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TEST METHOD FOR MEASURING THE SMOKE GENERATION CHARACTERISTICS OF SOLID MATERIALS

1. Scope

1.1 This method of test covers a procedure for measuring the smoke generation characteristics of solid materials and assemblies in thicknesses up to and including 1 in. (25.4 mm). Measurement is made of the attenuation of a light beam by smoke (suspended solid or liquid particles) accumulating within a closed chamber due to nonflaming pyrolytic decomposition and flaming combustion. Results are expressed in terms of specific optical density, which is derived from a geometrical factor and the measured optical density (absorbance), the single measurement most characteristic of the "concentration of smoke." The photometric scale used to measure smoke by this test method is similar to the optical density scale for human vision.

2. Significance

2.1 This method provides a means for comparing the smoke generated by materials and assemblies of given thickness and properties under the specified exposure conditions. The values determined by this test are specific to the material as tested and are not to be considered inherent, fundamental

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NOTE 1 - The values stated in U.S. customary units are to be regarded as the standard. The metric equivalents of U.S. customary units given in the standard may be approximate.

properties. Correlation with other fire conditions or with measurements by other test methods has not been established.*

3. Summary of Method[1/]

3.1 This method for measuring the smoke generation characteristics of materials employs an electrically-heated radiant energy source 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 mm) diameter 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. (25.4 mm) thick. This exposure provides the nonflaming condition of the test.

3.2 For the flaming condition, a six-tube burner is used to apply a row of equidistant premixed (air-propane) 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.

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* Other test methods for measuring smoke have been reviewed and summarized in "The Control of Smoke in Building Fires - A State-of-the-Art Review," Materials Research and Standards, pp. 16-23, 42, April 1971.

[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.

3.3 The test specimens are exposed to the flaming and non-flaming conditions within a closed 18 ft^3 (0.51 m^3) chamber. A photometric system with a 36 in. (914 mm) vertical light path measures the continuous decrease in light transmission as smoke accumulates.

3.4 Calibration procedures for the test equipment as described in Appendix A shall be followed. 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]

4. Apparatus

4.1 The apparatus shall be essentially as shown in Figs. 1 and 2. A more detailed description of suggested details (using the same paragraph numbers) is given in Appendix C. The apparatus shall include the following:

4.1.1 Test Chamber - As shown in Fig. 2, the test chamber shall be fabricated from laminated panels[3] to provide inside dimensions of 36 by 24 by 36 in. ± 1/8 in. (914 by 610 by 914 ± 3 mm) for width, depth and height, respectively. The

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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.

[3] Commercially available panels of porcelain-enameled steel (interior surface) permanently laminated to asbestos-cement board and backed with galvanized steel (exterior surface), total thickness 3/16 in., has been found suitable.

interior surfaces shall consist of porcelain-enameled metal, or equivalent coated metal resistant to chemical attack and corrosion, and suitable for periodic cleaning. Sealed 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, a pressure relief valve, a rod for remote positioning of the specimen holder, an aluminum foil (0.0010 in. approx. 0.025 mm or less) 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, the positioning rod, and an inlet vent shall be located on the floor of the chamber. When all openings are closed the chamber shall be capable of developing and maintaining positive pressure during test periods, in accordance with paragraph 8.10.

4.1.2 Radiant Heat Furnace - As shown in Fig. 3 an electric furnace with a 3 in (76.2 mm) diameter opening shall be used to provide a constant irradiance on the specimen surface. The furnace is to be located centrally along the long axis of the chamber with the opening facing toward and about 12 in. (305 mm) from the right wall. The centerline of the furnace shall be about 7 3/4 in. (195 mm) above the chamber floor.

The furnace control system shall maintain the required irradiance level under steady-state conditions with the chamber door closed to within ± .04 Btu/sec ft^2 (± .05 W/cm^2) for 20 minutes. The control system shall consist of an autotransformer or alternate control device, and a voltmeter or other means for monitoring the electrical output. Where line voltage fluctuations are present, a constant-voltage transformer may be required to maintain the prescribed irradiance level.

4.1.3 Specimen Holder - Specimen holders shall conform in shape and dimension to that shown in Fig. 4, and be fabricated to expose a 2 9/16 in. (65.1 by 65.1 mm) specimen area. For flaming exposure tests, and where melting occurs in nonflaming tests, a modified holder with trough shall be used. Also shown in Fig. 4 are the spring and rods for retaining the specimen within the holders.

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

4.1.5 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 materials under test. The system shall be shown in Fig. 6, and includes the following:

4.1.5.1 The light source shall be an incandescent lamp operated at a fixed voltage in a circuit powered by a voltage regulating transformer. The light source shall be mounted in a sealed and light-tight box located below the chamber. This box shall contain the necessary optics to provide a collimated light beam passing vertically through the chamber.

4.1.5.2 The photodetector shall be a photomultiplier tube, with an S-4 spectral sensitivity response and a dark current less than 10^{-9}A. A sealed box located directly opposite the light source shall be provided to house the photodetector and the focusing optics. A glass window shall be used to isolate the photodetector and its optics from the interior of the chamber.

4.1.6 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[4]. 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 body temperature of 200 ± 5 °F (93 ± 3 °C).

4.1.7 Thermocouples for Determining Chamber Wall Temperature - A thermocouple shall be provided for determining the chamber wall temperature prior to testing.

4.1.8 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 other suitable instrument capable of measurement over a range of 5 decades, or more. See Appendix C, paragraph C.4.1.5.

4.1.9 Manometer for Chamber Pressure Measurements - A simple water manometer with a range up to 6 in. (152 mm) 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. (See C4.1.11)

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

4.1.10 Multiple Flamelet Burner with Premixed Air-Propane Fuel - For a flaming exposure test, a six-tube burner, with construction details as shown in Fig. 4, shall be used.

The burner shall be centered in front of and parallel to the specimen holder. The tips of the two horizontal tubes shall be centered 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 exposures. A premixed air and propane (95% purity 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 air and 50 cm^3/min. for the propane.

5. Test Specimens

5.1 Size - The test specimens shall be 3 by 3 ± .03 in. (76.2 by 76.2 ± 0.7 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 and the original (uncut) surface tested. Multi-layer materials greater than 1 in. (25.4 mm) thick, consisting of a core material with surface facings of different materials shall be sliced to 1 in. (25.4 mm) thickness, and each original (uncut) surface tested separately if required under 5.3.1.

5.2 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.

5.3 Specimen Assembly

5.3.1 The specimen shall be representative of the materials or composite 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 should 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 should be tested.

5.3.1.1 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.

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

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

5.3.2.2 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 substtate alone and these values shall be recorded as supplemental to the measured values for the composite specimen.

5.3.2.3 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.

5.3.3 It is the intent of this test method to maintain the prescribed exposure conditions on the specimen for the test duration. If, duing a nonflaming exposure test, the specimen tends to melt or drip and fall away from the specimen holder, it shall be tested using the modified specimen holder (with trough) designed for the flaming test.

5.3.4 Specimen Mounting

5.3.4.1 All specimens, shall be covered across the back, along the edges, and over the front surface periphery with a single sheet of aluminum foil (0.0015 ± 0.0005 in. or approximately 0.04 mm). 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. Excess foil along the front edges should be trimmed off, after mounting. In using the modified holder with the trough, a flap of foil should be cut and bent forward at the spout to permit flow from melting specimens.

5.3.4.2 All specimens shall be backed with a sheet of asbestos millboard (see paragraph 4.1.3.). 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 below their normal thickness.

6. Specimen Conditioning

6.1 Specimens shall be predried for 24 hr. at 140 ± 5 °F (60 ± 3 °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.

7. Number of Test Specimens

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

8. Test Procedure

8.1 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.

8.2 Clean the chamber walls whenever periodic visual inspection indicates the need[5]. Clean the exposed surfaces of the glass windows separating the photodetector and light source housings 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.

[5/] An ammoniated spray detergent, and soft scouring pads have been found effective.

8.3 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 ± 4 °F (35 ± 2 °C), the chamber is considered to be at steady-state condition and ready for furnace calibration or testing. To increase chamber wall surface temperature to the stated level under adverse conditions, an auxiliary heater may be used; conversely, to decrease this temperature, the exhaust blower may be used to introduce cooler air from the laboratory. Calibrate the furnace output irradiance at periodic intervals according to test experience (normally 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.

8.4 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 pre-positioned stop. With the chamber door closed and inlet vent opened, the compressed air supply to the radiometer cooler is adjusted to maintain its body temperature at 200 ± 5 °C (93 °C). The autotransformer setting is adjusted so as to obtain the calibrated millivolt output of the radiometer corresponding to a steady-state irradiance of 2.2 ± .04 Btu/sec ft^2 (2.5 ± .05 W/cm^2) averaged over the central 1.5 in. (38.1 mm) diameter area.

The recorder or meter described in paragraph 4.1.8 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.

8.5 After the system has reached steady-state conditions, adjust meter and/or recorder zero. Adjust the amplifier sensitivity to obtain a full-scale reading of the photo-detector (100 percent transmittance) on the recorder or read-out meter. Determine the "dark current" (zero percent trans-mittance) on the maximum sensitivity range of the read-out meter by blocking the light, and adjust the "dark current" reading to zero.

8.6 For nonflaming 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 4.1.10. Check the burner distances relative to the "blank" specimen before fuel adjustment and ignition.

8.7 Before positioning the test specimen, flush the chamber with the door and exhaust and inlet vents open for about 2 minutes, and verify the starting temperature of the chamber, using the procedure described in paragraph 8.3.

8.8 Close the exhaust vent and blower. Place the loaded specimen holder on the bar support 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 only when the photometer indicates smoke.

8.9 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.

8.10 Observe the increase in chamber pressure with the manometer described in paragraph 4.1.9. A regulator (see C4.1.11) shall be used to maintain the pressure in the range of 4 ± 2 in. (100 ± 50 mm) of water during most of the test. If negative pressure develops after very intense specimen flaming, open the inlet vent slightly to equalize the pressure. As a result of pressure rise, the fuel and air valves must be adjusted during the flaming test to maintain constant flow rate.

8.11 Record any observations pertinent to the burning and smoke generating properties of the material under test, in accordance with paragraphs 10.1.6 and 10.1.7.

8.12 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.

8.13 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. Also any supplementary optical filter in the photometer system should be removed or displaced in order to extend the measuring range. If extraneous

light can reflect into the photometer during removal of the filter, turn the high voltage off or adjust the scale to minimize sensitivity. Replace the filter before exhausting smoke from the chamber.

8.14 Extinguish the burner on flaming exposures and start exhausting the chamber within one minute after reaching minimum transmittance. Displace the specimen from the front of the furnace by pushing the "blank" specimen holder with the positioning rod. 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.

9. Calculations

9.1 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.

9.2 Calculate the maximum specific optical density, D_m, using the formula in paragraph 9.1 with a light transmittance corresponding to the minimum level reached durint 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 8.14, 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:

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

9.3 For systems without "dark current" cancellation, a correction must be made for any light transmittance reading T, approaching the dark current value T_d. The corrected light transmittance T', is obtained from:

$$T' = 1 - \frac{1-T}{1-T_d}$$

and is used for the specific optical density calculations described in paragraphs 9.1 and 9.2.

9.4 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.

9.5 When the test is continued beyond the standard 20 minute exposure, all calculations are to be made in accordance with paragraphs 9.1 through 9.4 and the results identified as "Extended Exposure."

10. Report

10.1 The report (see Appendix E) shall include the following:

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

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

10.1.3 Test specimen conditioning procedure.

10.1.4 Number of specimens tested.

10.1.5 Test conditions: type of exposures, type of holder used, exposure period.

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

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

10.1.8 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 9 on calculations).

10.1.9 Test results calculated as described in Section 9, 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.

11. Precision and Accuracy

11.1 For D_m values above 100, the coefficient of variation of measurements on a uniform sample by an individual laboratory may range from 2 to 8 percent. For D_m values below 100, the

estimated standard deviation by an individual laboratory is about 10 or less. For measurements among laboratories, the coefficient of variation and standard deviation estimates may be greater by a factor of about 1.5.

APPENDIX A
Calibration of Test Equipment

A1.1 Photometric System

A1.1.1 Calibration of the photometer is checked by interrupting the light beam with calibrated neutral density filters. The filters should cover the full range of the instrument. Optical density values measured by the photometer shall be within ± 3% of the calibrated values.

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 from opposite sides of the beam at several points, 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. See C4.1.5.

A1.1.3 Shifts in dark current levels between tests, excessive zero shifts during test or lack of calibration indicates the need for inspection of the photometer system.

A1.2 Radiometer

Calibration of the radiometer is accomplished by placing it at suitable distances from a radiant energy source, while maintaining its body temperature at 200 ± 5 °F (93 ± 3 °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 ± .04 Btu/sec. ft^2 (2.5 ± .05 W/cm^2) is used to establish the furnace control settings discussed in paragraphs 4.1.2 and 8.3.

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 4.1.9. 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 Materials
For checking operational and procedural details of the equipment and method described herein, two standard materials may be used. Under nonflaming conditions, a single layer of nominal 0.030 in. (approximately 0.76 mm) thick alpha-cellulose (cotton linters) paper should provide repeatable maximum specific optical density values of 170 ± 10; under flaming conditions, a 0.032 in. (0.81 mm) thick plastic sheet should provide repeatable maximum specific opticla density values of 455 ± 15. These reference samples may be purchased from the Office of Standard Reference Materials, National Bureau of Standards, Washington, D.C. 20234. Use of these standard materials does not obviate the need for following the calibration and standardization procedure outlined in this Standard.

APPENDIX B

Presentation and Use of Test Results

B1. 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% 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., percent of the maximum density D_m. The smoke obscuration index incorporates 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 obsuration 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.

B2. 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.[6]

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

B3. 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[7], e.g.

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

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

6/ G. Williams-Leir, Private Communications.

7/ J. R. Gaskill, Fire Technology, August 1968.

B4. A principal advantage of using specific optical density is that the results can be related to (a) areas of materials which potentially could be involved in fire, (b) distances of light paths from observer to exitways, and (c) the volume of enclosing space. This may be accomplished by multiplying D or D_m by the involved areas (flaming and nonflaming) and the length of light path and dividing by the volume of the enclosed space, $\frac{AL}{V}$. See reference (1) for a more detailed discussion.

APPENDIX C
Construction Details

(Paragraph numbers correspond to applicable paragraphs in Section 4. Apparatus of main text).

C4.1.2 Radiant Heat Furnace

The furnace shall consist of a coiled wire or other suitable electrical heating element (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 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 the 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. (102 mm) 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 a rear cover of 3/8 in. (9.5 mm) 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. (305 mm) from the right wall. The centerline of the furnace shall be about 7 3/4 in. (195 mm) above the chamber floor.

C4.1.3 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. (0.6 mm) thick stainless steel to provide a 1 1/2 in. (38.1 mm) depth, and to expose a 2 9/16 by 2 9/16 in. (65.1 by 65.1 mm) specimen area. As described in paragraph 4.1.4, 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 ± 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.

C4.1.4 Support of Furnace and Specimen Holder

The framework as shown in Fig. 5 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 4.1.2. 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.

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 C4.1.3. 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.

C4.1.5 Photometric System

The photometric system shall consist of a tungsten-filament light source, (Type 1630 6.5 volt lamp, maintained at 4 ± 0.2V) and photodetector (Type 931V-A), oriented vertically to reduce variations in measurement brought about by stratification of the smoke generated by the specimens under test. The system shall be as shown in Fig. 6. The window in the chamber floor through which the light beam passes shall be provided with an electric heater to maintain a temperature of at least 125 °F (52 °C) to minimize smoke condensation. The collimated beam inside the chamber shall have a path length of 36 ± 1/8 in. (914 ± 3 mm) and a sensing cross-section of 1 1/2 ± 1/8 in. (38.1 ± 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 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 A1.1.1).

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.

C4.1.6 Radiometer

The body 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. long (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.

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

C4.1.7 Chamber Wall Thermocouple

A thermocouple shall be mounted with its junction secured to the geometric center of the inner rear wall panel of the chamber using a 1/4 in. (6.4 mm) thick polystyrene foam disk cover and epoxy cement.

C4.1.10 Burner

The Multiple flamelet burner shall be a six-tube burner, with construction details as shown in Fig. 4. The vertical tubes of the six-tube burner shall be made from 1/8 in. (3.2 mm) o.d. by 0.031 in. (0.8 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.

C4.1.11 Chamber Pressure Regulator

A simple pressure regulator consists of an open, water-filled bottle and a length of flexible tubing, one end of which is connected to a sampling port on the top of the chamber. The other end of the tubing is inserted 4 in. (10 mm) below the water surface. The bottle is located at the same level as the floor of the chamber.

APPENDIX D

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.

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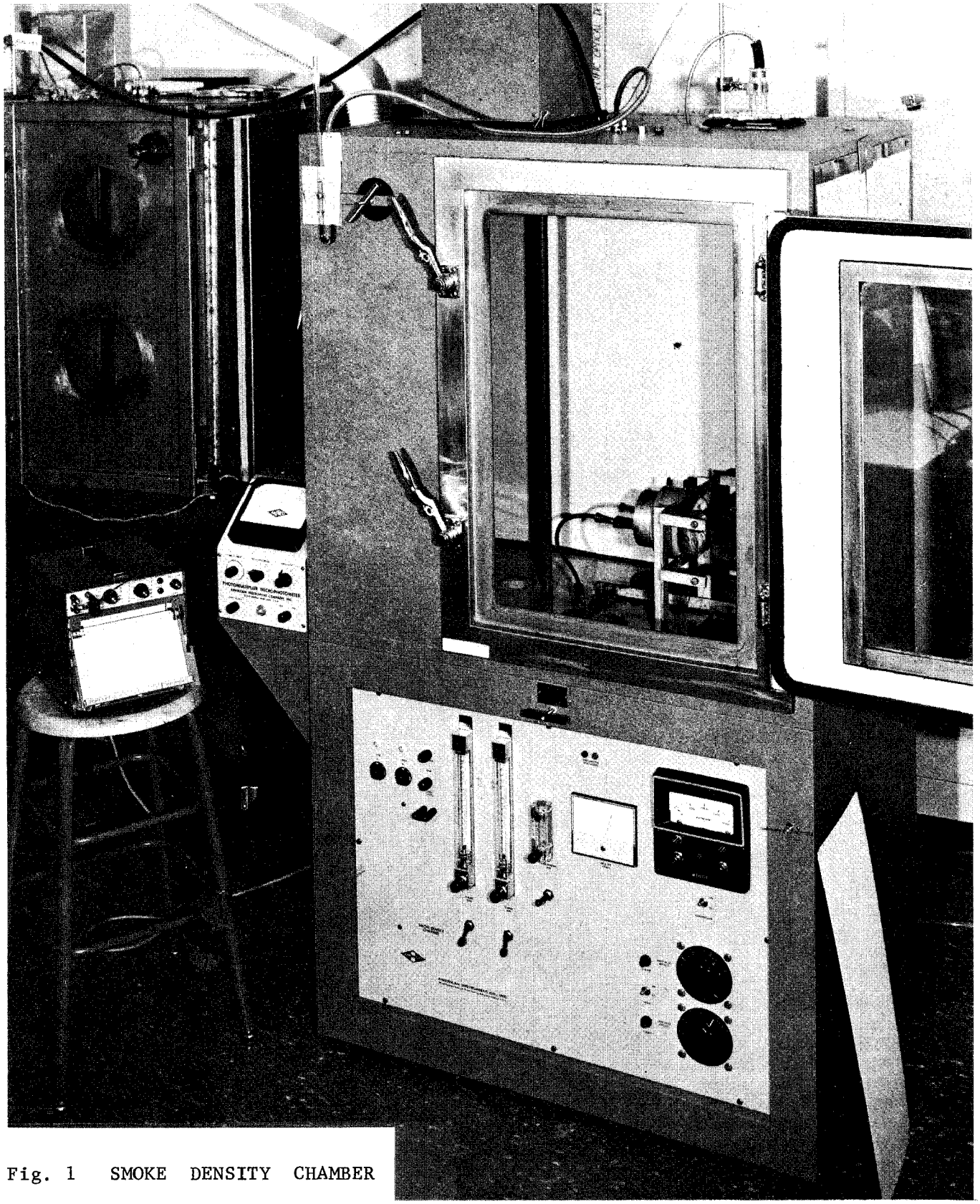


Fig. 1 SMOKE DENSITY CHAMBER

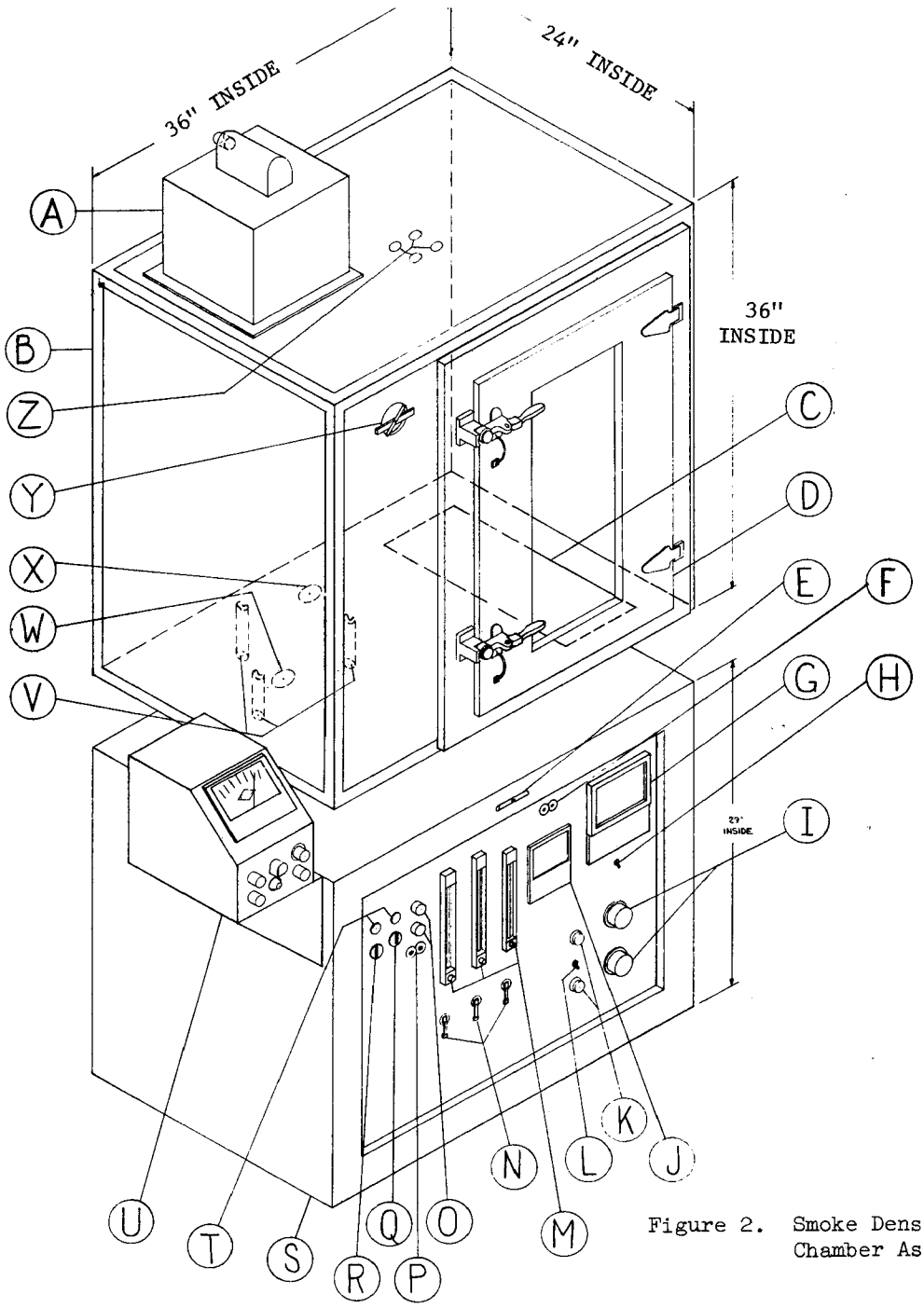
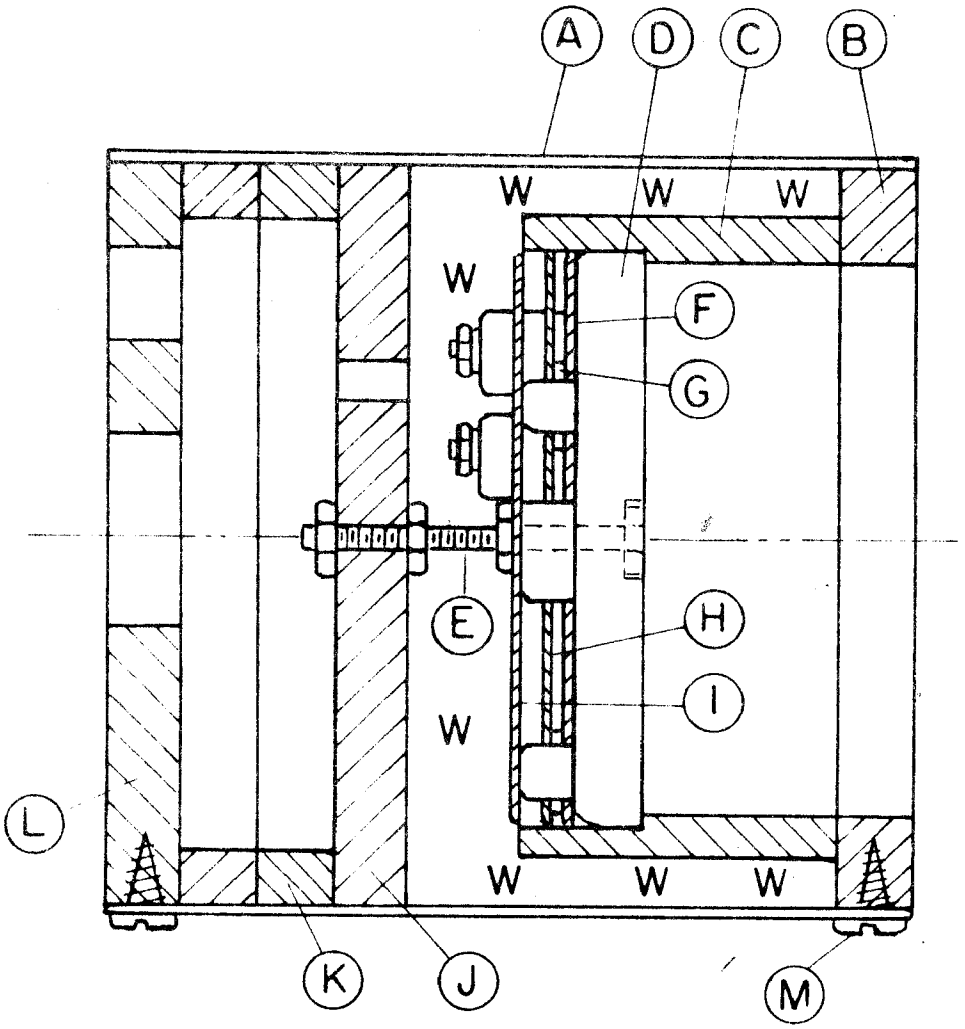


Figure 2. Smoke Density Chamber Assembly

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

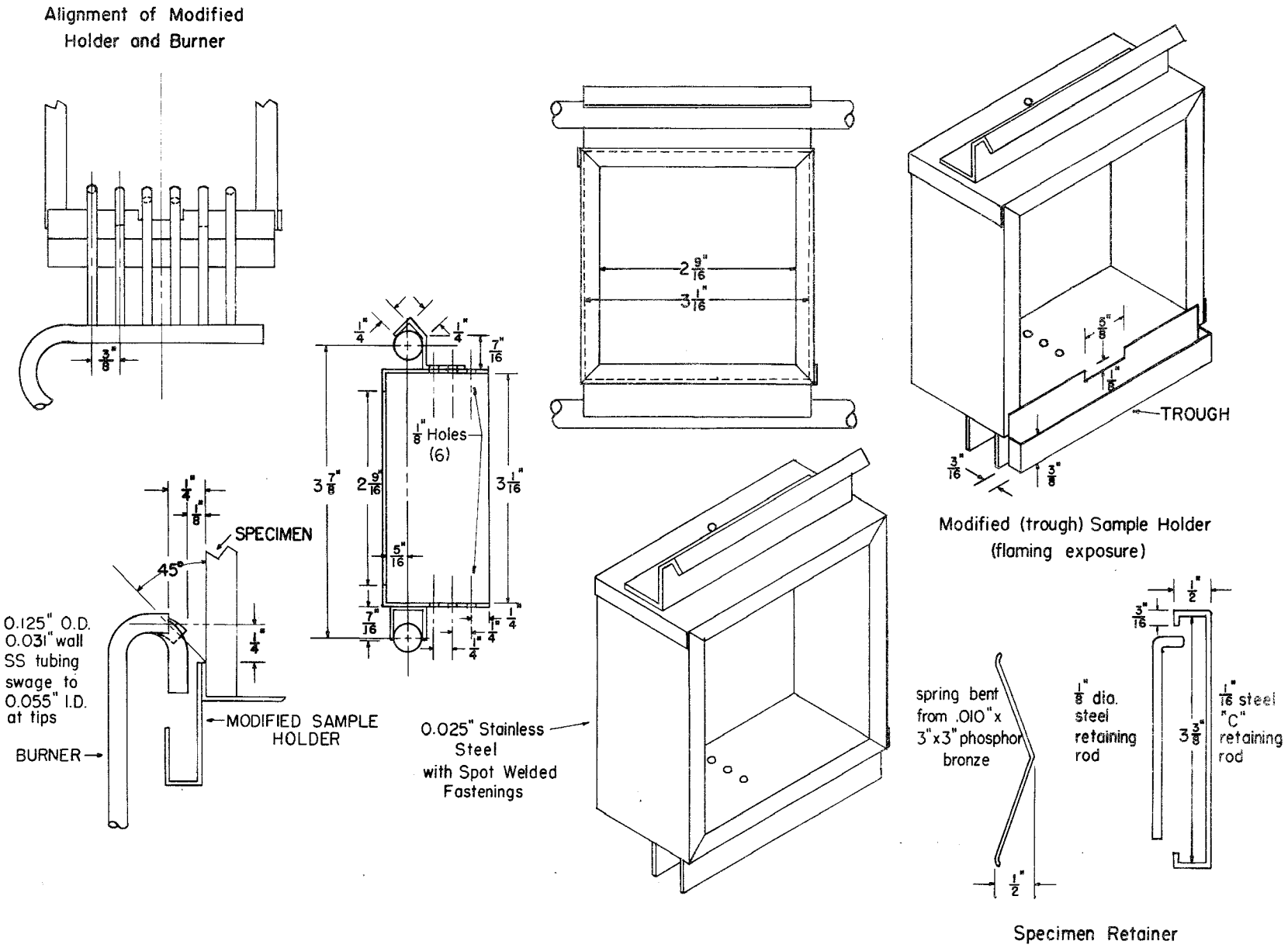


Fig. 4 DETAILS OF SPECIMEN HOLDERS AND PILOT BURNER

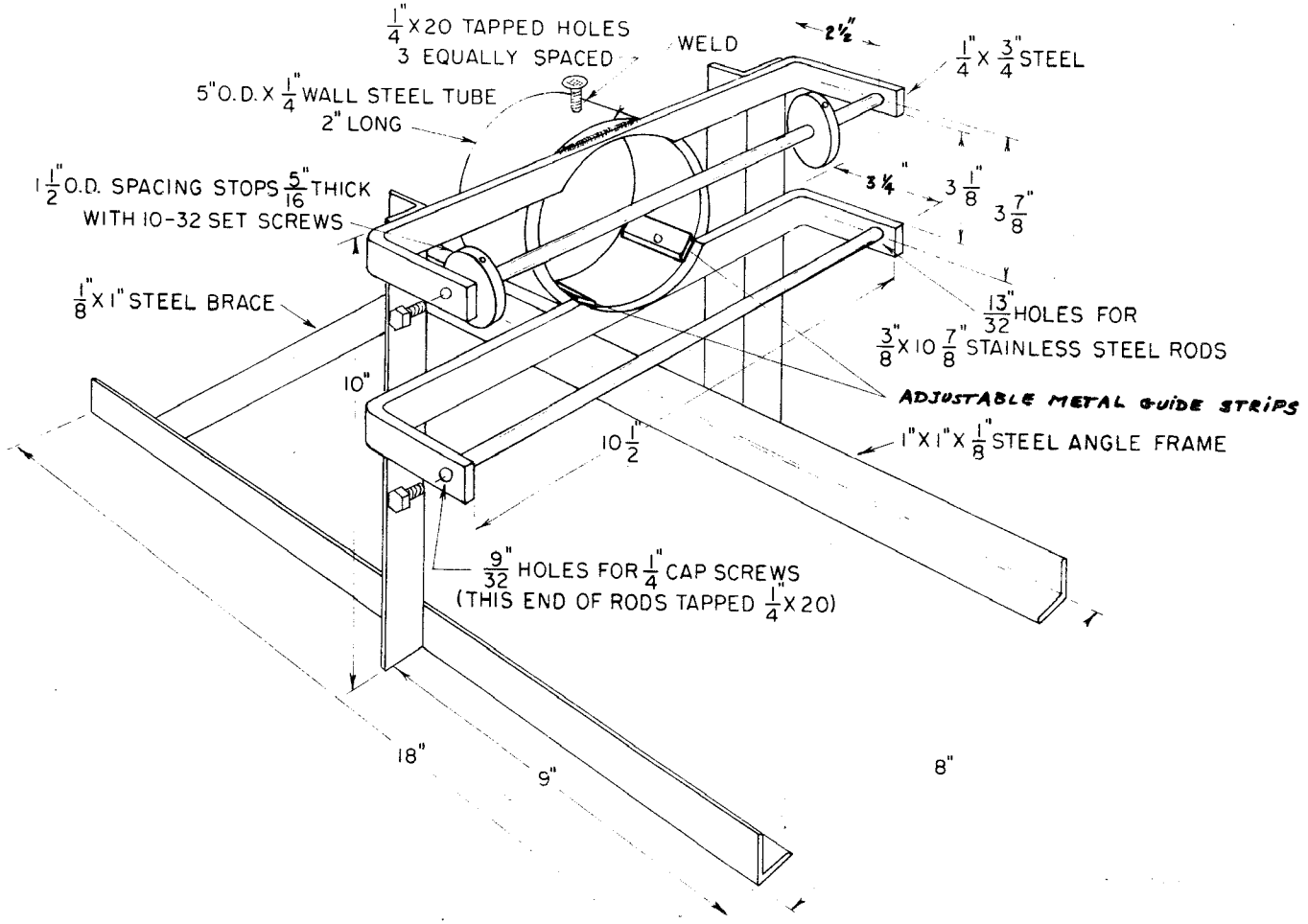


FIG. 5 – FURNACE SUPPORT

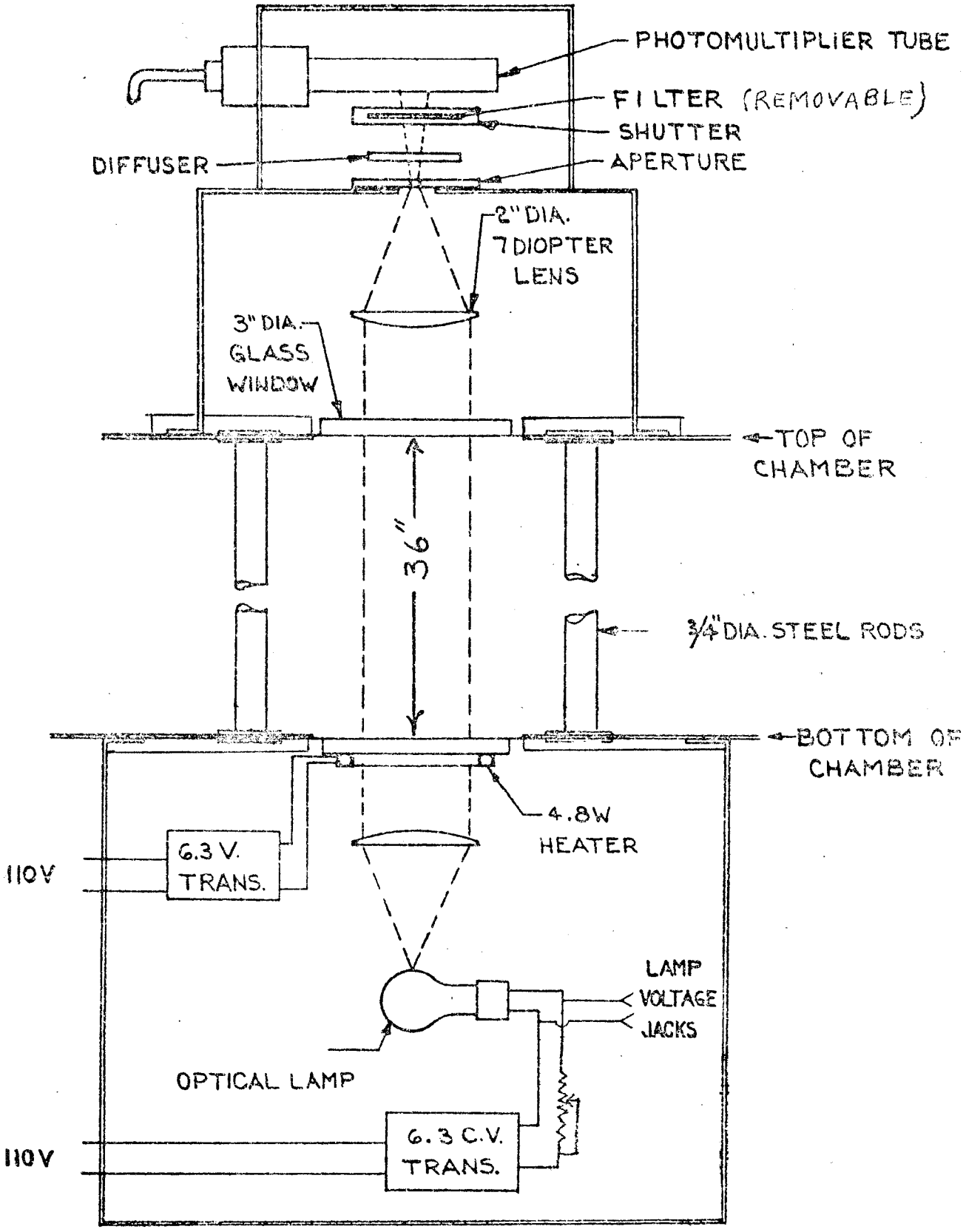
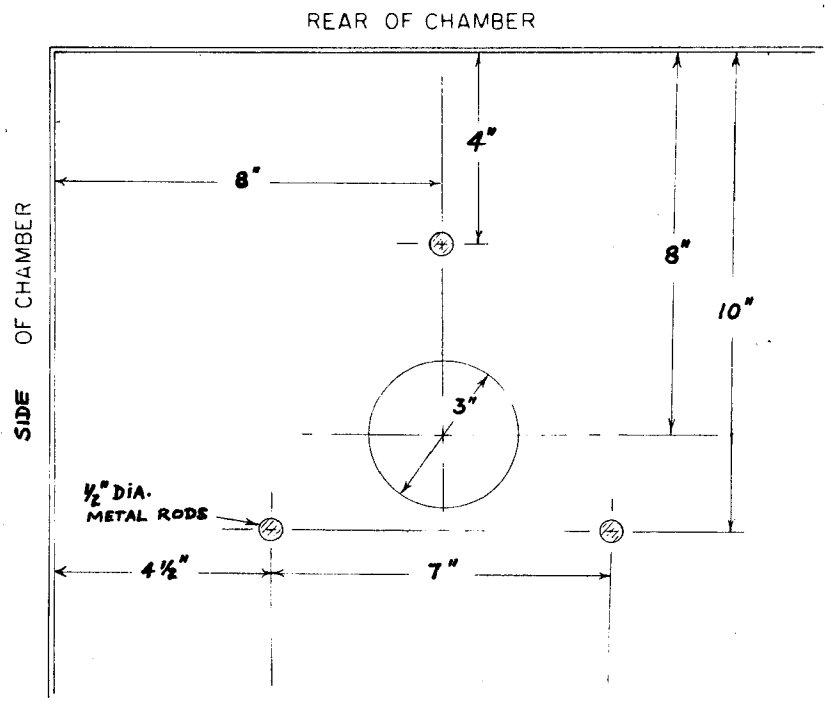


Fig. 6A Photometer Details



PHOTOMETER LOCATION
PLAN VIEW

Fig. 6B Photometer Location

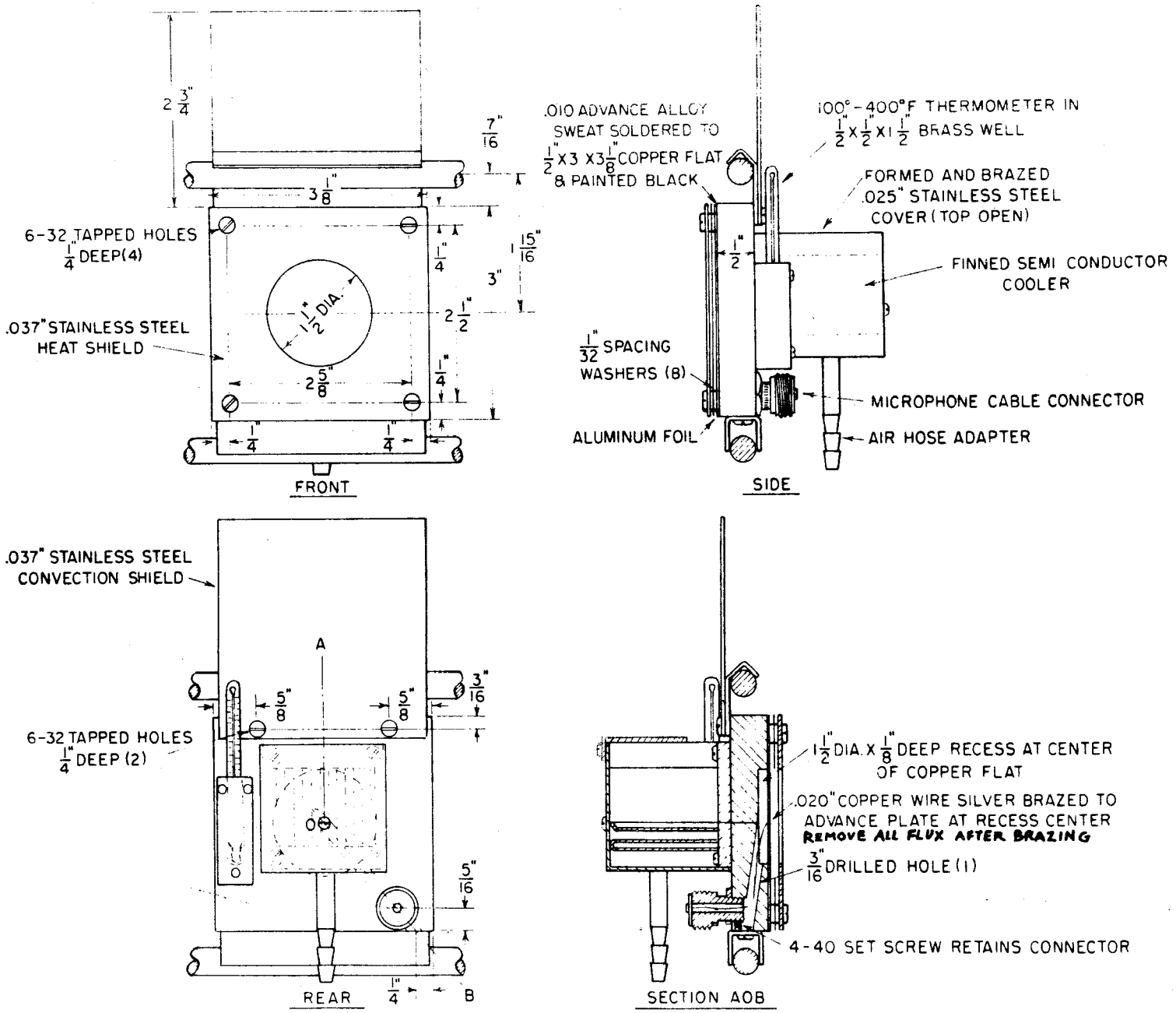


FIG. 7 - RADIOMETER DETAILS