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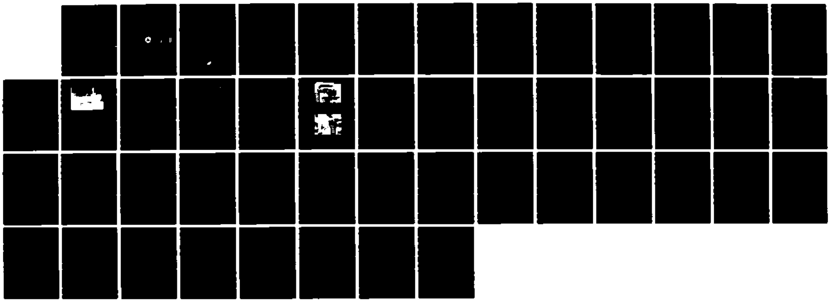

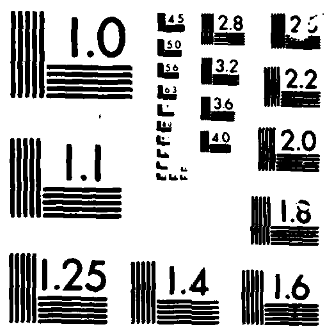


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REPORT NO: CG-D-19-84

AD-A167 204

SMOKE/GAS HAZARDS - SHIPBOARD COMPARTMENT FIRES


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U.S. Coast Guard Research and Development Center
Avery Point Groton, Connecticut 06340




APRIL 1984

FINAL REPORT





PREPARED FOR
U. S. DEPARTMENT OF TRANSPORTATION
UNITED STATES COAST GUARD

OFFICE OF RESEARCH AND DEVELOPMENT
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Avery Point, Groton, Connecticut 06340

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16. Abstract

This document summarizes the results of a program of work conducted jointly by the United States Coast Guard and the Canadian Coast Guard. The program was designed to develop a better understanding of the formation of hazardous life safety conditions resulting from accommodation quarters fires. The program was divided into work tasks corresponding to three classes of materials useage: bulkhead furnishes; deck coverings; and accommodation space furnishings. For each class of materials the rate of production of six selected toxic gases was quantitatively measured. The quantities obtained were then related to their potential for harm and their potential lethal hazard. The results and analysis indicates: (1) that deck covering materials in current useage do not make a signficiant contribution to smoke/gas hazards; (2) that the bulkhead and bulkhead finish materials tested vary in their potential for harm; and (3), that accommodation fire furnishings produce significant levels of "toxic" gases. Of the gases measured, carbon monoxide is the toxicant with the greatest potential hazard.

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# METRIC CONVERSION FACTORS

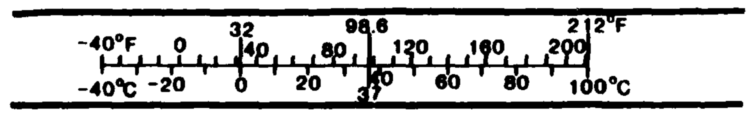
## Approximate Conversions to Metric Measures

| 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). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures. Price $2.25. SD Catalog No. C13.10.286.


## 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 BACKGROUND AND OBJECTIVES

### 1.1 Background

This document describes a program of work conducted by the United States and Canadian Coast Guards. The program was designed to develop a better understanding of the formation of smoke/gas hazards to life safety during ship fires and to outline their relation to materials for finishing or furnishing compartments. The investigations emphasized the measurement of selected gas concentrations resulting from the exposure to fire of selected materials. The project was formalized by Addendum Three to the Jamieson-Volpe agreement. This report summarizes the work performed during the three experimental work tasks and provides an analysis of those results.

For many years the Canadian and U.S. Coast Guards have recognized the hazards presented by smoke and toxic gases. Smoke and toxic gases produced in shipboard fires are recognized as a significant threat to life safety. Their effects can result in death by inhalation or by obscuration of passageways required to reach safety. Many of the existing regulations were designed to limit the use of materials which produce significant smoke obscuration or to limit the movement of smoke through the ship. One way materials are limited is to place restriction on their flame spread rate. Since the production of smoke is often directly correlated with the rate of flame spread, both the United States[1] and Canadian[2] regulations require that the surface finish of materials not exceed a flame rating of 20. The United States regulations further require that the smoke rating be ten or less. There are no accepted standards regulating the toxicity of fire gases.

### 1.2 Objective

The objective of this project was to evaluate quantitatively the rate of production of smoke and toxic gases that are generated during shipboard fires in accommodation spaces and relate these quantities to the development of important life safety hazards. To meet this objective the program was divided into three work tasks corresponding to three classes of material usage: bulkhead finishes; deck coverings; and accommodation space furnishings. The specific objective of each of the tasks was to determine the potential threat to life safety associated with the burning of selected bulkhead finishes, deck coverings, or furniture ensembles in a passageway adjacent to the room of fire origin.

## 2.0 TECHNICAL APPROACH

### 2.1 General Approach

The problem addressed by this project was to provide relevant information about the expected exposures that result from an unwanted fire in an accommodation compartment on board a ship. This information was then used to provide estimates of potential harm and safety acceptance criteria. The estimates of potential harm and safety acceptance criteria are illustrative in nature and reflect one possible approach that might be used to establish the relative hazard.

Fundamental concepts important to the development of these estimates include the definition of "smoke" and "risk." Smoke is defined by ASTM[3] as a complex mixture of the airborne solid and liquid particulates and gases evolved when a material undergoes pyrolysis or combustion. Smoke affects safety to life in two major ways: first, the reduction of visibility, and secondly the toxicological effect of the gases and particulates. The reduction in visibility limits or prevents the victim from leaving an area of danger. The toxicological effects result in disability or death.

Each exposure has an associated risk. Fire risk is defined by ASTM as the product of the probability that a fire will occur and the potential for harm to life and damage to property resulting from its occurrence. Roux[4] expressed risk, as applied to life safety as follows:

Risk = (expected frequency of an event) x
(expected exposure) x (potential for harm)

In this view risk is a number ranging from zero to a large value. Societal values and judgements determine the point along this scale above which risk is unacceptable (hazardous) and below which it is acceptable (safe).

### 2.2 Specific Approach

General: Information regarding the concentrations of toxicant gases and the optical density at pre-selected exposure locations in the passageway was obtained using a compartment fire simulated by liquid propane (L/P)/air burners. Three series of tests were conducted. Two of these series evaluated individual materials that may contribute to life safety hazards in an accommodation compartment. These materials were deck coverings and bulkhead panels. The third test series evaluated alternative furnishings and occupant items used on merchant ships and U.S. Coast Guard ships. The third test series also simulated the development of "real" fires on board a ship and formed the basis for an assessment of the relevant smoke/gas hazards.

Because of the variability that exists during real fires, a fire test can provide only an indication of the extent to which selected measurable fire parameters change in the fire compartment or adjacent areas. General factors of importance in evaluating a specific material for potential hazards include: the quantity of the material; its assembled end-use configuration and orientation; its placement in an assembled fuel array and the mode of ignition. Combustibility properties, including ignitability, flame area, rate of heat release and ventilation also strongly influence the development of fire conditions.

Whatever fire test is devised it represents only one member of a family of possible fire scenarios. However, the members of this family have at least three major elements in common. Two elements of importance include: (1) the "baking" effect of high temperatures; and (2) the oxidative pyrolysis of the test materials that occurs as a result of the direct impingement of flames onto their surface. A third element is the local concentration of oxygen in the compartment.

The process of making an assessment of the smoke or gas hazards has four major steps:

selection of fire test scenario

selection of location and duration of exposure selection of appropriate measurable exposure parameters that are relevant to life safety

estimate of minimum risk levels that can be considered to be hazardous

In this project a fire test scenario was chosen to reflect the effect of a pre-flashover fire on the test materials. An exposure location was chosen where the fire exposure could be expected to have important effect on life safety on board a ship. Appropriate exposure parameters chosen included: six selected gases (CO, $CO_2$, $O_2$, $SO_2$, $NO_x$ and total hydrocarbons), temperature, and optical density.

The fire scenario: A reproducible fire source of known fire intensity was developed using a series of LP/air burners. This approach provided a reproducible fire source. The gas flow through the burners was regulated to provide an equivalent fire load corresponding to a 55 lb wood-crib fire, thus simulating a typical pre-flashover fire involving an upholstered chair or mattress/bedding fire. The high compartment temperatures needed to simulate the "baking" effect were obtained using five large ring burners. The effects of direct flame impingement was modeled by directing a series of pipe burners directly onto the test specimen. For the bulkhead panel tests these pipe burners were oriented to direct flames at the bottom of the bulkhead panels. For the deck covering tests they were directed downward onto the deck covering materials. A description of the burner configurations is outlined in previous reports[5,6,7]. All materials were installed in their end-use configuration.

Location and duration of exposure: It was assumed that lethal conditions would exist in the fire compartment. Therefore the exposure location of interest was chosen in the adjacent passageway fifteen feet aft of the compartment door centerline. The passageway was of importance because of the requirements for personnel egress and the need for ingress for damage control personnel. A response time of fifteen minutes was assumed reasonable for the detection and arrival of damage control personnel. To establish exposure levels gas analysis data were taken at three levels in the passageway. These levels corresponded to those which represent the exposure conditions for a crawling man (16"), a crouching man (48") and the concentrations that would be found near the overhead (72").

Measured exposure parameters: Exposure parameters of interest to life safety were temperature, local gas composition and the optical density of smoke. Temperatures were recorded in the fire compartment and at each gas probe inlet positions in the passageway. Gas composition profiles were obtained for five gases, carbon monoxide, carbon dioxide, oxygen, nitrogen oxides, sulfur dioxide, and total hydrocarbons. Optical density was monitored at six elevations across the assigned exposure location.

Minimum risk levels: A limited analysis was made to outline the anticipated effect of the exposure parameters on life safety. Because of the lack of appropriate short-duration toxicological data these analyses are considered to be illustrative only and no recommendation for their use in the regulation of materials is intended.

# 3.0 EXPERIMENTAL

## 3.1 Facilities

The tests were performed on board the fire test vessel ALBERT E. WATTS. The test compartments were set up on the 01 deck of the after-deck house of the ship, on the port corridor. An overall view of the A.E. WATTS is shown in Figure 1. A schematic diagram of the port corridor of the after deck house is shown in Figure 2.

For all three test series the assumed exposure location was located 15'3" aft of the centerline of the compartment door. Figure 3 shows a plan view of the passageway and compartment area. Smoke obscuration was monitored using a system of six laser light sources and sensors spaced between the passageway deck and overhead. Flow velocity probes were located near the gas analyzer sample input lines and in the doorway.

Depending on the type of test being conducted, the ring and pipe burners were varied to provide the necessary heat and flame. Detailed schematic drawings of the burner and instrumentation placement are shown (Figures 4,5,6). There were five ring burners and four pipe burners for the bulkhead finish and bulkhead panel fire tests. The pipe burners were directed

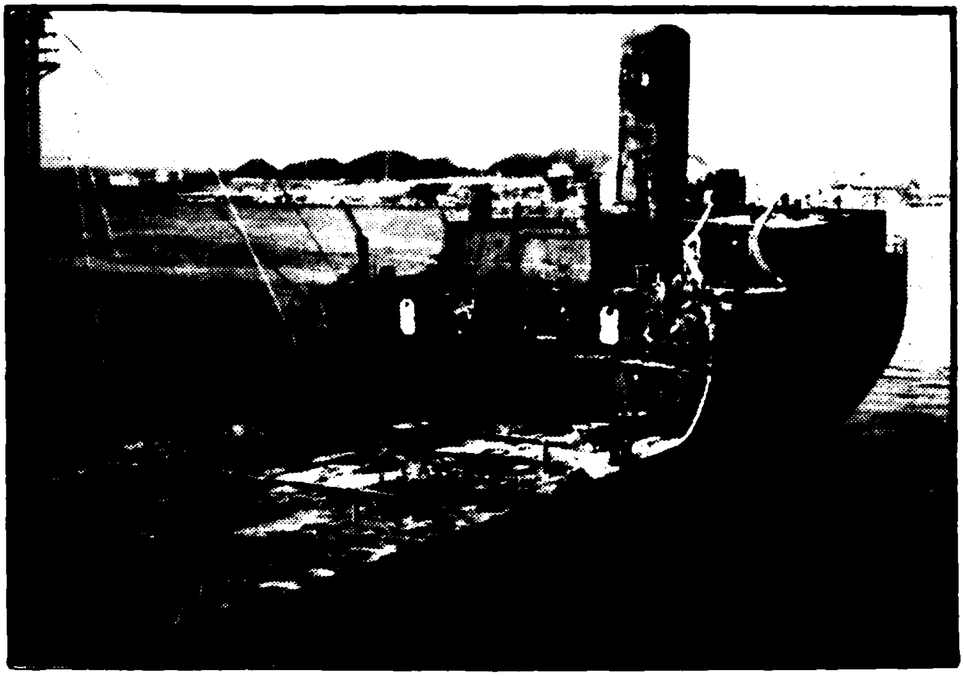

FIGURE 1. THE ALBERT E. WATTS FIRE TEST SHIP

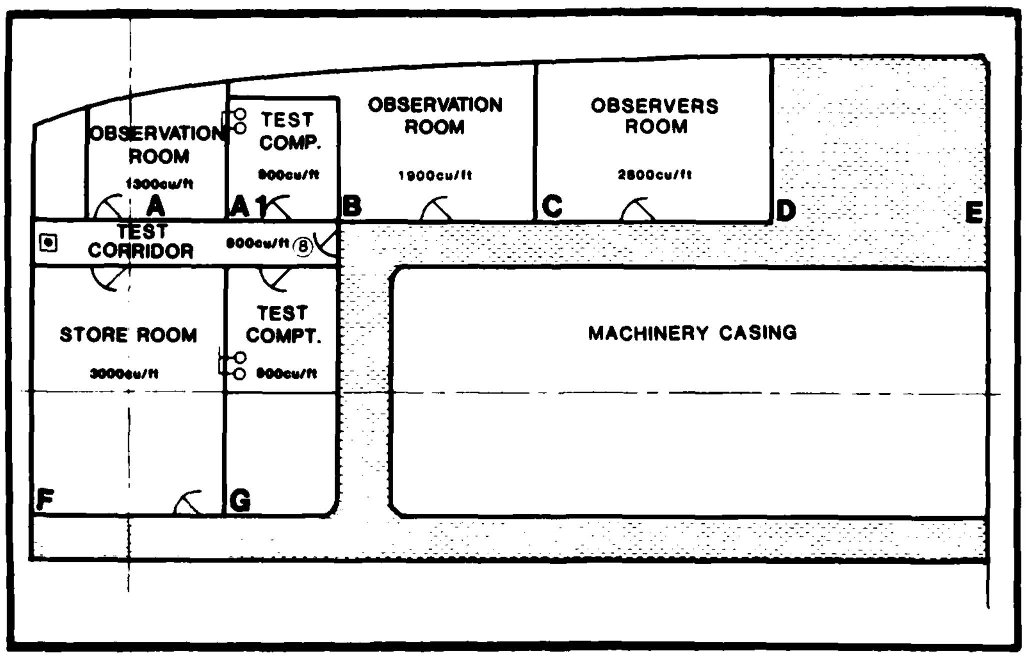


FIGURE 2. THE AFTER DECK HOUSE TEST AREA

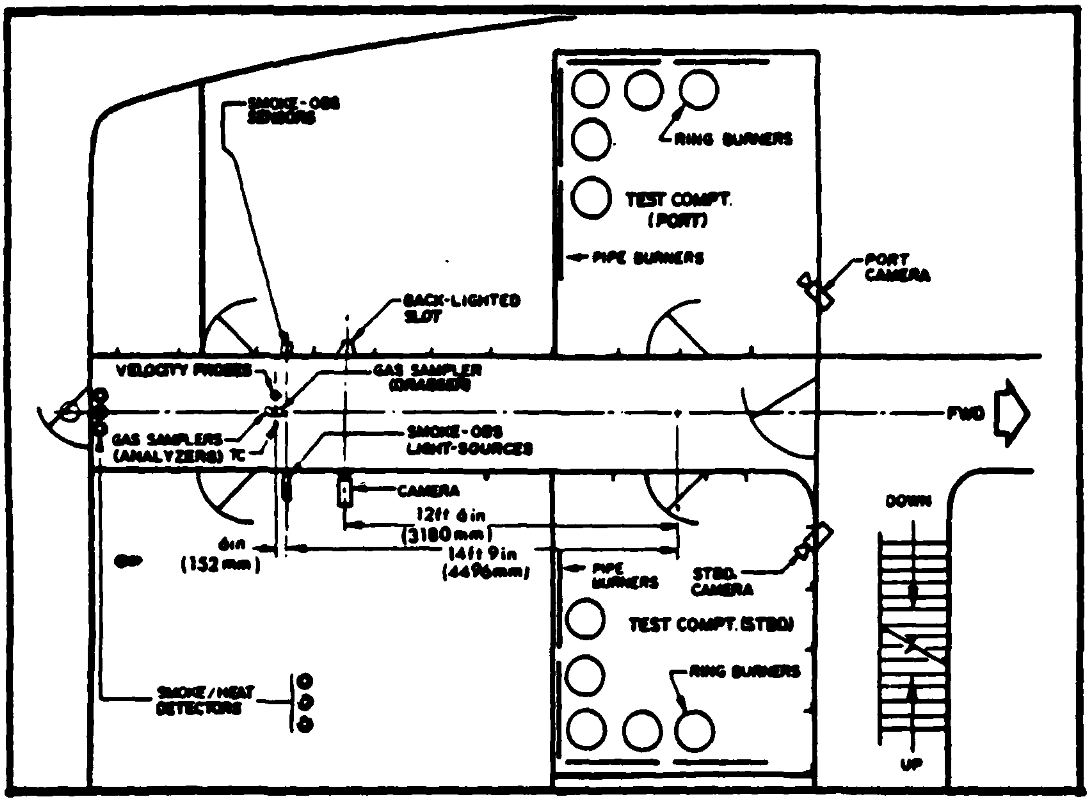


FIGURE 3. COMPARTMENT/PASSAGEWAY TEST AREAS

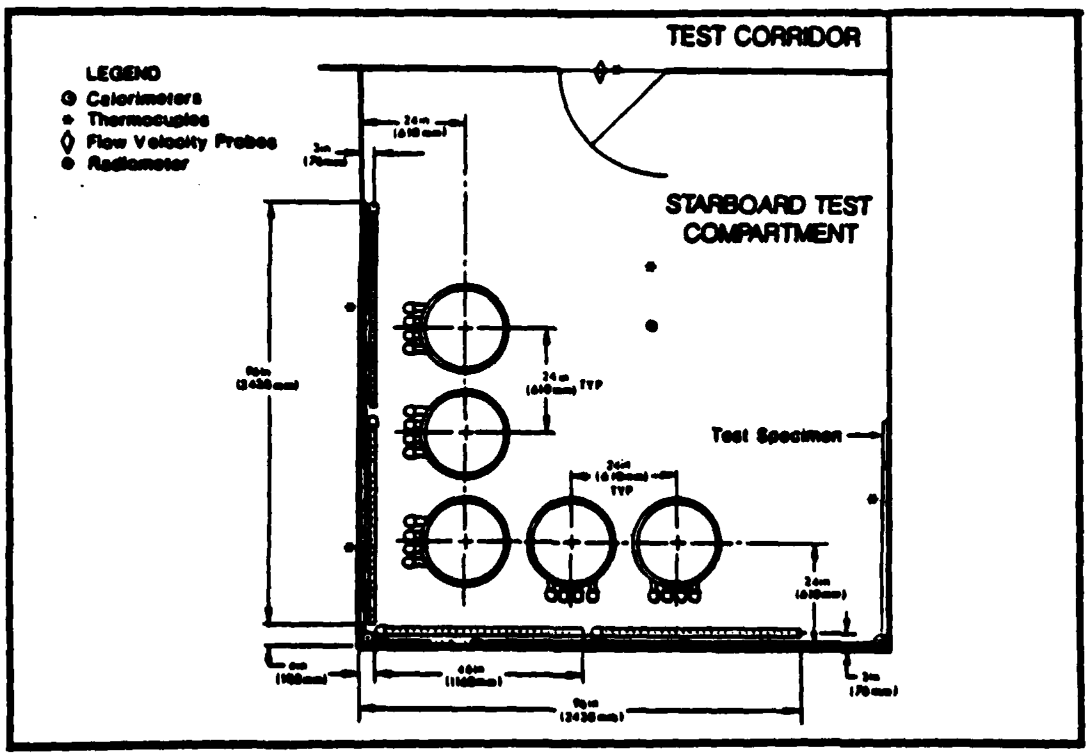


FIGURE 4. EXPERIMENTAL ARRANGEMENT OF THE TEST COMPARTMENT FOR THE BULKHEAD TEST SERIES

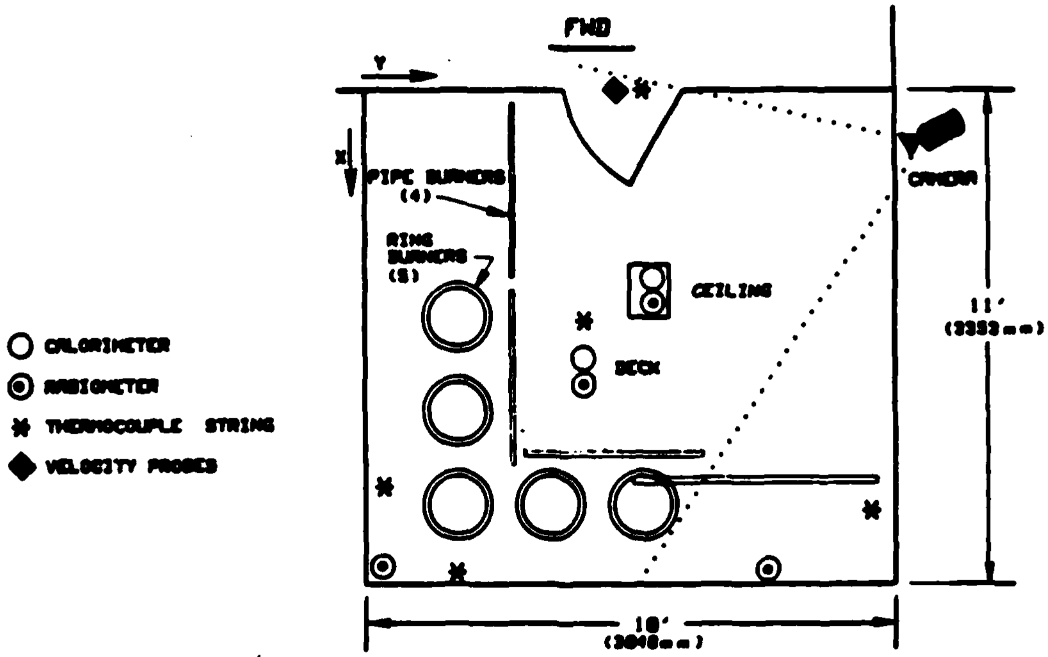


FIGURE 5. EXPERIMENTAL ARRANGEMENT OF THE TEST COMPARTMENTS FOR THE DECK COVERING TEST SERIES

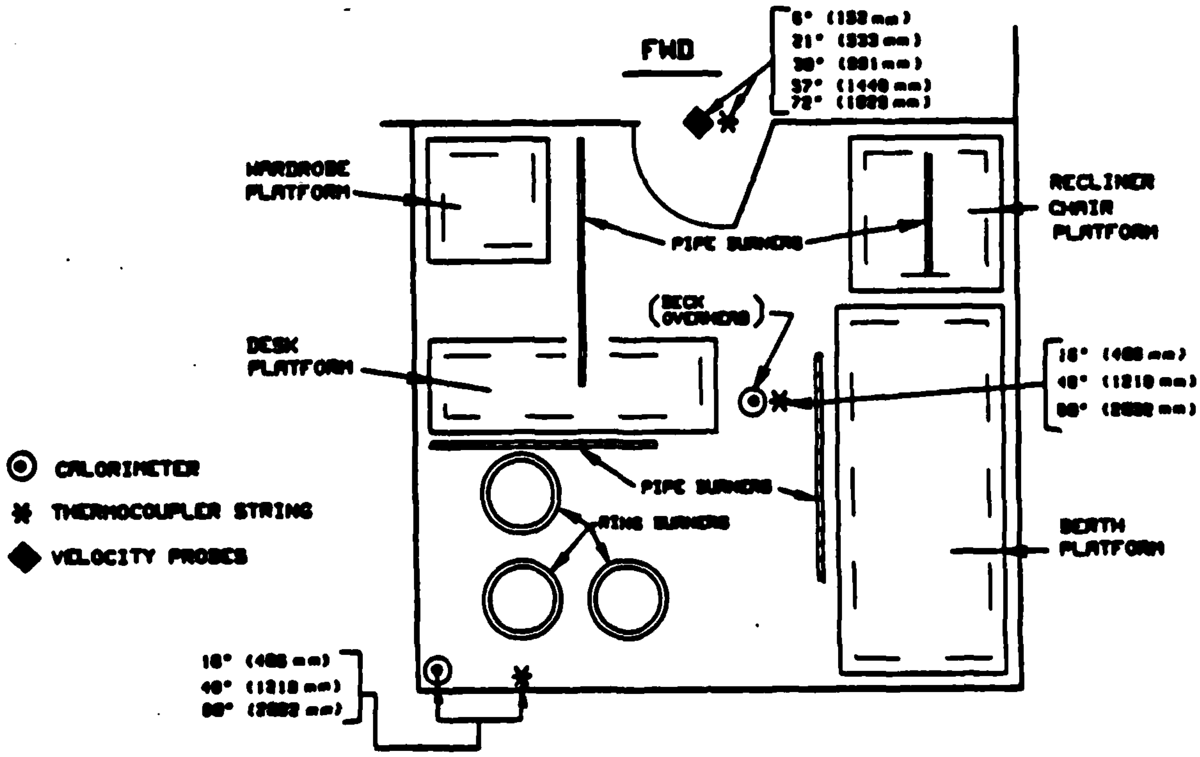


FIGURE 6. EXPERIMENTAL ARRANGEMENT OF THE TEST COMPARTMENT FOR THE MERCHANT AND U.S. COAST GUARD FURNISHINGS TEST SERIES

directly onto the exposed bulkhead surfaces about 6 inches above the deck (Figure 4). For the deck covering tests the pipe burners were mounted in the central part of the compartment and directed downward (Figure 5). For the furnishings tests only three ring burners were used and the pipe burners were placed to provide a strong direct ignition source on selected combustible fire loads (Figure 6). The tests were conducted from Observers Room C (Figure 2) and the burner control consoles together with the TV monitoring equipment are shown in Figures 7 and 8.

Because of watertight construction in a ship, ventilation air flows are of special importance during shipboard fires. An elevation view of the air conditioning system is outlined in Figure 9. Normal shipboard practice includes the closure of dampers to and from the area in the event of fire. When this is done the fire gases can exit only through an open hatch or through the make-up air shaft in the return air system. The specific conditions evaluated were a closed hatch and the make-up air damper was adjusted to allow 25% air flow into the heat pump unit. Air supply to the fire is then controlled either by infiltration from compartments within the fire zone (Figure 10) or by the flow of input/output air in the passageway, the exhaust system and make-up air grill. The air flow in the passageway is "outward" along the overhead, "inward" along the deck (Figure 10), and exits through the make-up air vent.

### 3.2 Materials

Three classes of materials were tested: bulkhead finishes, deck coverings, and compartment furnishings. The approach was to conduct full-scale fire tests in which actual shipboard conditions were simulated as closely as possible. Four sub-classes of buklkhead finish materials were evaluated: decorative laminates, decorative laminates bonded to a honeycomb core, polyvinylchloride bonded to sheet steel, and fire retarded (FR) paint applied to sheet steel. A brief outline of these materials is given in Table 1.

Five classes of deck covering materials were tested. These varied from combustible carpets to non-combustible magnesium oxychloride composite flooring. Carpet tests included 100% Nylon, 100% wool, 100% polypropylene,

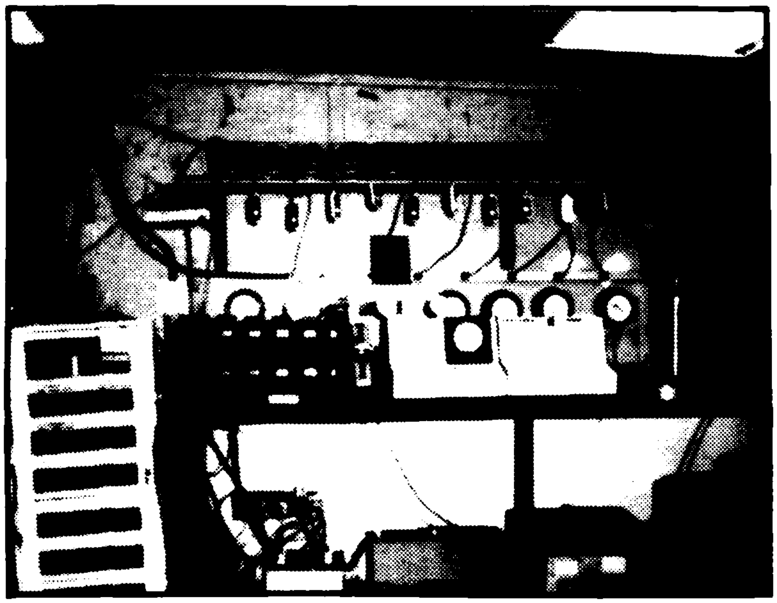

FIGURE 7. FIRE TEST CONTROL CONSOLE

FIGURE 8. TV MONITORING EQUIPMENT IN THE CONTROL ROOM

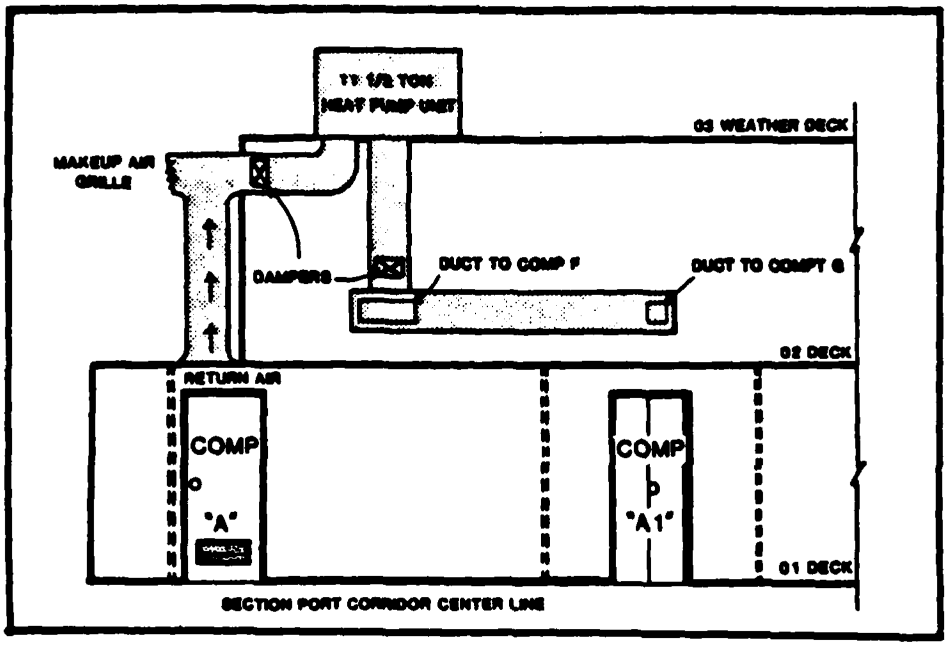


FIGURE 9. ELEVATION VIEW OF VENTILATION SYSTEM

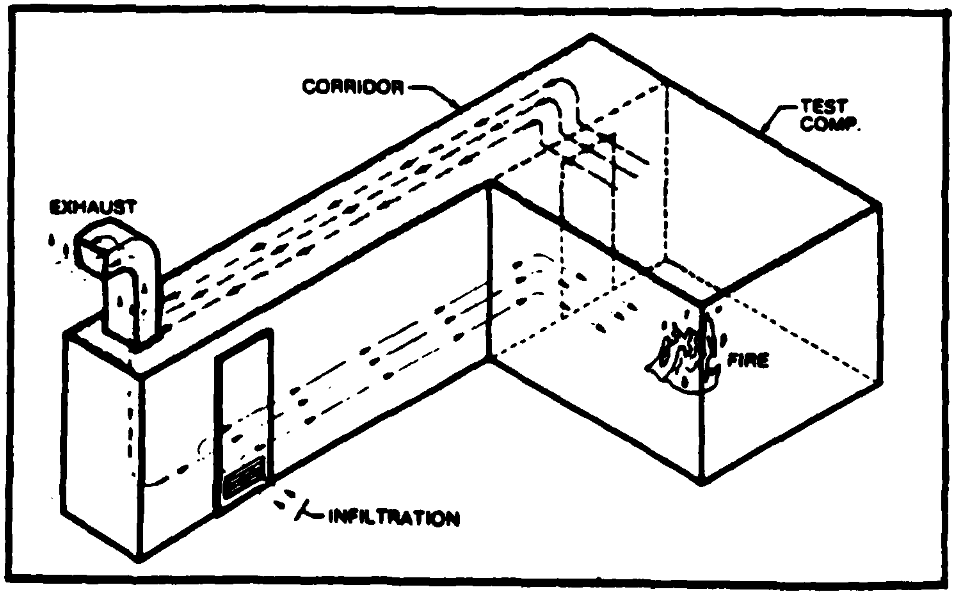


FIGURE 10. SCHEMATIC DIAGRAM OF FIRE-INDUCED AIR FLOWS

TABLE 1

BULKHEAD MATERIALS

| | | | |
|---|---|---|---|
| I. | Decorative Laminates | | Description |
| | USCG No. 1 | | 1/16" (1.6 mm) Decorative Laminate |
| | 2 | | 1/16" (1.6 mm) Melamine Decorative Laminate |
| | 3 | | 1/32" (0.8 mm) Melamine Decorative Laminate |
| | 4 | | 1.4 mm Decorative Laminate |
| | 5 | | 1/16" (1.6 mm) Decorative Laminate |
| | 6 | | 1/16" (1.6 mm) Decorative Laminate |
| II. | Decorative Laminates Bonded to Honeycomb Core | | |
| | USCG No. 13 | Type 1 | Decorative Laminate bonded to both sides of a honeycomb core |
| | 61 | Type 2 | Decorative Laminate bonded to both sides of a honeycomb core |
| | 62 | Type 3 | Decorative Laminate bonded to both sides of a honeycomb core |
| III. | PVC on Sheet Steel | | |
| | USCG No. 7 | | 0.2 mm PVC film (Type 1) bonded to 0.7 mm sheet steel using a resorcinal/formaldehyde adhesive |
| | 8 | | 0.2 mm PVC film (Type 2) bonded as above |
| | 9 | | 0.2 mm PVC film (Type 3) bonded as above |
| IV. | Paint on Sheet Steel | | |
| | USCG No. 101 | | Primer (60 sq. yd/gal) undercoat (66 sq. yd/gal) enamel (66 sq. yd/gal) applied to 20 AWG sheet steel |
| | 102 | | Primer (55 sq. yd/gal), 3 brush coats of FR undercoat (50 sq. yd/gal) applied to 20 AWG sheet steel |
| | 107 | | FR coating (2.5 sq. m/l) applied to 20 AWG steel |

and acrilan blends. A brief description of the carpet types is outlined in Table 2. Composite systems included magnesium oxychloride/vinyl systems; acrylic resin/aggregate systems; and, styrene-butadiene systems with selected topping materials. Miscellaneous deck covering systems included vinyl sheeting and poured polyurethane base decking.

The furnishings materials tests included: (1) occupant items only; (2) furniture only, and (3) combinations of occupant items and furniture. For convenience the tests were given a descriptive title indicated as follows:

| | |
|---|---|
| OCC | Occupant items only, with no furniture included. |
| CANFURN | Canadian Coast Guard (CCG) supplied wooden furniture. |
| CANCOMB | Combination of occupant items and CCG supplied wooden furniture, together with bulkhead finish materials and deck coverings. |
| ENECOMB | Combination of occupant items and USCG (G-ENE) supplied aluminum furniture without bulkhead finish materials or deck covering. |

An outline of the combustible loadings for the furnishings tests is given in Table 3.

### 3.3 Results

Bulkhead finish tests: There were 15 materials used during the bulkhead finish tests. Of these, twelve were supplied by the Canadian Coast Guard (Ship Safety Branch) and three by the United States Coast Guard (Office of Engineering). The Canadian-supplied materials comply with the Canadian regulatory requirements and those of the 1974 SOLAS convention[8] for surfaces requiring low flame spread.

A summary of the time-averaged values for the bulkhead finish exposure parameters is given in Table 4. The average was calculated from the beginning of the 11th to the end of the 30th minute. Data is presented in the form of "net" values in which the baseline test values were subtracted. Data is also given for the specific optical density for these tests as measured using NFPA 258-76.[9] During the full-scale tests, except for Specimen No. 6, the optical density for the decorative laminates ranged between 0 and 0.2.

## TABLE 2

## DECK COVERING MATERIALS

| | | USCG No. | Description |
|---|---|---|---|
| I. | Carpets | | |
| | Nylon | 1 | 100% Nylon, 28 oz. (792 gm) pile weight |
| | | 4 | 100% Nylon, 35 oz. (990 gm) pile weight |
| | | 8 | 100% Nylon, 29 oz. (820 gm) pile weight |
| | Wool | 7 | 100% Wool, 42 oz. (1189 gm) pile weight |
| | | 9 | 100% Wool -- |
| | | 12 | 100% Wool -- |
| | Polypropylene | 2 | 100% polypropylene, 28 oz. (792 gm) pile weight |
| | | 11 | 100% polypropylene, 20 oz. (566 gm) pile weight |
| | Blends | 5 | 80% Wool/20% Nylon, 34 oz. (962 gm) pile weight |
| | | 6 | 80% Wool/20% Nylon, 41 oz. (1160 gm) pile weight |
| | | 3 | 70% Acrilan/30% Nylon, 28 oz. (792 gm) pile weight |
| II. | Magnesium Oxychloride Systems | 16 | 1 inch, Mg OCl/Vinyl Composite |
| | | 19 | 1 inch, Mg OCl/Vinyl Composite |
| III. | Resin/ Aggregate Systems | 17 | 3/8 inch Acrylic Resin/Aggregate |
| | | 18 | 3/8 inch Acrylic Resin/Aggregate |
| IV. | Composite Systems | 15 | Styrene/Butadiene Underlay with tile topping |
| | | 20 | Styrene/Butadiene Underlay with sheet rubber topping |
| V. | Miscellaneous Systems | 10 | Vinyl Sheet |
| | | 13 | Poured Polyurethane Based Decking |

TABLE 3

WEIGHT OF FURNISHINGS TESTS MATERIALS (lbs)

| | MERCHANT SHIP (WOODEN FURNITURE) | | | | | | USCG CUTTER (ALUMINUM FURNITURE) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | BEST CASE | | WORST CASE | | | BEST CASE | | WORST CASE | |
| | CAN FURN | OCC-1 | CAN COMB-1 | OCC-2 | CAN COMB-2 | CAN COMB-3 | OCC-3 | ENE-1 | OCC-4 | ENE-2 |
| Test Number: | 2 | 1 | 5 | 3 | 6 | 10 | 4 | 7 | 9 | 8 |
| Furniture | 360 | - | 360 | - | 360 | 360 | - | - | - | - |
| Mattress | 12 | - | 12 | - | 12 | 12 | - | 70 | - | 70 |
| Bedding | - | 10 | 10 | 10 | 10 | 10 | 20 | 20 | 20 | 20 |
| Clothing | - | 35 | 35 | 70 | 70 | 70 | 80 | 80 | 140 | 140 |
| Publications | - | 50 | 50 | 95 | 95 | 95 | 125 | 125 | 180 | 180 |
| TOTAL (lbs) | 372 | 95 | 467 | 175 | 547 | 547 | 225 | 295 | 340 | 430 |

TABLE 4

AVERAGE NET VALUES OF EXPOSURE PARAMETERS FOR FOR FULL-SCALE BULKHEAD TESTS

| USCG Specimen | | SMOKE (OPTICAL DENSITY) | NITROGEN OXIDES (PPM) | SULFUR DIOXIDE (PPM) | OXYGEN (PERCENT) | CARBON DIOXIDE (PERCENT) | CARBON MONOXIDE (PPM) | HYDROGEN CYANIDE (PPM) | FORMALDEHYDE (PPM) |
|---|---|---|---|---|---|---|---|---|---|
| I. BASELINE DATA | | | | | | | | | |
| 0 | Propane only | | 4.35 | 147.7 | 16.2 | 3.15 | 1029 | 0 | 0 |
| | Baseline | | 0 | 0 | 16.2 | 0 | 0 | 0 | 0 |
| II. DECORATIVE LAMINATES | | | | | | | | | |
| 1 | | 183 | 21.4 | 16.5 | 14.9 | 0.84 | 1156 | 50 | 10 |
| 2 | | 194 | 27.6 | 57.0 | 13.9 | 2.20 | 2039 | 150 | 20 |
| 3 | | 109 | 16.7 | 8.8 | 15.2 | 0.76 | 823 | 15 | 10 |
| 4 | | 162 | 14.2 | 47.6 | 15.5 | 0.63 | 1813 | 30 | 10 |
| 5 | | 122 | 9.8 | 46.1 | 15.6 | 0.96 | 649 | 10 | 10 |
| 6 | | 159 | 18.9 | 48.5 | 15.5 | 0.96 | 3378 | 75 | 20 |
| III. DECORATIVE LAMINATES BONDED TO HONEYCOMB CORE | | | | | | | | | |
| 13 | | | 18.2 | 97.4 | 15.5 | 0.69 | 1132 | 0 | 0 |
| 61 | | | 15.1 | 51.3 | 14.5 | 1.04 | 868 | 0 | 2 |
| 62 | | | 20.9 | 59.8 | 16.9 | 0.00 | 4183 | 30 | 0 |
| IV. PVC ON SHEET STEEL | | | | | | | | | |
| 7 | | 83 | 9.3 | 15.3 | 15.6 | 0.40 | 280 | 10 | 5 |
| 8 | | 80 | 8.7 | 52.3 | 15.7 | 0.52 | 187 | 5 | 0 |
| 9 | | 62 | 7.7 | 43.0 | 15.4 | 0.71 | 308 | 0 | 0 |
| V. PAINT ON SHEET STEEL | | | | | | | | | |
| 101 | | 99 | 5.1 | 15.0 | 15.9 | 0.96 | 0 | 5 | 5 |
| 107 | | 203 | 10.0 | 24.2 | 15.1 | 0.00 | 156 | 2 | 5 |
| 102 | | 83 | 3.2 | 10.9 | 17.1 | 0.00 | 0 | 2 | 5 |

*Average observed values

For the Melamine laminates bonded to a honeycomb core values up to 2 were observed. It is probable that the high values may involve an instrument error due to thermal effects or condensation on the laser system since there was no obscuration visually during the test. Nitrogen oxides ranged from a low of 5.1 to a high of 27.6 ppm. Oxygen depletion resulted in average ambient oxygen levels of about 15.5%. Carbon monoxide levels ranged from nil to 4183 ppm with much lower values for FR paint or PVC on sheet steel. For two of the decorative finishes bonded to a honeycomb core the CO concentration was nil.

Deck covering tests: Results for the average "net" values of smoke, temperature and toxicant concentration for deck coverings are summarized in Table 5. Visibility from a viewing port during these tests was excellent and was confirmed by the low optical density values (0 to 0.03). Negative values shown for the selected gases result from subtraction of baseline test values from the observed experimental values. A systematic error appears to have resulted from the use of this technique for the total hydrocarbon values. Carbon monoxide varied from zero to 900 ppm. Nitrogen oxides ranged from 0.4 to 5 and corrected $SO_2$ values between 0 and 20 ppm. The $SO_2$ values may be unreliable due to an interference caused by water vapor in the detector. The data reported were taken from the highest gas sample inlet in the passageway where the highest concentrations are present.

Furnishing tests: Experimental values for the furnishings tests are reported in graphical format (Figures 11-18). Values for several tests are combined together on a single plot for conciseness of presentation. In these tests there was a "bake-out" period of 15 minutes using three ring burners. This period provided an internal calibration factor for the test. After the bake-out period was completed the pipe burners were ignited. Experimental values for optical density are given in Figures 11 and 12. (The numbers of the individual plots correspond to the assigned test number.) The ENECOMB tests 7 and 8 were fully furnished but did not have deck coverings or bulkhead finishes. Values for carbon monoxide (Figures 13, 14); percent oxygen (Figures 15, 16); nitrogen oxides (Figure 17); and temperature (Figure 18) are shown. Temperatures for the ENECOMB tests have a maximum of about 250°C and temperatures for Tests 6 and 10 exceed 500°C after 30 minutes.

TABLE 5

AVERAGE "NET" VALUES OF SMOKE, TEMPERATURE AND TOXICANT CONCENTRATIONS FOR DECK COVERINGS-OPEN VENT

| DECK COVERING | SMOKE (OPTICAL DENSITY) | OXYGEN DEPLETION (PERCENT) | CARBON MONOXIDE (PPM) | CARBON DIOXIDE (PERCENT) | NITROGEN OXIDES (PPM) | SULFUR DIOXIDE (PPM) | TOTAL HYDROCARBONS (PPM) |
|---|---|---|---|---|---|---|---|
| Carpets | | | | | | | |
| Nylon | 0 | 1 | 400 | 0.3 | 1.7 | 20 | -42* |
| | .03 | 0 | 500 | 0.1 | 2.5 | 20 | -30 |
| | .01 | 0 | 600 | -0.2 | 2.4 | 20 | -55 |
| Wool | 0 | 0 | 700 | 0 | 5.0 | 20 | -45 |
| | 0 | 0 | 0 | 0.1 | 4.3 | 0 | -35 |
| | 0 | 0 | 0 | 0.1 | 4.5 | 0 | -45 |
| Polypropylene | .02 | 0 | 100 | -0.2* | 1.1 | 10 | -57 |
| | .03 | 1 | 0 | 0.4 | 3.4 | 0 | -20 |
| Blends | .01 | 0 | 200 | -0.1* | 2.3 | 20 | 25 |
| | 0 | 0 | 300 | 0 | 6.2 | 20 | -34 |
| | 0 | 0 | 900 | -1.4* | 0.2 | 20 | -15 |
| Composite Systems | | | | | | | |
| $M_gO$ Cl/Vinyl | 0 | 1 | 400 | 0.1 | 1.5 | 10 | -40 |
| | 0 | 1 | 600 | 0.2 | 2.5 | 20 | -60 |
| Aggregate/Acrylic | 0 | 1 | 200 | 0 | 2.5 | 20 | -65 |
| | 0 | 1 | 200 | 0 | 0.4 | 10 | -25 |
| Styrene/Butadiene Underlay/Topping | 0 | 1 | 200 | 0.1 | 1.0 | 10 | -30 |
| | 0 | 0 | -100* | -0.1* | 1.8 | 0 | -60 |
| Vinyl Sheet | | 1* | 100 | -0.5* | -0.3* | 0 | -45 |
| Poured Polyurethane Base | 0 | 0 | -100** | -0.2* | 1.9 | -10* | -13 |
| Baseline | 0 | - | - | - | - | - | - |

* Negative with respect to values obtained during baseline fire
Corridor Temp °C

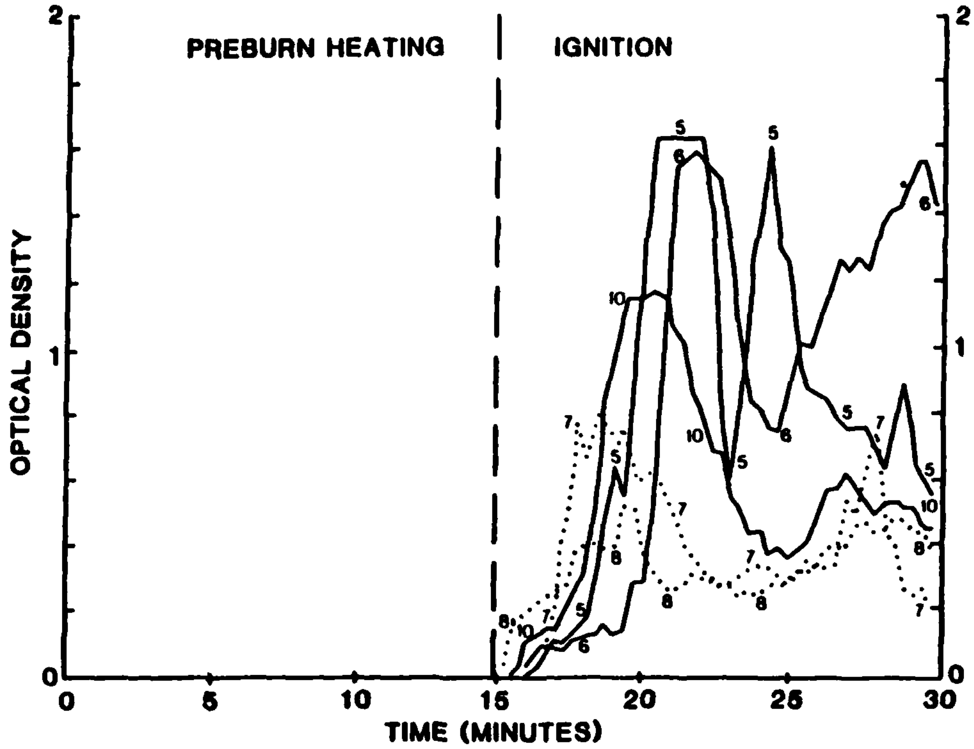


FIGURE 11. OPTICAL DENSITY VS. TIME - SMOKE/GAS HAZARDS - FURNISHINGS TESTS 5, 6, 7, 8, 10

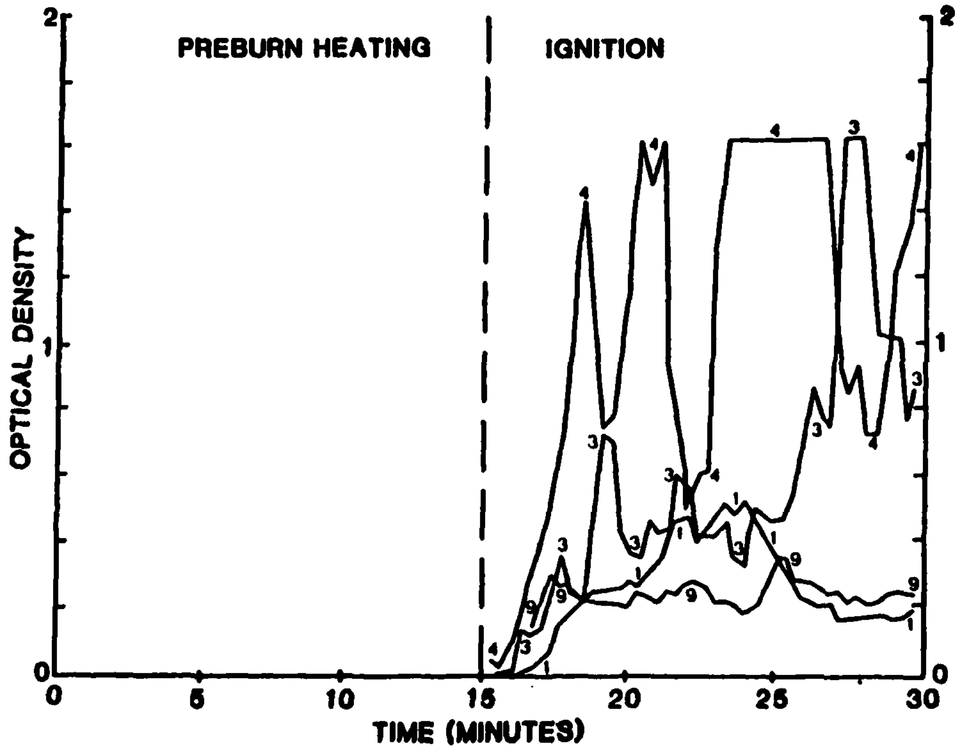


FIGURE 12. OPTICAL DENSITY VS. TIME - SMOKE/GAS HAZARDS - FURNISHINGS TESTS 1, 3, 4, 9

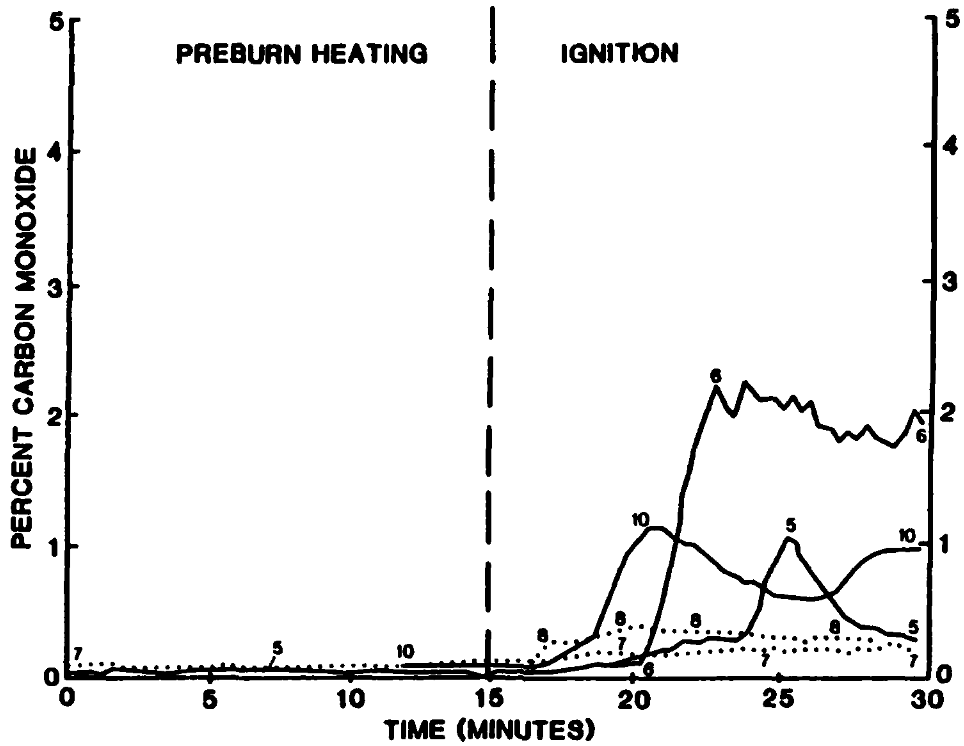


FIGURE 13. PERCENT CARBON MONOXIDE VS. TIME - SMOKE/GAS HAZARDS - FURNISHINGS TESTS 5, 6, 7, 8. 10

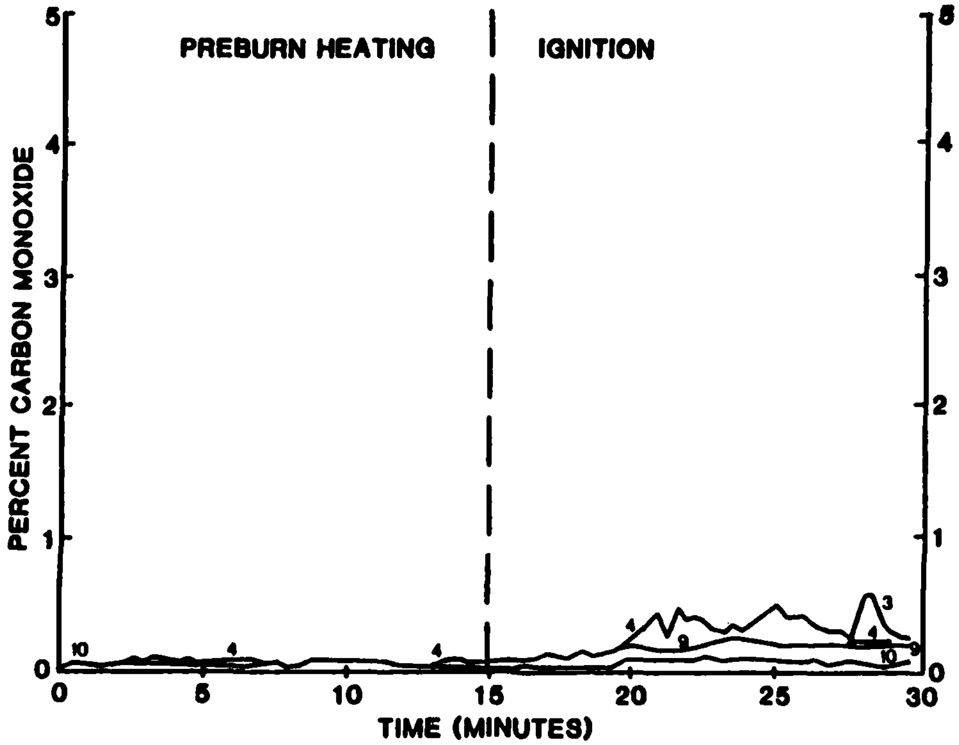


FIGURE 14. PERCENT CARBON MONOXIDE VS. TIME - SMOKE/GAS HAZARDS - FURNISHINGS TESTS 1, 3, 4, 9

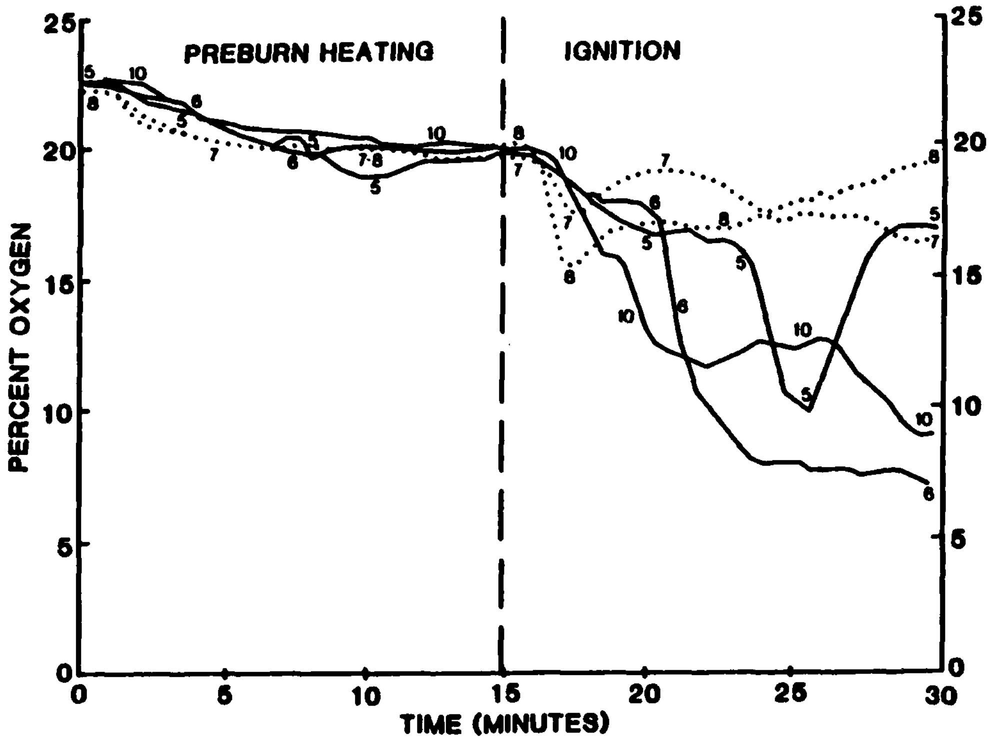


FIGURE 15. PERCENT OXYGEN VS. TIME - SMOKE/GAS HAZARDS - FURNISHINGS TESTS 5, 6, 7, 8, 10

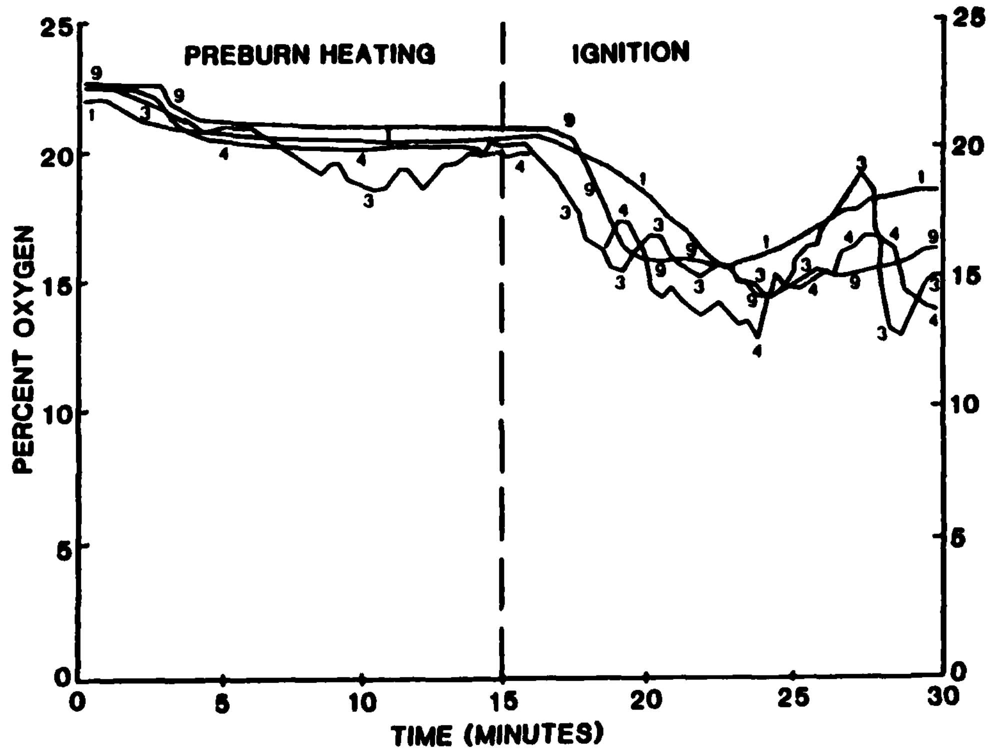


FIGURE 16. PERCENT OXYGEN VS. TIME - SMOKE/GAS HAZARDS - FURNISHINGS TESTS 1, 3, 4, 9

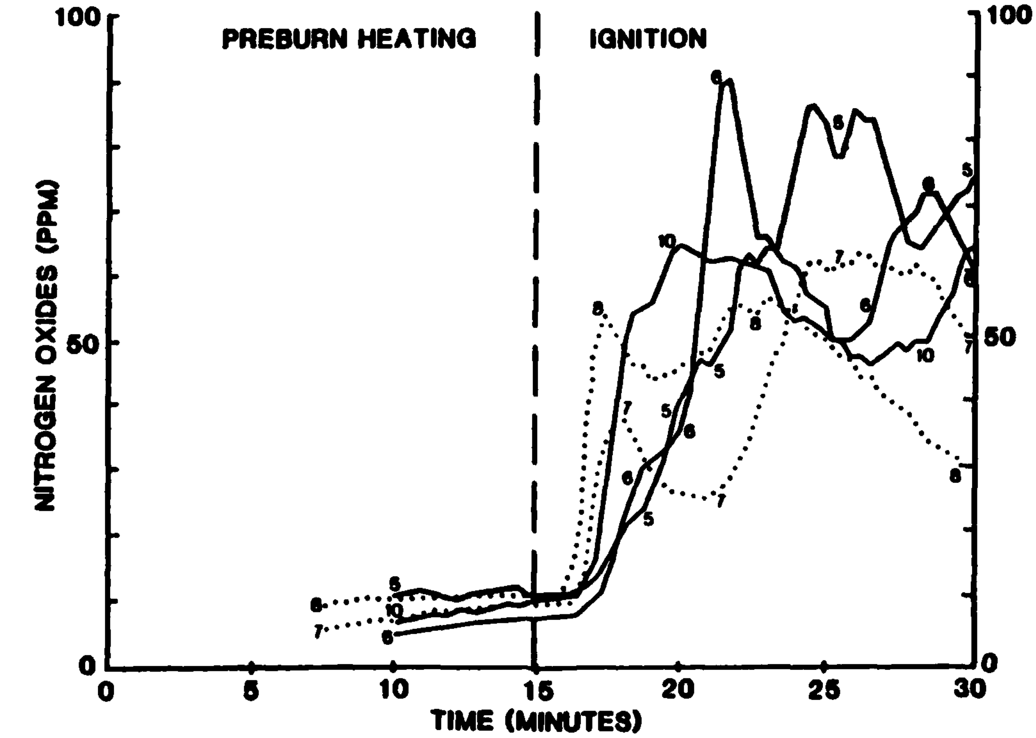


FIGURE 17. NITROGEN OXIDES ($NO_x$) VS. TIME - SMOKE/GAS HAZARDS - FURNISHINGS TESTS 5, 6, 7, 8, 10

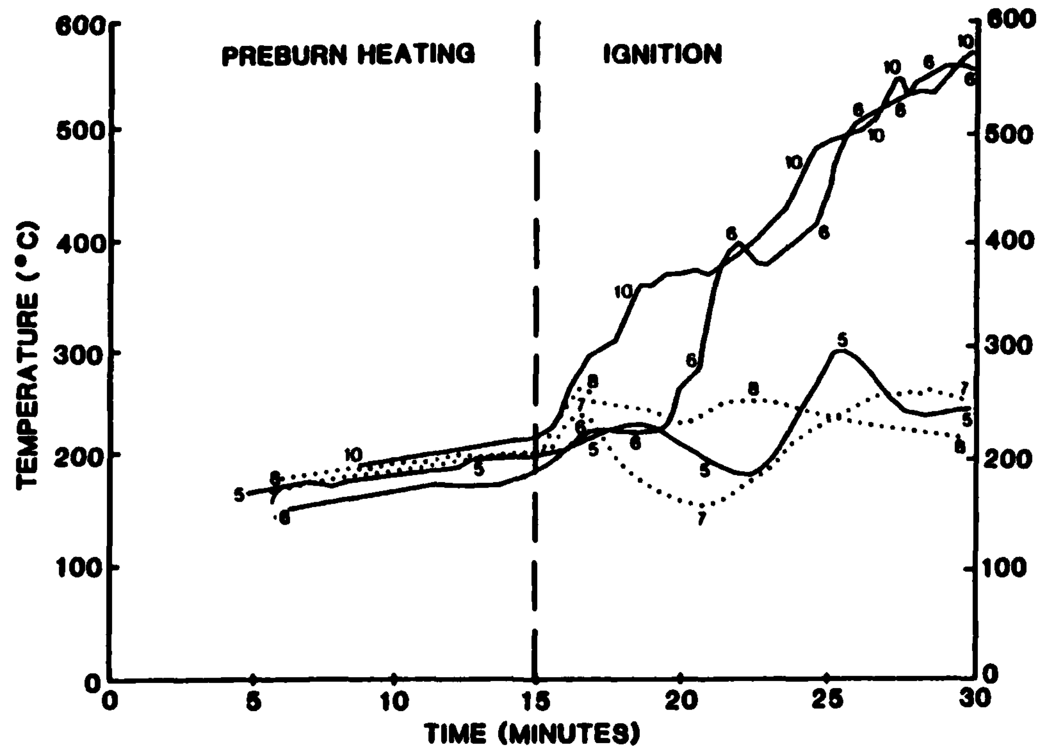


FIGURE 18. TEMPERATURE VS. TIME - SMOKE/GAS HAZARDS - FURNISHINGS TESTS 5, 6, 7, 8, 10

## 4.0 DISCUSSION

The overall objective of this program was to evaluate quantitatively the rate of production of smoke and toxic gases that are generated during shipboard fires in accommodation spaces and relate these quantities to the development of important life safety hazards. The specific objective of each of the tasks was to conduct a hazard analysis relative to threats to life safety associated with the involvement of selected bulkhead finishes, deck covering materials and furnishing ensembles in a passageway adjacent to the compartment of fire origin.

A hazard analysis involves four major elements: (1) the probabilities of occurrence, (2) exposures, (3) potential for harm or damage, and (4) non-acceptability threshold limits.

### 4.1 The Fire

In a fire test the probability of occurrence is set to unity by preselecting a specific fire scenario. Since all fires differ, the relation between the fire scenario selected and any real fire is always uncertain. Important factors which must be considered include: changes in fire loading, geometry of fuel arrays, compartment size, and ventilation. To perform a complete hazard analysis, a family of "typical" fire scenarios should be used. In practice, a single fire test is used primarily because of the cost of large-scale fire testing.

The baseline fire that was selected for this series of tests used an liquid propane/air fuel fire with a thermal output corresponding to a 55 lb oak wood crib fire. This fire exposure was chosen to simulate pre-flashover fire conditions. The temperatures reached at the ceiling in the fire compartment were between 350$^{o}$ to 400$^{o}$C. In the passageway they ranged from 180$^{o}$ to 260$^{o}$C. A typical time/temperature plot is shown in Figure 19. In this plot the passageway temperature remains approximately constant after 10 minutes at a level of 200$^{o}$C.

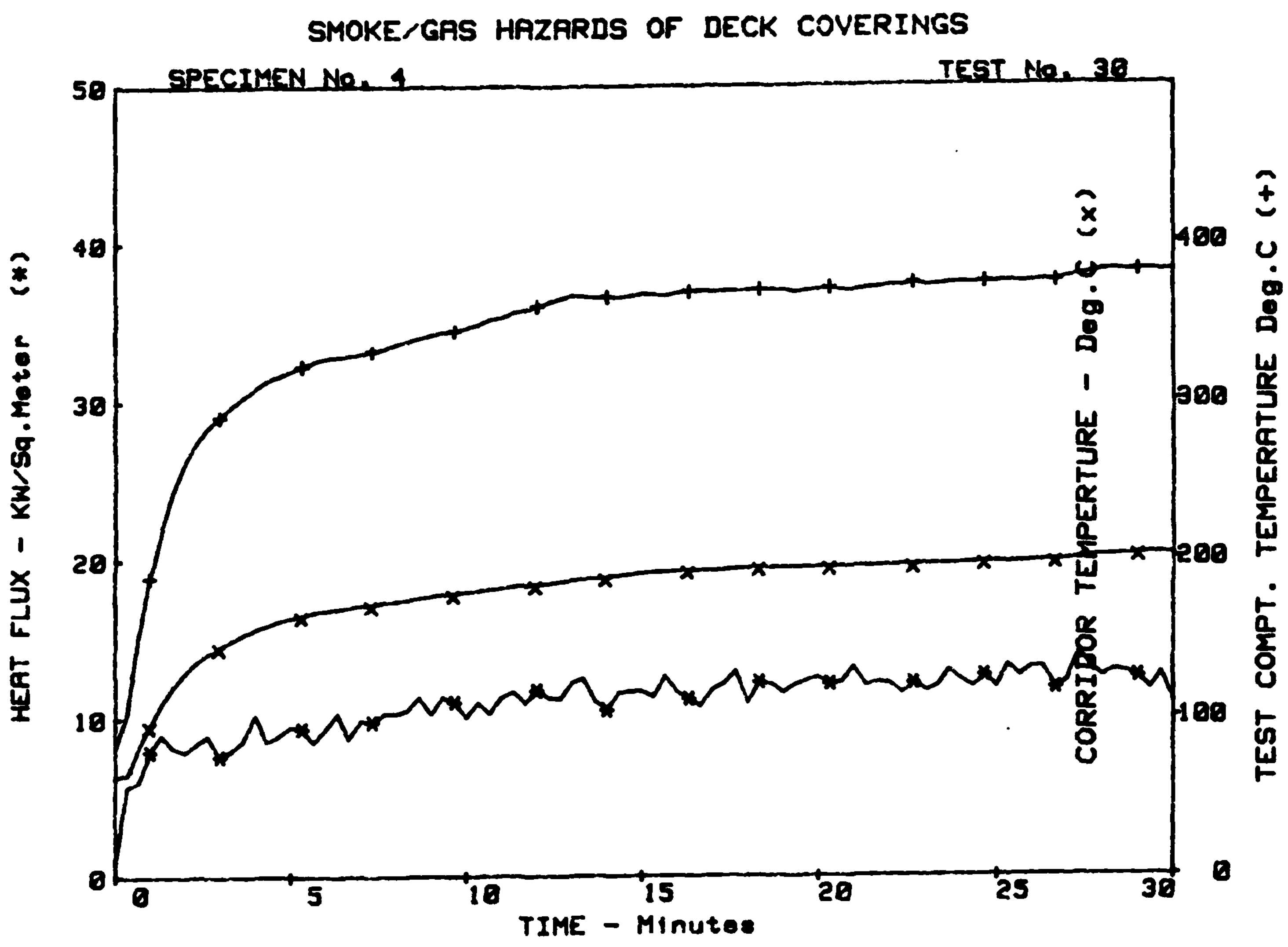


FIGURE 19. CEILING TEMPERATURES VS. TIME NEAR THE OVERHEAD IN THE TEST COMPARTMENT AND PASSAGEWAY

Temperature exposure levels may be expressed as the increase above the normal body temperature of 36.8$^{o}$C. It is estimated that exposures to temperatures greater than 88$^{o}$C will elevate the body temperature to critical levels (43-48$^{o}$C) within 10 minutes, causing heat exhaustion. Clearly temperatures in the fire compartment are too high for survival. Temperatures at the designated exposure point in the passageway are within the 10 minute maximum survival time at the 72" elevation. The temperature decreases from the overhead to deck. At the lower levels temperature becomes a less critical exposure parameter.

### 4.2 The Exposure

Each member of the family of "typical" fires has associated with it a second family of exposures which depend on the location, residence time of victim, etc. The determination of exposure requires measurements of the consequences of a fire, i.e. smoke, heat, toxic gas concentrations, etc. There measurements can be used to estimate the potential harm. Difficulties that arise in making these estimates include the selection of suitable locations for measuring devices and the appropriate length of exposure. Questions of importance to the establishment of exposure data are: (1) what is present; (2) where is it located; (3) how much is present, and (4) how long does it persist?

Perhaps the most difficult part of a hazard assessment is to estimate the "potential harm" resulting from exposure. As a first approximation, the major parameters are assumed to be linearly independent. This allows the independent evaluation of smoke, thermal impact, and toxicant gases or particulates. Additionally, it is often assumed that the effects of individual toxicants are independent, i.e. synergistic or antagonistic effects are not present. Further, it is assumed that there is a threshold value to each associated "potential harm" factor. The selection of harmful thresholds is often arbitrary and they may vary depending on changing value systems. For example a minor impairment of the future quality of life of a fire victim may be unacceptable during normal peacetime operations but be acceptable on a warship engaged in combat.

The development of "acceptable risk" criteria implies the determination of what is non-acceptable. In terms of life safety hazard assessment the non-acceptance criteria may be classified as either absolute or relative. For example the expectation that loss of life will occur is a sufficient condition for classification as an unacceptable risk and is an absolute criteria. Because of the subjective nature of "acceptable risk" criteria the selection of appropriate threshold values for specific toxicants is often the product of a group consensus process. Criteria may also be developed on a relative basis. For example, if the measured quantities of carbon monoxide emitted during a fifteen minute fire exposure of a bulkhead finish material exceeded 10% of that value found during baseline fire tests using inert materials then the material could present a "non-acceptable" risk. The use of both absolute and relative risk acceptance criteria is practiced in the engineering and regulatory fields.

When two or more toxic gases are present which act on the same body organ or system their combined effect should be considered.[11] The effects of the different hazards may be considered as additive. That is, if the sum of the fraction $C_i/T_i$ exceeds unity then the threshold limit of the mixture is exceeded. Thus the unacceptability threshold becomes:

$$\sum_{i=1}^{i=n} \frac{C_i}{T_i} \geq 1$$

where $C_i$ indicates the observed concentrations of component i and $T_i$ indicates the threshold limit of component i.

When two or more toxic gases are present which produce effects that are localized on different organs of the body or affect different metabolic systems, the effects are independent and the threshold limit is exceeded only when one member of the series has a value exceeding unity.

Threshold limit values for individual toxicants are listed in Table 6. The values from Kaplan[12] correspond to a lethality criteria. The short term

TABLE 6

THRESHOLD LIMIT VALUES FOR TOXICANTS

| | TWA[13] (8-hour exposure) | STEL[13] (short-term chronic exposure) | Kaplan, et al.[12] |
|---|---|---|---|
| Carbon Dioxide | 5000 ppm | 15,000 ppm | 2 to 5% (1 hr) |
| Carbon Monoxide | 50 ppm | 400 ppm | 4,000 (1 hr) |
| Nitric Oxide | 25 ppm | 35 ppm | 200 (10 min.) |
| Sulfur Dioxide | 2 ppm | 5 ppm | 500 (10 min.) |
| Oxygen Deficiency | -- | -- | 11% ("few" min.) |
| Total Hydrocarbon | -- | -- | -- |
| Hydrogen Cyanide | 10 ppm | -- | 350 (10 min.) |

chronic exposure values are for 10 minute peak exposures throughout an eight hour work day. The "TWA" values are cronic exposure levels for an eight hour continuous exposure during a work day. The validity of using a chronic exposure criteria for an emergency fire situation which involve acute exposures to toxicants combined with thermal effects is questionable. Only limited short term human acute exposure data is available for CO, $CO_2$ and $O_2$ deficiency and virtually nonexistant for most toxicants of interest.

### 4.3 Toxic Effect of "Smoke"

Smoke is a complex mixture of solid and liquid particulates, and combustion gases. Many different combustion products may be evolved during the course of ignition, fire growth and extinguishment. Therefore, the toxic effects of "smoke" are the result of complex mixtures of individual toxicants. The instantaneous or peak concentration of the fire gases are less important than the time averaged concentrations. The time averaged concentrations provide an indication of the dosage of toxicants contained in the fire gases which may cause biological dysfunction. The principle toxicant effects[12] of the toxic gases measured in this program are outlined below.

Oxygen Deficiency: When oxygen drops from its usual value of 21 percent in air to about 17 percent, motor coordination is impaired. In the range of 10 to 14 percent, a person is still conscious but judgement is impaired. In the range of 6 to 10 percent a person loses consciousness but may be revived if subjected to a few minutes exposure. Therefore, the lethal threshold value for acute exposure was taken to be 11% oxygen deficiency (i.e. 10% $O_2$ concentration) and the effect was assumed linear. The mechanism of toxicant effect is the reduction in rate of formation of oxygen complexes with hemoglobin.

Carbon Monoxide: Extensive investigations examining fire fatalities have demonstrated that carbon monoxide is the primary toxicant in smoke inhalation deaths. The toxicity of carbon monoxide is due to the formation of carboxyhemoglobin which results in a reduced ability of the blood to transport oxygen. Carbon monoxide concentrations are dangerous when inhaled for one hour at levels of 1,500 to 2,000 ppm. Carbon monoxide concentration of 4,000 ppm in air are believed to be fatal within one hour. Therefore, the threshold limit value of 4,000 ppm was assumed.

Hydrogen Cyanide: Hydrogen cyanide is a fast reacting toxicant. The toxicity of hydrogen cyanide is attributed to histotoxic anoxia in which oxygen is not effectively utilized by cells of critical body organs. An estimate of the short term (10 minute) lethal concentration threshold is 350 ppm.[12]

Nitrogen Oxides: Nitrogen oxides ($NO_x$) are strong pulmonary irritants capable of causing immediate death as well as delayed injury. The short term lethal threshold concentration is greater than 200 ppm.[12]

Sulphur Dioxide: Sulphur dioxide is a strong irritant which is intolerable well below the lethal levels. The short term (10 minutes) lethal concentration threshold is greater than 500 ppm.

Carbon Dioxide: Normally carbon dioxide is not formed at toxic levels in fires. Moderate concentrations stimulate the rate of breathing and an increase of 50% in rate and depth of breathing results at concentration of 2 percent. At 3 percent the rates are doubled and at 5 percent breathing becomes difficult. Although at 5 percent levels no serious after effects occur after one hour exposure, the lethal threshold level was assumed to have been reached. At lower levels, e.g. 2 percent, the effect is to modify the intake of other toxicants. For this analysis the effect was assumed linear between 0-2 percent. The result is a factor which is used to multiply the ingestion of other toxicants. The second role of carbon dioxide is as a toxicant with a threshold limit value of 5% since above this level breathing becomes increasingly shallow and the ventilation rate decreases rapidly. Hydrogen cyanide acts as a hyperventilation stimulant[15] but was not included in Class 3 because of lack of available data on humans.

## Toxicant Classes

For the purpose of analysis it is useful to place the individual toxicants into classes. Each class corresponds to a group of toxicants which act primarily on one body organ or one metabolic mechanism. For this analysis three classes were assumed corresponding to: (I) the ability of the body to effect oxygen exchange, (II) irritants, and (III) synergistic effects. The three members of Class I (oxygen exchange) are oxygen deficiency, carbon monoxide and hydrogen cyanide*. The two members of Class II (irritants) are sulphur dioxide and nitrogen oxide. A single member of Class III (synergists) was carbon dioxide. The division of measured toxicants into these classes implies a loss of independent action. For example, the effect of carbon monoxide is increased when there is a lowering of atmospheric oxygen. Analytically the combined effects were considered additive. This allows an estimation of the anticipated effects of a simultaneous exposure to several toxicants and provides a method for correlating results. In addition, for Classes I and II each fractional $C_i/T_i$ is multiplied by a "ventilation" factor, F, for $CO_2$. The "ventilation" factor was estimated as outlined previously in the section on $CO_2$. If any of the factors $C_i/T_i$ X F are equal to or greater than unity, then the toxicity threshold is exceeded. The result obtained is a measure of the potential for harm of the gas mixture for each class considered. Because Class I and Class II toxicants represent independent variables it is not proper to add the individual fractional sums for the two classes to obtain an overall value for the mixture.

## 4.4 The Development of a "Smoke/Gas Hazard" Analysis Procedure

Using the assumptions outlined in the preceeding section an analysis can be made to determine the smoke/gas hazard. The level of hazard can be expressed in terms of the Potential for Harm Index (PHI). In using this approach on a specific test program the general procedure was to measure the gas concentration at an assumed exposure location and calculate a PHI value for each class of toxicants. The PHI value that is relevant to the determination of risk is the highest PHI class value. This value provides an "absolute" quantitative measure for assessing hazard. It is noted that the numerical level of the index itself is dependent on the assumption of appropriate threshold limit values. In the present analysis values for acute

*See References 13, 14, and 15

toxicity based on lethality experiments were selected as most relevant.[12] Other threshold limit values could also have been utilized, for example, those developed by the American Hygenists Association for OSHA compliance. However, since the OSHA values are intended to be used for chronic exposures over either an eight hour day (TWA) or 10 minute time period (STEL) their use may be overly restrictive for application to real fire situations.

As indicated previously, another way to proceed is to develop and use a relative index. Such an index can be established by measuring the contribution of the material or construction being tested and comparing it to the potential harm which would be expected from a "typical" fire not containing the material. For example, in this project tests were performed which established PHI values for "typical" merchant ship cabin fires. Other tests were performed which established PHI values for deck covering materials and bulkhead finish materials. Assuming that there is a reasonable correlation between the fire exposures in the different tests, these results can be used to develop a relative criteria. For example, if the PHI of the deck covering materials are much less than the PHI of the fully furnished cabin room fires, the contribution of the deck covering materials to the overall fire hazard would be small. A "nonacceptable risk" level may be defined by agreeing that this value be no more than 10%. Of course, such a choice is arbitrary and subject to confirmation by either practical experience or group concensus.

### 4.5 Application of Hazard Analysis Procedure Using an Absolute PHI Index

Deck Covering Tests: Data for the entire group of deck covering tests was combined to provide an average concentration of toxicants. The results are shown in Table 7. The potential for hazard index for the Class I elements was 0.10. For the Class II the PHI value was 0.03. For both these classes the PHI values are well below the critical threshold value of 1.0 and well below those found in furnishing tests.

Bulkhead Finishes Tests: Data for the bulkhead finish materials were divided into four subdivisions. The average toxicant concentration for the individual elements of each class for these subdivisions is presented in

TABLE 7

DECK COVERINGS - POTENTIAL FOR HARM INDEX

| Class 1 | Ave. Conc. | $C_i/T_i$** | Factor | PHI |
|---|---|---|---|---|
| $O_2$* | .3% | .03 | 1.02 | .03 |
| CO | 270 ppm | .07 | 1.02 | .07 |
| HCN | -- | -- | | -- |
| | | | | .10 |
| **Class 2** | | | | |
| $NO_x$ | 2.1 ppm | .01 | 1.02 | .01 |
| $SO_2$ | 11.0 ppm | .02 | 1.02 | .02 |
| | | | | .03 |
| **Class 3** | | | | |
| $CO_2$ | .11% | -- | 1.02 | -- |

* $O_2$ deficiency
** Threshold values from Kaplan et al.

Table 8. The PHI subdivision values ranged between .73 and .07. For decorative laminates the PHI value of .73 was primarily a result of carbon monoxide (0.56). Similarly for laminated honeycomb panels the PHI value of .66 was primarily a result of the effect of CO (0.55). For both subdivisions the irritant gas toxicity effect was about half that of carbon monoxide alone.

For the PVC and FR paint on steel the PHI values are 0.15 and .07 respectively. These values are much less than the laminated bulkhead finishes. In both cases the irritant gas concentrations were either of the same or higher PHI values than those for carbon monoxide.

Accommodation Furnishings Tests: PHI values for the USCG and CCG tests are shown in Table 9. Values for these tests range between 2.0 for the USCG furnishing and 2.8 for the CCG merchant ship furnishings. The Class II irritant gas effect is about 5% (USCG) and 15% (CCG) relative to the Class I toxicants. In the CCG tests the levels of $CO_2$ observed were sufficiently high as to constitute a significant toxic hazard.

### 4.6 Application of Hazard Analysis Procedures Using a Relative PHI Index

A hazard analysis based on a relative PHI index can be developed that involves the use of PHI values for deck coverings (0.10) and CCG furnishings (2.8). Clearly the ratio of .10/2.8 is small and therefore the effect of deck covering materials negligible. A similar comparison for bulkhead finishes is more complex. The values for PVC (.15) and FR paint (0.07) are small compared to CCG furnishings (2.8). However, the laminated finishes (.77) and laminated honeycomb (.66) are approximately 25% of the PHI index for CCG furnishings (2.8). This may be interpreted to mean that toxic gas production for laminated finishes and laminated honeycomb bulkheads may be a significant factor relative to the base exposure fire in accommodation quarters. These results suggest that additional full scale work should be done to investigate the potential for harm for combinations of specific laminated finishes and bulkheads.

TABLE 8

BULKHEAD TESTS-POTENTIAL FOR HARM INDEX

Decorative Laminates

| Class 1 | Ave.Conc. | $C_i/T_i$** | Factor | PHI |
|---|---|---|---|---|
| $O_2$* | 1.2% | 0.10 | 1.25 | 0.12 |
| CO | 1700 ppm | 0.45 | 1.25 | 0.56 |
| HCN | 13 ppm | 0.04 | 1.25 | 0.05 |
| | | | | 0.73 |
| **Class 2** | | | | |
| $NO_x$ | 18 ppm | 0.09 | 1.25 | 0.11 |
| $SO_2$ | 38 ppm(est) | 0.08 | 1.25 | 0.10 |
| | | | | 0.21 |
| **Class 3** | | | | |
| CO | 1% | --- | 1.25 | --- |

Laminated Honeycomb

| Class 1 | | | | |
|---|---|---|---|---|
| $O_2$* | 0.7% | 0.06 | 1.15 | 0.07 |
| CO | 2000 ppm | 0.50 | 1.15 | 0.55 |
| HCN | 10 ppm | 0.033 | 1.15 | 0.04 |
| | | | | 0.66 |
| **Class 2** | | | | |
| $NO_x$ | 18 ppm | 0.01 | 1.15 | 0.11 |
| $SO_2$ | 70 ppm | 0.14 | 1.15 | 0.15 |
| | | | | 0.26 |
| **Class 3** | | | | |
| $CO_2$ | 0.6% | --- | 1.15 | --- |

* $O_2$ deficiency
** Threshold values from Kaplan et al

TABLE 8 (con't)

BULKHEAD TESTS-POTENTIAL FOR HARM INDEX

PVC on Steel

| Class 1 | Ave. Conc. | $C_i/T_i$ | Factor | PHI |
|---|---|---|---|---|
| $O_2$* | 0.6% | 0.06 | 1.10 | 0.07 |
| CO | 260 ppm | 0.06 | 1.10 | 0.07 |
| HCN | 5 ppm | 0.01 | 1.10 | 0.01 |
| | | | | 0.15 |
| Class 2 | | | | |
| $NO_x$ | 8.7 ppm | 0.043 | 1.10 | 0.05 |
| $SO_2$ | 36 ppm | 0.07 | 1.10 | 0.08 |
| | | | | 0.13 |
| Class 3 | | | | |
| $CO_2$ | 0.55% | --- | 1.10 | --- |

FR Paint on Steel

| Class 1 | Ave. Conc. | $C_i/T_i$ | Factor | PHI |
|---|---|---|---|---|
| $O_2$* | 0.2% | 0.018 | 1.1 | 0.02 |
| CO | 50 ppm | 0.012 | 1.1 | 0.01 |
| HCN | 3 ppm | 0.010 | 1.1 | 0.01 |
| | | | | 0.04 |
| Class 2 | | | | |
| $NO_x$ | 6 ppm | 0.03 | 1.1 | 0.033 |
| $SO_2$ | 18 ppm | 0.036 | 1.1 | 0.040 |
| | | | | 0.070 |
| Class 3 | | | | |
| $CO_2$ | .32% | --- | 1.1 | --- |

* $O_2$ deficiency

TABLE 9

FURNISHINGS-POTENTIAL FOR HARM INDEX

U.S.C.G. (T7,T8)

| Class 1 | Ave. Conc. | $C_i/T_i$** | Factor | PHI |
|---|---|---|---|---|
| $O_2$* | 3.2% | 0.33 | 1.75 | 0.6 |
| CO | 3300 ppm | 0.8 | 1.75 | 1.4 |
| HCN | --- | --- | --- | --- |
| | | | | 2.0 |

| Class 2 | Ave. Conc. | $C_i/T_i$** | Factor | PHI |
|---|---|---|---|---|
| $NO_x$ | 3 ppm | 0.015 | 1.75 | 0.03 |
| $SO_2$ | 15 ppm | 0.030 | 1.75 | 0.05 |
| | | | | 0.08 |

| Class 3 | Ave. Conc. | $C_i/T_i$** | Factor | PHI |
|---|---|---|---|---|
| $CO_2$ | 2.5% | -- | 1.75 | -- |

CCG (T5, T6, T10)

| Class 1 | Ave. Conc. | $C_i/T_i$** | Factor | PHI |
|---|---|---|---|---|
| $O_2$* | 8% | 0.77 | 1.0 | 0.77 |
| CO | 8000 ppm | 2.00 | 1.0 | 2.00 |
| HCN | 10 ppm | 0.03 | 1.0 | 0.03 |
| | | | | 2.80 |

| Class 2 | Ave. Conc. | $C_i/T_i$** | Factor | PHI |
|---|---|---|---|---|
| $NO_x$ | 56 ppm | 0.30 | 1.0 | 0.30 |
| $SO_2$ | 30 ppm | 0.06 | 1.0 | 0.06 |
| | | | | 0.36 |

| Class 3 | Ave. Conc. | $C_i/T_i$** | Factor | PHI |
|---|---|---|---|---|
| $CO_2$ | 10% | --- | 1.0 | --- |
| $CO_2$ | 10% | 2.0 | 1.0 | 2.0 |

* $O_2$ deficiency
** Threshold values from Kaplan et al

## 5.0 CONCLUSIONS

The following conclusions were made regarding the smoke/gas hazards of the deck coverings, bulkhead finishes and furnishing materials tested. The conclusions reached are indicative of the fire safety performance of these materials under conditions of fire exposure, at the exposure locations, and for the toxicants measured in this project only.

5.1 The deck covering materials evaluated do not make a major contribution to the smoke/gas hazards in a typical shipboard accommodations fire.

5.2 The bulkhead finish and composite materials tested varied in their potential for harm index. The rank order in terms of increasing hazard was (1) FR paint on steel, (2) PVC on steel, (3) composite honeycomb panel, and (4) decorative laminated finishes. As a class, the FR paint and the PVC on steel, did not make a major contribution to the smoke/gas hazard.

5.3 Merchant ship accommodation compartment furnishings have a high potential for harm index. USCG furnishings have a lower potential for harm index but still present a significant hazard.

5.4 Carbon monoxide is the toxicant with the greatest potential for harm. For systems where the total smoke/gas hazard is low, nitrogen oxide and other "irritant" gases may have a potential for harm similar to that of carbon monoxide.

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