable and Combustible Liquids

2203.4.1 Indoor Storage

2203.4.1.1 General. Indoor storage of flammable or combustible iiquids shall be in accordance with this section and Chapter 9.

2203.4.1.2 Exempt Amounts. When the amount of flammable or combustible liquids stored in one control area exceeds that specified in Table 2203.4.1A, such storage shall be within a room or building conforming to the Building Code and Chapter 9 requirements for the specific occupancies as follows:

Table 2203.4.1A
FLAMMABLE AND COMBUSTIBLE LIQUIDS EXEMPT AMOUNTS[1]

Condition	Class	Exempt Amount (gal)
Unprotected by sprinklers approved cabinet or safety containers	I-A	30
	I-B	60
	I-C	90
	Combination I-A, I-B, I-C[2]	120
	II	120
	III-A	330
	III-B	13,200
In sprinklered building, not in approved cabinet or safety containers	I-A	60
	I-B	120
	I-C	180
	Combination I-A, I-B, I-C[2]	240
	II	240
	III-A	660
	III-B	NL

NL: Not limited.

1. For storage requirements for any amount of flammable or combustible liquids, see Chapter 9.

2. Containing not more than the exempt amounts of Class I-A, Class I-B, or Class I-C flammable liquids.

Note: There is a conflict with Section 904.4.1 which limits the flammable and combustible liquids to 60 gal. and the maximum size of the container to 5 gal. This table is identical to that in BOCA and NFPA 30.

904.6 Storage in inside storage rooms.

904.6.1 Storage in inside rooms shall comply with Table 904.6.

Table 904.6
INSIDE STORAGE ROOMS

Automatic Extinguishing System Provide[1]	Fire Resistance (hr)	Maximum Size (sq ft)	Total Allowable Quantities Gals./sq ft of floor area
Yes	2	500	10
No	2	500	4
Yes	1	150	5
No	1	150	2

1. Fire protection system shall be sprinkler, water spray, carbon dioxide, dry chemical, halon or other system approved by the Fire Official.

904.6.2 Inside storage rooms shall contain at least one aisle with a minimum width of 3 ft. Storage shall be no closer than 3 ft to ceilings or automatic sprinklers.

904.6.3 Containers shall be stacked in accordance with table 904B.

904.6.4 The dispensing of flammable or combustible liquids shall be by approved pumps taking suction through the top of the container or other approved method.

Table 904B
INDOOR CONTAINER STORAGE[1,2]

Class[3] Liquid	Storage Level	Protected Storage[4] Maximum Per Pile		Unprotected Storage Maximum Per Pile	
		Gallons	Height (ft)	Gallons	Height (ft)
IA	Ground & Upper Floors	2750 (50)	3 (1)	660 (12)	3 (1)
	Basement	NOT PERMITTED			
IB	Ground & Upper Floors	5500 (100)	6 (2)	1375 (25)	3 (1)
	Basement	NOT PERMITTED			
IC	Ground & Upper Floors	16,500 (300)	6 (2)	4125 (75)	3 (1)
	Basement	NOT PERMITTED			
Combustible II	Ground & Upper Floors	16,500 (300)	9 (3)	4125 (75)	9 (3)
	Basement	5500 (100)	9 (3)	NOT PERMITTED	
Combustible III	Ground & Upper Floors	55,000 (1,000)	15 (3)	13,750 (250)	12 (4)
	Basement	8250 (450)	9 (3)	NOT PERMITTED	

NOTES:
1. Numbers in parentheses indicate corresponding number of 55 gal. drums.
2. Aisles shall be provided so that no container is more than 12 ft from the aisle.
3. When two or more classes of materials are stored in a single pile, the maximum gallonage permitted in that pile shall be the smallest of the two or more separate maximum gallonages.
4. Protected storage has a sprinkler or equivalent fire protection system installed in accordance with the applicable NFPA standards.

AEROSOL PAINT STORAGE

- Standard Fire Prevention Code 1993 proposed code change references NFPA 30B-90

4-7 Storage of Aerosol Products in Separate Inside Flammable Liquid Storage Rooms.

4-7.1 Storage of aerosol products shall be permitted in separate inside flammable liquid storage rooms of 500 sq ft (47 m^2) or less that meet the requirements of NFPA 30, *Flammable and Combustible Liquids Code*, up to a maximum quantity of 1,000 lb (454 kg) of Level 2 aerosol products or 500 lb (227 kg) of Level 3 aerosol products or 1,000 lb (454 kg) of combined Level 2 and Level 3 aerosol products.

4-7.2 Storage of aerosol products shall be permitted in separate inside flammable liquid storage rooms of greater than 500 sq ft (47 m^2) that meets the requirements of NFPA 30, *Flammable and Combustible Liquids Code*, up to a maximum quantity of 2,500 lb (1135 kg) of Level 2 aerosol products or 1,000 lb (454 kg) of Level 3 aerosol products or 2,500 lb (1135 kg) of combined Level 2 and Level 3 aerosol products.

Exception: Storage of Level 2 and Level 3 aerosol products shall be permitted in separate inside storage rooms up to a maximum of 5,000 lb (2270 kg), if the separate inside storage room is protected by an automatic sprinkler system that is designed in accordance with Tables 4-1 through 4-6, whichever is applicable.

- Standard Building Code

Section 408 on Hazardous Materials applies only if the exempt quantities are exceeded.

Where the exempt quantities are exceeded, special fire protection requirements for indoor storage rooms require the following:

1. Automatic Sprinklers - ordinary hazard, Group 3 (Section 408.2.2.1);
2. Explosion venting or Explosion suppression (Section 408.3.2.);

3. Spill control drainage and containment (Section 408.3.3);
4. Ventilation (Section 408.3.4);
5. Alarm and detection (Section 408.3.5);
6. Floors (Section 408.3.6);
7. Electrical (Section 408.3.9); and
8. Security (Section 408.3.11).

3.0 INTERNATIONAL CONFERENCE OF BUILDING OFFICIALS (ICBO)

- Uniform Fire Code, 1991 Edition.
  Quantity Limits, Manner of Storage and Storage Cabinets

Sec. 79.202. (a) **Quantity Limits.**

1. **Exempt amounts for control areas.** Indoor storage of flammable and combustible liquids within one control area shall not exceed the exempt amounts set forth in Table No. 79.202-A. Control areas shall be in accordance with Article 80, Division I. The manner of storage in control areas within Group B, Division 2 wholesale and retail stores and industrial buildings shall be in accordance with Section 79.202 (b).

2. **Quantities exceeding limits for control areas.** Indoor storage exceeding quantities allowed within control areas shall be within liquid storage rooms or liquid storage warehouses as specified in Sections 79.203 and 79.204.

(c) **Storage Cabinets.** 1. **General.** When other sections require that liquid containers are stored in storage cabinets, such cabinets and storage shall be in accordance with this subsection.

2. **Quantities.** The quantity of Class I or Class II liquids in a cabinet shall not exceed 60 gallons, and the total quantity of all liquids shall not exceed 120 gallons.

3. **Construction.** A. **Labeling.** Cabinets shall be conspicuously labeled in red letters on contrasting background FLAMMABLE – KEEP FIRE AWAY.

B. **Doors.** Doors shall be well-fitted, self-closing and equipped with a latch.

C. **Bottom.** The bottom of the cabinet shall be liquid tight to a height of at least two inches.

D. **Materials.** (i) **General.** Cabinets shall be constructed of wood or metal and approved by the chief. Cabinets shall be listed or constructed in accordance with Section 79.202 (c) 3 D (ii) or (iii).

(ii) **Unlisted metal cabinets.** Metal cabinets shall be constructed of steel having a thickness of not less than 0.044-inch (18 gage). The cabinet, including the door, shall be double-walled with 1-1/2-inch airspace between the walls. Joints shall be riveted or welded and shall be tightfitting.

(iii) **Wooden cabinets.** Wooden cabinets, including doors, shall be constructed of not less than one inch exterior grade plywood. Joints shall be rabbeted and shall be fastened in two directions with wood screws. Door hinges shall be of steel or brass. Cabinets shall be painted with an intumescent-type paint.

4. **Number of cabinets.** (i) **Group A Occupancies (Assembly).** Group A Occupancies shall not contain more than one cabinet.

(ii) **Other occupancies.** In occupancies other than Group A Occupancies, a room shall not contain more than three cabinets.

Table No. 79.202-A—EXEMPT AMOUNTS OF FLAMMABLE AND COMBUSTIBLE LIQUIDS MAXIMUM QUANTITIES STORED PER CONTROL AREA

Type of Liquid	Maximum Quantity Per Control Area (gallons)	
	Group B, Division 2, Drinking, Dining, Office or School Uses; Groups A, E, I and R Occupancies[1, 2]	All Other Uses[1, 3, 4]
Flammable		
Class I-A	0	30[5, 8]
Class I-B	0	60[5, 8]
Class I-C	0	90[5, 8]
Combination I-A, I-B, I-C	0	120[5, 7, 8]
Combustible		
Class II	0	120[5, 8]
Class III-A	0	330[5, 8]
Class III-B	13,200[4, 6]	13,200[6]
Flammable and Combustible		
Combination I, II	0	120[5, 7, 8]

[1]Flammable and combustible liquids are allowed to be used for maintenance purposes and operation of equipment when stored in cabinets which comply with Section 79.202 (c). Quantities not exceeding 10 gallons are allowed to be stored outside of a cabinet when in approved containers located in a private garage or an approved location.

[2]In Group A Occupancies used as classrooms or laboratories; Group B, Division 2 Occupancies used as offices, classrooms or laboratories; Group E Occupancies; and Group I Occupancies, flammable and combustible liquids are allowed to be stored in amounts necessary for use in demonstration, treatment of laboratory work not to exceed the allowable quantities for "All Other Uses." When quantities exceed 10 gallons, storage shall be in cabinets in accordance with Section 79.202 (c).

[3]For HPM flammable and combustible liquids, see Article 51.

[4]Quantities are allowed to be increased 100 percent when stored in approved storage cabinets. When Footnote No. 5 also applies, the increases for both footnotes are allowed.

[5]Quantities are allowed to be increased 100 percent in buildings equipped with an approved automatic sprinkler system. When Footnote No. 4 also applied, the increases for both footnotes are allowed.

[6]Quantities allowed in a building equipped with an approved automatic sprinkler system are not limited.

[7]Combination shall not contain more than the exempt amounts of any individual class.

[8]In buildings used for wholesale and retail sales which are protected by an approved automatic sprinkler system, the aggregate quantities of flammable and combustible liquids in control areas accessible to the public are allowed to be increased to a density of one gallon per square foot for Class I-A, and two gallons per square foot for Class I-B, Class I-C, Class II and Class III-A liquids. The floor area over which the density factor is applied shall be only that area actually being used for storage, including contiguous aisle space, and shall not exceed an aggregate area of 1,500 square feet. Allowable quantities in the flammable and combustible liquids storage area shall be uniformly distributed therein. Increases provided in Footnotes Nos. 4 and 5 shall not apply.

Liquid Storage Rooms

Sec. 79.203. (a) **General.** Quantities of liquids exceeding those set forth in Section 79.202 (a) for storage in control areas shall be stored in a liquid storage room complying with this section. Such rooms shall be classified as Group H, Division 3 Occupancies.

(b) **Quantities and Arrangement of Storage.**

1. **General.** The quantities and arrangements of liquid storage shall be in accordance with Table No. 79.202-A or 79.202-B and this section.

2. **Mixed storage.** When two or more classes of liquids are stored in a single pile or single rack section, the quantity in the pile or rack section shall not exceed the smallest of the maximum quantities for the classes of liquids stored.

3. **Separation and aisles.** Storage shall be arranged in piles or racks in accordance with Tables Nos. 79.202-A and 79.202-B. Piles shall be separated from each other by at least four foot aisles. Aisles shall be provided so that all containers are 12 feet or less from an aisle. Where the storage of liquids is on racks, a minimum four foot wide aisle shall be provided between adjacent rows of racks and adjacent storage of liquids. Main aisles shall be a minimum of eight feet wide.

Additional aisles shall be provided for access to doors, required windows and ventilation openings, standpipe connections, mechanical equipment, and switches. Such aisles shall be at least three feet in width, unless greater widths are required for separation of piles or racks, in which case, the greater width shall be provided.

4. **Stabilizing and supports for storage.** Containers and piles shall be separated by pallets or dunnage to provide stability and to prevent excessive stress to container walls. Portable tanks stored over on tier high shall be designed to nest securely without dunnage. See Section 2.304 (b) for requirements for portable tank design. Shelving, racks, dunnage, scuffboards, floor overlay and similar installations shall be of noncombustible construction or of wood not less than one-inch nominal thickness. Adequate materials-handling equipment shall be available to handle tanks safely at upper tier levels.

(c) **Sprinkler Systems.** Liquid storage rooms shall be protected by automatic sprinkler systems installed in accordance with the Building Code and Tables Nos. 79.203-C, 79.203-D and 79.203-E. In-rack sprinklers shall also comply with U.F.C. Standard No. 81-2. For in-rack sprinklers, alternate line shall be staggered and multiple levels of sprinkler heads shall be provided with water shields unless separated by horizontal barriers or unless the sprinkler heads are listed for such installations. Racks with solid shelves shall be provided with in-rack sprinklers at every tier or level.

Automatic foam-water systems and automatic aqueous film-forming foam-water sprinkler systems may be used when approved by the chief.

(d) **Spill Control and Drainage Control.** Liquid storage rooms shall be provided with spill control and drainage control as set forth in Section 79.115.

(e) **Storage in Basements.** Class I liquids shall not be stored in basements.

(f) **Dispensing and Mixing.** Liquids shall not be dispensed or mixed in liquid storage rooms unless such rooms comply with the electrical, heating and ventilation requirements for use, dispensing and mixing rooms in Division VIII. Liquid storage rooms in which liquids are in open use, dispensed or mixed shall be classified as Group H, Division 2 Occupancies.

(g) **Ventilation.** Liquid storage rooms shall be ventilated in accordance with Section 80.301.

- Uniform Building Code, Section 901 (d)

(d) **Liquid Storage Rooms.** Rooms in which Class I, Class II and Class III-A flammable or combustible liquids are stored in closed containers shall be constructed in accordance with the requirements for a Group H, Division 3 Occupancy and to the following:

1. Rooms in excess of 500 square feet shall have at least one exterior door approved for fire department access.

2. Rooms shall be separated from other areas by an occupancy separation having a fire resistive rating of not less than one hour for rooms up to 150 square feet in area and not less than two hours where the room is more than 150 square feet in area. Separations from other occupancies shall not be less than required by Chapter 5, Table No. 5-B.

3. Shelving, racks and wainscoting in such areas shall be of noncombustible construction or wood of not less than one inch nominal thickness.

4. Rooms used for the storage of Class I flammable liquids shall not be located in a basement.

Table No. 9-A—EXEMPT AMOUNTS OF HAZARDOUS MATERIALS, LIQUIDS AND CHEMICALS PRESENTING A PHYSICAL HAZARD BASIC QUANTITIES PER CONTROL AREA[1]

When two units are given, values within parentheses are in cubic feet (cu ft) or pounds (lbs)

(Note: Only Flammable and Combustible Liquids have been extracted from Table 9-A)

Condition		Storage[2]			Use[2]–Closed Systems			Use[2]–Open Systems	
Material	Class	Solid lbs.[3] (cu ft)	Liquid Gallons[3] (lbs)	Gas cu ft	Solid lbs (cu ft)	Liquid Gallons (lbs)	Gas cu ft	Solid lbs (cu ft)	Liquid Gallons (lbs)
1.1 Combustible liquid[5, 6]	II	N.A.	120[7]	N.A.	N.A.	120	N.A.	N.A.	30
	III-A	N.A.	330[7]	N.A.	N.A.	300	N.A.	N.A.	80
	III-B	N.A.	13,200[7,11]	N.A.	N.A.	13,200[11]	N.A.	N.A.	3,300[11]
3.3 Flammable liquid[5, 6]	I-A	N.A.	30[7]	N.A.	N.A.	30	N.A.	N.A.	10
	I-B	N.A.	60[7]	N.A.	N.A.	60	N.A.	N.A.	15
	I-C	N.A.	90[7]	N.A.	N.A.	90	N.A.	N.A.	20
Combination I-A, I-B, I-C		N.A.	120[7]	N.A.	N.A.	120	N.A.	N.A.	30

N.A. = Not applicable

[1]Control area is a space bounded by not less than a one-hour fire resistive occupancy separation within which the exempted amounts of hazardous materials may be stored, dispensed, handled or used. The number of control areas within a building used for retail and wholesale stores shall not exceed two. The number of control areas in buildings with other uses shall not exceed four.

[2]The aggregate quantity in use and storage shall not exceed the quantity listed for storage.

[5]For aerosols, see the Fire Code.

[6]Quantities may be increased 100 percent in sprinklered buildings. When Footnote No. 7 also applies, the increase for both footnotes may be applied.

[7]Quantities may be increased 100 percent when stored in approved storage cabinets, gas cabinets, fume hoods, exhaust enclosures or safety cans as specified in the Fire Code. When Footnote No. 6 also applies, the increase for both footnotes may be applied.

[11]The quantities permitted in a sprinklered building are not limited.

[13]Permitted in sprinklered buildings only. None is allowed in unsprinklered buildings.

Sec. 902 (a) **General.** Buildings or parts of buildings classed in Group H because of the use or character of the occupancy shall be limited to the types of construction set forth in Tables Nos. 5-C and 5-D (3700 sq ft in area for unprotected noncombustible construction).

(b) **Floors.** Except for surfacing, floors in areas containing hazardous materials and in areas where motor vehicles, boats, helicopters or airplanes are stored, repaired or operated shall be of noncombustible, liquid-tight construction.

(c) **Spill Control.** When required by the Fire Code, floors shall be recessed a minimum of four inches or shall be provided with a liquid-tight raised sill with a minimum height of four inches so as to prevent the flow of liquids to adjoining areas. When liquid-tight sills are provided, they may be omitted at door openings by the installation of an open-grate trench which connects to the room drainage system.

(d) **Drainage.** When required by the Fire Code, the room, building or area shall be provided with a drainage system to direct the flow of liquids to an approved location or, the room, building or area shall be designed to provide secondary containment for the hazardous materials and fire protection wear.

Drains from the area shall be sized to carry the sprinkler system design flow rate over the sprinkler system design area. The slope of drains shall not be less than one percent. Materials of construction for the drainage system shall be compatible with the stored materials.

Incompatible materials shall be separated from each other in the drain systems. They may be combined when they have been rendered acceptable for discharge by an approval means into the public sewer. Drainage of spillage and fire protection water directed to a neutralizer or treatment system shall comply with the following:

1. The system shall be designed to handle the maximum worst-case spill from the single largest container plus the volume of fire protection water from the system over the minimum design area for a period of 20 minutes.

2. Overflow from the neutralizer or treatment system shall be provided to direct liquid leakage and fire protection water to a safe location away from the building, any material or fire protection control valve, means of egress, adjoining property, or fire department access roadway.

(e) **Containment.** When required by the Fire Code, drains shall be directed to a containment system or other location designed as secondary containment for the hazardous material liquids and fire protection water, or the building, room or area shall be designed to provide secondary containment of hazardous materials liquids and fire protection water through the use of recessed floors or liquid-tight raised sills.

Secondary containment shall be designed to retain the spill from the largest single container plus the design flow rate of the sprinkler system for the area of the room or area in which the storage is located or the sprinkler system design area, whichever is smaller. The containment capacity shall be capable of containing the flow for a period of 20 minutes.

Overflow from the secondary containment system shall be provided to direct liquid leakage and fire protection water to a safe location away from the building, any material or fire protection control valve, means of egress, fire access roadway, adjoining property or storm drains.

When secondary containment is required, a monitoring method capable of detecting hazardous material leakage from the primary containment into the secondary containment is not practical, other approved means of monitoring may be provided. When secondary containment may be subject to the intrusion of water, a monitoring method for such water shall be provided. Whenever monitoring devices are provided, they shall be connected to distinct visual or audible alarms.

(f) **Smoke and Heat Vents.** Smoke and heat venting shall be provided in areas containing hazardous materials as set forth in the Fire Code in addition to the provisions of this code.

LIGHT, VENTILATION AND SANITATION

Sec. 905. (a) **General Ventilation.** In Group H Occupancy buildings, all enclosed portions customarily occupied by human beings, other than rooms and areas for which requirements are specified elsewhere in this section, shall be provided with natural light by means of exterior glazed openings with an area equal to one tenth of the total floor area of such portions, and natural ventilation by means of exterior openings with an operable area not less than one twentieth of the total floor area of such portions, or shall be provided with artificial light and a mechanically operated ventilation system. The mechanically operated ventilation system shall be capable of supplying a minimum of five cubic feet per minute of outside air per occupant, with a total circulated of not less than 15 cubic feet per minute per occupant in all occupied portions of the building. When recirculation of air is not permitted, the ventilation system shall be capable of providing not less than 15 cubic feet per minute of outside air per occupant.

AEROSOL PAINT STORAGE
Uniform Fire Code – Article 88

Table No. 88.203-A–LIMITED QUANTITY LEVEL 2 AND LEVEL 3 AEROSOL PRODUCT STORAGE GENERAL-PURPOSE WAREHOUSES AND STORAGE ROOMS MAXIMUM QUANTITIES

	MAXIMUM NET WEIGHT PER FLOOR (Pounds)[1]			
	Palletized or Solid Pile Storage		Rack Storage	
Aerosol Level	Unprotected	Protected[2]	Unprotected	Protected[3]
2	2,500	12,000	500	24,000
3	1,000	12,000	500	24,000
Combination 2 and 3	2,500	12,000	500	24,000

[1]In any 50,000 square foot area.

[2]Automatic fire sprinkler system protection and storage arrangement in accordance with Table No. 88.301-A or 88.301-B for aerosol storage area with sprinkler system extended 20 feet beyond the aerosol storage area.

[3]Automatic fire sprinkler system protection and storage arrangement in accordance with Tables Nos. 88.301-C through 88.301-F for aerosol storage area with sprinkler system extended 20 feet beyond the aerosol storage area.

4.0 NATIONAL FIRE PROTECTION ASSOCIATION

- NFPA 30, 1990 Edition.

4-3 Design, Construction, and Capacity of Storage Cabinets.

4-3.1 Not more than 120 gal. (454 L) of Class I, Class II and Class IIIA liquids may be stored in a storage cabinet. Of this total, not more than 60 gal. (227 L) may be of Class I and Class II liquids, and not more than three (3) such cabinets may be located in a single fire area, except that, in an industrial occupancy, additional cabinets may be located in the same fire area if the additional cabinet, or group of not more than three (3) cabinets, is separated from other cabinets or group of cabinets by at least 100 ft (30 m).

4-3.2* Storage cabinets shall be designed and constructed to limit the internal temperature at the center. One inch (2.5 cm) from the top, to not more than 325°F (162.8°C) when subjected to a 10 minute fire test with burners simulating a room fire exposure using the standard time-temperature curve as given in NFPA 251, *Standard methods of Fire Tests of Building Construction and Materials*. All joints and seams shall remain tight and the door shall remain securely closed during the fire test. Cabinets shall be marked in conspicuous lettering: "FLAMMABLE – KEEP FIRE AWAY."

The cabinet is not required to be vented for fire protection purposes; however, the following shall apply:

(a) If the cabinet is vented for whatever reasons, the cabinet shall be vented outdoors in such a manner that will not compromise the specified performance of the cabinet, as acceptable to the authority having jurisdiction.

(b) If the cabinet is not vented, the vent openings shall be sealed with the bungs supplied with the cabinet or with bungs specified by the manufacturer of the cabinet.

4-3-2.1 Metal cabinets constructed in the following manner are acceptable. The bottom, top, door, and sides of cabinet shall be at least No. 18 gage sheet steel and double-walled with 1-1/2 inch (3.8 cm) air space. Joints shall be riveted, welded, or made tight by some equally effective means. The door shall be provided with a three-point latch arrangement and the door sill shall be raised at least two inches (5 cm) above the bottom of the cabinet to retain spilled liquid within the cabinet.

4-3.2.2 Wooden cabinets constructed in the following manner are acceptable. The bottom, sides, and top shall be constructed of exterior grade plywood at least one inch (2.5 cm) in thickness, which shall not break down or delaminate under fire conditions. All joints shall be rabbetted and shall be fastened in two directions with wood screws. When more than one door is used, there shall be a rabbetted overlap of not less than one inch (2.5 cm). Doors shall be equipped with a means of latching, and hinges shall be constructed and mounted in such a manner as to not lose their holding capacity when subjected to fire exposure. A raised sill or pan capable of containing a two inch (5 cm) depth of liquid shall be provided at the bottom of the cabinet to retain spilled liquid within the cabinet.

4-3.2.3 Listed cabinets that have been constructed and tested in accordance with 4-3.2 shall be acceptable.

4-4 Design, Construction, and Operation of Separate Inside Storage Areas. *(See Section 1-2, "Definitions.") (For additional information, see Appendix D.)*

4-4.1 Inside Rooms and Hazardous Materials Storage Lockers Used Inside. Inside rooms and hazardous materials storage lockers that are used as inside rooms shall meet the requirements set forth in 4-4.1.1 through 4-4.1.9, as applicable.

4-4-1.1 Inside rooms shall be constructed to meet the selected fire resistance rating as specified in 4-4.1.4. Such construction shall comply with the test specifications given in NFPA 251, *Standard Methods of Fire Tests of Building Construction and Materials.* Except for drains, floors shall be liquid-tight, and the room shall be liquid-tight where the walls join the floor. Where an automatic fire protection system is provided, as indicated in 4-4.1.4, the system shall be designed and installed in accordance with the appropriate NFPA standard for the type of system selected.

4-4.1.2 Openings in interior walls to adjacent rooms or buildings shall be provided with the following:

(a) Normally closed, listed 1-1/2 hour (B) fire doors for interior walls with fire resistance rating of two hours or less. Where interior walls are required to have greater than two hour fire resistance rating, the listed fire doors shall be compatible with the wall rating. Doors may be arranged to stay open during material handling operations if doors are designed to close automatically in a fire emergency by provision of listed closure devices. Fire doors shall be installed in accordance with NFPA 80, *Standard for Fire Doors and Windows.*

(b) Noncombustible, liquid-tight raised sills or ramps at least four inches (10 cm) in height or otherwise designed to prevent the flow of liquids to the adjoining areas. A permissible alternative to the sill or ramp is an open-grated trench, which drains to a safe location, across the width of the opening inside of room.

4-4.1.3 Wood at least one inch (2.5 cm) nominal thickness may be used for shelving, racks, dunnage, scuffboards, floor overlay, and similar installations.

4-4.1.4 Storage in inside rooms shall comply with the following:

Automatic Fire Protection* Provided	Fire Resistance	Maximum Floor Area	Total Allowable Quantities Gallons/Sq Ft/Floor Area
Yes	2 hr	500 sq ft	10
No	2 hr	500 sq ft	4**
Yes	1 hr	150 sq ft	5
No	1 hr	150 sq ft	2

SI Units: 1 sq ft = 0.09 m^2; 1 gal = 3.8 L.

* Fire protection system shall be sprinkler, water spray, carbon dioxide, dry chemical, halon, or other approved system.

** Total allowable quantities of Class IA and IB liquids shall not exceed that permitted in Table 4-4.2.7 and the provisions of 4-4.2.10.

4-4.1.5 Electrical wiring and equipment located in inside rooms used for Class I liquids shall be suitable for Class I, Division 2 classified locations; for Class II and Class III liquids, shall be suitable for general use. (NFPA 70, *National Electrical Code*, provides information on the design and installation of electrical equipment).

4-4.1.6 Every inside room shall be provided with either a gravity or a continuous mechanical exhaust ventilation system. Mechanical ventilation shall be used if Class I liquids are dispensed within the room.

(a) ust air shall be taken from a point near a wall on one side of the room and within 12 inches (30 cm) of the floor with one or more make-up inlets located on the opposite side of the room within 12 inches (30 cm) of the floor. The location of both the exhaust and inlet air openings shall be arranged to provide, as far as practicable, air movements across all portions of the floor to prevent accumulation of flammable vapors. Exhaust from the room shall be directly to the exterior of the building without recirculation.

EXCEPTION: Recir[illegible] is permitted where it is monitored continuously using a fail-safe system that is designed to automatically sound an alarm, stop recirculation, and provide full exhaust to the outside in the event that vapor-air mixtures in concentration over one-fourth of the lower flammable limit are detected.

If the ducts are used, they shall not be used for any other purpose and shall comply with NFPA 91, *Standard for the Installation of Blower and Exhaust Systems for Dust, Stock, and Vapor Removal or Conveying*. If make-up air to a mechanical system is taken from within the building, the opening shall be equipped with a fire door or damper, as required in NFPA 91, *Standard for the Installation of Blower and Exhaust Systems for Dust, Stock, and Vapor Removal or Conveying*. For gravity systems, the make-up air shall be supplied from outside the building.

(b) Mechanical ventilation systems shall provide at least one cubic foot per minute of exhaust per square foot of floor area (1 m^3 per min per 3 m^2), but not less than 150 cfm (4 m^3 per min). The mechanical ventilation system for dispensing areas shall be equipped with an airflow switch or other equally reliable method that is interlocked to sound an audible alarm upon failure of the ventilation system.

4-4.1.7 In every inside room, an aisle at least 3 ft (0.90 m) wide shall be maintained so that no container is more than 12 ft (3.6 m) from the aisle. Containers over 30 gal. (113.5 L) capacity storing Class I or Class II liquids shall not be stored more than one container high.

4-4.1.8 Where dispensing is being done in inside rooms, operations shall comply with the provisions of Chapter 5.

4-4.1.9 Basement Storage Areas. Class I liquids shall not be permitted in inside storage rooms in basement areas.

Appendix B

FIRE IMPACT ANALYSIS TREE

Test	Door Position at Start	Detection	Door Activity	Installed Suppression System	Potential of Flashover
1	Closed	Smoke	Opened	None	3
2				Automatic carbon dioxide	1
3				Manual carbon dioxide	2
4				Automatic water	2
5				Manual water	2
6				Automatic dry chemical	1
7				Manual dry chemical	2
8				Automatic foam	1
9				Manual foam	1
10	Closed	Smoke	Kept Open	None	0
11				Automatic carbon dioxide	0
12				Manual carbon dioxide	0
13				Automatic water	0
14				Manual water	0
15				Automatic dry chemical	0
16				Manual dry chemical	0
17				Automatic foam	0
18				Manual foam	0
19	Closed	Heat	Opened	None	4
20				Automatic carbon dioxide	2
21				Manual carbon dioxide	3
22				Automatic water	3
23				Manual water	3
24				Automatic dry chemical	2
25				Manual dry chemical	3
26				Automatic foam	2
27				Manual foam	2

Test	Door Position at Start	Detection	Door Activity	Installed Suppression System	Potential of Flashover
28	Closed	Heat	Kept Closed	None	0
29				Automatic carbon dioxide	0
30				Manual carbon dioxide	0
31				Automatic water	0
32				Manual water	0
33				Automatic dry chemical	0
34				Manual dry chemical	0
35				Automatic foam	0
36				Manual foam	0
37	Closed	None	Opened	None	4
38				Automatic carbon dioxide	2
39				Manual carbon dioxide	3
40				Automatic water	3
41				Manual water	3
42				Automatic dry chemical	2
43				Manual dry chemical	3
44				Automatic foam	2
45				Manual foam	2
46	Closed	None	Kept Closed	None	0
47				Automatic carbon dioxide	0
48				Manual carbon dioxide	0
49				Automatic water	0
50				Manual water	0
51				Automatic dry chemical	0
52				Manual dry chemical	0
53				Automatic foam	0
54				Manual foam	0
55	Open	Smoke	Closed	None	5
56				Automatic carbon dioxide	2
57				Manual carbon dioxide	2
58				Automatic water	4
59				Manual water	4
60				Automatic dry chemical	2
61				Manual dry chemical	2
62				Automatic foam	1
63				Manual foam	1

Test	Door Position at Start	Detection	Door Activity	Installed Suppression System	Potential of Flashover
64	Open	Smoke	Kept Open	None	7
65				Automatic carbon dioxide	2
66				Manual carbon dioxide	2
67				Automatic water	4
68				Manual water	4
69				Automatic dry chemical	2
70				Manual dry chemical	2
71				Automatic foam	1
72				Manual foam	1
73	Open	Heat	Closed	None	6
74				Automatic carbon dioxide	3
75				Manual carbon dioxide	2
76				Automatic water	4
77				Manual water	4
78				Automatic dry chemical	3
79				Manual dry chemical	2
80				Automatic foam	1
81				Manual foam	1
82	Open	Heat	Kept Open	None	8
83				Automatic carbon dioxide	3
84				Manual carbon dioxide	3
85				Automatic water	5
86				Manual water	5
87				Automatic dry chemical	3
88				Manual dry chemical	3
89				Automatic foam	1
90				Manual foam	2
91	Open	None	Closed	None	6
92				Automatic carbon dioxide	3
93				Manual carbon dioxide	2
94				Automatic water	4
95				Manual water	4
96				Automatic dry chemical	3
97				Manual dry chemical	2
98				Automatic foam	1
99				Manual foam	1

Test	Door Position at Start	Detection	Door Activity	Installed Suppression System	Potential of Flashover
100	Open	None	Kept Open	None	8
101				Automatic carbon dioxide	3
102				Manual carbon dioxide	3
103				Automatic water	5
104				Manual water	5
105				Automatic dry chemical	3
106				Manual dry chemical	3
107				Automatic foam	1
108				Manual foam	2