NATIONAL BUREAU OF STANDARDS REPORT

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NAVAL SHIPBOARD FIRE RISK CRITERIA

Final Report Phase I – Evaluation of Fire Test Requirements

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

NATIONAL BUREAU OF STANDARDS

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Final Report Phase I – Evaluation of Fire Test Requirements

by

Fire Research Section
I. Benjamin & D. Gross

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ABSTRACT

This report covers the work done on Phase I of a project to evaluate the fire risk criteria for construction materials on board Naval ships. A review was made of the existing specifications for shipboard construction materials; and the test methods used to determine fire performance. The survey indicated that a wide variety of tests were being used in conjunction with differing criteria to evaluate materials designated for identical usage.

A set of three standardized tests are recommended in lieu of all the existing tests: flame spread, potential heat, and smoke generation properties. All materials can be adequately evaluated by these three tests to determine their fire resistance properties. Performance levels are recommended for the tests depending upon the designated usage of the material.

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1.0 INTRODUCTION

Fires on board ships at sea are not uncommon. In view of the large number of people on board a Naval ship and the large variety of operations in progress the incidence of fire is predictable. Fortunately, most of these fires are quickly brought under control with little loss to property or life. However, occasionally fires of larger order of magnitude do get started. If so, the judicious control of the materials in the ship's construction can be helpful in preventing the spread of fire. Basically, the materials chosen for use on board ship should minimize the spread of fire and smoke; and minimize the amount of additional fuel which they will contribute to an on-going fire. Within the context of these thoughts, the present program has been designed to help Naval personnel evaluate the contribution of shipboard materials to a fire on-board ship.

The research project was structured in two phases. Phase I, covered in this report, had as its objective a survey of the fire risk criteria used in the selection of materials for Navy ships; and the suggestion of possible modifications to the present material specifications that might be expected to improve fire safety evaluation. Phase II, now in progress, has as its objective the development of needed test methods to supplement those now existing; and the conduct of large scale burn tests to determine rational limits for the use of combustible shipboard materials.

Agreement was reached in conversations with the contracting personnel for this project that:

> The recommendations for modifications in the material specifications would reflect the "current state of the art" in terms of our knowledge of fire behavior and testing procedures. The project would be limited to construction materials used on board ship. In particular, this eliminated outfitting materials and the multitudinous types of materials and packaging which go into ships' stores.

2.0 WHAT WE DID

A review was made from "General Specifications for Ships of the United States Navy" of all the material specifications pertaining to ship construction. These specifications were culled to evaluate those which incorporated fire test methods. (See Tables I and II.)

Materials representative of many of these specifications were then ordered and evaluated according to the indicated test procedures. In a few cases, commercial materials of the same type were purchased for comparison with that being provided under the MIL Specifications.

The same materials were also subject to three standardized tests for: flame spread, fuel contribution and smoke production.

Using the three standardized tests as a base, criteria were proposed to provide for uniform material controls for all materials designated for the same end usage. These criteria were partly based on the performance of the materials now considered acceptable.

3.0 GENERAL DISCUSSION OF SPECIFICATIONS

From the review, 23 material specifications were found which incorporated requirements for fire resistance and 11 which did not. These represented materials which were part of the ship's construction; and materials which were used extensively enough to require control. The materials were put into three categories:

Insulation

Deck Coverings

Miscellaneous

The miscellaneous materials include paint, adhesives, coating compounds and lagging.

In terms of the quantities of materials used, the bulkhead insulation and deck covering categories should both be subject to control because of the large quantities which are present. The insulation material should be considered as the most critical item, not only because of its extensive use, but also because of its use on bulkheads--a critical location for fire spread.

Reviewing Table Ia, which is a list of 16 insulation material specifications, there are eight separate test criteria indicated for evaluating the fire performance of insulation materials. Seven materials had no test procedure indicated. Since none of these test procedures are equivalent in either the fire severity to which the materials are exposed or in the properties which they measure, the fire safety requirements for insulation would have to be considered nonuniform. More important, the use of different test procedures prevents the designer from making an intelligent choice of materials based on relative fire hazards.

The history and background of the development of these specifications would possibly show that each of the currently used tests was adopted for a specific material based on the currently used test at that time, and so the test was incorporated into the specification. This procedure ratified current practice and made readily available the use of new materials. However, as a result of this practice there now exists the anomalous situation in which materials which are being designated for identical uses must satisfy diverse and non-equivalent requirements.

One basic recommendation is that the same standard tests be used for all materials designated for a given usage. The fact that specifications are set up primarily on a material basis rather than a use basis presents

some difficulty. For example, insulation felt material MIL-I-22023C can be used for refrigeration spaces, for duct lining, or for insulating bulkheads. These are three separate use categories and three different fire hazard situations. Preferably the specifications should be able to designate different requirements for the material depending upon its usage and the associated fire hazard. As a long-range recommendation we would suggest that the subdivisions in the specifications have different levels of fire resistance to correlate to the uses designated in the "General Specifications for Ships of the United States Navy."

The second category of material, listed in Table Ib, is deck coverings. With the exception of carpeting, the deck covering fire tests are all specified under Method No. 6411 of Federal Test Method Standard No. 501a. This test method was developed by NASL Brooklyn approximately 25 years ago. However, as indicated in Table III, there are different sets of test criteria used; and the terminology used does not allow for comparison. For example, measurement of surface burning is designated by average char length, linear damage, and material damage beyond exposed area--and different values are indicated for the term used in the given specification.

The tests for carpets and rugs is separate from that for other deck covering materials and no test is specified for the rug pad. Although the carpeting is limited to living areas for officers' quarters, these areas should probably have the same degree of safety as other comparable areas of the ship.

The third category listed in Table Ic is miscellaneous. There are two different vapor barrier coatings--each with a different fire test. One lagging material has a fire test--the other none. There are two specifications for damping tile--and two different tests. There is no performance requirement for the fire resistance of the paint since the formulation has been designed to produce the desired end product.

4.0 COMMENTS ON TEST PROCEDURES

4.1 GENERAL

Prior to discussing the test procedures now specified, some general information on fire performance may be helpful. The basic reactions of a material to fire can be listed as follows:

1. Ignition
2. Flame Spread
3. Heat Contribution
4. Smoke Generation

4.1.1 Ignition

There is no standard test for ease of ignition at this time. Nor do any of the tests which are now being used measure this property uniquely. The ease of ignition is a function of the energy input into the specimen and the time-rate of this energy input. The two factors are related so that the relationship between total energy input and time of exposure is a function of the level of the energy input. A standard test procedure is needed in this area and will be part of the Phase II development of this program.

4.1.2 Flame Spread

The propagation of flame is basically a surface property phenomenon. However, it is not unrelated to the base (substrate) on which the material is applied. In general, the flame spread is a function of the thermal conductivity, heat capacity, density and thickness of the material. The rate of flame spread will, in general, be higher for coatings on a combustible substrate than on a non-combustible one. The comparative test for a coating, shown in Table VIII, illustrates this point. The flame spread of the coating went from 0 to 73 when the substrate was changed from steel to tempered hardboard.

The flame spread rating is a measure of the speed at which fire will propagate along the surface and consequently involve adjacent areas.

There are basically two standard methods for evaluating flame spread. These are ASTM Standards E-84, Surface Burning Characteristics of Building Materials; and E-162, Surface Flammability of Materials Using a Radiant Energy Heat Source. The two methods give comparable values in the range of flame spread values that are of interest here; and can be considered as equivalent test procedures. The radiant panel test is quite useful

for evaluating small samples of materials. The larger E-84 tunnel test is better for evaluating constructions when such things as the method of support and joints enter into consideration.

4.1.3 Heat Contribution

The heat contribution to a fire determines the degree of intensity and the severity of the fire. Intensity may be defined as the level of temperature which the fire reaches, and severity the total energy release, sometimes expressed in terms of the area under the temperature-time curve. By limiting the available heat which can be made available to the fire, by controlling the amount that is available in the materials on board ship, one can control the contribution of the construction to the severity of the fire.

The Btu content of a material which can be released in a simulated fire is best measured by the potential heat method (Appendix A). This test gives meaningful values for all types of simple and composite construction materials and has undergone extensive interlaboratory testing. The method measures the total amount of Btu released in a standard fire exposure but does not reflect the rate at which the heat is released from the material.

The rate of heat release also affects the intensity of fire which can be developed. No existing test procedure measures this rate. The development of a new test method for this property is also part of Phase II of this program.

4.1.4 Smoke Generation

With the growth in use of synthetic materials, the problem of smoke and toxic products has become acute. This problem is even more acute on board ship because of the enclosed spaces and the reliance on forced ventilation to maintain tolerable levels of visibility and prevent build-up of toxic products during a fire. None of the test methods in the MIL Specifications include a quantitative measurement for smoke, although a few tests require that observations be made on the smoke developed. A standard method for measuring smoke generation is available, and a copy is attached as Appendix B.

4.2 PRESENT SPECIFICATIONS

There are 13 fire tests in the current MIL Specifications. The tests and the associated materials are shown in Table II. The current test methods indicated are reviewed and evaluated here. They are classed into bench tests and severe exposure tests. In general, the bench tests are characterized by fire exposures which have a low energy input to the sample--in other words they do not represent a severe or realistic simulation of a fire. Although the purpose of many of these tests is to measure the flammability or flame spread resistance of the material, experience has shown that materials which pass these bench tests may not perform adequately in large scale fires.

4.2.1 Bench Tests

Candle Test - MIL-P-15280E

The "Fire Resistance" test in MIL-P-15280E (as amended 21 March 1969) for elastomeric plastic foam insulation, requires that a candle flame be applied to the lower end of a 1 by 1/2 by 6 inch specimen mounted with its longitudinal axis inclined at 45 degrees (See Figure 1). The candle conforming to Federal Specification C-C-91D is moved so as to keep the specimen continuously in the flame as the specimen warps or bends. The candle flame is applied for 15 seconds after which the candle is removed. Measurements are made of the burning time after removal of flame and the loss in weight on ten specimens. A flammability index is calculated using the following expression:

$$I = w + b + t$$

where I = flammability index
w = average weight loss, calculated to the nearest 0.1 percent
b = number of specimens which burned after removal of flame
and t = average burning time (seconds) = $\frac{\text{sum of burning times}}{b}$

The "Fire Resistance" test in MIL-P-40619 for cellular expanded polystyrene, and the "Fire Retardance" test in MIL-R-20092 for synthetic cellular rubber are somewhat similar, but each is different. The latter employs a standard candle applied to the end of a horizontal specimen for 1 minute. If the specimen does not burn more than 30 seconds after the flame is removed, it is considered "fire-retardant" (Class 1). A combination flaming/smoldering test involving a hot rivet placed on a 1 square foot section of the material is used as a "Fire Resistance" test (Class 3; "fire-resistant").

Flammability of Plastic Foam Test - ASTM D-1692

This test method requires a 1/2 by 2 by 6 inch specimen supported horizontally on hardware cloth, with one edge subjected to a 1-1/2 inch high flame from a Bunsen burner for 1 minute (See Figure 2). If flames travel past two gage marks spaced 4 inches apart, the specimen is judged to be "burning by this test" and a burning rate may be calculated; if after the removal of the burner flame, there is no evidence of ignition, such as flame or progressive glow, the specimen is judged to be "nonburning by this test"; if there is evidence of ignition, but no flame past the second gage mark, the specimen is judged "self-extinguishing by this test."

The scope of this ASTM test procedure states clearly, "this method is not intended to be a criteria for fire hazard." The test was designed for comparing characteristics of different materials. Self-extinguishing materials have been found to burn readily and contribute substantially to actual fires.

Flammability of Rigid Plastic Over 0.05 Inch Thickness - ASTM D-635

This test uses a Bunsen burner with a 1 inch high blue flame applied to the end of a 1/2 inch by 5 inch specimen supported with its longitudinal axis and its transverse axis inclined at 45 degrees to the horizontal.

Method 5903T, Federal Test Standard CCC-T-191B

This method suspends a 2-3/4 by 12 inch specimen vertically in a metal clip inside a box. A Bunsen burner is applied to the lower edge and the rate of burning and the char length of the material is measured.

This is a standard test for evaluating flame retardancy of textile materials.

Method 2023 of Federal Test Method Standard No. 406

A 1/2 by 5 inch specimen is held in a vertical position and subject to a heating coil. The coil is energized with a current of 55 amp and the spark plugs are flashed to ignite gases coming from the surface of the specimen.

The test indicates that it is designed for studying the flammability of plastics that are "difficult to ignite." This is another small scale test comparable to the candle and the D-1692 test for studying materials; and does not predict performance in fire.

MIL-G-20241 Burner Test

A 1 by 6 inch specimen is suspended vertically over a Bunsen burner and the flame is allowed to hit the midpoint of the bottom of the specimen. Flaming for less than 2 seconds after the burner is removed determines if the material is self-extinguishing.

DDD-C-95 Pill Test

A 12 by 12 inch sample is put in a box. A methanamine tablet is ignited and placed in the center of the sample.

This test is used to measure the flammability and ease of ignition of carpeting but has been judged to be inadequate for control of carpeting by the Public Health Service. The Public Health Service has issued new and more rigorous standards controlling the flammability of carpeting.

4.2.2 Severe Exposure Tests

Heated Tube Test

This test method, included in part of MIL-I-742C, requires that a 1-1/2 by 1-1/2 by 2 inch specimen be inserted in a furnace maintained at 750 °C (1382 °F) for 15 minutes and the degree of flaming and temperature rise within the specimen and on its surface be noted. As stated in the

quoted reference, USCG Specification 164.009, if the temperature rise does not exceed 20 °C (i.e., a temperature of 770 °C), if there is no glow brighter than the walls of the heated tube, and if there is no direct flaming (with noted exceptions) or ignition of flammable vapors, the material is considered "incombustible" (noncombustible). For fibrous type materials, the requirements hold only for the last 13 minutes of the test, providing a 2 minute relaxation for materials of relatively low density. The same apparatus is employed in defining noncombustibility by ASTM E-136, although the permissible temperature rise is 30 °C, flaming is limited to the first 30 seconds, and no relaxation for fibrous materials is included.

To be rated as incombustible, fibrous type insulation materials are also required to pass a reheating test, which measures the extent (or self-heating) when a section of steel shafting at 900 °C is inserted in the center of a 1 cubic foot pile of the insulation. (This test was not performed.) In addition to this, Section 4.4.7 of MIL-I-742C requires a smoldering test of a somewhat similar nature.

Flame Resistance Test (Ref CS131-46)

This test apparatus has been used in a number of Federal and Military Specifications, including:

1. CS131-46 Industrial Mineral Wool Products
2. HH-I-521C Mineral Wool Building Insulation (refers to CS131)
3. SS-A-118B Acoustical Units, Pre-fabricated (has since been revised)
4. MIL-I-22023C Fibrous Glass Insulation Felt
5. MIL-I-22344B Fibrous Glass Pipe Insulation
6. MIL-A-23054 Fibrous Glass Acoustic Board

The apparatus, see Figure 3, consists of a 5 foot high steel frame to support a horizontally mounted specimen over a vertically oriented gas burner. Heat and flame from the gas burner impinges on the center of the specimen and is controlled to produce a prescribed time-temperature exposure, as indicated by a thermocouple located 1 inch below the lower surface of the specimen. For Specification 3, the prescribed time-temperature exposure is the same as in a standard fire endurance test (1,000 °F at 5 minutes; 1,300 °F at 10 minutes; 1,550 °F at 30 minutes). All the other specifications use the prescribed "Columbia" time-temperature curve (1,275 °F at 5 minutes; 1,458 °F at 10 minutes; 1,700 °F at 30 and 40 minutes).

Materials in board form and 36 by 36 inch size are placed directly on the flat surface of the steel frame to cover the 30 by 30 inch opening. Pipe

insulation material (Specification 5) in a 36 inch length is secured to an equal length of steel pipe and placed centrally on the flat surface of the frame. (There appears to be no requirement that the remainder of the 30 by 30 inch opening be closed with an incombustible backing.)

Specimens are rated in one of several classifications of which only "incombustible" and "fire-retardant" are employed in Specifications 4, 5 and 6. Slight changes have been made from the following definitions (from Specification 1):

> "Incombustible" - The material has remained in place, no flame issued from it, no glow has appeared at its edge, and no smoldering afterward was evident.
>
> "Fire-Retardant" - The material has remained in place, no sustained flame has issued from it and any flame which occurs shall be limited to intermittent short flame from the area directly exposed to the test flame. No flame from the specimen has reached the angle frame at any point. No glow has appeared at its edge, all the flaming has stopped within 2 minutes of the test flame and no smoldering afterward was evident.

Hot Rivet Test

Specimens of insulation 12 inches square are cut and arranged in tiers. A 1450 degree rivet or bolt is placed between them for 1 hour and evidence of smoldering is looked for.

This is a smoldering test; but it is applied to only one, MIL-I-22023C, of all the insulation materials designated. The test is useful to determine if material will smolder, particularly when large quantities are stored and subject to sparks or other hot objects. The test is comparable to a Coast Guard test, 164.009-3(e) also using a hot rivet, which measures the amount of temperature rise which occurs inside insulation pack. Both tests are applicable more to material in storage than to the material as it is used.

Deck Covering Test Apparatus

This apparatus was developed at the Naval Applied Science Laboratory (NASL), Brooklyn, approximately 25 years ago. The apparatus is not available commercially, and the NASL setup is one of only two or three in use in the country.

The apparatus consists of a communicating horizontal and vertical flue constructed of 1/16 inch steel sheeting lined with 1/8 inch asbestos [-cement] board with the exception of the horizontal bottom plate which is all steel. The deck covering to be tested is applied to a specimen

holder made of 1/8 inch mild steel plate 31-1/2 inches long by 7 inches wide. The holder is mounted in the horizontal flue so that hot gases can pass beneath the holder and be vented through the vertical flue. Flames and hot gases can also travel above the holder and be vented through the vertical flue. Exposure is by means of four open blast burners mounted side by side at one end of the horizontal flue, and the flames impinge both at the lower (steel) and upper (specimen) edges of the holder. The total rate of heat supply by the burners is approximately 400 Btu/minute providing a moderately severe exposure.

The test is used to measure a variety of specimen properties: ignitibility, flame spread, charring, glowing and smoke production. The apparatus is used in many test specifications with variations in test observations and performance requirements. These include:

MIL-C-7176D - Carpet, Aircraft

MIL-D-3134F - Deck Covering Materials

MIL-D-3135D - Deck Covering Underlay Materials

MIL-D-16680C - Deck Covering, Magnesia Aggregate Mixture

MIL-D-23003 - Deck Covering Compound, Nonslip, Lightweight

MIL-M-15562C - Matting, Floor, Rubber

MIL-T-18830A - Tile, Plastic, Fire-Retardant

The test method is described in Method 6411 (Fire Resistance) of Federal Test Method Standard No. 501a "Floor Coverings, Resilient, Non-Textile: Sampling and Testing." This description is slightly more detailed than the Military Specifications in terms of measurement tolerances and could serve as a common reference to the method, with any exceptions noted in the individual specification.

Although the test is prescribed and performed in a nominally identical manner in these test methods, the terminology and evaluations vary. For example:

1. The duration of flaming may be prescribed in terms of "combustion plus ignition time" (also "ignition plus combustion time") or "flaming time after shutoff of burners."

2. The specimen damage after test may be defined as "average char length" or "linear damage", that is the length of specimen permanently damaged by burning, charring, blistering or imbrittlement.

3. Materials may be rated "fire retardant", "fire resistant", or "slow burning" based on different criteria.

In addition, interpretation of specifications may vary. For example, an alternate interpretation of combustion plus ignition time would be the duration of flaming from the time at which the specimen ignites (as evidenced by flashing, yellow or longer flames) rather than the time of "initial application of burner flames" at the start of the test. The amount of flame distributed above and below the specimen varies with the specimen thickness, and is a critical function of the applied draft.

Table III summarizes the performance requirements of these test methods.

4.3 TESTS OF FIRE PROPERTIES

4.3.1 Radiant Panel Test Apparatus

Measurements were made using the radiant panel flame-spread test apparatus (Figure 4). The detailed test procedure is outlined in ASTM Designation E-162. In brief, the test requires a 6 by 18 inch specimen, facing and inclined 30 degrees to a vertically-mounted, gas-fired radiant panel. The energy output of the panel is controlled to be the same as that from a blackbody of the same dimensions operating at a temperature of 670 °C (1238 °F). Ignition is initiated at the upper edge of the test specimen and observations made of the progress of the flame front down the specimen surface, as well as the temperature rise of the thermocouples in a stack supported above the test specimen. The test duration is 15 minutes, or until sustained flame propagates down the entire 18 inch length of specimen, whichever time is less. The flame-spread index, I_s, is computed as the product of the flame-spread factor, F_s, and the heat evolution, Q, or $I_s = F_s Q$, where

$$F_s = 1 + \frac{1}{t_3} + \frac{1}{t_6 - t_3} + \frac{1}{t_9 - t_6} + \frac{1}{t_{12} - t_9} + \frac{1}{t_{15} - t_{12}}$$

The symbols t_3 to t_{15} correspond to times in minutes from specimen exposure until arrival of the flame front at a position 3 to 15 inches, respectively, along the length of the specimen. The heat evolution Q is proportional to the observed maximum temperature rise of the stack thermocouples.

This test procedure has been used in building codes for the control of building materials. Flame-spread index values vary from 0 for asbestos-cement board to 100 for red oak flooring and considerably higher for various types of cellulose-base and synthetic materials.

In an evaluation of the combustibility of submarine hull insulation, the Mare Island Naval Shipyard developed a somewhat similar test method utilizing a radiant energy exposure from electrical strip heaters [1]. This method uses specimens 7 by 32 inches by 1/2 inch thick glued to a tray which can be tilted to face the radiant panel at various angles, normally 45 degrees for foam insulation. Measurements and test criteria are based on ignition time, self-extinguishing time, weight loss, and char propagation distance. No information has been received on the results of material testing and evaluation, or on the current status of this method.

4.3.2 Potential Heat Test

This test [2] provides a quantitative measure of the total heat released under typical fire exposure conditions without regard to the rate at which the heat is released. The test procedure is given in Appendix A of this report.

The method makes use of standard calorimetric techniques in which the burning of small quantities of combustible in an otherwise inert material is assured by use of a combustion promoter which is added prior to test. By measuring heat of combustion by an oxygen bomb calorimeter both before and after exposure to a "standardized fire" [2 hours in air at 750 °C) the difference may be considered as the potential heat of the material.

The method is applicable to a variety of materials including metals and especially materials of low combustible content. Determinations may be made on simple materials, or on composite assemblies of materials from which a representative sample can be taken and pulverized into a homogeneous mixture.

Recently, an interlaboratory comparison of the potential heat test method involving 11 laboratories and five materials was carried out under the sponsorship of ASTM [3]. Statistical analysis of these round robin test results indicated the general magnitude of within-laboratory repeatability and between-laboratory reproducibility for composite materials of generally low potential heat. The test method has also been used to evaluate a series of mineral wool and glass fiber insulation materials of varying binder content. The potential heat was found to be proportional to binder content, which illustrated the quantitative nature of the potential heat test.

4.3.3 Smoke and Combustion Products

The smoke produced during the burning of the test specimens was collected and measured photometrically, employing a laboratory test method developed for the purpose (Figure 5). The test method is given in Appendix B of this report. This method provides more meaningful and reproducible smoke data under closely controlled conditions, than those obtainable from conventional fire-resistance or flame spread test methods.

As shown in Figure 5, the test utilizes a closed chamber of 18 cu. ft. volume containing an electrically-heated furnace which provides an irradiance of 2.5 w per sq cm (2.2 Btu/sec sq ft) on the surface of a nominal 3 inch square specimen. The method assumes the applicability of Bouguer's law to the attenuation of light by smoke, and smoke quantity is therefore reported in terms of optical density rather than light absorptance. Optical density is the single measurement most characteristic of a "quantity of smoke" with regard to visual obscuration. To take into account the optical path length L, the volume of the chamber V, and the specimen surface area producing smoke A, a specific optical density is defined as $D_s = V/LA\ (\log_{10} 100/T)$, where T is the percent light transmittance. Thus, for a selected exposure in the test chamber, and within certain limitations, a single test permits rough extrapolation to surface areas and to chamber volumes of other size.

Studies have indicated that when certain synthetic materials are very highly treated to inhibit flame spread, their smoke generation properties may be severely accentuated. In addition, many of these inhibited materials release combustion products which may be quite hazardous in the event of accidental fire.

During the smoke chamber tests, indications of the maximum concentrations of CO, $HC\ell$, HCN, and other selected potentially toxic combustion products may be obtained by drawing a sample of the gas mixture through commercial colorimetric detector tubes. Essentially, a colorimetric tube is a small-bore glass tube containing a chemical packing which changes color when exposed to a specific component of a gas mixture, and the length of color stain is related to the concentration of that component, for a given quantity and rate of gas flow.

Unlike the measurement of optical density of smoke, which is recorded continuously to obtain a maximum, the indicated concentration values may not necessarily be the true maximum values. The indicated concentrations refer to the same exposed area of specimen ($0.0456\ ft^2$) and chamber volume ($18\ ft^3$), but to a wide range of specimen weights. More details on the sampling procedures, and on the operation, accuracy, and limitations of the detector tubes are given in a publication dealing with aircraft interior materials [4]. Where $HC\ell$ is one of the products, the gas may also be absorbed in water and analyzed by a chlorine ion electrode to provide a more accurate indication at high concentrations.

5.0 OUR TEST PROGRAM

Samples were procured of construction materials which were representative of the specifications listed in Table I. In addition, some comparable commercial materials were purchased, which presumably did not meet the specification, to be used for comparison.

The materials were tested to determine their fire characteristics according to the existing MIL requirements. In addition, most of the specimens were subject to three tests which were considered to be germane to the fire hazard properties of materials:

1. E-162 Radiant Panel Test
2. Potential Heat Test
3. Smoke Density Chamber Test

5.1 TEST RESULTS

The performance of the materials under the current test methods; and under the flame spread, smoke density and generation of potential heat are given in Tables IV to IX and are arranged according to test method within use categories: deck coverings, insulation, and miscellaneous. Table X is a summary of all test results.

5.1.1 Deck Coverings

Test observations on a variety of deck covering materials, including those currently used by the Navy, are summarized in Table IV. Data and observations were taken in a uniform manner--even when not called for by the applicable specification. It may be noted from Table IV that all materials ignited within 1 minute and burned for periods ranging from a least 1 minute 10 seconds to over 15 minutes. Observation of the maximum flame length was somewhat difficult due to unsteady flaming and to limited visibility through the sight windows, which were occasionally smoked-up. For thick materials, particularly the carpets, the burner flames were almost entirely below the plate, resulting in slower and more variable flaming. The extent of specimen damage after test (average char length) was also difficult to measure particularly when soot deposits remained after test. Glowing persisted on the vinyl asbestos tile for periods ranging up to 1-1/2 minutes, on the rubber matting up to about 3 minutes and on carpeting for considerably longer periods. Glowing was generally very localized and its presence could be noted only with extreme care, e.g., darkening of the room for better visibility.

Visual estimation of smoke production depends entirely upon the individual operator and is unreliable.

Based upon the test requirements in Table III and the test observations in Table IV, the following conclusions may be reached:

1. On materials purchased to Navy specifications:

   a. Vinyl asbestos tile (AD) fails the requirements of MIL-T-18830A; combustion plus ignition time 4:05 versus 4:00 minutes; maximum flame length 24 inches versus 13 inches; barely passes on average char length (9 inches versus 10 inches).

   b. Flight deck compound (N) passes the requirements of MIL-D-23003, but char length was within 1/2 inch of the 6-inch limit.

   c. Deck covering underlay (Q), in 1/16-inch thickness, passes the requirements of MIL-D-3135D. The underlay was not tested at the required 1/4-inch thickness.

   d. Rubber matting (R) fails the requirements of MIL-M-15562C; maximum flame length 18 inches versus 10 inches; "flaming time after burner shutdown" extended beyond 60 seconds in one specimen (if occasional local reignition of glowing material is considered flaming); also average char length of 9 inches was within 1 inch of the 10-inch limit of linear damage.

2. On other materials:

   a. Of the carpeting materials tested--wool, nylon, acrylic, acrylic/modacrylic and polypropylene--all carpets flamed for a minimum of 6-1/2 minutes (i.e., 2-1/2 minutes after burner flames were turned off). All the carpets except the two wool specimens spread flame the full length of the holder. The average char length on the wool carpets was 12 and 13 inches compared to 22 inches and over for the others. Glowing in both the carpet and the hair pad (or integral foam cushion for material H) was noted on all materials after flames died out.

   b. The MIL-T-18830A vinyl asbestos tile was noticeably better than a commercial vinyl asbestos tile and a commercial vinyl tile. When the MIL-T-18830A tile was applied with a commercial adhesive (AE), flame travel was considerably more rapid compared to an assembly using MIL-A-21016E adhesive (AD), although the maximum flame travel was very similar. The presence of a longitudinal joint did not have a very marked effect on the results. Commercial linoleum (LE) and battleship linoleum (S) spread flames to a considerably greater degree than the other resilient deck coverings tested.

The same deck covering materials were tested by the radiant panel method, and the results are summarized in Table IV. A flame-spread factor of 1.0 (materials N and Q) indicates that no flames propagated along the specimen down to the 3-inch position. On vinyl asbestos tile (AD) flames traveled beyond 3 inches, but this occurred after a considerable time delay. Thus, this flaming contributes only slightly to the flame-spread factor. On the other hand, material P, which ignited earlier and spread flames faster and farther than the other materials tested, had a flame-spread factor of 18.8. The flame-spread index values ranged from 0 for materials N and Q to 440 for material P. Photographs of specimens after test are shown in Figure 6.

It is informative to plot the flame travel versus time data on semilograthmic coordinates as in Figure 7. A material which has a regular pattern of surface flaming will usually plot as a straight line or nearly so.

In terms of potential heat, the MIL-T-18830A vinyl asbestos tile produced 2249 Btu/lb (1960 Btu/sq ft). The measured potential heat of the flight deck compound MIL-D-23003 was 1473 Btu/lb (590 Btu/sq ft), and of the deck covering underlay (MIL-D-3135D) was 528 Btu/lb (210 Btu/sq ft). Thus, neither of the latter two materials would be expected to contribute significantly to growth of fire.

On the other hand, a deck covering reported to meet the requirements of MIL-D-3134F, was found to have a potential heat of 2382 Btu/lb (9720 Btu/sq ft). This may be considered roughly equivalent to 17% carbon or 30% wood. Probably, all the heat within a 1 inch thick layer of this material would not be released even under severe fire exposure.

5.1.2 Insulation

Heated tube test results on several pipe and sheet insulation materials are given in Table V. Where two or three replicate tests were performed, the values given represent averages.

The asbestos pipe insulation covered by Military Specification MIL-I-2781D is a basically inert material (there is a high-temperature test but no fire test requirements included in this specification). In the heated tube test, the outer layer of brattice cloth was responsible for most of the flaming but had no noticeable effect on the temperature rise. The two materials were considered to be "incombustible" but there was a question of interpreting the specification relating to the observed flaming, since flaming is strictly permissible from "painted or paper coated surfaces."

Potential heat values for this material are listed in Table V. The very low values (11 and 19 Btu/lb) are a clear indication of the negligible heat contribution which these materials would make under fire conditions. However, flames may spread along the brattice cloth outer layer as the flame spread index of 92 in the radiant panel test indicates.

The cellular glass pipe insulation (HH-I-551C) is also a basically inert material passing the heated tube test with no flaming, glowing or excessive temperature rise, and having a very low potential heat (17 Btu/lb). There was no spread of flame or heat evolution in the radiant panel test. However, the application of a vapor barrier coating compound (MIL-C-19565B, Type I), over the cellular glass, results in a very flammable assembly (Flame spread index = 330).

Glass fiber insulation, in pipe and board form, contains a combustible organic binder for strength and serviceability. In the heated tube test, pipe insulation covered by MIL-I-22344B, containing approximately 15 percent binder, barely passed the requirements for incombustibility. Its measured potential heat was 1,266 Btu/lb. Glass fiber acoustical board (MIL-A-23054) containing about the same percent binder but a density of one-half, failed the heated tube test by temperature rise. Its potential heat, on a weight basis, was 2048 Btu/lb.

An interesting comparison is available on the properties of fibrous glass thermal insulation board. Material conforming to the superceded ("A") version of MIL-I-742 failed the heated tube test and had a measured potential heat of 1931 Btu/lb. The fire test requirement in MIL-I-742A was the flame resistance test (See Section 7.0). Material conforming to the present version, MIL-I-742C, from three different sources, passed the heated tube test, and had an average potential heat of 504 Btu/lb.

During performance of the "flame resistance" test (in CS131-46 and other specifications), observations and interpretations were deemed difficult and ratings are therefore not included. The following comments seem appropriate:

> Since the brattice cloth covering of the glass fiber pipe insulation (MIL-I-22344B) and the asbestos pipe insulation burns and tends to glow, and since glass fiber melts (forming "icicles" which do not "remain in place") a strict interpretation would not permit such material to be classed either as "incombustible" or "fire-retardant" by this test. The lack of procedural details and comment on melting behavior appears to be a defect in MIL-I-22344B intended for fibrous glass insulation. The specifications for fibrous glass insulation felt (MIL-I-22023C) and fibrous glass acoustic board (MIL-A-23054) permit burned or disintegrated material having a total area of less than 50 square inches to fall from it. The rating of materials in this test depends upon certain visual observations and interpretations. For example:
>
> "Sustained" versus "intermittent Short Flames"
>
> Material to "remain in place"
>
> Flames reaching angle frame
>
> (Degree of) glow appearing at edge
>
> Continuance of smoldering

Some of these observations are difficult to make and are not of a quantitative nature. Also, application of this test method to pipe insulation (MIL-I-22344B) without a backing board to simulate a heat retaining overhead changes the heat input and makes interpretation difficult.

5.1.3 Plastic Foam Insulation

The "Fire Resistance" test in MIL-P-15280E was used to evaluate several plastic foam insulation materials most of which were purchased locally. The group includes at least one material which is currently approved by the NAVY. The results are shown in Table VI which also includes results from the Radiant Panel Test on the same materials. The "Fire Resistance" test in MIL-P-40619 for cellular expanded polystyrene is somewhat similar and test results for this material are also included in Table VI. The results indicate that ASTM E-162 provides a distinct separation in flammability behavior of the various types of foam insulation.

Test results on five plastic foams by ASTM D-1692 are included in Table VI. Four of the five materials were rated "nonburning by this test" and the fifth "self-extinguishing by this test" due to the continuation of flaming for up to 10 seconds after removal of the burner flame.

The test method scope indicates that the test is not suitable for "materials which exhibit pronounced shrinking and curling upon heating." These materials tended to curl to a greater or lesser degree during the test exposure.

Also, the suitability of the test method for flammability evaluation of foams must be seriously questioned in light of the following observation:

> When the burner flame was placed beneath the center of the specimen (all other conditions being the same), the polystyrene foam, judged to be "nonburning by this test", was almost entirely consumed in flames.

The classification system, i.e. the use of the terms "nonburning" and "self-extinguishing" is misleading, as noted by others [5].

5.1.4 Hull Insulation

A separate study was made of the flammability of composite materials proposed for use as submarine hull insulation. A description of the material and radiant panel test results (ASTM E-162) are given in Table VII.

Material No. 1, a polymeric blend of nitrile rubber and polyvinyl chloride plastic, did not flame during the test, but charred down to 16 inches. It

was partially reduced to ash, while generating a small quantity of heat; its flame spread index was 1.

Materials No. 2 and 3 both flamed down their full length and an appreciable amount of heat was released. The flaming pattern appeared to be similar in these two materials and was assumed to be due primarily to a (vapor-barrier) coating on the porous asbestos cloth, although there was considerable contribution by the vinyl layers and the insulating foam. Approximately 80% of the vinyl and foam portions of these materials were burned out or deeply charred in the test. Their flame spread index values were high, 144 and 242, respectively.

Material No. 5 and its reverse, Material No. 7, contained a vapor-barrier treated asbestos cloth as one component, but this was not from the same batch as the previous materials. Flames traveled down to 16 inches slowly on Material No. 5 which had a flame spread index of 36. With the glass fiber batt as the exposed surface, there was a very rapid spread of flame with very little heat evolution and the flame spread index was 7. The flaming was attributed to the organic binder content in the glass fiber batt.

In Material No. 6, which presumably had little or no organic coating on the exposed asbestos cloth face, flames traveled down to 16 inches. The flame spread index was 20, with flame spread probably due to organic vapors passing through the asbestos cloth from the glass fiber batt.

No flaming and no heat release were obtained with the aluminum-faced fibrous glass, Material No. 4. Flame spread index was 0.

5.1.5 Paint

Table VIII summarizes flame spread data on chlorinated alkyd resin enamel. The MIL-E-17970C specification states that this enamel provides a degree of flame resistance ("nonflaming"), but includes no performance test. (The performance is controlled by formulation.) There was no flame propagation on a 6-mil coating on steel, but a similar coating applied to a combustible substrate, permitted appreciable flame propagation (I_s = 73).

In a previous study, it was found that the flame spread index increased with increasing thickness of a conventional oil-base paint coating, when applied on a steel sheet. For oil-base paint coatings of 5, 10, 15 and 20 mils, the flame spread index of a No. 18 gage red-lead primed steel sheet was 1, 7, 69 and 110, respectively.

A similar comparison was made using multiple coats of the MIL-E-17970C enamel on 20 gage steel. As noted in the table, the flame spread index was 0 (no flame propagation) for coating thicknesses up to 23 mils. For

coating thicknesses up to 52 mils, the flame spread index only reached 8 with flame propagation limited to less than 6 inches on the specimen. Compared to conventional oil-base paint, the chlorinated alkyd enamel is clearly superior in its flame spread characteristics.

Dry paint layers, even when retardant-treated to reduce or prevent surface spread of flame, will contribute heat when exposed to fire. The measured potential heat of MIL-E-17970C paint when dry was 3200 Btu/lb. This corresponds to approximately 35 Btu/ft^2 for each 1 mil thickness. This value represents a negligible contribution unless the paint buildup becomes excessive.

5.1.6 Smoke and Combustion Products

Smoke accumulation tests were performed under both flaming and nonflaming (smoldering) exposure conditions and the results are presented in Table IX, in terms of the maximum smoke accumulation, D_m, and the time to reach 90% of maximum, $t_{.9D_m}$. The listed values generally represent averages of duplicate tests. Previous data has shown that the mean standard deviation on duplicate tests was approximately 9 to 12 for D_m values up to 200, and slightly higher for D_m >200.

For the deck coverings tested, the maximum smoke accumulation values ranged from 5 for magnesium oxychloride (MIL-D-3134F) to approximately 350 for vinyl asbestos tile (MIL-T-18830A). The standard deck covering underlay (MIL-D-3135D) and flight deck compound (MIL-D-23003) were in the range 25 to 70. The various carpeting materials (wool, nylon, acrylic, polypropylene) ranged between 300 to over 600.

Of the pipe insulation materials tested, the asbestos (MIL-I-2781D), the cellular glass (HH-I-551C) and the glass fiber (MIL-I-22344B) materials all gave maximum smoke accumulation values of less than 20.

The maximum D_m for glass fiber thermal insulation board conforming to MIL-I-742C was 11, while the acoustical glass fiber board (MIL-A-23054) had a D_m of 131. All of the tested cellular plastics (Ensolite, neoprene, polystyrene) had D_m values exceeding 250.

In the case of chlorinated fire retardant enamel (MIL-E-17970C) on steel, the maximum smoke accumulation depends upon the paint thickness. The D_m value was 61 for a 12 mil coating and 230 for a 52 mil coating.

For a majority of the materials tested, the smoke density was noticeably higher under active flaming conditions. However, in some cases, an equal or greater smoke density was obtained under the smoldering exposure condition. The higher of the two values was recorded.

Also listed in Table IX are the maximum indications of gas concentration as measured periodically with commercial colorimetric tubes. The values listed are not necessarily the true maximum values and are based on the manufacturer's calibrations for the selected gases. In every case, the concentrations refer to the same exposed area of specimen (0.0456 ft^2) and the chamber volume (18 ft^3) used; but for a wide range of specimen weights. In a previous study, it was found that indications of maximum gas concentrations in replicate tests were on the order of ± 20% for CO and HCN and ± 30% for $HC\ell$ [4].

For the materials tested, the highest indicated concentrations were 3000 ppm CO, 110 ppm HCN and 2600 ppm $HC\ell$. The high HCN indications were obtained with acrylic/modacrylic carpet and with the vibration damping tile (MIL-P-22581B). The high $HC\ell$ indications were obtained with vinyl and vinyl asbestos tile (not NAVY specification material) and rubber matting (MIL-M-15562C). The latter finding implies that the "rubber" matting may contain a high percent of poly (vinyl chloride) or other chlorine-containing component. The chlorinated fire retardant enamel gave an $HC\ell$ indication of 15 ppm for a 12 mil coating and 105 ppm for a 52 mil coating. The nitrile rubber/PVC blend gave $HC\ell$ indications of 100 to 150 ppm.

Nitrous gases ($NO + NO_2$) were found in lower concentrations (5 to 50 ppm) for most materials tested, and sulfur-containing materials produced measurable quantities of SO_2.

5.1.7 General

By arranging the data according to use categories, Tables IV to IX, it becomes obvious that certain insulations, for example, are greater fire hazards than others, when they are compared on the basis of the same test. This comparison has been obscured under the current method of evaluation since different tests were used for different types of insulation materials. This arrangement of materials does indicate the comparative fire performance of the various types of materials employed for comparable usage. Although fire performance may not be the sole determining factor for choosing materials, it should be put into the equation when the evaluation is made.

6.0 DISCUSSION

The fire performance of a material is determined not only by its properties, but also by the nature of its usage in relation to the properties of the enclosed space. A material used on a ceiling (or the upper third of the wall height) can be considered more critical than the same material used on the deck. Materials used in the engine room, where the possibility of fire is greater, must be evaluated much more critically than those used in a less hazardous environment.

The surface area of exposed combustible insulation is also a factor in its fire performance. A large bulkhead covered with insulation would normally present a far greater fire hazard than a small duct or a run of piping covered by the same material in the same enclosure. These factors should be taken into account in giving weight to the fire hazard potential of the materials and the allowable controls set on their properties.

6.1 INSULATION

For insulation materials the flame spread and smoke generating properties are the two most important to be considered. The flame spread property, which none of the existing material control tests now measure directly, is an indication of how fast the flame will travel along the surface and contribute to spread into another area, either in the same enclosure or an adjacent enclosure.

The smoke producing property of the materials is a new parameter for which quantitative controls appear desirable. Although we feel that some reduction should be made in the smoke generating properties of the materials currently being used, at this time we are primarily describing the materials in terms of their present capability.

In some cases, high smoke production has been the result of formulating the materials to inhibit flame spread. These two characteristics - smoke and flame spread - appear to be inverse to each other: The more the flame spread is inhibited the greater will be the smoke produced. By specifying the smoke production at the existing levels we are at least precluding the use of new materials which would produce even more smoke.

At this time it is quite difficult to draw a balance between these two properties so no changes are being suggested. Our observations on fires have generally indicated that smoke movement was much faster and more extensive than flame spread; smoke often becomes a more disabling factor than the actual spread of fire. For this reason we feel that the smoke generating properties be closely looked at in Phase II

of this project and eventually the allowable amounts of smoke generation be reduced in the material specifications.

6.2 DECKS

For decks the spread of flame is generally more dependent upon the thermal environment than for overheads and bulkheads. Studies have shown that the rate of spread of flame on a deck surface is a critical function of the amount of radiation which that surface receives from burning on the walls and ceiling. In buildings, the thermal radiation imposed on floors has been related to the flame spread properties of the ceiling and walls; and a fair degree of latitude can be allowed in the flame spread properties of the floor material if the flame spread of the walls and ceilings is closely controlled. Data from preliminary studies essentially shows that fire spreads slower on floors than on ceilings and walls.

However, in the case of a ship's deck we have the added possibility of fire existing on the underside of the deck. If not fire, at least heating of the deck from the underside is a distinct possibility, particularly if no insulation is applied to the underside of the steel deck. In view of this additional heating to the deck which does not occur in building fires, another parameter is added to the problem of flame spread on the deck of a ship. This parameter is one which is outside of our existing knowledge at this time. As a result, we have applied the same flame spread restrictions for deck materials as for bulkhead and overhead materials.

6.3 POTENTIAL HEAT

Potential heat is a measure of how much heat or added fuel will be released in a fire. It is a quantitative measure which can be conveniently expressed in BTU per square foot or BTU per pound. The quantity of combustibles present in any area can contribute to the spread of fire in many ways: For example, a large BTU contribution may heat the overhead deck and cause the fire to spread by ignition of combustibles in the room above. At lower heat levels enough heat may still be transmitted to cause materials to smoke so as to make the rooms or corridors impassable.

Although there is no direct relationship between the potential heat and the flame spread properties the release of a large number of BTU may heat the air in a space high enough to cause flash ignition of other combustibles in the room.

6.4 SPECIAL PROBLEMS

This investigation did not go into a study of the insulation on electrical cables. However, cognizance should be taken of the fact that there are many miles of cable on board ship which contain various types of plastic insulation. In certain critical areas of the ship, particularly in areas where computer and electronic equipment is located, the smoke and reactive gases generated from these insulation materials could be disabling to the equipment.

We have had past experience where a low level fire has generated enough HCl, from the decomposition of a PVC insulation, to disable computer equipment by corroding through 42 gauge enameled wire which was employed in the computer memory units. We have not gone into a study of all the various cable insulations. We do know, for example, that HCl is released from PVC at as low a temperature as about 450°F--well before any dark smoke or soot can be seen.

We introduce this potential problem for further consideration by the Navy. Upon request we could conduct a specific study on the comparative potential damage to computer units caused by the pyrolysis products of various types of cable insulation.

7.0 RECOMMENDATIONS

In establishing recommended limits, tests on materials meeting the current MIL specifications have provided a guide to performance levels. Thus, no new materials should be accepted which indicate a flame spread, potential heat or smoke generation in excess of that demonstrated by materials currently accepted. The ultimate range of limits selected should be based on the minimum values of fire hazard which must be allowed for the material to perform its selected function, and should provide a means for equitable comparison of new materials with currently accepted materials serving essentially the same function.

At present, we recommend that all the fire resistance requirements in the Navy Specifications be governed by only three tests:

Flame Spread

Potential Heat

Smoke Density

The recommended material specifications are given in Table XI. They have been broken down into various categories according to the usage indicated. The actual criteria vary from one usage to another in accordance with our evaluation of the fire hazard. They are designed to replace the 12 tests which have been used in the past. The recommended criteria for these tests reflect the following:

The state of the art and knowledge of fire safety.

The allowable use of present materials, with a few exceptions as later indicated.

A minimization of fire hazards on board ship.

Consistent criteria and test procedures for materials used for the same purpose.

The proposed recommendations have been left in outline form since it was our understanding that the Navy would wish to do the detailed revision of the applicable specifications. However, we offer our services for consulting as the specifications are rewritten.

The use of standardized test procedures with variable criteria (limits) provides flexibility. By varying the criteria the same test can be used for a variety of fire hazards. The criteria can also be varied in the future to fit with new knowledge of fire hazards and improved materials.

The criteria reflect:

The location of the material as it might appear in a compartment--whether it is used on an overhead, bulkhead or deck.

The surface area of the material which may be expected to be involved in a compartment fire.

The extent of the overall use of the material on board ship.

As mentioned above the current recommendations also reflect the availability of materials for the stated usage. Therefore, in some cases the fire related properties are not as fully controlled as may be desirable.

Table XII shows the materials which we studied, and whether or not they meet the recommended controls. In most cases they do, though there are some exceptions. In these cases, we believe that alternate materials can be used; or the materials now available can be readily modified to meet tighter controls. A few of the materials shown on the table were not tested since our previous knowledge and experience with these materials indicates that they will readily pass the designated criteria.

These recommendations represent a major departure from existing specifications in materials control for fire resistance. We suggest their adoption by the Navy for the following reasons:

1. Consistent and uniform requirements for all materials for a given usage, regardless of material used.

2. Use of standardized test procedures which can be easily run by commercial laboratories in various parts of the country.

3. Provide a standard specification control for approval of new materials. (Eliminating the need for developing a new fire test procedure for each new material.)

8.0 PROJECTION

The Phase II part of the program includes the development of test procedures for ease of ignition and rate of release of heat. We would expect that the ease of ignition would be an added test to eventually include in the material specifications to fill an existing gap.

The rate of heat release would be a modification of or addition to the potential heat test so designed as to give a more accurate reading of the significance of the Btu contributions by including a time factor in the calculations. However, the future modification of the test should not preclude the adoption of the current test, as suggested in the recommendations above.

The criteria or limits that have been suggested for the three test methods will be subject to modification when large scale tests are conducted to investigate the relative contribution of these variables. However, the values given at this time represent the state of the art and the available materials; and should be considered as valid criteria to give safety equal or slightly improved over that now available.

9.0 REFERENCES

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[4] Gross, D., Loftus, J. J., Lee, T. G. and Gray, V. E., "Smoke and Gases Produced by Burning Aircraft Interior Materials", Building Science Series 18, NBS

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Appendix A. Tentative Method of Test for

POTENTIAL HEAT RELEASE OF MATERIALS IN BUILDING FIRES

Scope

1. This method of test provides a means of determining the potential release of heat of materials involved in building fires. The method is applicable to a variety of materials including metals, and especially materials of low combustible content. Determinations may be made on simple materials, or on composite assemblies of materials from which a representative sample can be taken and pulverized into a homogeneous mixture.

Definition

2. Potential heat of a material is the difference between the heat of combustion of a representative sample of the material and the heat of combustion of any residue remaining after exposure to a simulated standard fire, using combustion calorimetric techniques.

Summary of Method*

3. One of two specimens removed from the material to be tested is pulverized, pelleted, and burned in a high-pressure oxygen atmosphere. The process is generally as described in ASTM D 271 (Laboratory Sampling and Analysis of Coal and Coke), but with certain modifications or permissible exceptions, to be noted in the test procedure. This determines the gross heat of combustion of the material. The second specimen is heated in air for 2 hr at a temperature of 1382 F (750 C), conditions adopted as representing a standard fire exposure. A portion of the resulting residue of this specimen, if any, corresponding to a predetermined weight of original material, is ground or pulverized, mixed with a combustion promoter, and pelleted for burning as was the first specimen. After correcting for the heat produced by the combustion promoter, the difference in heating values of the two specimens is the potential heat, as defined in par. 2. The test procedure is illustrated schematically in fig. A1.

Apparatus and Materials for Test

4. The apparatus and materials required for the test are listed below.

(a) Oxygen bomb calorimeter, including firing circuit and fuse wire.

(b) Muffle furnace (having small opening or port for passage of air supply tube).

* See Reference [2].

(c) Hand mill (or ball mill).

(d) Pelleting press.

(e) Microbalance, weighing to 0.1 mg.

(f) Oxygen cylinder and accessory equipment.

(g) Compressed air supply.

(h) Standard alkali solution.

(i) Combustion promoter, National Bureau of Standards standard material, sample 39 i, benzoic acid (calorimetric standard).

(j) Parts associated with muffle furnace firing (illustrated in fig. A2).

(1) Specimen container for use in the muffle furnace; a suitable part may consist of a fused silica or ceramic tube, 1-1/4 inches inside diameter by 4 inches long, closed at one end.

(2) Cap to fit open end of specimen container; cap to be provided with an opening to pass an air supply tube with loose fit.

(3) Air supply tube; may be of porcelain, fused silica, or corrosion-resistant metal; inside diameter 3/16 inch minimum; length to extend beyond port of muffle furnace.

(4) Wire specimen holder; of corrosion-resistant metal; formed to support the specimen away from the walls of the specimen container, for circulation of air about specimen.

(5) Support of fire brick or similar material shaped to hold the specimen container and its cap in alignment with the muffle furnace port, so that the air supply tube may be positioned in the specimen container.

Test Specimens

5. Two air-dry test specimens representative of the material or assembly involved are required for each determination. A specimen is considered "air-dry" when it has reached constant weight in an atmosphere maintained at 73 ± 2 F (23 ± 1 C) and 50 ± 5 percent relative humidity. If the test subject is an assembly or composite material, it is essential that the several elements of the subject

are contained in the test specimen in the same proportions that they occur in the subject. The two specimens are subjected to separate test procedures.

Procedure for Direct Bomb Test

6. (a) The specimen shall be pulverized into a form suitable to pass a No. 60 sieve. Grinding, filing or milling operations, whether manual or mechanical, should be effected on the cross-section which is normal to the grain, fiber or other process-induced orientation. Particular care care should be taken to avoid segregation or separation of components. The representative specimen shall not be smaller than 1/2 inch by 3 inches by the thickness as supplied, nor shall the resultant powder weigh less than 10 grams. For grossly, heterogeneous materials, a representative specimen should be obtained by combining samples of material from different units (or sheets) and from different locations on each unit.

Note: While many materials may be suitably reduced using a clean carbide double bastard file and/or mortar and pestle, it may sometimes be useful to (dry-ice) freeze materials containing asphaltic, mastic or plastic components prior to filing, or to use mechanical blendors, ball or hammer mills, grinders, milling or lathe cutters, etc. For laminated materials, it may be preferable to separate into component layers and to grind, file or pulverize each component separately. The powdered components may then be intimately mixed in proportion to their original weight fractions and the mixture tested, or, alternately, each component may be tested separately and the contributions of heat combined in proportion to their original weight fraction.

(b) A pellet, weighing approximately 1 g, shall be prepared from an intimate mixture of the powder, and then weigh

Note 1: All weight measurements shall be to the nearest 0.1 mg.

Note 2: Pellets shall be made in accordance with the method for the particular pelleting press in use and of a size convenient for the specimen cup. The pellets shall be no harder than necessary to prevent their disintegration when fired.

(c) The prepared pellet is the test specimen for the procedure for determination of the heat of combustion in accordance with ASTM D271-64, par. 51-55 (oxygen bomb test). Also see ASTM E-144, Recommended Practice for Safe Use of Oxygen Combustion Bombs.

Note 3: Modifications and exceptions to the requirements of ASTM D271-64 are listed in the Addendum.

Note 4: For tests on specimens which are predominantly metallic, the use of a silica combustion capsule is recommended. The water equivalent of the calorimeter using the silica capsule should be measured and used.

(d) If, after being fired in the oxygen bomb, the pellet is found to have burned completely, or to have left no significant amount of residue or ash, the heat of combustion on an air-dry basis may be computed, and the following three steps (3), (f), (g), shall be omitted.

(e) If the pellet does not burn, or a residue remains after the firing, another 1 g pellet shall be prepared using approximately 1/2 g portions of the powdered sample and a standard sample of benzoic acid combustion promoter. Weigh each portion accurately to 0.1 mg, mix together thoroughly and pelletize. Record the weight of the pellet to 0.1 mg. Any loss in weight after mixing and pelletizing should be subtracted from the sample and the combustion promoter in proportion to their original weight fractions, and the corrected weights used in the heat of combustion calculations.

(f) The pellet prepared with the added benzoic acid is used as a test specimen following the same procedures as for the original specimen.

(g) A correction for the heat of combustion of the benzoic acid present in the pellet is applied to the measured heat released by the specimen. The heat of combustion of the sample material, on an air-dry basis, is then computed.

Procedure for Muffle Furnace and Bomb Test

7. (a) An air-dry specimen representative of the test material or assembly shall be cut in the form of a rectangular prism 1/2- by 3/4- by 3-inches. Sheet materials may be folded or laminated to these dimensions.

(b) The muffle furnace is preheated to 1382 ± 18 F (750 ± 10 C). The specimen is weighed, and placed on the wire support 4. (j) (4) in the specimen container 4. (j)(1). The container is closed with its cap 4. (j)(2), and placed in the firebrick base 4. (j)(5) in the muffle furnace in such position as to align the muffle furnace port and the opening in the specimen container cap. The external air supply tube 4. (j)(3) is passed through the port into the container in proximity to the specimen. Firing is continued for 2 hr with a regulated air flow of 0.1 ft^3 per min, referred to 60 F and 30.0 inches Hg, supplied to the specimen. If ignition should occur immediately upon placing the specimen in the furnace, application of air shall be delayed until the initial flaming has stopped.

(c) The container with the specimen shall be cooled in a desiccator, after which the weight of the residue is determined.

(d) If the residue from the muffle firing procedure is less than 5 percent of the initial weight of the specimen, the following steps (e) and (f) are omitted, and the heat of combustion previously determined under the direct bomb test, par. 6 (d), shall be reported as the potential heat of the material.

(e) If the residue after the muffle firing is in excess of 5 percent of the original specimen weight, the residue shall be pulverized, mixed with an equal weight of benzoic acid and treated as specified in the procedure for direct bomb test to determine the heat of combustion (of the residue).

(f) To determine the heat of combustion of the residue per unit weight of original specimen, multiply the heat of combustion determined in par. 7. (e) above by the ratio of residue weight, 7. (c) to the original specimen weight 7. (b).

Potential Heat

8. The potential heat of a material is determined by subtracting the heat of combustion of the residue remaining from the muffle furnace firing, par. 7. (f), from the heat of combustion of the material

established in the direct bomb test, par. 6 (g). The potential heat is thus a measure of the heat released by a material in the muffle furnace firing, the conditions of which are considered to simulate a standard fire. For most materials, potential heat may be reported in heat units per unit weight, or where appropriate to the material and its use, it may be expressed on the basis of volume or surface area of the material. For materials such as metals where the combustion process is relatively slow, and is a function of surface area, potential heat should appropriately be reported on a surface area basis only.

ADDENDUM

Modifications and exceptions to the requirements of ASTM D 271-64 are as follows:

par. 52 (e) Fuse wire may be that provided for the bomb in use; a suitable correction factor for the wire shall be applied.

par. 53 (b) Benzoic acid is a suitable substance for standardization procedures (see 4. (i) of this standard).

par. 54 (a) Alternate method of Note 36 for materials of high ash content not used; in cases of incomplete burning, a combustion promoter is added (see 6. (e)).

par. 54 (f) An ignition system supplied for the bomb may be substituted.

par. 54 (h) Where materials leave a residue, remove the cup containing the residue, then proceed to rinse out the bomb and titrate as described in this paragraph.

par. 55
(Note 44) The method of this test for potential heat release of materials gives the gross heat of combustion of a material in an air-dry condition; net calorific value (net heat of combustion) calculations are not normally a part of this procedure. (see footnote*).

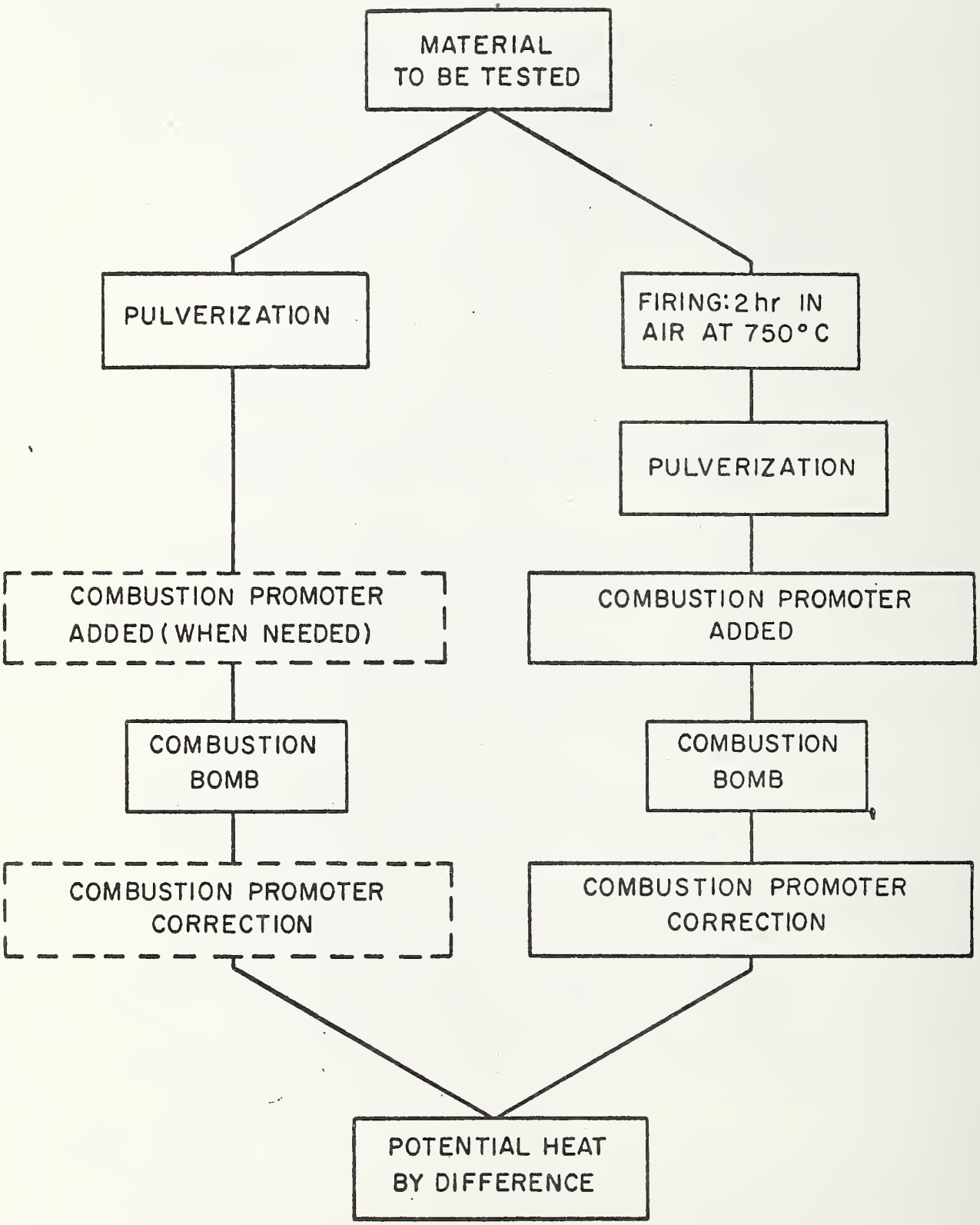

Fig. A1 Schematic Diagram of Test Procedure for Potential Heat Measurements

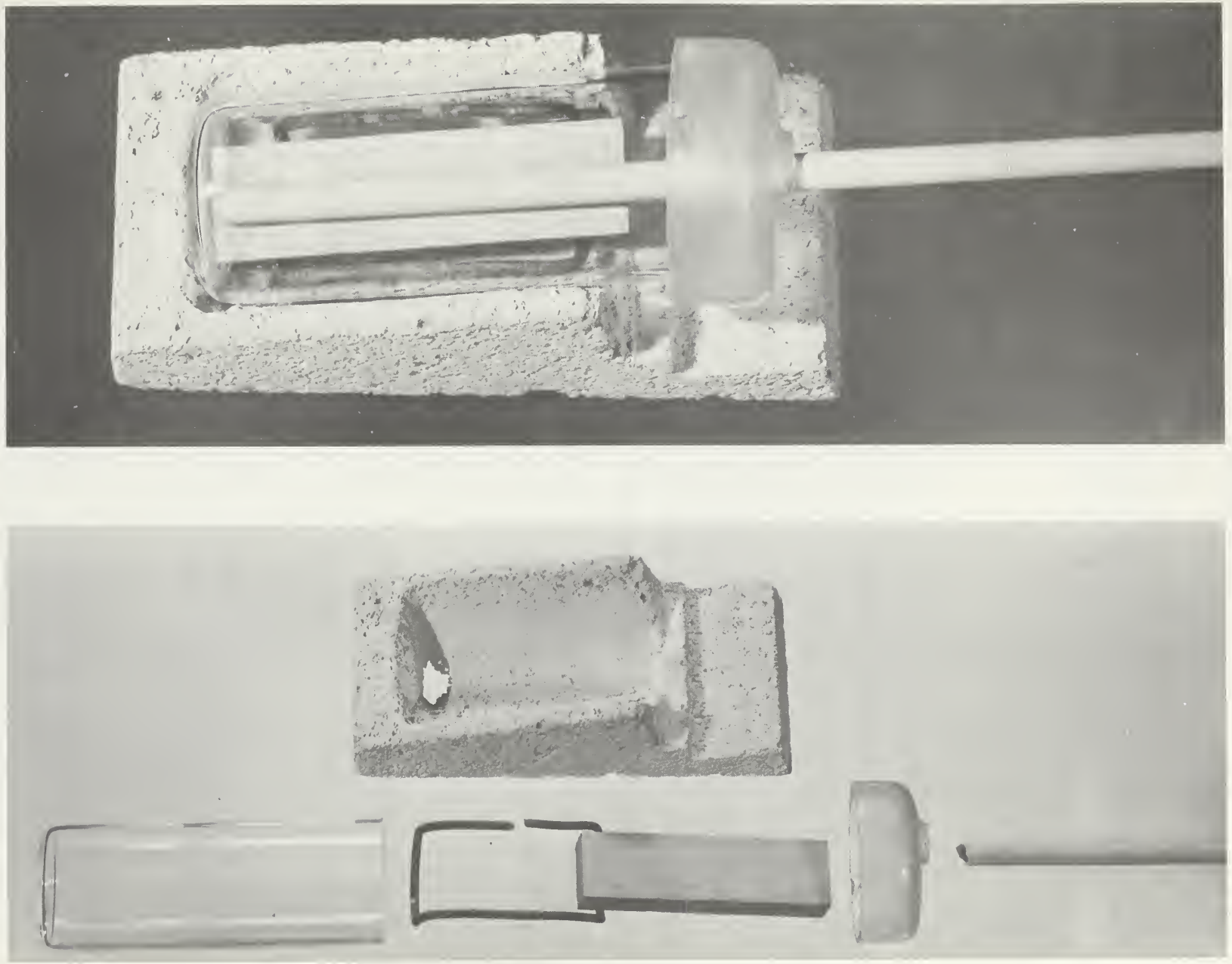

Fig. A2 Equipment for Performing Muffle Furnace Test
Top: Assembly Bottom: Component Parts

APPENDIX B

TENTATIVE TEST METHOD FOR MEASURING THE SMOKE GENERATION CHARACTERISTICS OF SOLID MATERIALS

1. Scope

1.1 This method measures the smoke generation characteristics of solid materials of given thickness and shape, when mounted and tested in the manner and with the apparatus described. Measurement is made of the attenuation of a light beam by smoke (suspended solid or liquid particles) accumulating within a closed chamber due to pyrolytic decomposition (smoldering) and flaming combustion. Results are expressed in terms of the specific optical density values over a 20 minute test period. Optical density (absorbance) is the single measurement most characteristic of the "concentration of smoke."

1.2 This method measures smoke produced under specified thermal exposure conditions comparable to those experienced in accidental fire situations. Materials are tested in simple, composite or assembly form as intended for use. The normally exposed surface of the material faces the radiant source, and materials which are "orientation sensitive" (as in the warp and fill directions of some fabrics) are tested in the worst case condition. The method and apparatus is also suitable for the collection and

analysis of the products of combustion and measurement of the effects of ventilation, higher irradiance, and other parameters.

1.3 The photometric scale used to measure smoke by this test method is similar to the optical density scale for human vision.

2. Summary of Method[1]

2.1 This method for measuring the smoke generation characteristics of materials employs as a radiant heat source, a glowing electrical heating element mounted within an insulated ceramic tube and positioned so as to produce an irradiance level of 2.2 Btu/sec ft^2 (2.5 W/cm^2) averaged over the central 1.5 in. (38.1 cm) dia. area of a vertically mounted specimen facing the radiant heater. The nominal 3 by 3 in. (76.2 by 76.2 mm) specimen is mounted within a holder which exposes an area measuring 2 9/16 by 2 9/16 in. (65.1 by 65.1 mm). The holder can accommodate specimens up to 1 in. (2.5 cm) thick. This exposure provides the nonflaming (smoldering) condition of the test.

2.2 For the flaming condition, a six-hole burner is used to apply a horizontal row of equidistant premixed (air-propane)

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[1] D. Gross, J. J. Loftus and A. F. Robertson, "Method for Measuring Smoke from Burning Materials," ASTM Special Technical Publication No. 422 (1967), describes factors in the development of this method and provides comparative test data on the measurement of the smoke generating characteristics of materials.

flamelets across the lower edge of the exposed specimen area. This application of flame in addition to the specified irradiance level from the heating element constitutes the flaming combustion exposure.

2.3 The test materials are exposed to the flaming and non-flaming conditions within a closed air-tight, 18 ft^3 (0.51 m^3) chamber. A photometric system with a 36 in. (91.4 cm) vertical light path measures the continuous decrease in light transmission as smoke accumulates.

2.4 Calibration procedures for the test equipment are described in Appendix A. The light transmittance measurements are used to express the smoke generation characteristics of the test materials in terms of the specific optical density during the time period to reach the maximum value.[2]

3. Apparatus

3.1 The apparatus shall be essentially as shown in Figs. 1 and 2 and shall include the following:

3.1.1 Test Chamber - As shown in Fig. 2, the test chamber shall be fabricated from continuously welded or soldered

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[2]Additional parameters, such as the maximum rate of smoke accumulation, time to a fixed optical density level, or a smoke obscuration index may be more appropriate in particular situations. See Appendix B

sheet metal or laminated panels[3] to provide inside dimensions of 36 by 24 by 36 in. (91.4 by 61.0 by 91.4 cm) for width, length and height, respectively. The interior surfaces shall consist of porcelain-enameled metal, or equivalent coated metal resistant to chemical attack and corrosion, and suitable for periodic cleaning. Openings shall be provided to accommodate a vertical photometer, power and signal connectors, air and gas supply tubes, an exhaust blower, inlet and exhaust vents, pressure and gas sampling taps, pressure relief valve, an aluminum foil (0.0010 in. or less; approx. 0.025 mm) safety blowout panel, at least 125 in.^{2} (806 cm^2) in area, and a hinged front mounted door with an observation port or window. All openings except the gas sampling taps and inlet vent shall be located on the floor of the chamber. Gas sampling taps should be located at or near the geometric center of the top surface. When all openings are closed the chamber shall be capable of developing and maintaining positive pressure during test periods, in accordance with paragraph 7.10 of Section 7. The chamber shall be supported on a suitable angle-iron frame which may be provided with casters. The controls and other instrumentation shall be mounted to facilitate their use.

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[3]Porcelain-enameled steel (interior surface) permanently laminated to asbestos-cement board and backed with galvanized steel (exterior surface), total thickness 3/16 in., by Alliance Wall Corporation has been found suitable.

3.1.2 Radiant Heat Furnace - An electric furnace with a 3 in. (76.2 mm) diameter opening shall be used to provide a constant irradiance on the specimen surface. In accordance with Fig. 3, the furnace shall consist of a coiled wire heating element[4] (525 W or greater) mounted vertically in a horizontal ceramic tube 3 in. (76.2 mm) i.d. by 3 3/8 in. (85.7 mm) o.d. by 1 5/8 in. (41.3 mm) long. The tube is bored out at one end to 3 1/32 in. (77.0 mm) i.d. and to a depth of 5/8 in. (15.9 mm) to accommodate the heating element. A 1/16 in. (1.6 mm) asbestos paper gasket, three stainless steel spacing washers, and two 1/32 in. stainless steel reflectors are mounted behind the heating element. A 3/8 in. (9.5 mm) asbestos millboard disc, provided with ventilation and lead wire holes, shall be positioned behind the heating element and used to center assembly with respect to the front 3/8 in. (9.5 mm) asbestos millboard ring by means of a 6-32 stainless steel screw. The adjustment nuts on the end of the centering screw shall provide proper spacing of the furnace components. The cavities adjacent to the heating element assembly shall be packed with glass wool. The furnace assembly shall be housed in a 4 in. (10.2 cm) o.d. by 0.083 in. (2.1 mm) wall by 4 1/8 in. (10.5 cm) long stainless steel tube. Two additional 3/8 in. (9.5 mm) asbestos board spacing rings and

[4]A Silex Percolator Element (e.g., Silex-Bloomfield Type EK6, or Eagle Electric, Cat. No. 385) has been found satisfactory for this purpose when the ceramic shoulder projection and the steel connector prongs are removed so that no obstructions extend beyond the base diameter.

a rear cover of 3/8 in. asbestos board shall complete the furnace. The furnace is to be located centrally along the long axis of the chamber with the opening facing toward and about 12 in. (30.5 cm) from the right wall. The centerline of the furnace shall be about 7 3/4 in. (19.5 cm) above the chamber floor.

The furnace control system shall consist of a thermocouple-actuated temperature controller with two autotransformers. One autotransformer ("low") shall be adjusted to provide the required irradiance level under steady-state conditions with the chamber door closed, and the second autotransformer ("high") adjusted to a slightly higher level. This arrangement prevents large power fluctuations (e.g., when the chamber door is open and the exhaust fan is on, or when a specimen undergoes active flaming.)

3.1.3 Specimen Holder - The specimen holder shall conform in shape and dimension to Fig. 4 and be fabricated by bending and brazing (or spot welding) 0.025 in. (approximately 0.60 mm) thick stainless steel to provide a 1 1/2 in. (38.1 mm) depth and expose a 2 9/16 by 2 9/16 in. (65.1 by 65.1 mm) specimen area. As described in paragraph 3.1.4, the holder shall have top and bottom guides to permit accurate centering of the exposed specimen area in relation to the furnace opening. A 3 by 3 in. (76.2 by 76.2 mm) sheet of 1/2 in. (12.7 mm) asbestos millboard, having a nominal density of 50 $\pm$ 10 lb/ft^3

(0.85 ± 0.17 g/cm^3), shall be used to back the specimen. A spring bent from 0.010 in. (approximately 0.25 mm) thick phosphor bronze sheet shall be used with a steel retaining rod to securely hold the specimen and millboard backing in position during testing. Also shown in Fig. 4 are sketches of a special holder and a special burner for specimens that melt during the test, and a modified retaining rod for use with specimens from 5/8 to 1 in. (1.6 to 2.5 cm) thick.

3.1.4 Framework for Support of the Furnace and Specimen Holder - The furnace and specimen supporting framework shall be constructed essentially in accordance with Fig. 5 and provide the following:

3.1.4.1 The framework shall have welded to it a 5 in. (12.7 cm) o.d., 1/4 in. (6.4 mm) wall, 2 in. (50.8 mm) long horizontally oriented steel tube to support the radiant heat furnace described in paragraph 3.1.2. This support tube shall have provision to accurately align the furnace opening so that it is: (1) 1 1/2 in. (38.1 mm) away from, (2) parallel to and (3) centered with respect to the exposed specimen area.

Three tapped holes with screws equidistantly positioned around the furnace support tube, or one screw at the top of the support in conjunction with two adjustable (vertically along the support tube) metal guide strips mounted horizontally inside to the tube, shall provide adequate alignment.

3.1.4.2 The framework shall have two 3/8 in. (9.5 mm) diameter transverse rods of stainless steel to accept the guides of the specimen holder described in paragraph 3.1.3. The rods shall support the holder so that the exposed specimen area is parallel to the furnace opening. Spacing stops shall be mounted at both ends of each rod to permit quick and accurate lateral positioning of the specimen holder.

3.1.5 Photometric System - The photometric system shall consist of a light source and photodetector, oriented vertically to reduce variations in measurement brought about by stratification of the smoke generated by the materials under test. The system shall be as shown in Fig. 6, which includes the following:

3.1.5.1 The light source shall be an incandescent prefocused (15 W or greater) lamp powered by a voltage regulating transformer. Two variable resistors in series shall provide coarse (100 ohms, 25 W) and fine (10 ohms, 25 W) intensity adjustment. The light source shall be mounted in a sealed and light-tight box extending from the top or bottom of the chamber. This box shall contain the necessary optics for collimating the light beam.

3.1.5.2 The photodetector shall be a 1P39 single-stage vacuum tube, or a photomultiplier tube, with an S-4 spectral sensitivity response and a dark current less than 10^{-9} A. Another

sealed box located directly opposite the light source shall be provided to house the photodetector and the focusing optics. A 3/16 in. (4.8 mm) dia. circular stop at the focal plane of the lens, serves to collimate the beam and to minimize the entry of scattered light from off-axis illumination. A glass window shall be used to isolate the photodetecter and its optics from the interior of the chamber. The collimated beam shall have a path length of 36 in. (91.4 cm) and a sensing cross-section of 1 1/2 $\pm$ 1/8 in. (38.1 $\pm$ 3.2 mm) diameter (see Appendix A, paragraph A1.1.2). The approximately circular light "spot" shall be centered entirely within the sensing area of the detector. A battery (45 or 67.5 V) or D.C. power supply, a load resistor (which may be the fixed input impedance of the indicator or recorder) and an electrically shielded cable complete the photometer circuit for a single-stage vacuum tube photometer system. (A typical photomultiplier photometer system will require a high-voltage D.C. power supply and a neutral density filter of sufficient optical density to produce a convenient signal level for the indicator or recorder.) The photometer system used shall be capable of permitting the recording of reliable optical densities up to 5.0, corresponding to transmittance values of 0.001 percent of the incident light. (See Appendix A, paragraph A1.1.1).

3.1.5.3 The two optical platforms and their housings shall be kept in alignment with three metal rods, 1/2 in. (12.7 mm) in diameter, fastened securely into 5/16 in. (7.9 mm) thick externally mounted top and bottom plates, and symmetrically arranged about the collimated light beam.

3.1.6 Radiometer - The radiometer for standardizing the output of the radiant heat furnace shall be of the circular foil type, the operation of which was described by Gardon[5]. The construction of the radiometer shall be as shown in Fig. 7. It shall have a stainless steel reflective heat shield with a 1 1/2 in. (38.1 mm) aperture on the front and a finned cooler supplied with compressed air mounted on the rear to maintain a constant cold junction temperature.

The body (cold-junction) temperature of the radiometer shall be monitored with a 100-220°F (38-100°C) thermometer in a 1/2 by 1/2 by 1 1/2 in. (12.7 by 12.7 by 38.1 mm) brass well drilled to accept the thermometer with a close fit. Silicone grease may be used to provide good thermal contact.

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[5]R. Gardon, "An Instrument for the Direct Measurement of Intense Thermal Radiation, "Review of Scientific Instruments, Vol. 24, pp. 366-370, (1953).

The circular receiving surface of the radiometer shall be spray-coated with an infrared-absorbing black paint containing a silicone vehicle[6]. The radiometer shall be calibrated calorimetrically in accordance with the procedure summarized in paragraph A1.2 of Appendix A.

3.1.7 Thermocouples for Determining Chamber Wall Temperature and Controlling Furnace Output - Thermocouples for determining the chamber wall temperature prior to testing and to provide temperature control of the furnace shall be made from chromel and alumel wires 0.032 in. (approximately 0.80 mm) in diameter or smaller. The thermocouples shall be mounted as described in the following:

3.1.7.1 The wall thermocouple junction shall protrude inward about 0.06 in. (1.5 mm) through a small hole drilled at the geometric center of the chamber back wall. The protruded section shall be bent in reverse to contact the inside surface of the chamber. A 3/8 in. (9.5 mm) diameter, 1/4 in. (6.4 mm) thick polystyrene foam disc and epoxy cement shall cover and seal the thermocouple to the wall.

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[6]Type 8X906 Flat Black Paint, Midland Industrial Finishes Co., Inc. has been found suitable for this purpose. A thin coating (one mil) of this paint provides an absorptivity of approximately 0.93.

3.1.7.2 One thermocouple shall be positioned within the radiant heat furnace about 1/16 in. (1.6 mm) from the surface of the ceramic tube and 1/4 in. (6.4 mm) from the heating coils to provide a temperature sensing input to a controller (see paragraph 3.1.2.). This thermocouple shall be enclosed in a thin stainless steel shielding tube.

3.1.8 Portable Recorder or Read-Out Meter - The outputs of the radiometer and the thermocouples shall be monitored by a suitable recorder or read-out meter. The photodetector output shall be recorded or monitored with a potentiometer or high-impedance instrument capable of measurement over a range of 5 decades, or more.

3.1.9 Manometer for Chamber Pressure Measurements - A simple water manometer with a range up to 6 in. (15.2 cm) of water shall be provided to monitor chamber pressure and leakage (see Appendix A). The pressure measurement point shall be through a gas sampling hole at the top of the chamber. A simple water column or relief valve shall be provided to permit control of chamber pressure.

3.1.10 Multiple Flamelet Burner with Premixed Air-Propane Fuel - For a flaming exposure test, either a six-hole "Tee" burner or a more durable six-tube burner, with construction

details as shown in Fig. 4, shall be used. The vertical tubes of the six-tube burner shall be made from 1/8 in. (3.2 mm) o.d. by 0.063 in. (1.6 mm) thick-wall stainless steel tubing. All tubes should be crimped at the tip to reduce the opening diameter to 0.055 in. (1.4 mm). The horizontal manifold section of the burner shall consist of 1/4 in. (6.4 mm) o.d. by 0.035 in. (0.9 mm) wall stainless steel tubing. The other end is attached to a fitting in the chamber floor by bending and by using appropriate fittings.

The burner shall be centered in front of and parallel to the specimen holder. The holes or tip of the nozzles shall be 1/4 in. (6.4 mm) above the holder edge and 1/4 in. (6.4 mm) away from the specimen surface. Provision shall be made to rotate or move the burner out of position during non-flaming (smoldering) exposures. A premixed air and propane (technical grade or better) test gas shall be used. The air and propane shall be metered by calibrated rotameters and needle valves at 500 cm^3/min. for the air and 50 cm^3/min. for the propane.

3.1.11 Special Burner For Melting Specimens - If, under a normal flaming exposure, the specimen melts or shrinks away from the pilot burner or drips from the holder and thus fails to ignite, a special specimen holder and burner shall be used. The construction details are shown in Fig. 4. Using

the outer two tubes as guides, the burner shall be aligned relative to the specimen holder as described in 3.1.10 for the standard burner and holder . In cases where there is question as to the appropriate burner to use, comparison tests shall be made using each burner.

4. Test Specimens

4.1 Size - The test specimens shall be 3 by 3 in. (76.2 by 76.2 mm) by the intended installation thickness up to and including 1 in. (25.4 mm) thick. Specimens provided in thicknesses in excess of 1 in. (25.4 mm), shall be sliced to 1 in. (25.4 mm) thickness for testing.

4.2 Specimen Orientation - If visual inspection of the specimen indicates a pronounced grain pattern, process-induced surface orientation, or other nonisotropic property, the specimen shall be tested in two or more orientations. The highest smoke density value and the test orientation shall be stated.

4.3 Specimen Assembly

4.3.1 The specimen shall be representative of the materials or composite as intended for use and shall be prepared in accordance with recommended application procedures. However,

flat sections of the same thickness and composition may be supplied and tested in place of curved, molded or specialty parts. Substrate or core materials for the test specimens shall be the same as those for the intended application. Where a material or assembly may be exposed to a potential fire on either side, both sides shall be tested.

4.3.1.1 Finish materials, including sheet laminates, tiles, fabrics and others secured to a substrate material with adhesive, and composite materials not attached to a substrate, may be subject to delamination, cracking, peeling, or other separations affecting its smoke generating characteristics. To evaluate these effects, supplementary tests performed on a scored (slit) exposed surface, or on interior layers or surfaces, may be necessary. When supplementary tests are conducted for this purpose, the manner of performing such supplementary tests, and the test results, shall be included in the report with the conventional test.

4.3.2 For comparative tests of finish materials without a normal substrate or core, and for screening purposes only the following procedures shall be employed:

4.3.2.1 All sheet or film materials shall be tested by the standard procedure regardless of thickness.

4.3.2.2 Liquid film (paints, adhesives, etc.) intended for application to combustible base materials, shall be applied to the smooth face of 1/4 in. (6.4 mm) thick tempered hardboard, nominal density 50 to 60 lb/ft^3 (0.8 to 0.97 g/cm^3), using recommended (or practical) application techniques and coverage rates. Tests shall also be conducted on the hardboard substrate alone and these values shall be recored as supplemental to the measured values for the composite specimen.

4.3.1.3 Liquid films, (paints, adhesives, etc.) intended for application to noncombustible substrate materials, shall be applied to the smooth face of 1/4 in. (6.4 mm) thick asbestos-cement board, nominally 120 lb/ft^3 (1.9 g/cm^3) in density, using recommended (or practical) application techniques and coverage rates.

4.3.3 It is the intent of this test method to maintain the prescribed exposure conditions on the specimen for the test duration. If, during any test, the specimen tends to melt or drip and fall away from the specimen holder, it shall be tested using a specimen holder which has been modified to retain the fallen residue so that it remains exposed to the radiant heat source throughout the test period. For flaming condition, a special pilot burner (see Fig. 4) should also be used with the modified holder.

4.3.4 Specimen Mounting

4.3.4.1 All specimens, shall be covered across the back, along the edges, and over the unexposed front surface periphery with a single sheet of aluminum foil (0.0015 $\pm$ 0.0005 in. or approximately 0.04 mm). The less reflective surface of the foil is to be placed against the specimen back surface. Care shall be taken not to puncture the foil or to introduce unnecessary wrinkles during the wrapping operation. Fold in such a way so as to minimize losses of melted material at the bottom of the holder. Excessive foil along the front edges may be trimmed off, after mounting. In using the special holder (with trough), a flap of foil should be bent forward at the spout to permit flow.

4.3.4.2 All specimens shall be backed with a sheet of asbestos millboard (see paragraph 3.1.3.). The specimen and its backing shall be secured with the spring and retaining rod. A modified 'C'shape retaining rod shall be used with specimens from 5/8 to 1 in. (1.6 to 2.5 cm) thick. Do not compress flexible specimens beyond their normal thickness.

5. Specimen Conditioning

5.1 Specimens shall be predried for 24 hr. at 140°F (60°C) and then conditioned to equilibrium (constant weight) with an ambient temperature of 73 ± 5°F (23 ± 3°C) and a relative humidity of 50 ± 5 percent.

6. Number of Test Specimens

6.1 At least three tests under flaming exposure and three tests under nonflaming (smoldering) exposure shall be conducted on each material (total of six specimens) in accordance with the conditions described herein.

7. Test Procedure

7.1 All tests shall be conducted in a room or enclosed space having a ambient temperature of 73 ± 5°F (23 ± 3°C) and relative humidity of 50 ± 20 percent at the time of test.

7.2 Clean the chamber walls whenever periodic visual inspection indicates the need[7]. Clean the exposed surfaces of the glass windows separating the photodetector and light source housings

[7]An ammoniated spray detergent (e.g. "Whistle") and soft scouring pads (e.g. "3M") have been found effective.

from the interior of the chamber, before each test (ethyl alcohol is generally effective). Charred residues on the specimen holder and horizontal rods should be removed to avoid contamination.

7.3 During the warm-up period all electric systems (furnace, light source, photometer readout etc.) should be on; the exhaust vent and chamber door closed; and the inlet vent open. When the temperature on the center surface of the back wall reaches 95 $\pm$ 4°F (35 $\pm$ 2°C), the chamber is considered to be at a steady-state condition and ready for furnace calibration or testing. Calibrate the furnace output irradiance at least twice per test day.

A "blank" specimen holder, with the asbestos millboard backing exposed should always be directly in front of the furnace except when displaced to the side by (1) the specimen holder during a test or (2) the radiometer during calibration. It should be returned immediately to this position when testing or calibration is completed.

7.4 During calibration, the radiometer is placed on the horizontal rods of the furnace support framework and accurately positioned in front of the furnace opening, by sliding and displacing the "blank" specimen holder against the prepositioned

stop used for test specimens. With the chamber door closed and inlet vent opened, the compressed air supply to the radiometer cooler is adjusted to maintain its body (cold-junction) temperature at 200°F (93°C). The "low" autotransformer setting is adjusted to produce the calibrated millivolt output of the radiometer corresponding to a steady-state irradiance of 2.2 Btu/sec ft^2 (2.5 W/cm^2) averaged over the central 1.5 in. (38.1 cm) dia. area. The "high" autotransformer setting should be about 2 to 5 volts above the "low" setting. The temperature setting of the controller should be approximately 10°C below that corresponding to steady-state conditions, so that a temperature decrease of 10°C is required to switch to the "high" autotransformer. Under normal operation, the on-off cyclic control is required only occasionally.

The recorder or meter described in paragraph 3.1.8 is used to monitor the radiometer output. After the prescribed irradiance level has reached steady-state, the radiometer is removed from the chamber and replaced with the "blank" specimen holder.

7.5 After the system has reached steady-state conditions, adjust the lamp resistor to obtain a full-scale reading of the photodetector (100 percent transmittance) on a convenient range of the recorder or read-out meter. Verify the zero

reading (zero percent transmittance) on the recorder or read-out meter by shorting the input and covering the light.

7.6 For nonflaming (smoldering) exposures, the multiple flamelet burner is removed. For flaming exposures, the burner is positioned across the lower edge of the specimen as described in paragraph 3.1.10. Check the burner distances relative to the "blank" specimen before fuel adjustment and ignition.

7.7 Before positioning the test specimen, verify the starting temperature of the chamber, using the procedure described in paragraph 7.3. Flush the chamber with the door and exhaust and inlet vents open for about 2 minutes.

7.8 Close the exhaust vent and blower. Place the loaded specimen holder on the bar supports and push it into position in front of the furnace (with burner in position for flaming exposure) by displacing the "blank" holder. Quickly close the chamber door and simultaneously start the timer, and/or recorder chart drive. Close the inlet vent completely when the photometer indicates smoke.

7.9 Record light transmittance and the corresponding time either as a continuous plot with a multi-range recorder or at

sufficient time intervals with a multi-range meter read-out. Make and note the necessary full-scale range changes in decade steps.

7.10 Observe the increase in chamber pressure with the manometer described in paragraph 3.1.9. A regulator shall maintain the pressure in the range of 4 $\pm$ 2 in. (10 $\pm$ 5 cm) of water. As a result of pressure rise, the fuel and air valves must be adjusted, during the flaming test, to maintain constant flow rate.

7.11 Record any observations pertinent to the burning and smoke generating properties of the material under test, in accordance with paragraphs 9.1.6 and 9.1.7.

7.12 Continue the test until a minimum light transmittance value is reached or after an exposure of 20 minutes; whichever occurs first. If desired, the test may be conducted for periods in excess of 20 minutes, when minimum transmittance levels have not been reached during the 20 minute exposure. The term "Extended Exposure" is to be used to identify data developed in tests longer than 20 minutes in duration.

7.13 If transmittance falls below 0.01%, the chamber window should be covered with an opaque screen to avoid possible light scattering effects from room light.

7.14 For photometer systems with no provision for dark current cancellation, record "dark current" light transmittance, for correction of light transmittance readings of 0.01% or less, by switching off power to the photometer light source and setting the recorder or read-out meter at suitable high sensitivity. Again, verify the zero reading by shorting the meter input.

7.15 Extinguish the burner on flaming exposures and start exhausting the chamber within one minute after reaching minimum transmittance or after a 20 minute exposure. Remove the specimen from the front of the furnace by pushing the "blank" specimen holder with a rod inserted from a small hole at the back of the chamber. Continue to exhaust with the inlet vent open until maximum transmittance is reached. Record this transmittance value as the T_c, "clear beam" reading which is to be used to correct for deposits on the photometer windows.

8. Calculations

8.1 Calculate specific optical density, D_s, from the reduction in light transmittance, T, caused by the smoke generated from an exposed specimen area, A, in the closed chamber of volume, V, and over a light path, L, as follows:

$$D_s = \frac{V}{LA} \left[\log_{10} \left(\frac{100}{T}\right)\right] = G \left[\log_{10} \left(\frac{100}{T}\right)\right]$$

where G represents the geometrical factor associated with the dimensions of the chamber and specimen.

8.2 Calculate the maximum specific optical density, D_m, using the formula in paragraph 8.1 with a light transmittance corresponding to the minimum level reached during the test. Correct all maximum specific optical density values by substracting the specific optical density equivalent for soot and other deposits on the photometer windows. As described in paragraph 7.15, the "clear beam" transmittance reading T_c is used to calculate a specific optical density equivalent D_c, using the same formula but with different subscript. A corrected maximum specific optical density calculation is expressed as follows:

$$D_m \text{ (corr.)} = D_m - D_c$$

8.3 Determine $t_{.9D_m}$, the time for the smoke to accumulate to 90 percent of the uncorrected maximum specific optical density value from a plot of specific optical density versus time or from the tabulated data.

8.4 When the test is continued beyond the standard 20 minute exposure, all calculations are to be made in accordance with paragraphs 8.1 through 8.4 and the results specially identified as "Extended Exposure."

9. Report

9.1 The report (see Appendix D) shall include the following:

9.1.1 Complete description of the material tested including: type, manufacturer, shape, thickness and/or other appropriate dimensions, weight or density, coloring, etc.

9.1.2 Complete description of the test specimens, including: substrate or core, special preparation, mounting, etc.

9.1.3 Test specimen conditioning procedure.

9.1.4 Number of specimens tested.

9.1.5 Test conditions: type of exposures, type of burners and holders used, exposure period.

9.1.6 Observations of the burning or smoldering characteristics of the specimens during test exposure, such as delamination, sagging, shrinkage, melting, collapse, etc.

9.1.7 Observations of the smoke generating properties of the specimens during exposure, such as, color of the smoke, nature of the settled particulate matter, etc.

9.1.8 A record of the geometrical factor, G, as calculated from measured values of chamber volume, V, photometer light path length, L, and exposed specimen area, A (see Section 8 on calculations).

9.1.9 Test results calculated as described in Section 8, including the average and range on each set of specimens for D_m (corr.), $t_{.9D_m}$, D_c and others (see Appendix B.) if required.

APPENDIX A

Calibration of Test Equipment

A1.1 Photometric System

A1.1.1 Linearity of the photometer is checked by interrupting the light beam at several points along its path with wire screens of known open area and/or calibrated neutral density filters. The screens or filters should cover a wide range of light transmittance, to .01 percent or lower. Plot the known transmittances versus the recorded transmittance readings of the photometer. Observation of the plot or tabulated readings will establish the linearity of the system.

A1.1.2 Effective light beam cross-section measurements are made at the top and bottom of the chamber, by inserting an opaque sheet of material into the beam path at the front, back and sides of the beam, and noting the point at which the light transmittance reading decreases. Using these measurements, the average diameter of the sensing area to the phototube may be determined.

A1.1.3 Shifts in dark current levels between tests, excessive zero shifts during test or lack of linearity should prompt inspection of the photometer system and replacement of the phototube or battery, as necessary.

A1.2 Radiometer

Calibration of the radiometer is accomplished by placing it at suitable distances from a radiant energy source, while maintaining its body (cold-junction) temperature at 200°F (93°C) with controlled air flow through the rear-mounted cooler, and measuring its electrical output as a function of the irradiance level. The irradiance level is determined calorimetrically by measuring the rate of temperature rise of a blackened thin copper disk of known weight, area (1 1/2 in., 38.1 mm dia), specific heat and absorptivity in place of the radiometer.

The measured millivolt output of the radiometer, at a body temperature of 200°F (93°C), corresponding to an irradiance level of 2.2 Btu/sec. ft^2 (2.5 W/cm^2) is used to establish the furnace control settings discussed in paragraphs 3.1.2 and 7.3.

A1.3 Chamber Pressure Manometer - Leakage Rate Test

For purposes of standardization, periodically conduct a leakage rate test using the manometer and tubing described in paragraph 3.1.9. Pressurize the chamber to 3 in. (approximately 76 mm) of water by introducing compressed air

through a gas sampling hole in the top. Time the decrease in pressure from 3 to 2 in. (approximately 76 to 50 mm) of water with a stop watch. This time should not be less than 5.0 minutes.

A1.4 Standard Smoke Generating Material

For checking operational and procedural details of the equipment and method described herein, a single layer of nominal 0.030 in. (approximately 0.76 mm) thick alpha-cellulose (cotton linters) paper[8] should provide repeatable maximum specific optical density values of 165 $\pm$ 10. Use of this standard material does not obviate the need for following the calibration and standardization procedure outlined in this Standard.

APPENDIX B

Presentation of Test Results

The smoke chamber test results in a curve of specific optical density versus time. The maximum specific optical density, D_m, represents total smoke accumulation. Since the time to reach this point is often indistinct, the time to reach 90%

[8]Grade 448 alpha-cellulose (cotton linter) paper, nominally 0.030 in. (approximately 0.76 mm) thick, by Hercules, Inc., has been used.

of D_m, $t_{.9D_m}$, generally represents a more easily defined and repeatable point. Additional parameters which may be of particular value include:

R_m: Maximum rate of increase in specific optical density per minute, measured over a 2-min. period.

$t_{D_s=16}$: Time to reach $D_s=16$ (T = 75%), or other smoke level.

This is a simple measure of smoke generation rate, particularly where time is important.

$$SOI = \frac{D_m^2}{2000\ t_{D_s=16}} \left(\frac{1}{t_{.3}-t_{.1}} + \frac{1}{t_{.5}-t_{.3}} + \frac{1}{t_{.7}-t_{.5}} + \frac{1}{t_{.9}-t_{.7}}\right)$$

where $t_{.1}$, $t_{.3}$, etc., indicate the time in minutes at which the smoke accumulation reaches 10, 30, etc., per cent of the maximum density D_m. Smoke obscuration index, incorporating the effects of total smoke, generation rate and time to reach $D_s = 16$. (See footnote 1 of main text)

$$SON_4 = D_1 + D_2 + D_3 + D_4$$

Smoke obscuration number based on the simple addition of the 1, 2, 3 and 4 minute values of

Specific optical density. This index represents a weighted rate of smoke generation over a 4 minute interval only.

The preceding parameters are obtained for the flaming and nonflaming exposures separately, and the highest value could presumably be used. There may be some merit in combining values from the flaming and nonflaming tests to yield a single composite index, e.g.

$$SOI_c = [\ (SOI)_f \ . \ (SOI)_n\ ]^{1/6}$$

A more comprehensive approach to smoke hazard evaluation of a material might include the effects of smoke obscuration under a bracketing set of fire conditions[9], e.g.

$$MSOU = \sum_{i=1}^{8} (SOI)_i$$

for i = 1, nonflaming test (std)

i = 2, flaming test (std)

i = 3, nonflaming test with forced ventilation

i = 4, flaming test with forced ventilation

i = 5, nonflaming test at high irradiance level

i = 6, flaming test at high irradiance level

i = 7, nonflaming test at high irradiance level and forced ventilation

[9] J. R. Gaskill, Fire Technology, Ausust 1968.

i = 8, flaming test at high irradiance level and forced ventilation.

APPENDIX C

Analysis of Products of Combustion

Although not specifically required as a part of the method, products of combustion may be drawn from the chamber at various times during the progress of the test for analysis. The physical properties of the smoke may be investigated by electrostatic or impact collection and various methods of particle analysis. The presence and concentrations of various toxic and irritating gaseous products may be determined using colorimetric gas detector tubes, gas chromatography methods, ion-selective electrodes, or other techniques.

APPENDIX D
Sample Data Sheet

Sample Code ____________ Test No. ________ Date ____________

Lab Code ____________ Operator ____________ Time ____________

Recorded Data or Curve

Time, min.	% Trans.	D_s
0	100	0

Operating Conditions

Radiometer Reading ______mV; Irradiance ______W/cm^2

Furnace Voltage ________V

Burner Fuel_____cc/min air; ________cc/min propane

Thermal Exposure: flaming smoldering

Chamber Pressure __________inch H_2O

Chamber Temperature ________°C

Chamber Surface Condition ____________________

____

Burner & Holder: standard special

Sample

Description - ____________________

Manufacturer - ____________________

Preconditioning: Temp. ______°C; Duration ______hr.

Conditioning: Temp.______°C; RH ____%; Duration ______

Thickness -______in.; Density______g/cm^3 or lb/ft^3

Initial Wt.________; Final Wt.________; % Loss______

Special Conditions - ____________________

____

Results

Min. Trans. __________% at __________ min.

Max. Specific Optical Density, D_m = __________

Time to Reach 90% D_m = __________

Clear Beam Reading =________%; Equiv. D_c ________

D_m (corr.) = $D_m - D_c$ = __________

Optional Presentation of Results

Time to Develop $D_s = 16$ = __________

Max. Rate, $R = \frac{dD_s}{dt}$ = __________

$SoN_{(5\ min)} = D_1 + D_2 + D_3 + D_4 + D_5$ = __________

Remarks

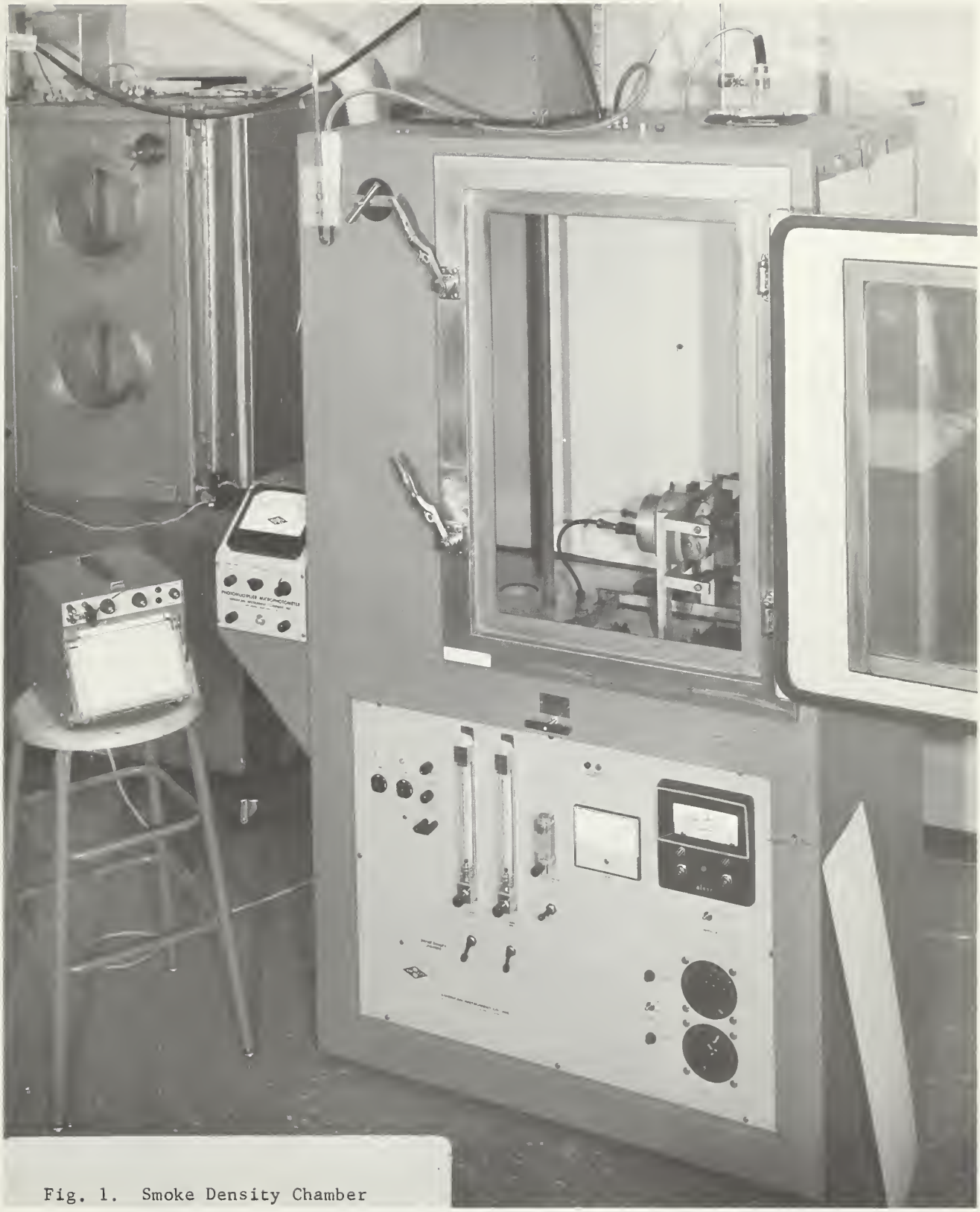


Fig. 1. Smoke Density Chamber

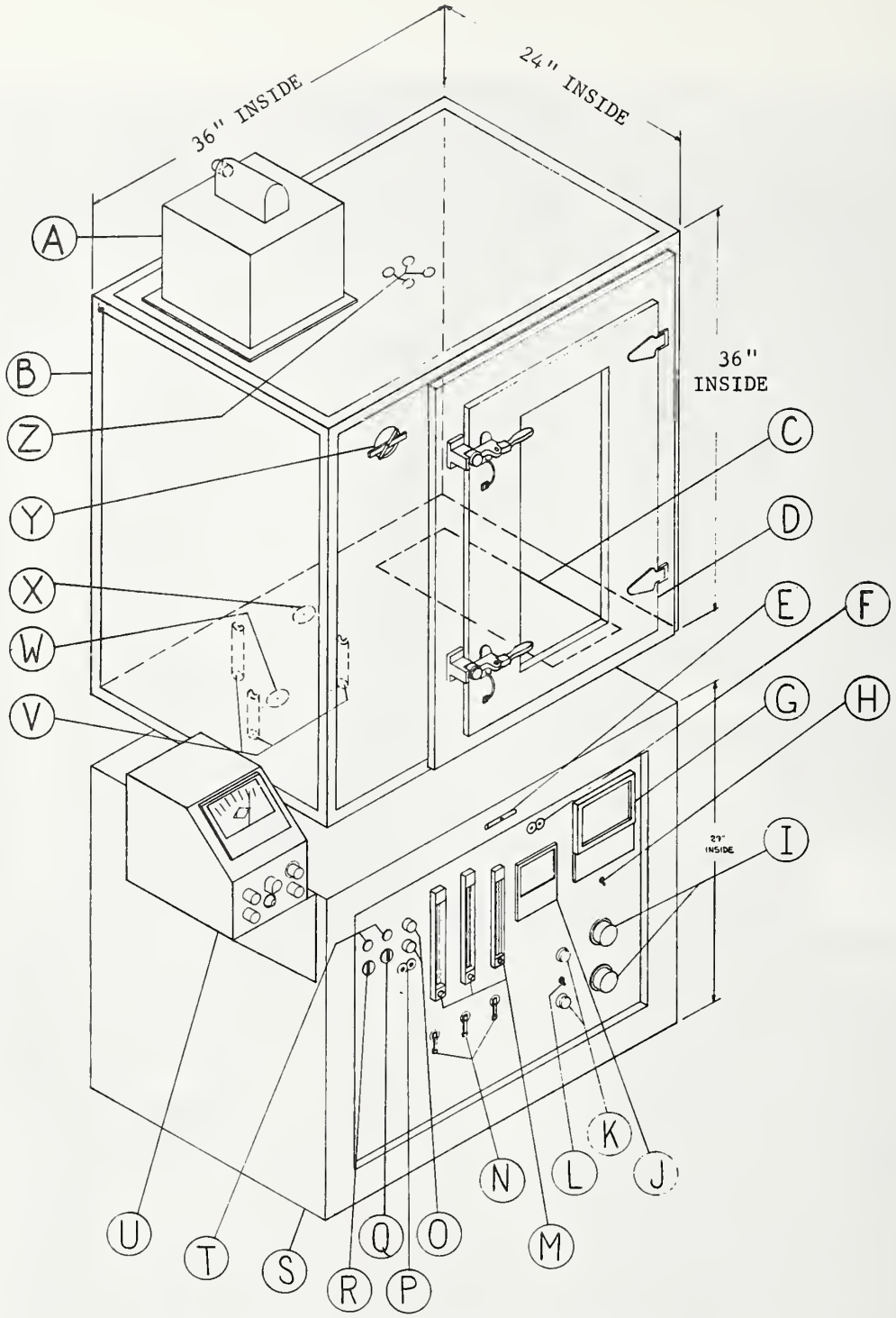
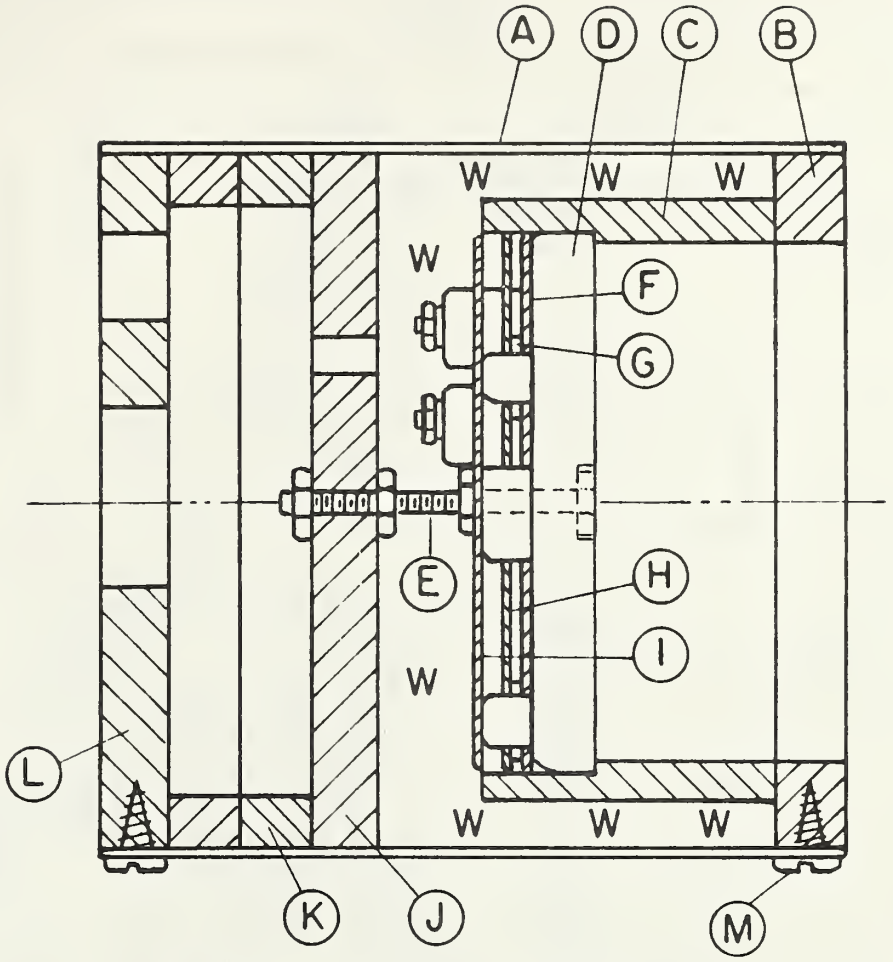


Figure 2. Smoke Density Chamber Assembly

A - Phototube Enclosure
B - Chamber
C - Blowout Panel
D - Hinged Door with Window
E - Exhaust Vent Control
F - Radiometer Output Jack
G - Temperature Controller
H - Temperature Controller Switch
I - Autotransformers
J - Voltmeter (furnace)
K - Fuse Holders
L - Furnace Heater Switch
M - Gas & Air Flowmeters
N - Gas & Air Shutoff Valves
O - Light Intensity Controls
P - Light Voltage Measuring Jack
Q - Light Source Switch
R - Line Switch
S - Support Frame
T - Indicating Lamps
U - Photometer Readout
V - Rods
W - Glass Window
X - Exhaust Vent
Y - Inlet Vent
Z - Access Ports



A - STAINLESS STEEL TUBE
B - ASBESTOS BOARD
C - CERAMIC TUBE
D - HEATING ELEMENT, 525 W
E - STAINLESS STEEL SCREW
F - ASBESTOS PAPER GASKET
G - STAINLESS STEEL SPACING WASHERS (3)
H - STAINLESS STEEL REFLECTOR
I - STAINLESS STEEL REFLECTOR
J - ASBESTOS BOARD
K-ASBESTOS BOARD RINGS
L-ASBESTOS BOARD COVER
M-SHEET METAL SCREWS
W-PYREX GLASS WOOL

FIG. 3 -FURNACE SECTION

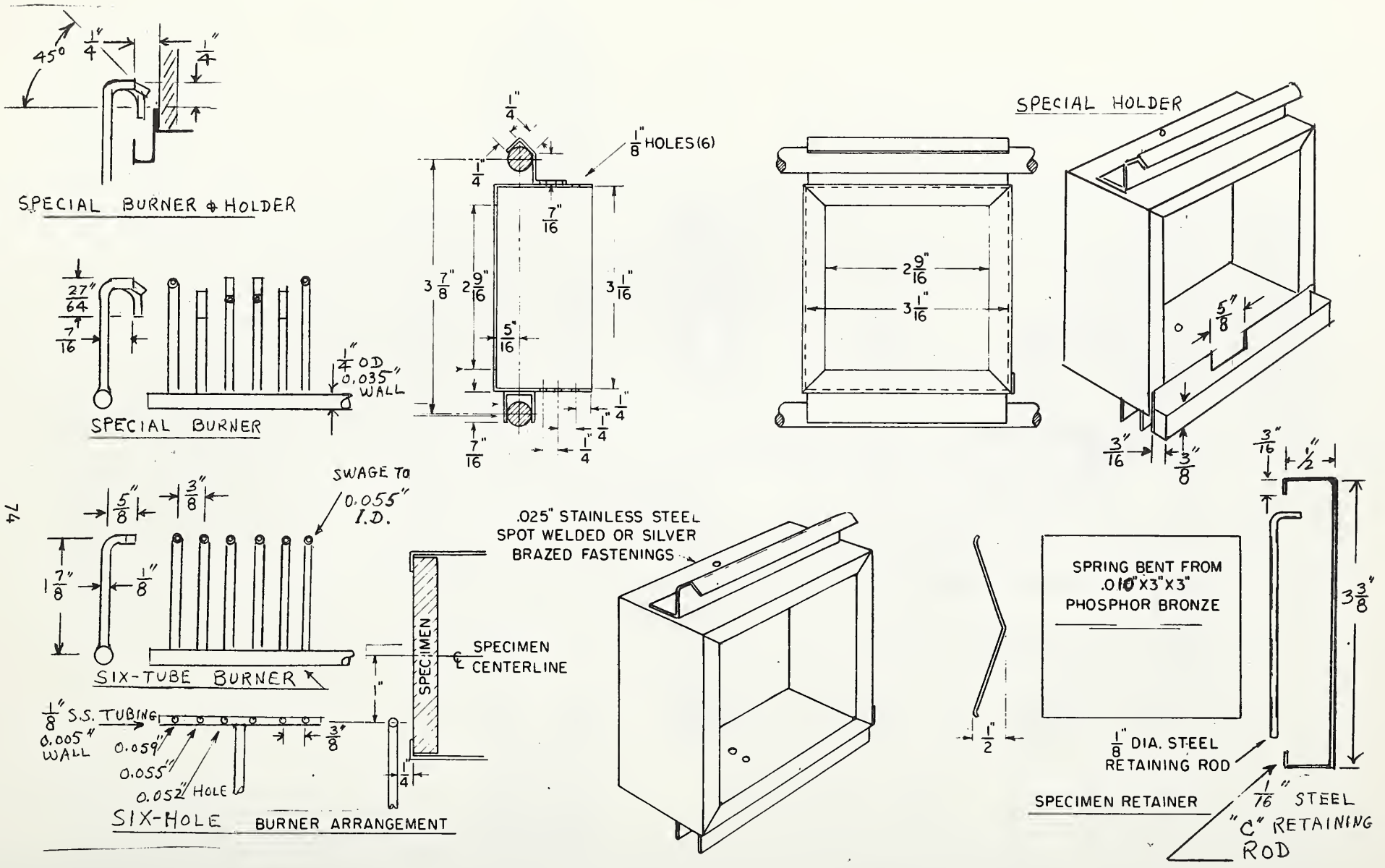


FIG. 4 - DETAILS OF SPECIMEN HOLDER AND PILOT BURNER

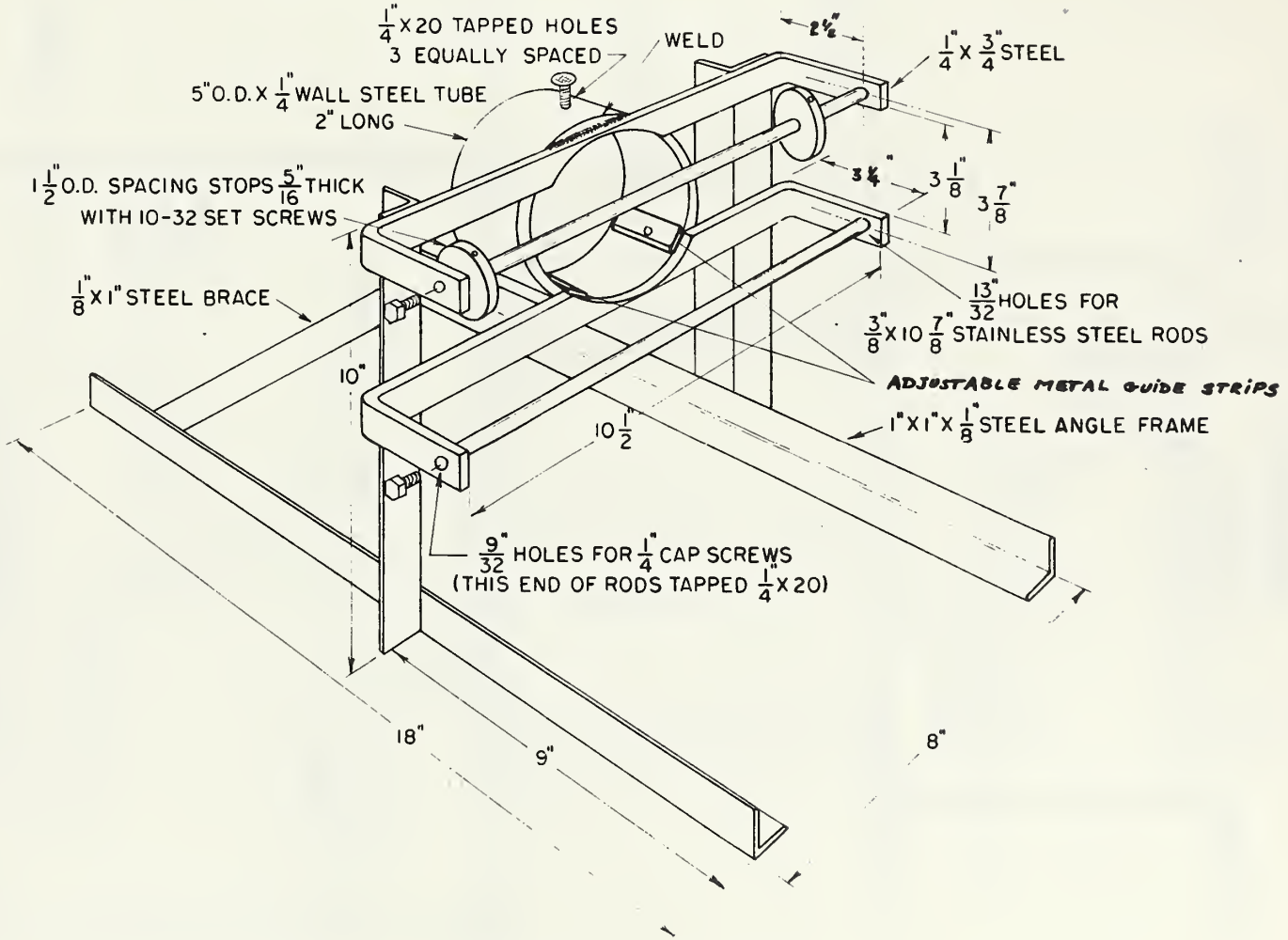


FIG. 5 – FURNACE SUPPORT

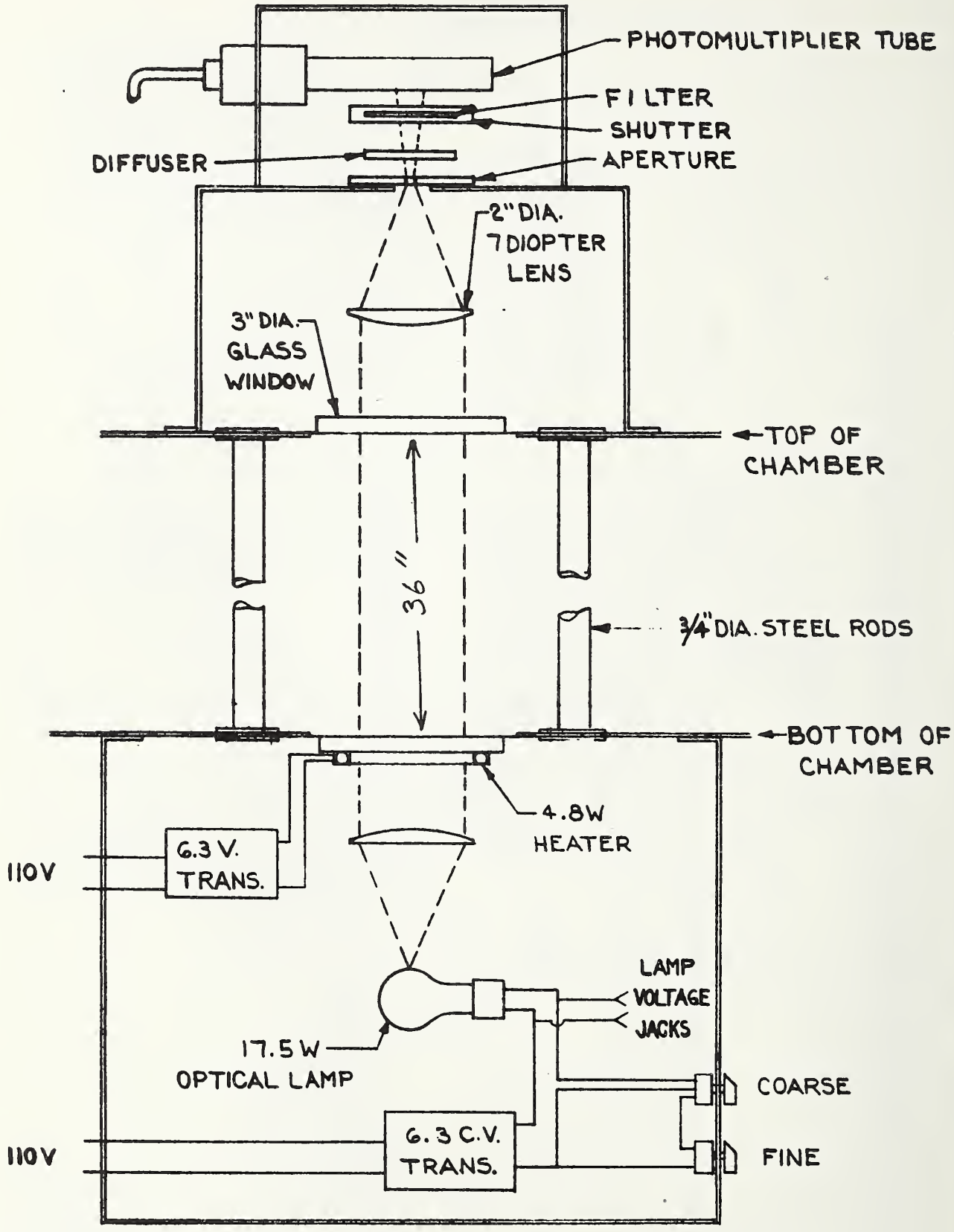
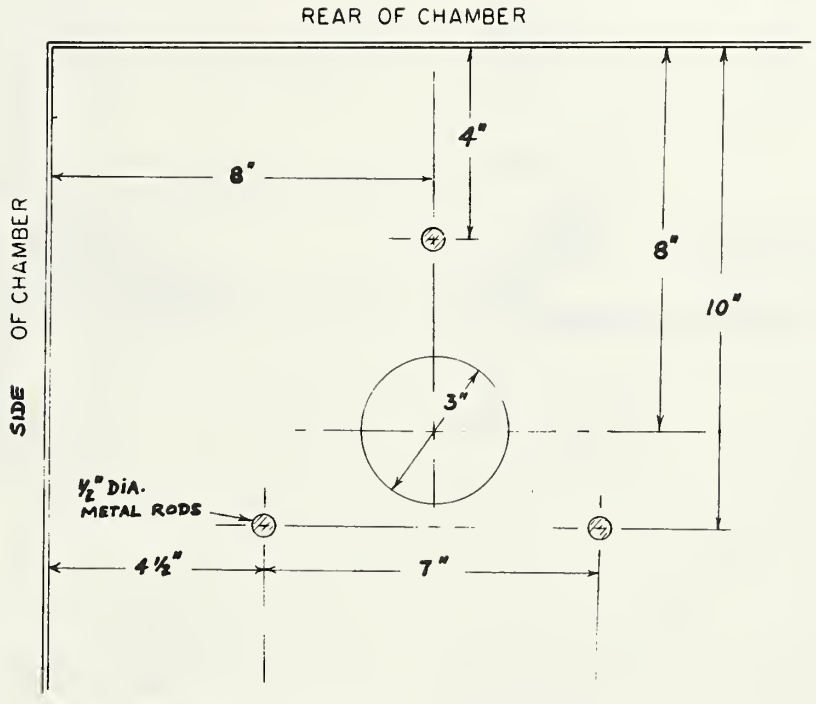


Fig. 6A - Photometer Details



PHOTOMETER LOCATION

PLAN VIEW

Fig. 6B PHOTOMETER LOCATION

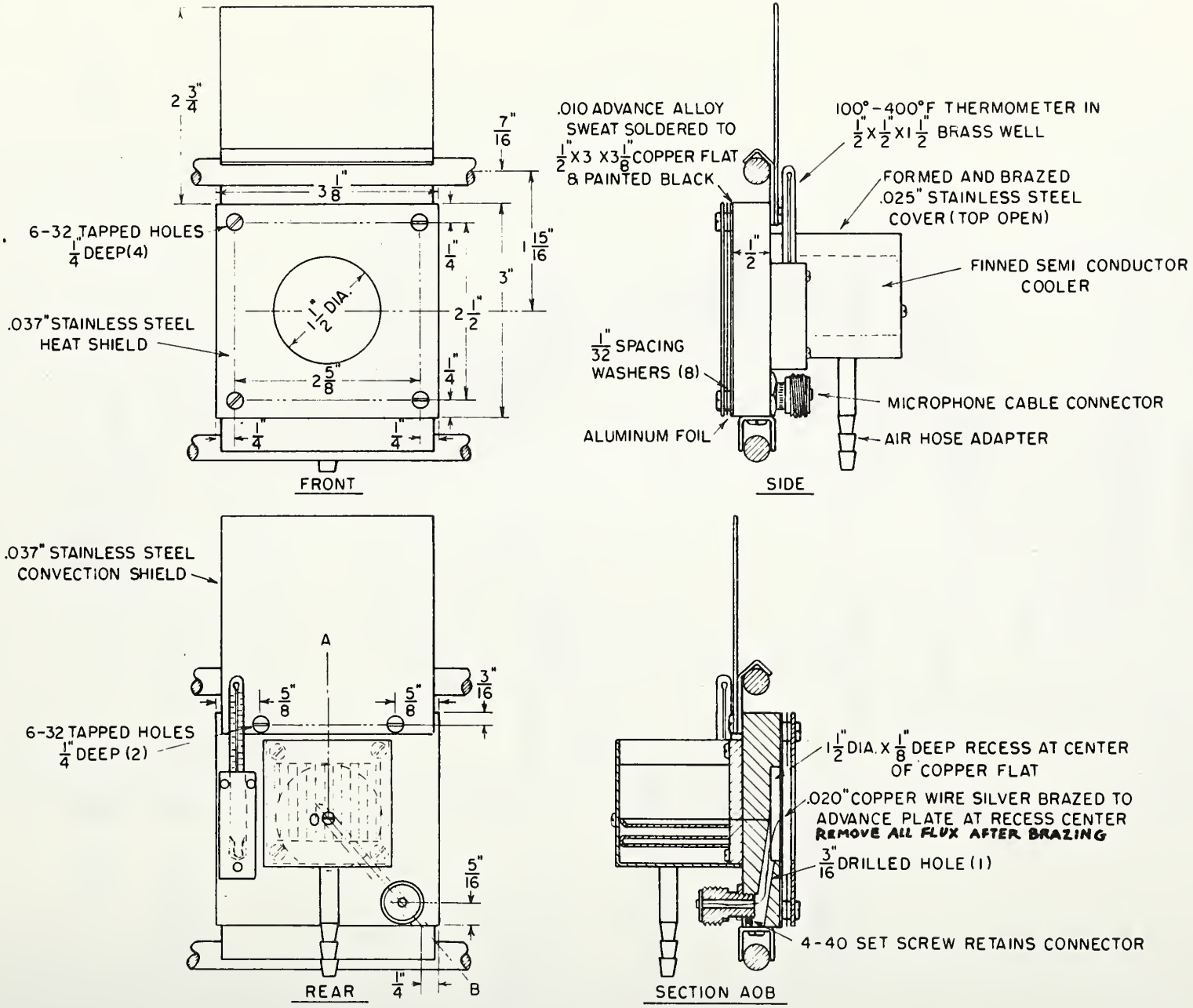


FIG. 7 - RADIOMETER DETAILS

TABLE I

SPECIFICATIONS FOR FIRE TESTS

NAVY SHIPBOARD CONSTRUCTION MATERIALS

Ia - Insulation

Specification	Name	Current Test	Usage
MIL-A-23054	Acoustical Absorptive Board, Fibrous Glass, Perforated Fibrous Glass Cloth Faced	CS 131-46	Bulkheads
HH-I-525	Insulation Board, Thermal Cork	None	Ducts (Submarine)
HH-I-551C	Insulation Block, Pipe Covering and Boards, Thermal (Cellular Glass)	E 84 (UL 723)	Pipe Covering
MIL-I-742C	Insulation Board, Thermal Fibrous Glass	U.S.C.G. 164.009-3(d)	Ducts Bulkheads
MIL-I-2781D	Insulation, Pipe, Thermal	None	Pipe Covering
MIL-J-2819E	Insulation Block, Thermal	None	Machinery
MIL-I-15091C	Insulation Felt, Thermal, Asbestos Fiber	None	Machinery, Pipe Covering
MIL-I-15475B	Insulation Felt, Thermal, Fibrous Glass, Semirigid	None	Refrigeration
MIL-I-16411D	Insulation Felt, Thermal, Glass Fiber	None	Machinery
MIL-I-16688C	Insulation Felt, Thermal, Fibrous Mineral	None	Refrigeration
MIL-I-22023C	Insulation Felt, Thermal and Sound Absorbing Felt, Fibrous Glass, Flexible	CS 131-46 (Sec. 41-45) and Hot Rivet	Refrigeration, Ducts Bulkheads
MIL-I-22344B	Insulation, Pipe, Thermal, Fibrous Glass	CS 131-46	Pipe Ducts Machinery
MIL-I-24172	Insulation, Plastic, Cellular Polyurethane, Rigid, Preformed and Foamed in Place	D-1692 non-burning	Stores and Refrigeration

TABLE I

Ia - Insulation (Cont'd.)

Specification	Name	Current Test	Usage
MIL-P-15280E	Plastic Material, Unicellular, (Sheets & Tubes)	Candle (Flammability Index)	Pipe Covering
MIL-P-17549	Plastic Laminates, Fibrous Glass Reinforced, Marine Structural	No. 2023	Refrigeration Room
MIL-P-40619	Plastic Material, Cellular Polystyrene	Candle, Self-Extinguishing	Refrigeration Room Decks

* Usage indicated in "General Specifications for Ships of the United States Navy."

Ib - Deck Coverings

Specification	Name	Current Test	Usage
MIL-A-21016E	Adhesive, Resilient Deck Covering	No. 6411	Tile Adhesive
DDD-C-95	Carpet and Rugs, Wool Nylon, Acrylic, Modacrylic	Pill Test	Living Areas
MIL-D-3134F	Deck Covering Materials	No. 6411	Deck Covering
MIL-D-3135D	Deck Covering Underlay Materials	No. 6411	Underlay
MIL-D-16680C	Deck Covering, Magnesia Aggregate Mixture	No. 6411	Deck Covering
MIL-D-23003	Deck Covering Compound, Nonslip, Lightweight	No. 6411 Jet Exhaust	Nonslip Coating
C-F-202C	Felt Sheet and Felt Roll	None	Rug Pad
MIL-M-15562C	Matting, Floor, Rubber	No. 6411	Electrical Protection
MIL-T-18830A	Tile, Plastic, Fire Retardent	No. 6411	Interior Decks

Ic - Miscellaneous

Specification	Name	Current Test	Usage
MIL-A-3316B	Adhesive, Fire Resistant, Thermal Insulation	CS 131-46 No. 5903T	Adhesive
MIL-A-24084	Adhesive, Plastic Sheet Vibration Damping	None	Adhesive
MIL-C-788D	Cloth, Brattice, Cotton, Fire-resistant	No. 5903 T	Pipe Lagging
MIL-C-19565B	Coating Compounds, Thermal Insulation Pipe Covering	CS 131-46	Vapor Barrier
MIL-C-19993	Coating Compound, Fibrous Glass Insulation Board, Water Vapor Barrier	Meker Burner	Vapor Barrier
MIL-C-20079D	Cloth, Glass; Tape, Textile, Glass; and Thread, Glass	None	Pipe Lagging
MIL-E-17970C	Enamel, Non-flaming (dry) Chlorinated Alkyd Resin	None (Controlled by formulation)	General Interior
MIL-G-20241C	Gasket Material, Wool Felt, Impregnated, Adhesive, Pressure Sensitive	Bunsen burner	Submarine Damping (Sandwich)
MIL-P-22581B	Plastic Sheet, Vibration Damping	D 635 (Modified)	Damper Tile

TABLE II

LIST OF FIRE TEST PROCEDURES IN MIL SPECIFICATIONS

METHOD NO. 6411

(Federal Test Method Standard No. 501a)

MIL-T-18830A	Tile, Plastic, Fire Retardent
MIL-D-3134F	Deck Covering Materials
MIL-D-3135D	Deck Covering Underlay Materials
MIL-M-15562C	Matting, Floor, Rubber
MIL-A-21016E	Adhesive, Resilient, Deck Covering
MIL-D-23003	Deck Covering Compound, Non-Slip Lightweight
MIL-C-7176D	Carpet, Aircraft
MIL-D-16680C	Deck Covering, Magnesia Aggregate Mixture

PILL TEST

DDC-C-95	Carpet and Rugs, Wool, Nylon, Acrylic, Modacrylic

U.S.C.G. 164.009-3(d)

MIL-I-742C	Insulation Board, Thermal, Fibrous Glass

CANDLE

MIL-P-15280E	Plastic Material, Unicellular
MIL-P-40619	Plastic Material, Cellular Polystyrene

D 1692

MIL-I-24172	Insulation, Plastic, Cellular Polyurethane, Rigid, Preformed and Foamed in Place

CS 131-46 (Sec. 41-45)

MIL-I-22023C	Insulation Felt, Thermal and Sound Absorbing Felt, Fibrous, Glass, Flexible

CS 131-46 (Sec. 41-45) Cont'd.

MIL-I-22344B	Insulation, Pipe, Thermal Fibrous Glass
MIL-C-19565B	Coating Compounds, Thermal Insulation Pipe Covering
MIL-A-23054	Acoustical Absorptive Bound Fibrous Glass, Perforated Fibrous Glass Cloth Faced
MIL-A-3316B	Adhesive, Fire Resistant, Thermal Insulation

HOT RIVET

MIL-I-22023C	Insulation, Felt, Thermal and Sound Absorbing Felt, Fibrous Glass, Flexible

METHOD NO. 2023

(Federal Test Method Standard No. 406)

MIL-P-17549	Plastic Laminate, Fibrous Glass Reinforced, Marine Structural

BUNSEN OR MEKER BURNER

MIL-G-20241C	Gasket Material, Wool Felt, Impregnated Adhesive, Pressure Sensitive
MIL-C-19993	Coating Compound, Fibrous Glass Insulation Board, Water Vapor Barrier

METHOD 5903T

(Federal Test Method Standard No. CCC-T-191)

MIL-C-788D	Cloth, Brattice, Cotton, Fire-resistant
MIL-A-3316B	Adhesive, Fire Resistant, Thermal Insulation

D 635

MIL-P-22581B	Plastic Sheet, Vibration Damping

E 84

HH-I-551C	Insulation Block, Pipe Covering and Boards, Thermal (Cellular Glass)

TABLE III PERFORMANCE REQUIREMENTS FOR FIRE-RESISTANCE TEST

	TEST REQUIREMENTS											
	MIL-C-7176D*				MIL-D-23003	MIL-D-3134F			MIL-D-3135D	MIL-M-15562C	MIL-T-18830A	MIL-D-16680C
	Incomb	Fire-Resist	Slow-Burn	Combustible		Incomb	Fire-Ret'd	Slow-Burn				
Combustion + Ignition Time, min					≤4-1/4		**		≤4-1/2		≤4	≤0
Flaming Time After Shut-Off of Burners, sec										≤60		
Glow Time							**					
Flash or Flame, in	None	Slight				None	Slight			≤10	≤13	
Average Char Length, in					≤6				≤8		≤10	
Linear Damage, in							**			≤10		≤3
Material Damage Beyond Exposed Area	None	Not Burned Beyond 6"	Burned 6<D<10	D>31-1/2		None	Not Burned Beyond 7"	Burned 7<D<31-1/2				
Smoke											Light	

* Use of 2 instead of 4 burners, and other test method variations.
** Items to be noted, but may not form part of acceptance criteria.

TABLE IV DECK COVERINGS

Fire Resistance and Radiant Panel Test Results

Material Code Designation	Material Description	Color	Thickness	Weight	Fire Resistance Test						Radiant Panel Test (ASTM E162)		
					Ignition Time[a]	Combustion Plus Ignition Time[b]	Maximum Flash or Flame Length	Average Char Length (Material Damage)	Clow Time (Beyond 4 min)	Smoke	F_s	Q	I_s
			in	psf	min:sec	min:sec	in	in	min:sec				
AD	Vinyl Asbestos Tile (MIL-T-18830) Adhesive (MIL-A-21016E)	Brown	.075	.87	0:25	4:05	24	12 (9)[c]	0:30	Light	1.30	4.1	5
AE	Vinyl Asbestos Tile (MIL-T-18830) Adhesive ("Commercial")	Brown	.075	.87	0:15	4:00	25	15 (11)[c]	~1:00 (Faint)	Light	4.08	6.6	27
AE	Same but with Longitudinal Joint	Brown	.075	.87	0:07	4:00	30	14 (10)[c]	1:30 (Faint)	Light	4.82	5.8	28
BD	Vinyl Asbestos Tile (L-T-00345) Adhesive (MIL-A-21016E)	White-Grey	.120	1.32	0:05	5:45	>31-1/2	21 (15)[c]	----	Light	3.69	6.3	23
CE	Vinyl Tile (L-F-00450b) Adhesive ("Commercial")	White/Black	.120	1.10	0:03	6:45	>31-1/2	21	----	Moderate	4.97	10.5	56
FM	Nylon Carpet (DDD-C-95) Hair Pad	Cold	.25								13.2	23.6	312
CM	Wool Carpet (DDD-C-95) Hair Pad	Brown/Black	.3 .3	.52 .35	0:15	9:00	24	13	>5:00	Very Light	6.36	7.3	46
H	Acrylic/Modacrylic Carpet (DDD-C-95) Integral Foam Cushion	Olive/Brown	.45	.52	0:00	6:30	>31-1/2	22	>2:30	Light/Moderate	6.76	10.4	52
IM	Acrylic Carpet (DDD-C-95) Hair Pad	Gold	.3 .3	.57 .35	0:10	10:30	>31-1/2	26	>11:00	Heavy	12.8	7.4	95
JM	Wool Carpet (DDD-C-95) Hair Pad	Gold	.3 .3	.54 .35	0:15	7:00	15	12	8:15	Light	11.6	7.4	87
KM	Nylon Carpet (DDD-C-95) Hair Pad	Cold	.3 .3	.37 .35	0:05	>15:00	>31-1/2	>31-1/2	----	Light/Moderate	9.97	20.9	206
LE	Linoleum (LLL-F-1238) Adhesive ("Commercial")	Grey	.120	.92	0:07	>4:00	>31-1/2	>31-1/2	Not Measured	(Heavy)	6.27	16.5	103
N	Flight Deck Compound (MIL-D-23003)	Red	1/8	.4	0:30	2:15	6	5-1/2	----	None	1.0	0	0
P	Polypropylene Carpet Hair Pad	Red	.4 .3	.52 .35	0:10	>4:00	>31-1/2	>31-1/2	Not Measured	Light (Increasing after 4 min)	18.8	23.6	440
Q	Deck Covering Underlay (MIL-D-3135)	Grey	1/16	.4	0:50	>2:00 <4:00	5	0	0	Negligible	1.0	0	0
R	Rubber Matting (MIL-M-15562)	Grey	.18	1.15	0:02	4:45	18	9	~3:00	Moderate	2.64	2.7	7
S	Battleship Linoleum (LLL-F-1238) Adhesive (MIL-A-21016E)	Green	.120	.87	0:00	>4:00	>31-1/2	>31-1/2	Not Measured	Light/Moderate	3.72	19.0	68

[a] Ignition time = time at which specimen ignited as evidenced by flashing, by yellow flames or by longer flames.

[b] Combustion + Ignition Time measured from initial application of the burner flames.

[c] Initial value based on visual observation of blackened area immediately after test. Value in parentheses based on area of actual material damage (not softening, blistering, or discoloration) after cleaning with solvent to remove soot.

TABLE V

SEVERE EXPOSURE AND FIRE HAZARD TESTS

Material	Thickness in	Density pcf	Moisture Content %	Heated Tube Test: Weight Loss %	Flame Ouration sec	Specimen Temp: Peak °C	Specimen Temp: 2 min °C	Noncombustible(N) or Combustible(C)	Heat of Combustion: Direct BTU/lb	Heat of Combustion: Residue BTU/lb	Potential Heat Test: Residue %	Potential Heat Test: Weight Basis BTU/lb	Potential Heat Test: Volume Basis BTU/ft³	Potential Heat Test: Area Basis BTU/ft²	Radiant Panel Test: F_s	Radiant Panel Test: Q	Radiant Panel Test: I_s	Flame Resistance Test
INSULATION																		
Asbestos Pipe Insulation (MIL-I-2781D)		14.5	4.9	20	18	715	155	N	34	19	80.9	19	280		49.	1.9	92	**
Asbestos Pipe Insulation (MIL-I-2781D)		13.8	4.0	18	16	743	169	N	65	66	82.5	11	150		49.	1.9	92	**
Class Piber Pipe Insulation (MIL-I-22344)		10.0	1.0	20	9	790	763	N	1439	202	85.4	1266	12700		92.	0.5	44	**
Cellular Glass Pipe Insulation (HH-I-551C)	1	8.5	0.1	4	0	730		N	59	42	100.0	17	140		1.0	0	0	
Cellular Class Pipe Insulation (HH-I-551C) plus Coating Compound (MIL-C-19565 B, Type I)	1-3/16	14.8													28.	12.0	330	
Glass Fiber Acoustical Board (MIL-A-23054)	1	5.3		19			802	C	2141	116	80.1	2048	10900	910	8.8	0.5	4	
Fibrous Glass Thermal Insulation Board (MIL-I-742A; superceded)	1	4.2			13	826	791	C	1888	137	82.2	1775	7440	620	14.1	2.8	39	
Fibrous Class Thermal Insulation Board (MIL-I-742C); Average 3 manufacturers	1 to 1-1/4	4.0			20	755	740	N	717	230	92.0	504	2040	178	1.0	0	0	
Fibrous Class Insulation Felt (MIL-I-22023C)	1	1.7													1.0	0.5	1	
Unicellular Plastic ("Ensolite")(MIL-P-15280E)	1/2	6.2							7077	156	27.0	7035	43600		1.0	0.8	1	
Plastic Laminate,Fibrous Glass Reinforced (MIL-P-17549C)	1/2	125.							4601	154	58.5	4511	564000		2.3	3.6	8	
Plastic Sheet, Vibration Damping (MIL-P-22581B)	5/8	84.							4263	8	70.1	4257	358000		4.3	14.0	60	
DECK COVERINGS																		
Deck Covering (MIL-D-3134F)	1.1	44.5	12.8	33	>600	861		C	2378	-13	32.8	2382	106000	9720	1.0	0.8	1	
A Vinyl Asbestos Tile (MIL-T-18830)	.075	139							2112	-210	65.1	2249	313000	1960	1.30	4.1	5	
N Flight Deck Compound (MIL-D-23003)	1/8	38.4							1673	220	91.1	1473	56600	590	1.0	0	0	
Q Deck Covering Underlay (MIL-D-3135)	1/16	76.4							657	135	95.4	528	40300	210	1.0	0	0	

*Plaming was limited to brattice cloth covering. This may be interpreted as permissible, since "flame from painted or paper coated surfaces may be permitted for not longer than 30 seconds during the first two minutes". Section 164.009-3(d)(5)(i)

**Tested but not rated; see discussion page 18.

TABLE VI PLASTIC FOAM INSULATION

Material	Thickness	Density	Fire Resistance Test MIL-P-15280E				Radiant Panel Test ASTM E 162			Flammability of Plastic Foams ASTM D 1692			
			w	b	t	I	F_s	Q	I_s	Weight Loss During Test	"Nonburning by This Test"	"Self-extinguishing by This Test	"Burning by This Test"
	in.	lb/ft^3								%			
1. Armstrong	1/2	6.0	4.4	7	1.2	12.6	7.1	9.3	64	6.0		X	
2. B. F. Goodrich	1/2	5.1	4.7	10	1.5	16.2	14.8	4.3	60	4.3	X		
3. Griswald	1/2	33.2	Not Tested				11.3	37.7	426	Not Tested			
4. Rubatex	1/2	7.7	Not Tested				1.0	4.0	4	Not Tested			
5. Uniroyal (Ensolite)	1/2	6.2	2.6	0	0	2.6	1.0	0.8	1	3.3	X		
6. Shields (ASTM C 534)	1/2	7.4	3.3	10	1.2	14.5	7.9	8.0	64	5.3	X		
7. Polystyrene (MIL-P-40619)	1/4	2.0	---	--	---	*	67.	8.3	560	10.2	X		

* Flames extended over entire length of 24 in. long specimen.
Flammability index of MIL-P-15280E not applicable.

TABLE VII RADIANT PANEL TEST RESULTS ON HULL INSULATION

Material Description	Nominal Thickness in.	Measured Density pcf	ASTM E 162 Test		
			F_s	Q	I_s
1. "Ensolite" (nitrile rubber and PVC)	1	6.0	1.0	0.6	1
2. Asbestos cloth/.010" lead loaded PVC laminated to 2" polyester foam	2	5.6	17.7	8.1	144
3. Asbestos cloth with vapor barrier/two layers of 1/4 in. polyurethane foam with .010" lead loaded PVC/ 1/2 in. polyurethane foam	1-1/16	17.1	19.7	12.3	242
4. Aluminum foil (.010") over 1/2" fibrous glass	1/2	9.2	1.0	0	0
5. Asbestos cloth with vapor barrier over glass fiber batt	.61		11.8	3.1	36
6. Asbestos cloth over glass fiber batt	.60		15.9	1.3	20
7. Glass fiber batt over asbestos cloth with vapor barrier	.64		39.3	0.2	7

TABLE VIII RADIANT PANEL TEST RESULTS ON CHLORINATED ALKYD RESIN ENAMEL (MIL-E-17970C)

	F_s	Q	I_s
0.006 in. thick on 1/8 in. steel	1.0	0	0
0.006 in. thick on 3/16 in. tempered hardboard	3.1	23.2	73
0.011 in. thick on 20 gage steel	1.0	0	0
0.016 in. thick	1.0	0	0
0.023 in. thick	1.0	0	0
0.031 in. thick	1.6	1.5	2
0.052 in. thick	1.7	4.7	8

TABLE IX-SMOKE AND COMBUSTION PRODUCTS

Material Code		Specimen Weight g	Test Exposure F=Flaming N=Nonflaming	Smoke Dm	Smoke $t_{.9Dm}$	Gas CO	Concentration[a] ppm HCl	HCN	$NO+NO_2$	Others
	DECK COVERINGS									
A	Vinyl Asbestos Tile (MIL-T-18830)	24.5	F	356	3.2	570	680	8	8	
			N	240	6.8	330	150	8	2	
B	Vinyl Asbestos Tile (L-T-00345)	36.8	F	355	5.0	900	240	0	38	
			N	240	12.2	700	2300	0	3	
C	Vinyl Tile (L-F-00450a)	30.3	F	507	6.1	1800	850	25	25	
			N	455	10.4	800	2600	9	4	
F	Nylon Carpet (DOO-C-95)	10.3	F	280	3.3	330	25	8	19	
			N	460	10.3	900	0	6	6	NH_3:83
G	Wool Carpet (DOD-C-95)	12.8	F	176	6.8	780	0	44	55	NO_2:2
			N	336	10.3	425	0	35	2	NH_3:400
H	Acrylic/Modacrylic Carpet (DDD-C-95)	15.4	F	271	11.0	1150	80	38	50	
			N	628	5.0	650	170	110	3	
I	Acrylic Carpet (DDD-C-95)	23.0	F	217	5.8	500	150	30	25	
			N	453	8.5	750	50	85	3	
J	Wool Carpet (DDD-C-95)	14.6	F	273	5.7	500	0	28	40	SO_2:80
			N	361	12.7	600	0	75	5	SO_2:100
K	Nylon Carpet (DDD-C-95)	9.6	F	205	2.6	360	0	5	40	
			N	333	8.0	750	0	13	2	
L	Linoleum (LLL-F-1238)	26.3	F	291	3.5	500	0	0	20	SO_2:30
			N	631	11.6	500	0	0	2	
M	Flight Deck Compound (MIL-D-23003)	3.6	F	68	9.1	310	3	2	8	
			N	41	16.8	200	2	2	1	
P	Polypropylene Carpet	13.3	F	391	2.9	400	0	2	23	
			N	666	8.4	1000	0	2		
Q	Deck Covering Underlay (MIL-D-3135)	10.2	F	33	9.3	190	8	0	4	
			N	27	17.6	160	0	0	1	
R	Rubber Matting (MIL-M-15562)	31.3	F	382	3.6	1300	1600	2	8	SO_2:55 & NO_2:0
			N	385	6.4	325	900	0		SO_2:0
S	Battleship Linoleum (LLL-F-1238)	25.3	F	247	3.5	225	0	0	20	
			N	715	12.0	450	0	0	8	
T	Deck Covering (MIL-D-3134)	116.7	F	5	>20.	1000	120	<1		
			N	2	>20.	350	20	0		
	INSULATION									
	Fibrous Glass Acoustic Board (MIL-A-23054)	10.4	F	131	3.2	300	4	16	8	
			N	89	11.9	200	0	6	1	
	Cellular Glass Pipe Insulation (HH-I-551C)	20.4	F	1	19.8	20	0	0	4	
			N	1	19.8	0	0	0	0	
	Fibrous Glass Insulation Board (MIL-I-742C)	9.6	F	8	9.7	100	0	5	10	
			N	11	4.6	20	0	3	1	
	Asbestos Pipe Insulation (MIL-I-2781D)	33.9	F	4	16.9	80	0	0	3	
			N	5	0.9	100	0	0	0	
	Fibrous Glass Insulation Felt (MIL-I-22023C)	3.6	F	5	7.0	120	0	1		
			N	8	5.0	20	0	0		
	Fibrous Glass Pipe Insulation (MIL-I-22344C)	11.2	F	5	11.0	250	0	8	13	
			N	19	0.5	200	0	5	10	
	Glass Reinforced Plastic Laminate (MIL-P-17549)	142.2	F	409	15.3	2000	380	2		
			N	373	17.9	900	120	0	5	
	Cellular Polystyrene (MIL-P-40619)	4.8	F	328	1.0	500	150	19	15	
			N	166	6.0	160	8	2	1	
	Unicellular Foam ("Ensolite") (MIL-F-15280E)	7.1	F	279	2.7	500	100	20	15	
			N	222	7.5	120	26	12	1	
	Plastic Foam "A"	7.2	F	523	1.7	800	860	12	12	SO_2:130
			N	265	4.1	200	40	6	2	
	"C"	5.9	F	264	1.7	500	300	15	12	
			N	257	2.7	200	50	11	2	
	"R"		F	381	3.4					
			N	390	3.0					
	"S"	9.0	F	557	2.4	1500	400	25	15	
			N	440	4.8	730	130	20	3	
	MISCELLANEOUS									
	Fire Resistant Adhesive (MIL-A-33168)	1.9	F	135	10.2	400	40	0		
			N	75	13.7	170	40	0		
	Coating Compound (MIL-C-19565B)	47.1	F	474	4.4	2660	58	1		
			N	537	10.5	2500	50	2		
	Coating Compound (MIL-C-19993) (On fibrous glass insulation board)	11.0	F	60	6.6	200	110	10		
			N	29	4.9	60	80	1		
	Vibration Damping Tile (MIL-P-22581B)	126.8	F	818	9.0	3000	370	100		
			N	634	13.4	125	10	5	1	
	Chlorinated Alkyd Enamel Resin (MIL-D-17970C) 12 mil coating	3.6	F	61	5.1	250	15	0		
			N	57	9.2	30	10	0		
	Chlorinated Alkyd Enamel Resin (MIL-D-17970C) 52 mil coating	17.2	F	230	6.2	600	105	0		
			N	159	5.0	250	23	0		

TABLE X SUMMARY OF TEST RESULTS

MATERIAL	TEST METHOD														
	Radiant Panel E 162	Heated Tube	Potential Heat		Fire Resistance MIL-T-18830A (Method 6411, Fed. Std. 501a)	Flame Resistance CS 131-46	Fire Resistance MIL-P-15280E		ASTM D1692	Smoke Chamber[a]					
										Smoke	Gas Concentration, ppm				
	I_s		BTU/lb	BTU/ft^2						D_m	CO	HCN	HCl	NO+ NO_2	Others
A. INSULATION															
Fibrous Glass Acoustic Board (MIL-A-23054)	4	C	2048	910						131	300	16	4	8	
Cellular Glass Pipe Insulation (HH-I-551C)	0	N	17							1	20	0	0	4	
Fibrous Glass Insulation Board (MIL-I-742A)	14	C	1775	620											
Fibrous Glass Insulation Board (MIL-I-742C)	0	N	718	280											
Fibrous Glass Insulation Board (MIL-I-742C)	0	N	342	110											
Fibrous Glass Insulation Board (MIL-I-742C)	0	N	453	130						11	100	5	0	10	
Asbestos Pipe Insulation (MIL-I-2781D)	92	N	19			NR									
Asbestos Pipe Insulation (MIL-I-2781D)	92	N	11			NR				5	100	0	0	3	
Fibrous Glass Insulation Felt (MIL-I-22023C)	1									8	120	1	0		
Fibrous Glass Pipe Insulation (MIL-I-22344B)	15	N	1266			NR				19	250	8	0	13	
Unicellular Foam ("Ensolite") (MIL-P-15280E)	1		7035	1820			F	NB		279	500	20	100	15	
Plastic Foam "A"	64						F	SE		523	800	12	860	12	SO_2:130
Plastic Foam "G"	60						F	NB		264	500	15	300	12	
Plastic Foam "R"	4									390					
Plastic Foam "S"	64						F	NB		557	1500	25	400	15	
Glass Reinforced Plastic Laminate (MIL-P-17549C)	B		4511	23500						409	2000	2	380	5	NO_2:2
Cellular Polystyrene (MIL-P-40619)	560							NB		328	500	19	150	15	
B. DECK COVERINGS															
A Vinyl Asbestos Tile (MIL-T-18830A)	5		2249	1960	F					356	570	8	680	8	
B Vinyl Asbestos Tile (L+T-00345)	23				F					355	900	0	2300	38	
G Vinyl Tile (L-F-00450b)	56				F					507	1800	25	2600	25	
F Nylon Carpet (DDD-C-95)	312									460	900	8	0	19	NH_3:83
G Wool Carpet (DDD-C-95)	46				F					336	780	44	0	55	NH_3:400
H Acrylic/Modacrylic Carpet (DDD-C-95)	52				F					628	1150	110	170	50	
I Acrylic Carpet (DDD-C-95)	95				F					453	750	B5	150	25	
J Wool Carpet (DDD-C-95)	B7				F					361	600	75	0	40	SO_2:100
K Nylon Carpet (DDD-C-95)	206				F					333	750	13	0	40	
L Linoleum (LLL-F-1238)	103				F					631	500	0	0	20	SO_2:30
N Flight Deck Compound (MIL-D-23003)	0		1473	590	F					68	310	2	3	8	
P Polypropylene Carpet	440				F					666	1000	2	0	23	
Q Deck Covering Underlay (MIL-D-3135D)	0		528	210	F					33	190	0	8	4	
R Rubber Matting (MIL-M-15562C)	7				F					385	1300	2	1600	8	SO_2:55
S Battleship Linoleum (LLL-F-1238)	68				F					715	450	0	0	20	
T Deck Covering (MIL-D-3134F)	1		23B2	9720						5	1000	0	120		
C. MISCELLANEOUS															
Fire-resistant Adhesive, 12-1B mil on steel (MIL-A-3316B)	0									135	400	0	40		NO_2:0
Coating Compound (on cellular glass insulation)(MIL-C-19565B)	330									537	2660	2	58		NO_2:0
Chlorinated Alkyd Resin Enamel, 6 mil on hardboard (MIL-E-17970C)	73														
Chlorinated Alkyd Resin Enamel, 6 mil on steel	0		3200	210											
Chlorinated Alkyd Resin Enamel, 11 mil on steel	0		3200	385						61	250	0	15		NO_2:0
Chlorinated Alkyd Resin Enamel, 52 mil on steel	B		3200	1800						230	600	0	105		NO_2:0
Vibration Damping Tile (MIL-P-225B1B)	60		4257	18600						634	3000	100	370		NO_2:3
Coating Compound (MIL-C-19993) (on fibrous glass insulation board)	1									60	200	10	110		

C = Combustible
N = Noncombustible

P = Pass
F = Fail

NB = "Nonburning by this test"
SE = "Self-extinguishing by this test"

NR = Not rated (See discussion)

[a] Highest Value from flaming or nonflaming test exposure. See Table IX Gas concentrations based on 0.0456 ft^2 exposed area in 18 ft^3 chamber.

Table XI
Summary of Requirements

Type Material	Category	Controls Fs	HP	Dm
			BTU/sq ft/in	
Insulation				
	Bulkheads	25	500	150
	Pipe	25		300
	Machinery	25	500	300
	Ducts	25	500	150
	Refrigeration*	25		450
Miscellaneous Materials				
	Vapor Barrier Coating	100		300
	Lagging	100		300
	Adhesive	100		300
	Coatings	25		150
	Damping (Hull)	75		
Deck Coverings				
	Flooring-general	25	3,000**	450
	-special purpose	100		450
	Underlayments	100		

* Materials not normally exposed FS increased to 75 and no requirement for Dm
** BTU/lb

TABLE XII PERFORMANCE LEVELS OF VARIOUS MATERIALS

a. Insulation

CATEGORY (Reference Section 9390 General Specifications)	TYPICAL SPECIFICATION	CONTROLS Fs	Hp	D_m
			Btu/board ft	
Bulkheads		25	500	150
	MIL-I-22023C, Type II	✓	✓	✓
	MIL-A-23054	✓	x	✓
	MIL-I-742C	✓	✓	✓
Pipe		25		300
	MIL-I-2781D	✓		✓
	MIL-I-22344B	✓		✓
	MIL-P-15280E, Form T	✓		✓
	MIL-I-15091			
	HH-I-551	✓		✓
Machinery		25	500	300
	MIL-I-15091			
	MIL-I-2819			
	MIL-I-16411			
Ducts		25	500	150
	MIL-I-742, Type I or II	✓	✓	✓
	MIL-I-22023, Type I	✓	✓	✓
	MIL-I-22344	✓	x	✓
	HH-I-525			
Stores and Refrigeration		25*		450*
	MIL-I-15475B			
	MIL-I-22023, Type I	✓		✓
	MIL-I-24172			
	MIL-P-17549, Grade W	✓		✓
	MIL-I-16688C	✓		✓
	MIL-P-40619, Type I	x		✓

✓ Meets performance level
x Does not meet performance level
* Materials not normally exposed Fs increased to 75 and no requirement for D_m

TABLE XII (Cont'd.)

b. Deck Coverings

CATEGORY (Reference Chapter 9140 BUSHIPS Technical Manual)	TYPICAL SPECIFICATION	CONTROLS Fs	Hp Btu/lb	D_m
Flooring - General		25	3000	450
	MIL-T-18830A	✓	✓	✓
	MIL-D-16680C			
	MIL-D-3134F	✓	✓	✓
- Special Purpose		100		450
	MIL-M-15562C	✓		✓
	DDD-C-95, Type III	✓		✓
	** MIL-D-23003, Type II	✓		✓
Underlay		100		
	MIL-D-3135D	✓		
	MIL-A-21016E			
	C-F-202C			

** This specification also has a provision for evaluating the softening properties using a jet exhaust.

TABLE XII (Cont'd.)

c. Miscellaneous

CATEGORY	TYPICAL SPECIFICATION	CONTROLS Fs	Hp	D_m
Vapor Barrier Coating		100		300
	MIL-C-19993	✓		✓
	MIL-C-19565B	x		x
Lagging		100		300
	MIL-C-20079D			
	MIL-C-788D			
Adhesive (Insulation)		100		300
	MIL-A-3316B	✓		✓
	MIL-A-24084			
Coatings		25		150
	MIL-E-17970C	✓		✓
Damping		75		
	MIL-P-22581B	✓		
	MIL-G-20241C			

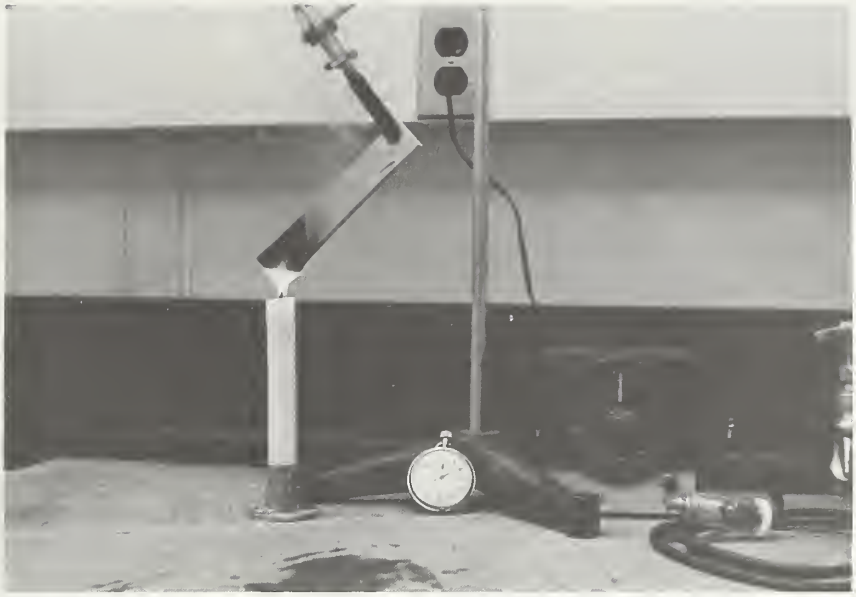


Fig. 1 Candle Test, MIL-P-15280E

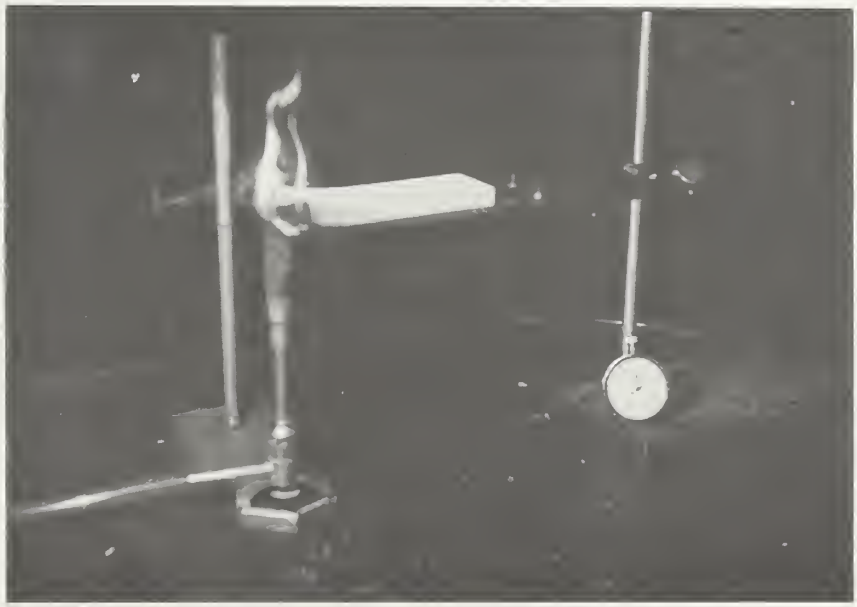


Fig. 2 Flammability Test, ASTM D 1692

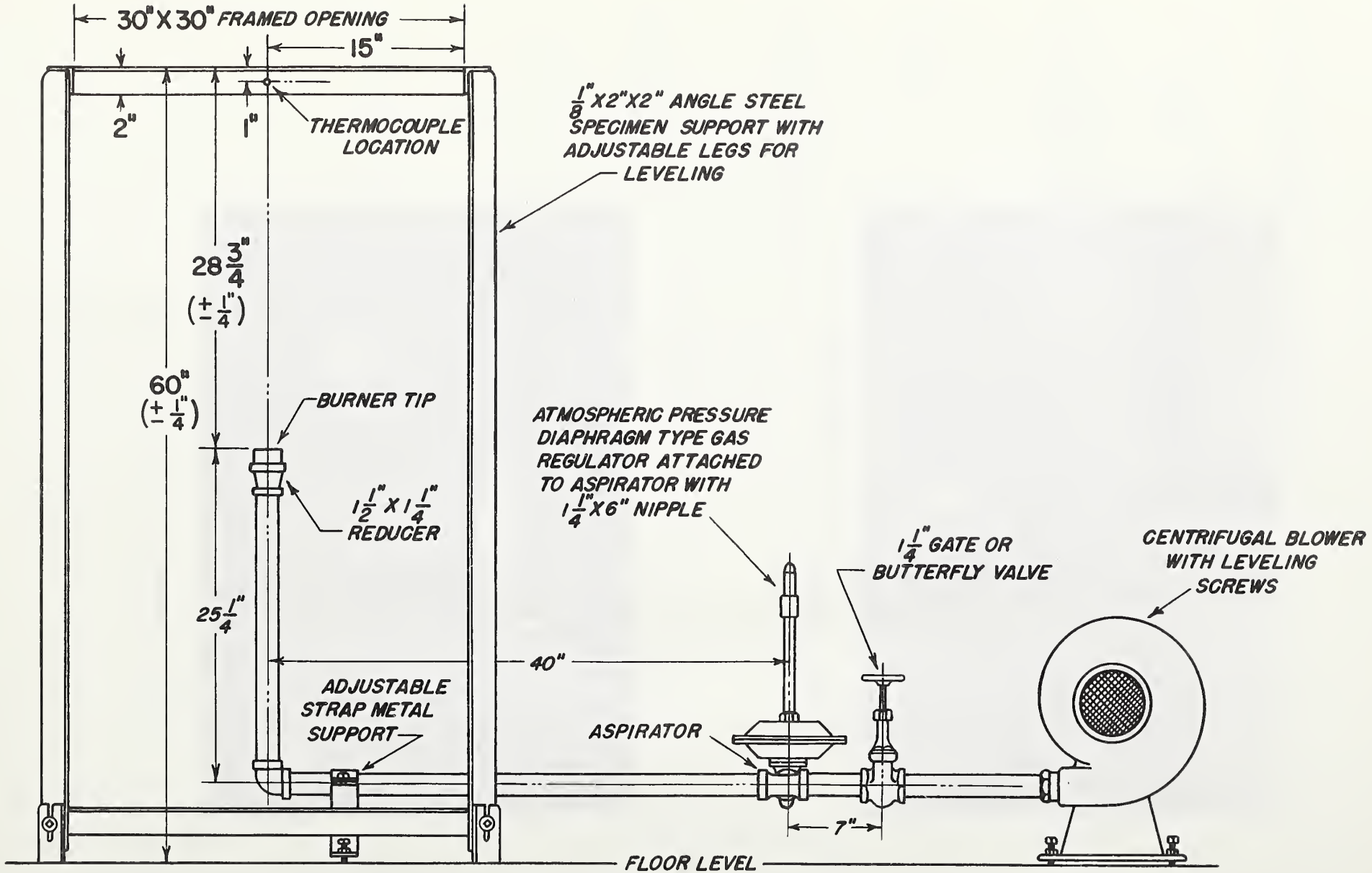


Fig. 3. Apparatus for Flame Resistance Test
(CS131-46)

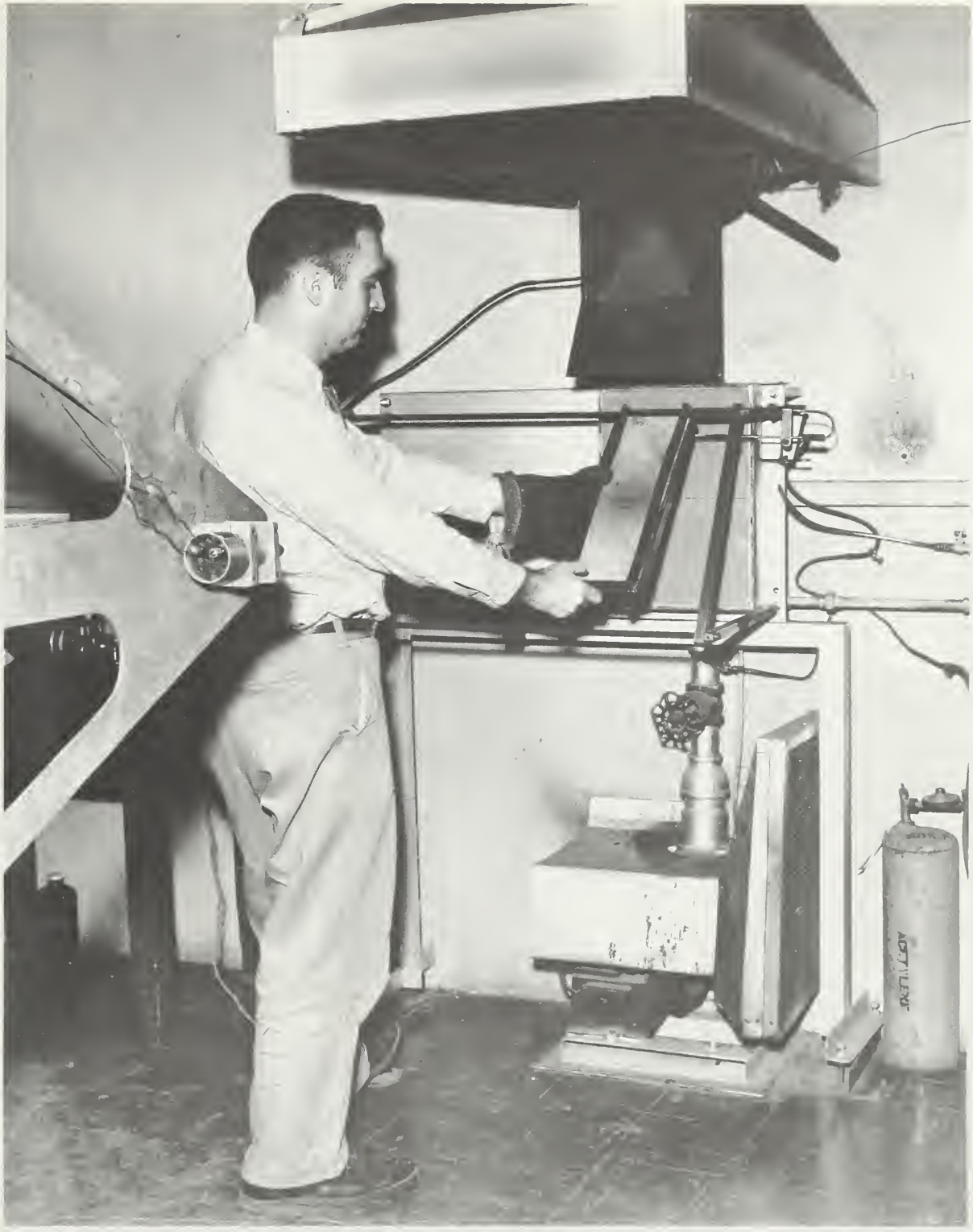


Fig. 4. Radiant Panel Flame-Spread Test Apparatus

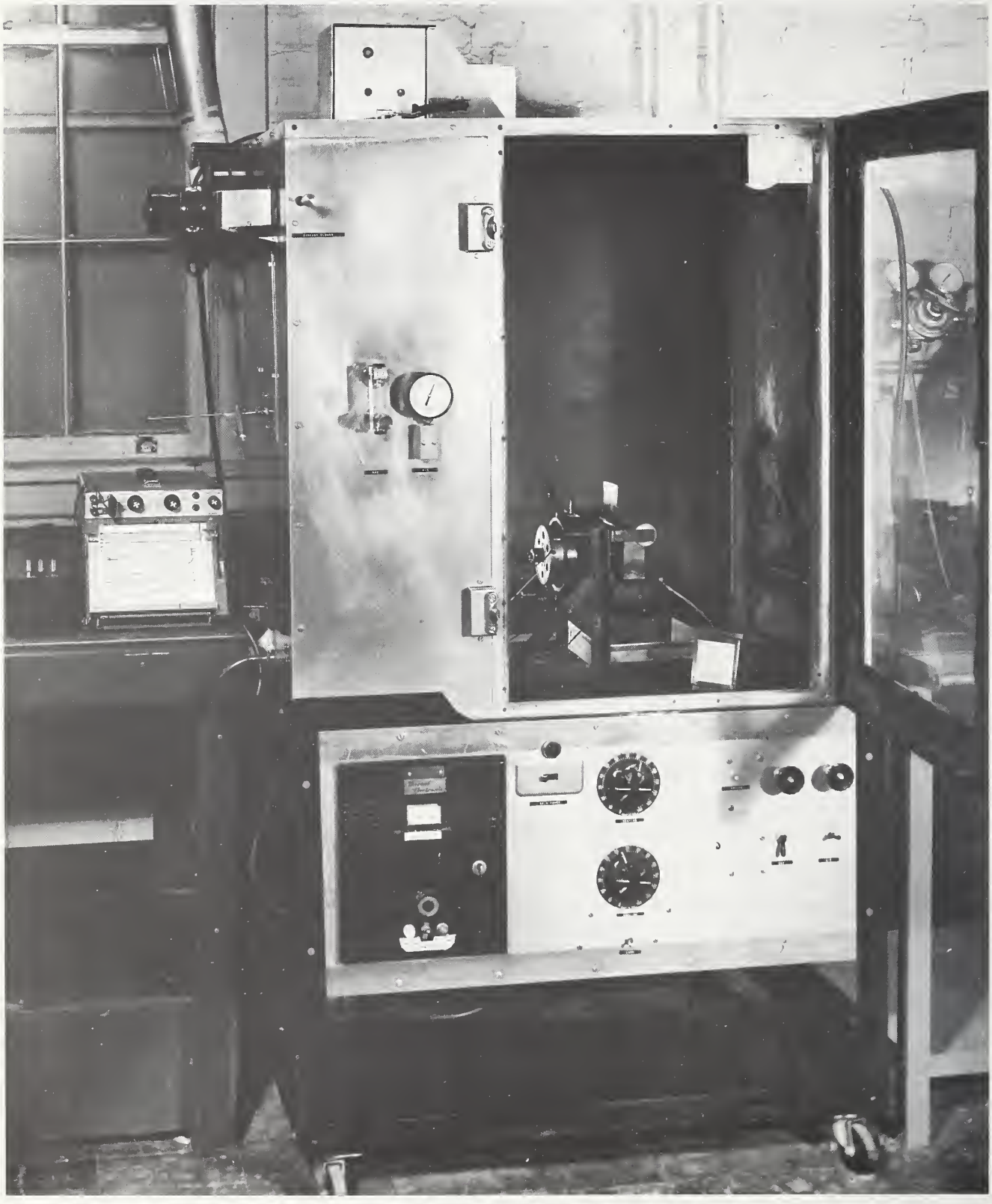


Fig. 5. Smoke Test Chamber

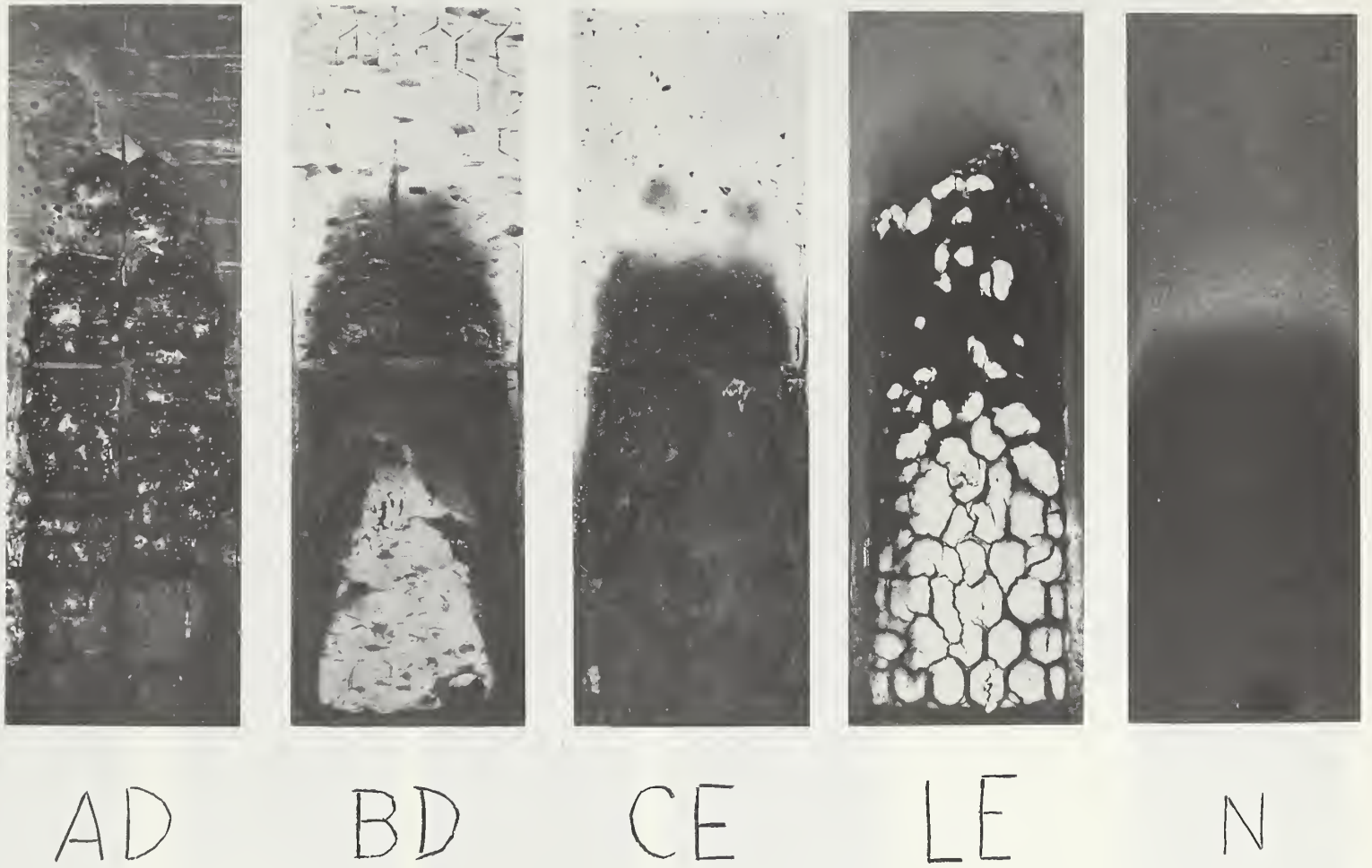


Fig. 6a. Deck Covering Specimens After Radiant Panel Test

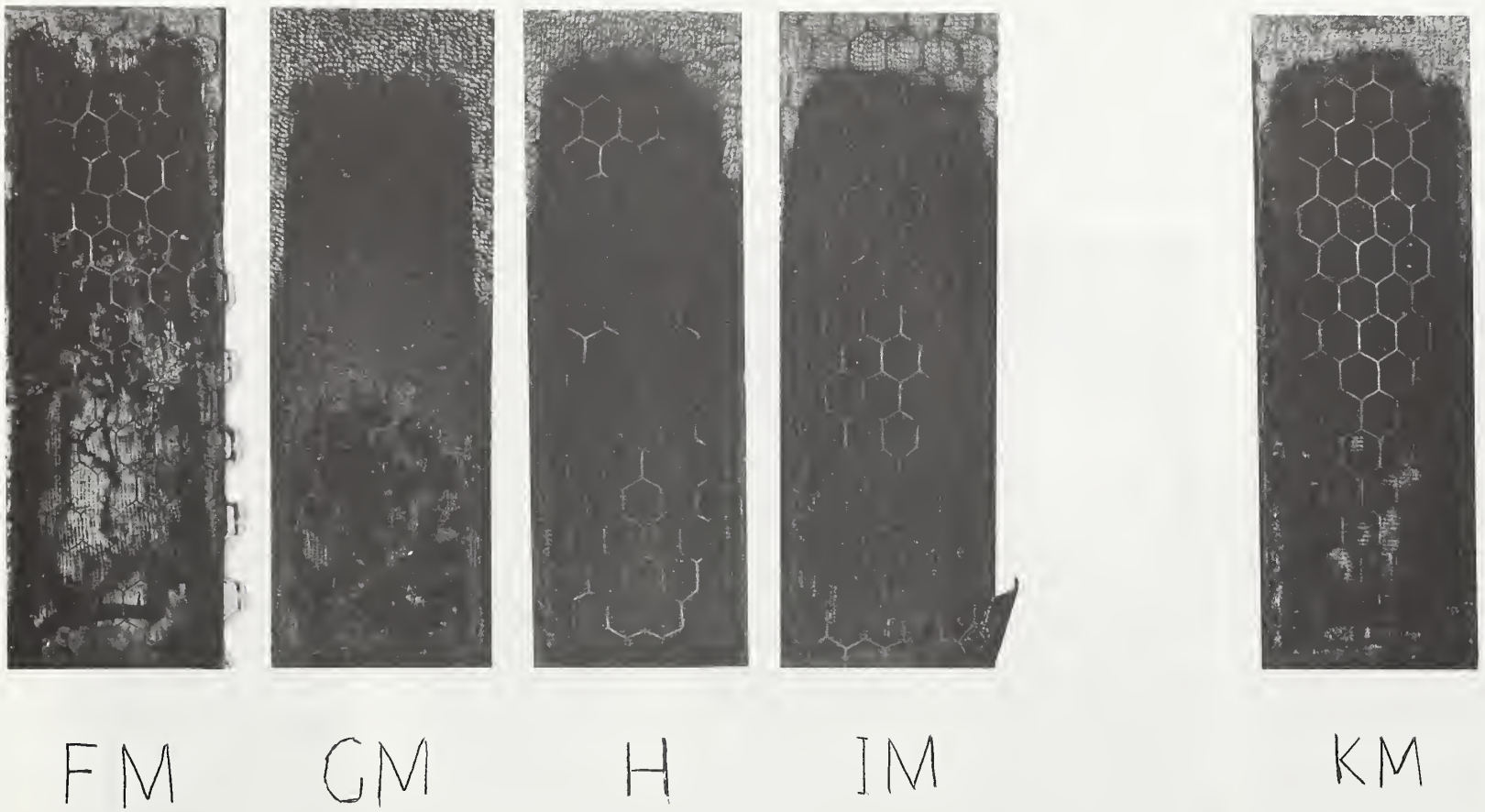


Fig. 6b. Deck Covering Specimens After Radiant Panel Test

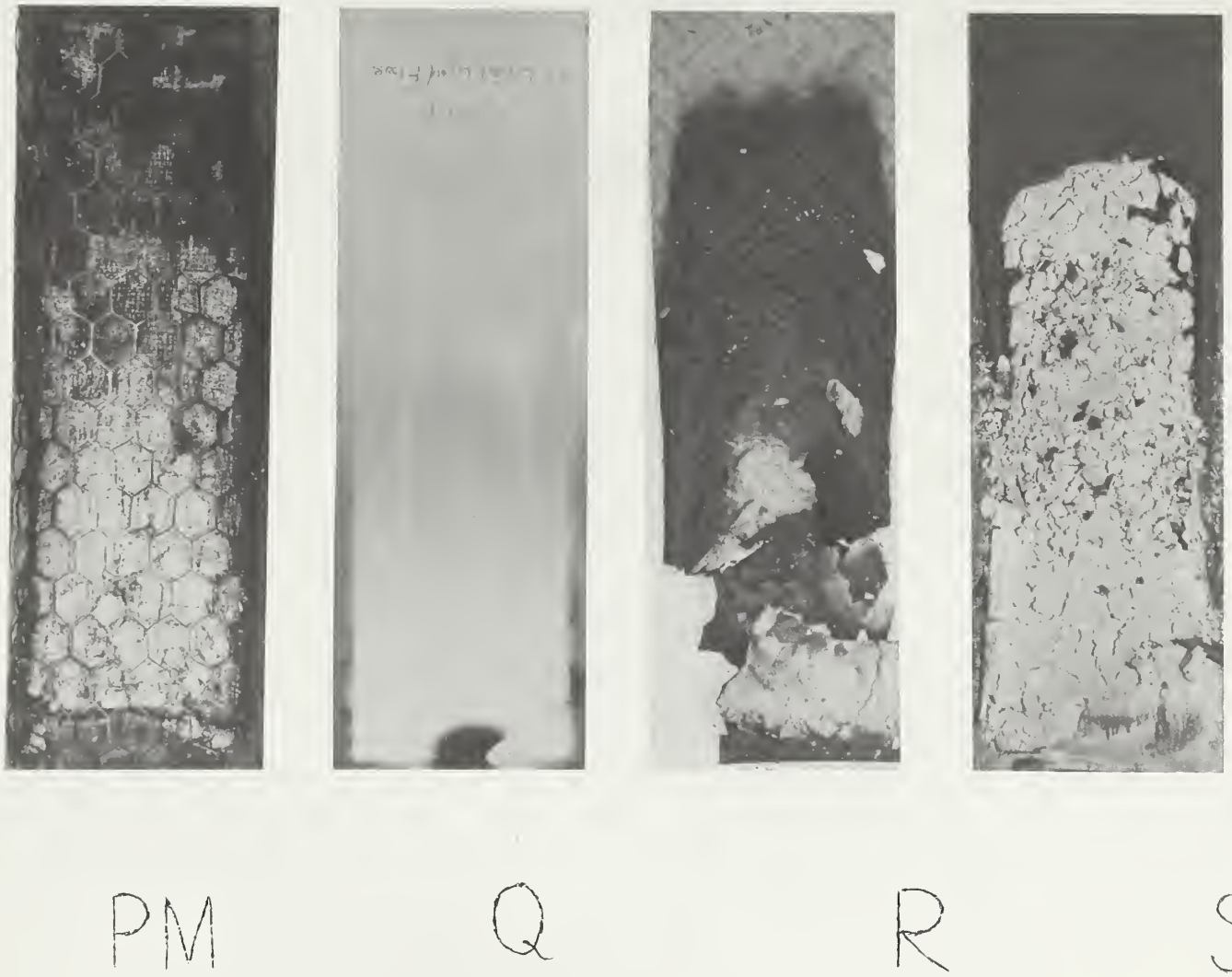


Fig. 6c. Deck Covering Specimens After Radiant Panel Test

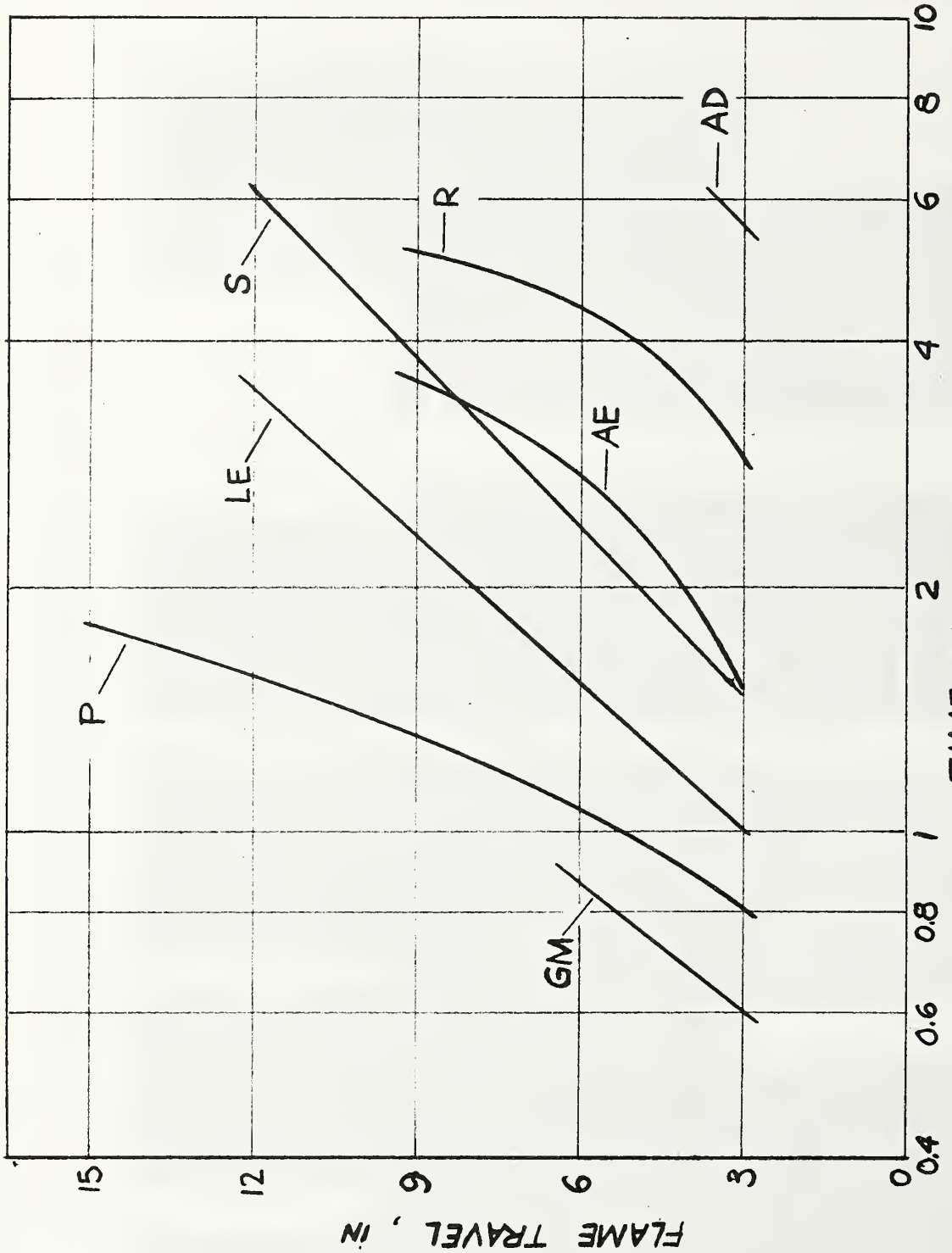


Fig. 7. Flame Travel Data in Radiant Panel Test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