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A LABORATORY TEST FOR MEASURING SMOKE FROM BURNING MATERIALS

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U.S. DEPARTMENT OF COMMERCE
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ABSTRACT

As a result of extended laboratory investigations equipment has been assembled for quantitative measurement of the smoke produced when material is burned or pyrolyzed in a closed volume. This report provides the first complete description of the equipment. It is presented at this time to permit others, who so desire, to duplicate facilities for their own use. A later report will be prepared describing the work leading to development of the test method and reporting results obtained with a variety of building finish materials.

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1. Introduction

In a previous report [1], preliminary results were presented of the smoke production characteristics of several materials within the Rohm and Haas XP 2 Smoke Density Test Chamber [2]. These results indicated that a small-scale laboratory test chamber appeared to be a useful and desirable means for evaluating the smoke generation characteristics of materials under simulated building fire conditions. This study has been extended to establish test criteria and procedures which would permit simple, reproducible and meaningful smoke measurements. An improved test chamber has been designed and built for this purpose. This report gives a detailed description of the chamber design and the test requirements on which it was based.

2. Requirements

The basic requirements for any laboratory test method are that it be simple in concept and easy to operate, and that it yield realistic, reproducible results based on sound principles. It should be relatively insensitive to minor variables, but be capable ofoperating over a sufficiently wide range of conditions. In terms of smoke measurement, the following conditions were considered appropriate:

A. The specimen be exposed and generate smoke from one surface only. This simulates the usual case in accidental building fires, and permits evaluation of the effectiveness of surface coatings in reducing smoke.

B. The method be suitable for smoldering (non-flaming) as well as active flaming conditions.

C. Smoke and combustion products (including water vapor) result only from specimen burning and not from the heat source.

D. The results be reported in units providing a measure of smoke quantity and comparative obscuring power.

3. Test Equipment

A. Chamber

The smoke chamber consists of a 16 ga. sheet metal box, 3 ft. x 2 ft. x 3 ft. high. As shown in Figs. 1 and 2, openings were provided to accomodate a photometer (C & I) with a 3 ft. vertical light path, power and signal lead wires, air and gas supply tubes, an exhaust blower and damper (B), an aluminum foil blowout panel (D), and a hinged door with a window (E). The chamber is tightly closed and normally not ventilated during test. It is supported on an angle iron frame (L), on which are mounted the electric (N, O, & P), and gas and air controls (S & Q). A multi-range meter and timer, or alternately, a recorder, are used for taking data.

The interior of the chamber and all parts used therein are either anodized black or painted with a flat black paint which should be resistant to corrosive decomposition products.

B. Furnace and Control System

To provide a fairly uniform irradiance on the surface of the 3 by 3 in. square specimen, an electrically-powered furnace with a 2-15/16 in diameter opening is used. As shown in Fig. 3 A, a 525 watt Type "End" Silex heating element (D) is mounted within a 2-15/16 in. i.d. by 3-3/8 in. o.d. by 1-5/8 in. long ceramic tube (C), bored out to 3-1/32 in. i.d., 5/8 in. deep to accomodate the heating element. Behind the heating element are mounted a 1/16 in. thick asbestos paper gasket (F), three 1/16 in. stainless steel spacing washers (G) and two 1/32 in. stainless steel reflectors with 6 holes (H) and 3 holes (I) respectively. The heating element assembly is centered with respect to the front 3/8 in. asbestos board (B) and the 3/8 in. asbestos board centering disk (J) by means of a 6-32 stainless steel screw (E), and the adjustment of the nuts on the end of this screw provides the proper spacing of the furnace components. Pyrex glass wool (W) is used to fill in the spaces in the heating element assembly. Two spacing rings (K) of 3/8 in, asbestos board, a rear cover (L) of 3/8 in. asbestos board and a 4-in. o.d. by .083 in. wall by 4-1/8 in. long stainless steel welded sanitary tube (A), 180 grit polished inside and outside, complete the furnace assembly. Three sheet metal screws (M), No. 6 by 1/2 in., are used around the periphery at each end. Appropriate holes are provided in the centering disk for asbestos-covered copper lead wires to the heating element and in the rear cover for a motor base plug and six 1/2 in. ventilation holes on a 2-1/2 in. dia. circle.

Although the materials and dimensions used are given in detail, they are not considered critical, provided the construction can withstand continuous operation and provided the geometry of the furnace opening is not materially altered.

The control system consists (Fig. 2) of a temperature controller (M), two autotransformers (P) and a sensing thermocouple placed within and close to the surface of the ceramic core of the furnace opening. The temperature set point of the controller is arranged so that a radiometer, placed at the same location as the specimen, will measure the prescribed irradiance level. The two autotransformers provide high and low voltage levels (rather than on and off), and can be adjusted to minimize power fluctuations to the heating element.

C. Photometric System

The light path/was arranged vertically to reduce errors in measurement due to smoke stratification effects. The light source was a 30 watt, 120 Volt, S-11, Type BLC film viewer lamp powered by a voltage regulating transformer. It was mounted in a box (C, Fig. 2) extending above the top of the smoke chamber, which contained in order, the source, a 7-diopter collimating lens and an adjustable metal finger. See Fig. 4. A glass window, gasketed for smoke-tightness, was mounted permanently in the ceiling of the chamber. The lamp was always operated at the same voltage (and hence same color temperature, approx. 2630° K) and adjustments of the light intensity were made with the metal finger.

Another box (I, Fig. 2) containing the photometer was located directly below the source and attached to the bottom of the smoke chamber. Below a similarly-mounted glass window in the chamber floor were, in order, a 7-diopter lens forming an image of the source, a 3/16 in. dia. circular stop in the focal plane of the lens and a 1P39 singlestage vacuum phototube having an S-4 spectral sensitivity response. This lens and stop combination did not permit the receiver to register rays departing from parallel by more than a few degrees, and reduced to a negligible amount the effect of the "beam broadening" caused by smoke particles scattering light from the original beam.

The phototube circuit load comprised the input resistance of the recorder and an adjustable load resistor arranged to provide a convenient signal level. When the full-scale output for the clear, smoke-free condition, was adjusted to 1 volt (using the metal finger and load resistor adjustments), ten-fold reductions in light transmission could be accommodated without appreciable loss in accuracy, by decade range changes of the recorder down to 0.1 millivolts full scale. This permitted the recording of reliable optical densities of about 4, corresponding to transmission values of .01 percent of the incident light. At the lowest levels of light transmissions, a correction becomes necessary for the dark current of the vacuum phototube, since this represents zero light transmission.

D. Specimen Holder

The 3 x 3 in. specimen is placed in a holder Fig. 5 designed for rapid positioning and for maintaining, by means of the furnace support (Fig. 3B), the specimen surface 1½ inch in front of and parallel to the furnace opening. The furnace support also serves as a positioning mount for a radiometer, Fig. 6, which establishes the prescribed irradiance level at the specimen surface just prior to its exposure.

The stainless steel specimen holder is fabricated by bending and brazing (or spot welding) to give a 2-9/16 in. square exposed area. The back, edges, and front non-exposed surfaces of the specimen are covered with a single sheet of thin aluminum foil to prevent smoke passage at any but the exposed specimen surface. Behind the specimen is placed a 3 x 3 x 1/2 in. thick sheet of asbestos millboard (conforming to Fed. Spec. HH-M-351). A phosphor bronze spring and a steel pin are used to maintain a snug assembly.

When the proper spacing (9-3/8 in.) is maintained between the spacing stops of the furnace mount (Fig. 3B), the loaded specimen may be quickly and accurately positioned by placing it on the support bars and sliding the radiometer or another holder to the limit of its travel.

E. Radiometer

The desired irradiance level (2.5 w/cm^2) at the specimen surface is measured by means of a circular foil radiometer of the type described by Gardon [3]. It is of simple construction, has a sufficiently rapid time-constant and produces an emf, which is nearly proportional to the irradiance level. The use of a reflective heat shield, with aperture, on the front of the radiometer and a finned convector supplied with compressed air on the rear, help to maintain the radiometer body at a more constant temperature and to minimize effects due to variable convective and radiative losses. The receiving surface was spraycoated with an infrared-absorbing black paint containing a silicone vehicle. * The absorptivity of the paint to visible and infrared energy is approximately 0.93 to 0.95 for a film thickness of 1 mil.

Details of the radiometer construction are shown in Fig. 6. The air-cooled radiometer was calibrated by placing it at suitable distances from a radiant energy source and measuring its electrical output as a function of the irradiance level, Fig. 7. The latter was determined calorimetrically by measuring the rate of temperature rise of a totally-absorbing copper disk of known weight, area and specific heat.

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*Type 8 X 906 SICON Flat Black Paint, Midland Industrial Finishes Co., Inc. Waukegan, Illinios

4. Suggested Test Procedure

All specimens, prepared in the 3-by 3 inch size, should be predried for 24 hours at 140° F and then conditioned to equilibrium with an ambient of 73 ± 5° F and 50 ± 5 percent relative humidity. The specimen should be representative of the material or assembly as intended for use and should be prepared by the intended application procedures. Where the intended application of a finish material is not specified, or may be any of several, the finish material may be prepared for test as follows:

(a) Surface finish materials, in either liquid or sheet form, including those intended to control and reduce the smoke produced by supporting base materials, should be tested in the assembly or assemblies proposed for use. In the absence of specific information, the finish material should be applied to the smooth surface of 1/4 in. thick tempered hardboard using recommended (or practical) application techniques and spreading rates.

(b) Liquid films, such as sealers, adhesives, etc., and other materials intended for application to non-combustible base materials or being tested for their inherent smoke contribution shall be applied to the smooth surface of 1/4 inch thick asbestos cement board of 120 pcf density, using recommended spreading rates.

(c) Materials intended for air-backed applications, such as suspended ceilings or hanging drapes, shall be mounted in a specimen holder providing a 1/8 in. air space behind the specimen. This may be accomplished by use of an asbestos board back fitted with 1/8 in. thick, 1/4 in. wide asbestos strips at the borders.

To perform a test, turn on the electrically-powered furnace and associated controls. Place the radiometer in a specimen holder and position it in front of the furnace. Turn on the compressed air supply to the radiometer convector and adjust the flow rate (or pressure) to correspond to the value used for calibration. Adjust the controller temperature setting to produce a millivolt output of the radiometer corresponding to an irradiance of 2.5 w/cm^2. Adjust the two autotransformers to suitable voltage levels (approximately 70 and 90 volts) to minimize cyclic variations in irradiance.

Turn on power to the photometer light source and the recording or indicating meter. Using the metal finger and load resistor adjustment, set the output reading to full-scale on the 1-volt range. Verify the zero reading on the most sensitive range, and others if required, by shorting the meter input.

Mount a preconditioned specimen in a cool specimen holder using a single sheet of aluminum foil along the back, edges and front inside surfaces of the specimen, taking care not to puncture the foil. Back the specimen with a sheet of 1/2 inch asbestos millboard and assemble into the holder snugly, using the spring and pin.

For non-flaming (smoldering) tests, place the loaded specimen holder on the bar supports and slide it into position by displacing the radiometer. Start the timer (or recorder chart) simultaneously. Turn off the air supply to the radiometer and close the door. Record values of light transmission versus time, making full-scale range changes (in decade steps for maximum convenience) as appropriate. Observe and note any characteristic smoking or burning patterns, the color and nature of the smoke, etc. Continue until a minimum light transmission value is reached or 15 minutes, which ever is lesser. Record the "dark current" light transmission by switching off power to the photometer light source and setting the recorder at a suitable high sensitivity. Verify the zero reading by shorting the meter input. Open the door a small amount and turn on the exhaust fan to clear the chamber of smoke. Discard the specimen and clear the chamber completely of smoke. With the photometer light on, record the final light transmission value under clear air conditions in the chamber, making the appropriate meter range changes. Clean the glass windows (ethyl alcohol generally satisfactory) in preparation for the succeeding test.

For tests employing pilot ignition, supply gas to the pilot burner (See Fig. 5) at a rate of 200 Btu/hr (0.2 SCFH of natural gas, or equivalent). Ignite the horizontally-oriented gas jet using an electrically-powered platinum "hot wire". Swing the lighted pilot burner up to impinge on the specimen surface when the loaded specimen holder displaces the radiometer in front of the furnace. It the pilot burner is blown out during a test, reignite it using the platinum hot wire. Proceed as before.

5. Test Results

The result of a smoke measurement test of a meterial is a curve of optical density (per foot) versus time. The report of such a test should also include the following:

A. Identification of the material, including data such as density, thickness, and type of base material(if used).

B. Test conditions, including irradiance level (2.5 w/cm^2), flaming (pilot) or smoldering (no pilot) exposure, etc.

C. Important visual observations of specimen, color and nature of smoke, and test chamber conditions both during and after test.

The reduction in the light transmission caused by smoke in the photometer light path is measured using a recorder or a meter and timer. The transmission data is converted to optical density per foot using the relation:

$$D = \frac{1}{L} \left(\log_{10} \frac{100}{T}\right)$$

where T is the percent transmission and $L = 3$ ft. is the length of the optical path.

For each test, retain a record of (a) the "dark current" light transmission (with photometer light source off and recorder set at a suitably high sensitivity), and (b) the final transmission value (after removing specimen and clearing chamber of smoke).

6. References

[1] D. Gross, J.J. Loftus, and R. Harris, "Wall Cladding Materials: Smoke Production Measurements Under Simulated Fire Conditions" First Progress Report, NBS Report No. 8398, July 14, 1964

[2] Anon., "A Method of Measuring Smoke Density" NFPA Quarterly 57, pp. 276-87. January 1964

[3] R. Gardon, "An Instrument for the Direct Measurement of Intense Thermal Radiation," Rev. Sci. Inst. 24, pp. 366-70. May 1953

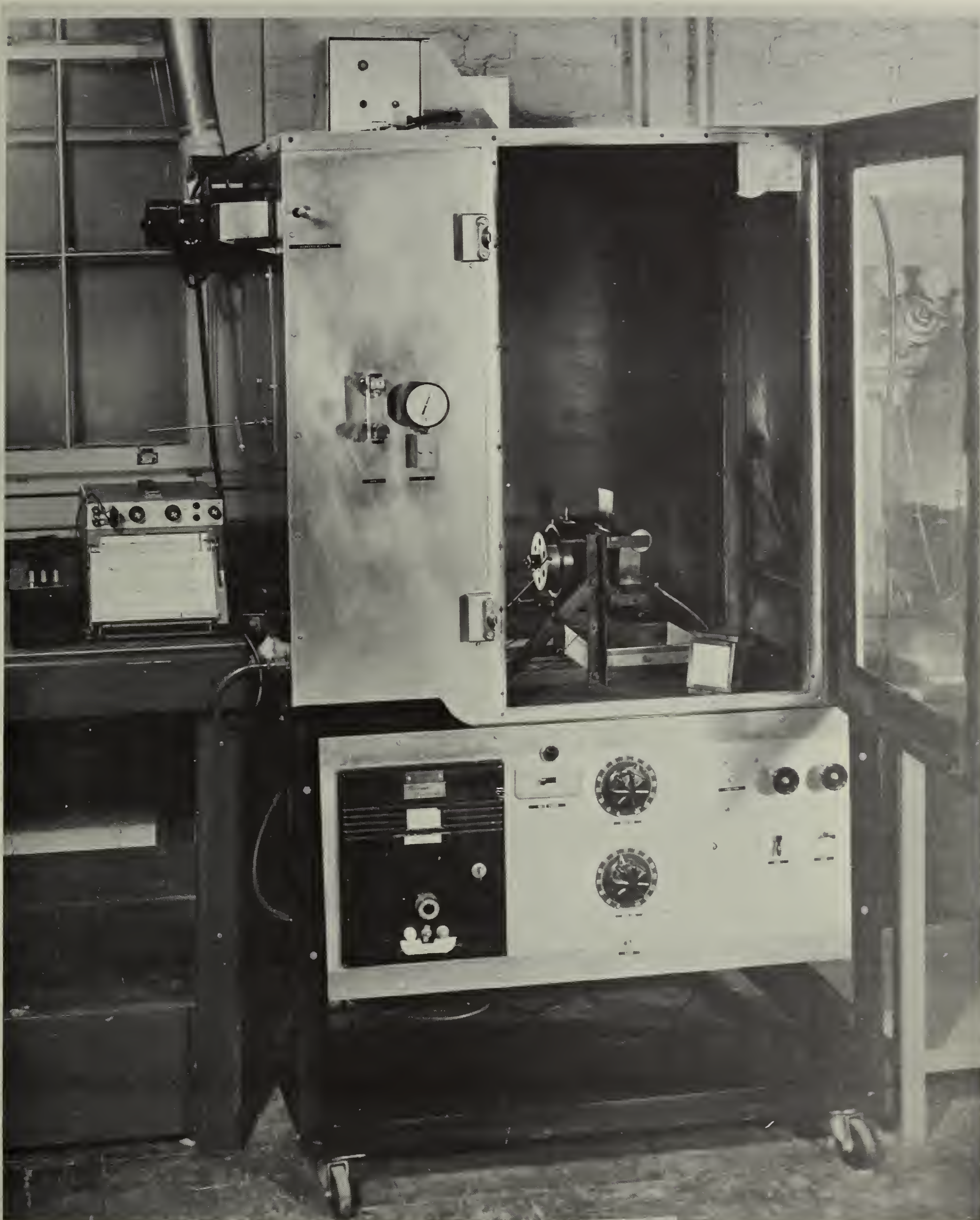


Fig. 1 - Smoke Test Chamber

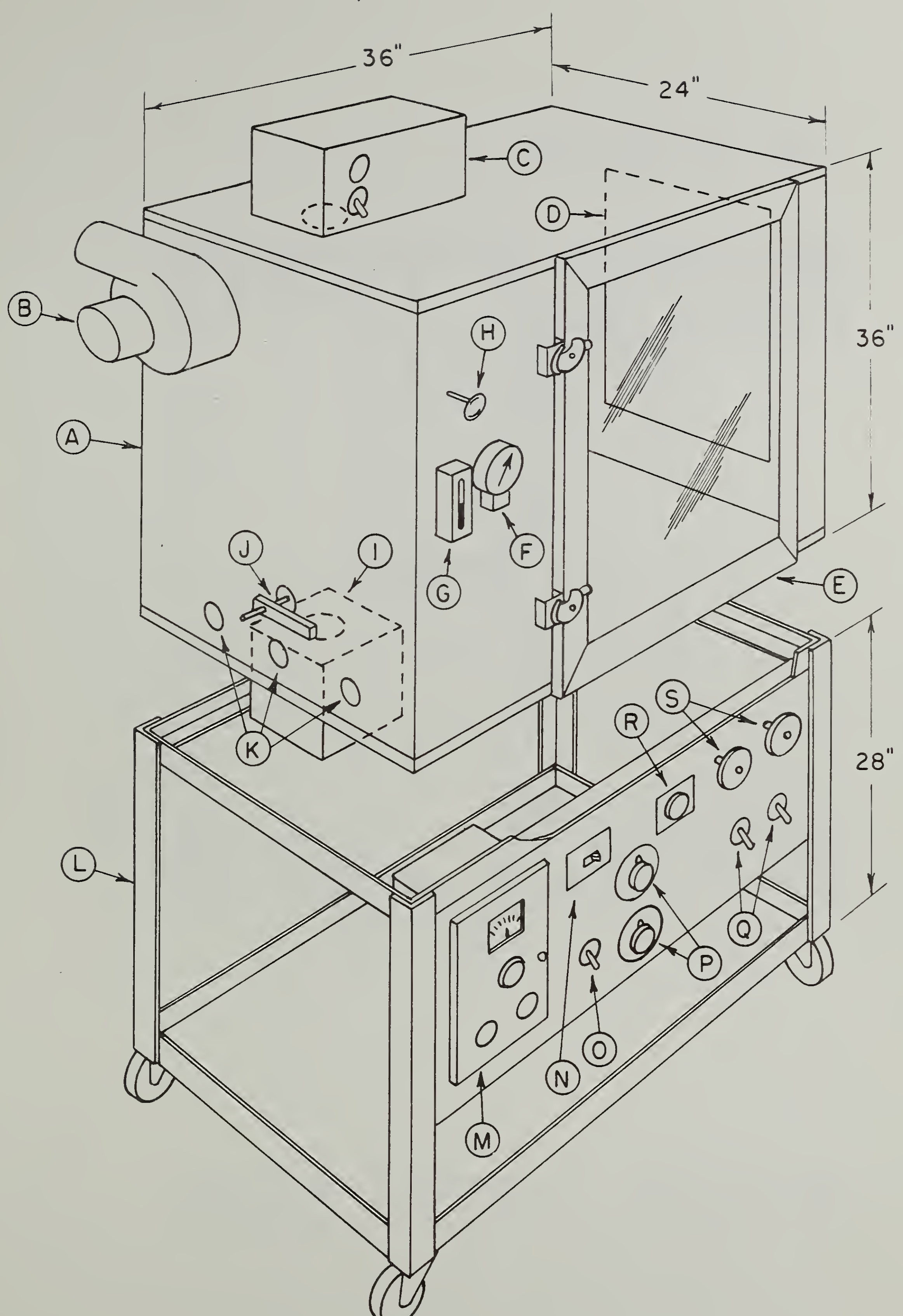


FIG. 2 - SMOKE CHAMBER ASSEMBLY

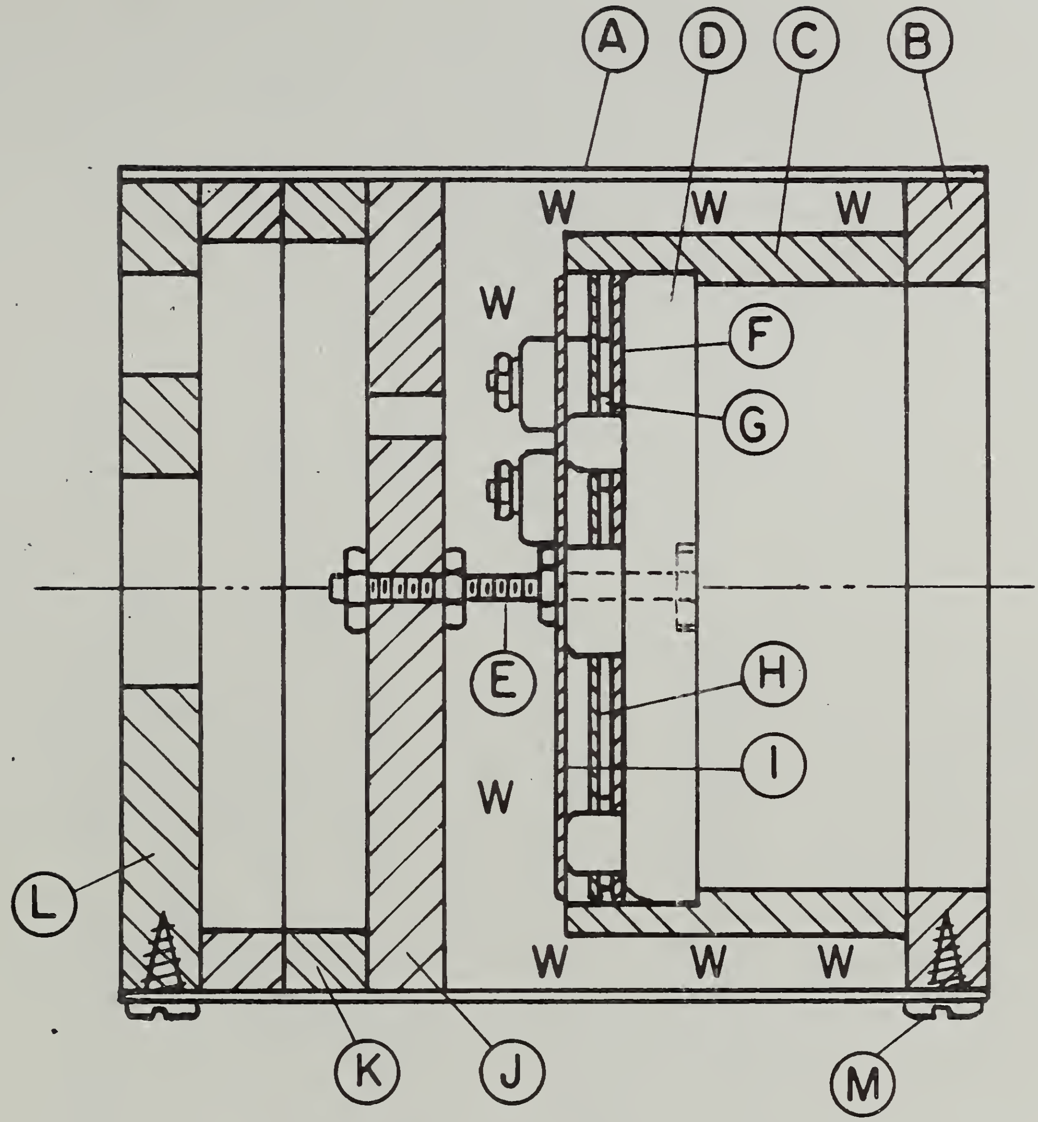


FIG. 3A-FURNACE SECTION

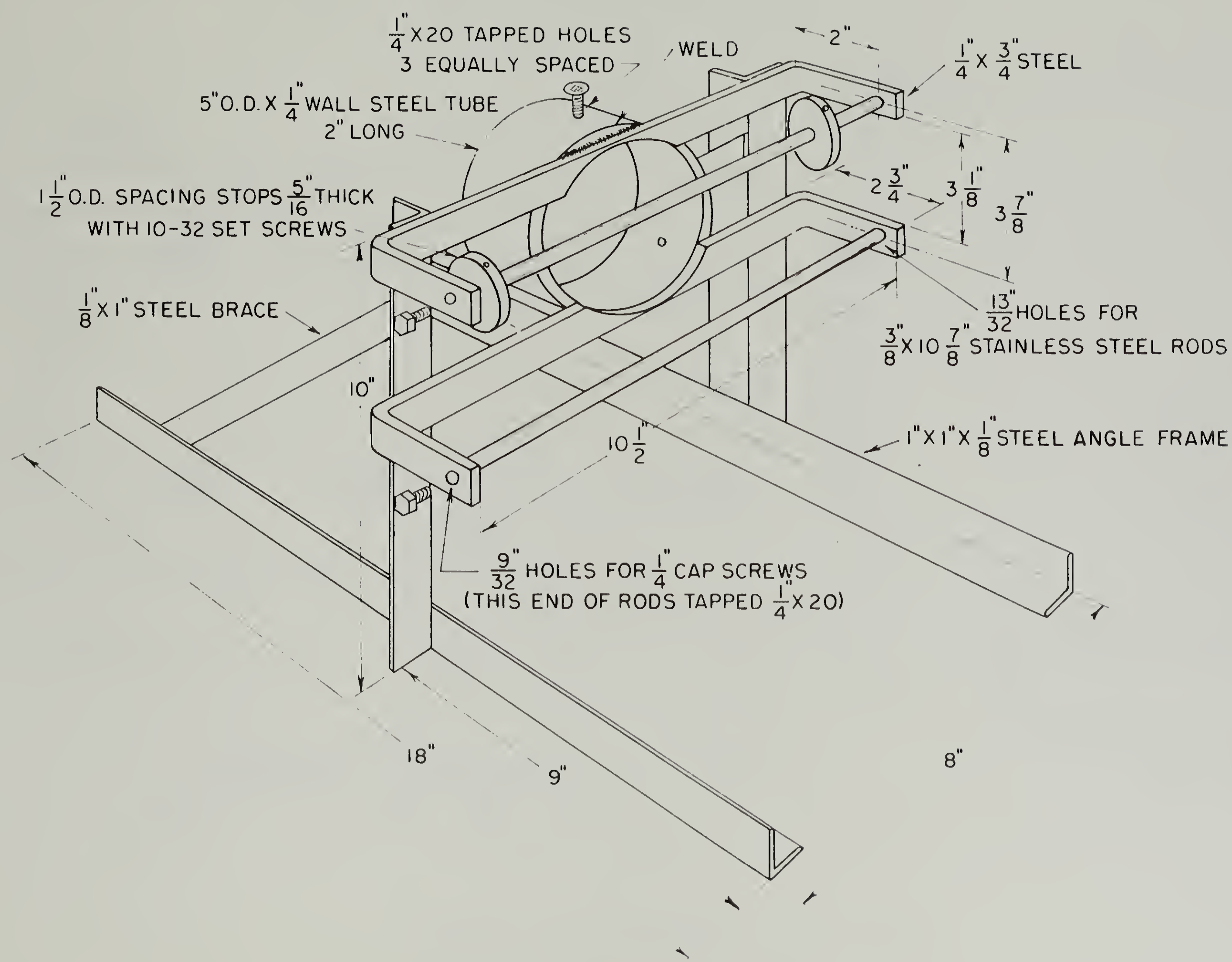
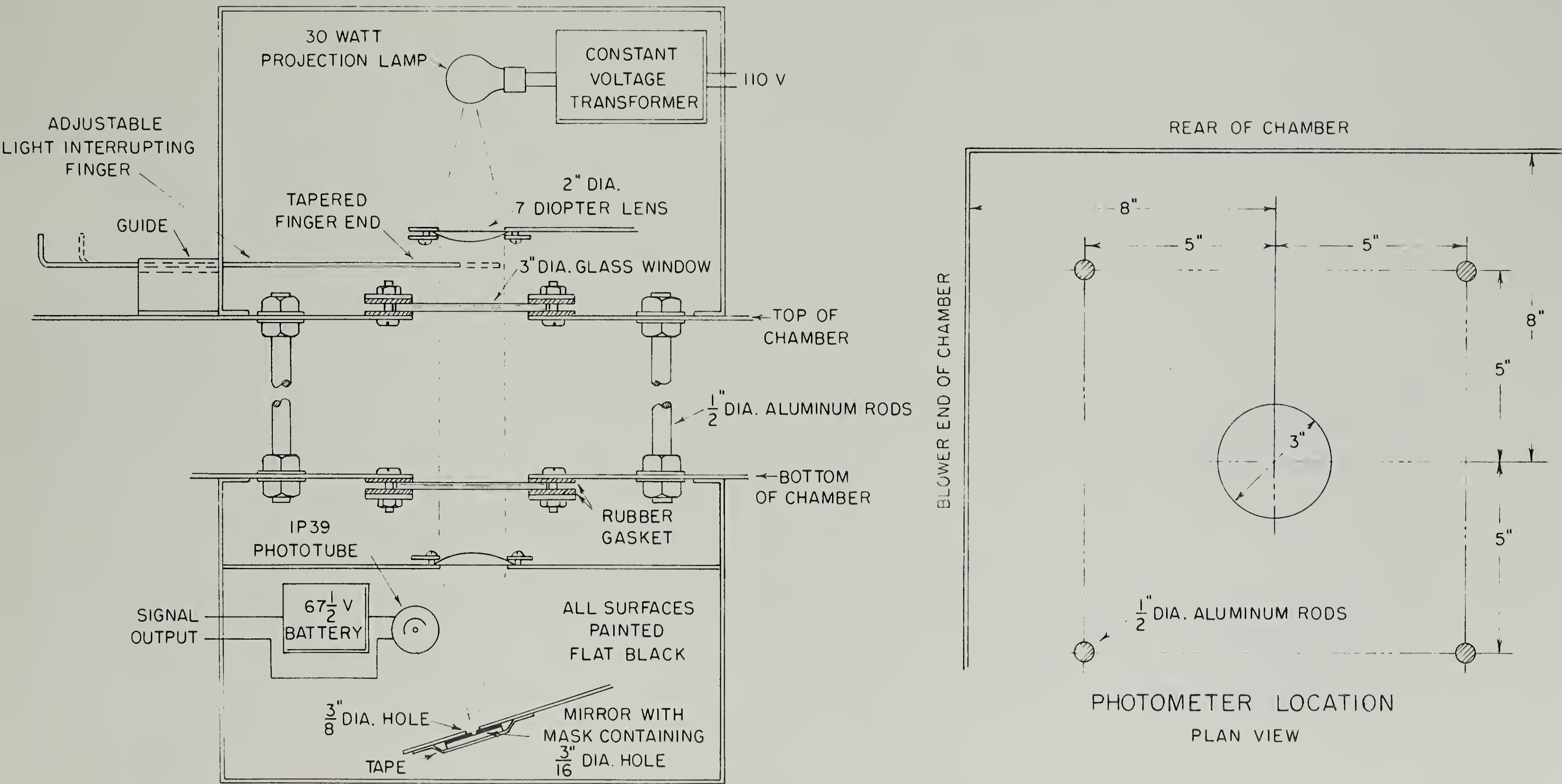


FIG. 3B – FURNACE SUPPORT



PHOTOMETER LOCATION
PLAN VIEW

FIG. 4 - PHOTOMETER DETAILS

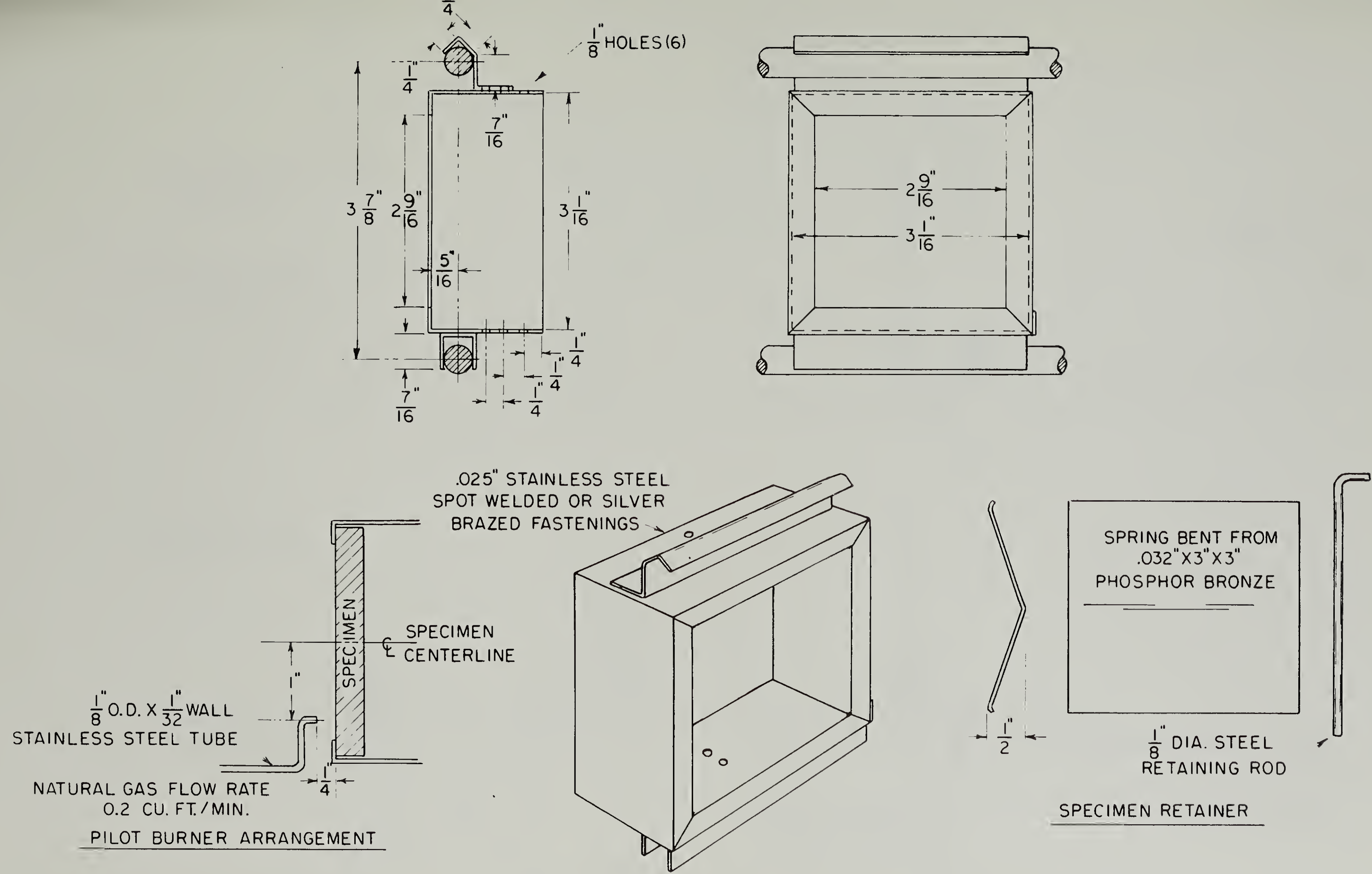


FIG. 5 - DETAILS OF SPECIMEN HOLDER AND PILOT BURNER

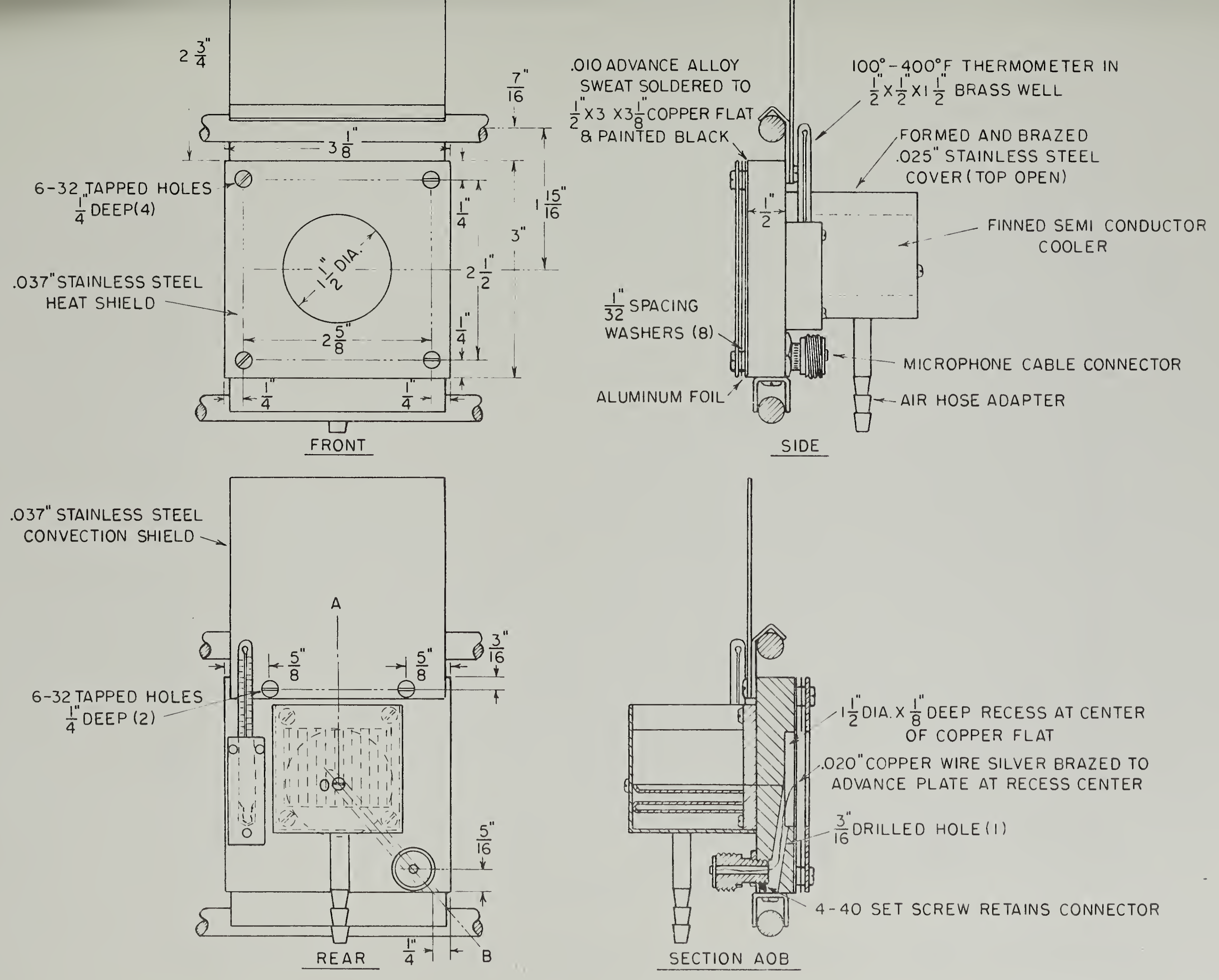


FIG. 6 - RADIOMETER DETAILS

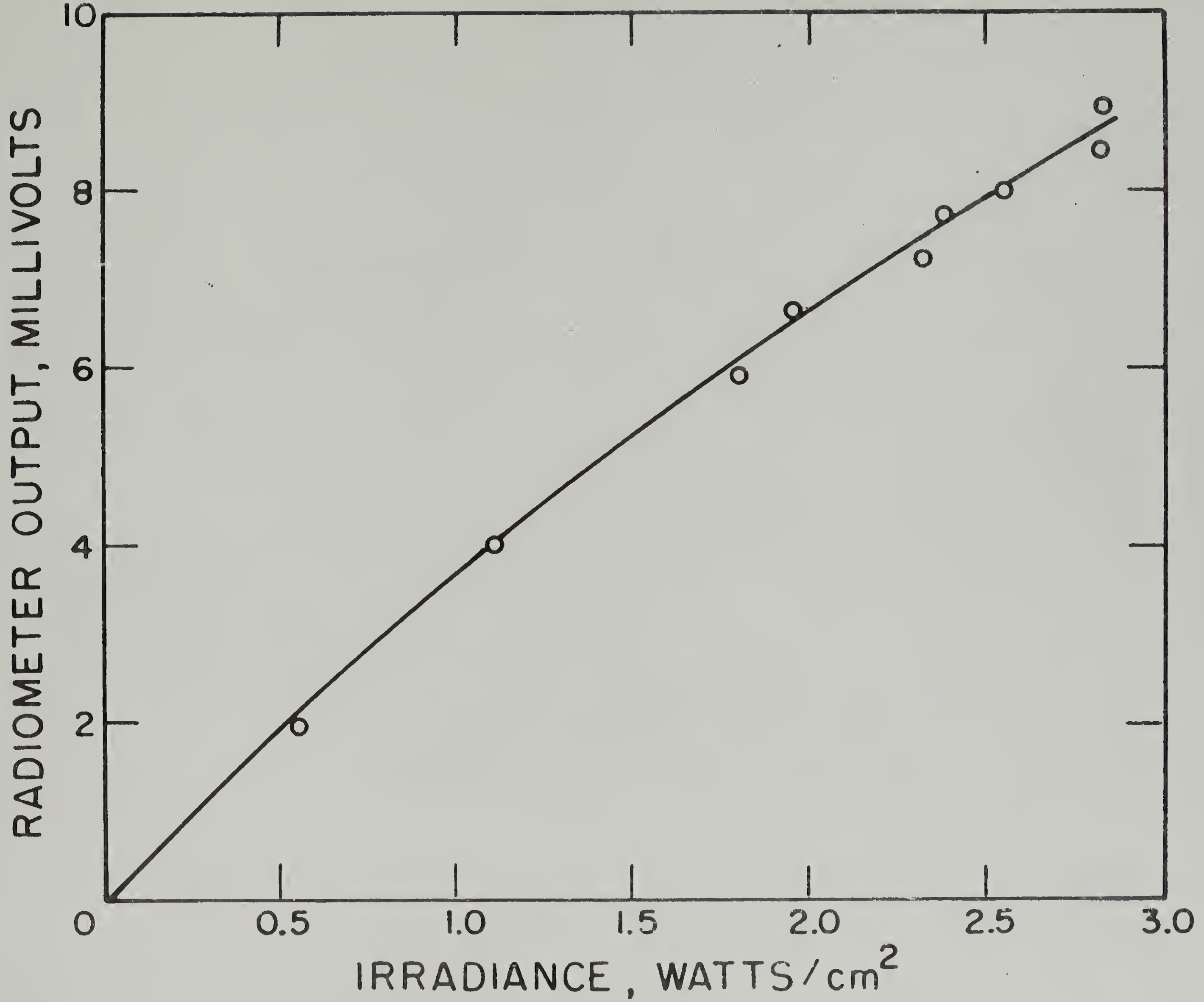


FIG. 7 – RADIOMETER CALIBRATION CURVE

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