Designation: E1678 − 15

An American National Standard

Standard Test Method for
Measuring Smoke Toxicity for Use in Fire Hazard Analysis[1]

This standard is issued under the fixed designation E1678; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

The pyrolysis or combustion of every combustible material or product produces smoke that is toxic. It is, therefore, desirable to establish a test method for the development of data characterizing smoke toxicity as an element of fire hazard analyses for both pre-flashover and post-flashover fires. The test method includes quantification of the toxicity of the smoke and ascertain whether the observed toxicity can be attributed to the major common toxicants.

1. Scope

1.1 This fire-test-response standard covers a means for determining the lethal toxic potency of smoke produced from a material or product ignited while exposed to a radiant heat flux of 50 kW/m^2 for 15 min.

1.2 This test method is limited to test specimens no larger than 76 by 127 mm (3 by 5 in.), with a thickness no greater than 51 mm (2 in.). Specimens are intended to be representative of finished materials or products, including composite and combination systems.

1.3 Lethal toxic potency values associated with 30-min exposures are predicted using calculations that use combustion atmosphere analytical data for carbon monoxide, carbon dioxide, oxygen (vitiation) and, if present, hydrogen cyanide, hydrogen chloride, and hydrogen bromide. The predictive equations are therefore limited to those materials and products whose smoke toxicity can be attributed to these toxicants. An animal check determines the extent to which additional toxicants contribute to the lethal toxic potency of the smoke.

1.4 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.5 This standard measures and describes the response of materials, products, or assemblies in response to heat under controlled conditions, but does not by itself incorporate all factors required for fire hazard of fire risk assessment of the materials, products, or assemblies under actual fire conditions.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations (particularly with regard to the care and use of experimental animals) prior to use.* For specific hazards statements, see Section 7 and Note X1.1.

2. Referenced Documents

2.1 *ASTM Standards:*[2]
E176 Terminology of Fire Standards
E800 Guide for Measurement of Gases Present or Generated During Fires

2.2 *ISO Document:*
TR 9122 (Parts 1–5) Toxicity Testing of Fire Effluents[3]

2.3 *FFPA Standard:*[4]
NFPA 269–2012 Standard Test Method for Developing Toxic Potency Data for Use in Fire Hazard Modeling

3. Terminology

3.1 *Definitions*—For definitions of general terms used in this test method, refer to Terminology E176.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *carboxyhemoglobin saturation, n*—the percent of blood hemoglobin predominately converted to carboxyhemoglobin from reaction with inhaled carbon monoxide.

3.2.1.1 *Discussion*—The chemical reaction between carbon

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monoxide and hemoglobin in blood is reversible. The effect of carbon monoxide on the exposed person may not be reversible.

3.2.2 *concentration-time curve, n*—a plot of the concentration of a gaseous toxicant as a function of time.

3.2.2.1 *Discussion*—The concentration-time curve can also be used to represent the sum total of all combustion products instead of just a single one.

3.2.3 *Ct product, n*—the concentration-time product in (µL/L)·min obtained by integration of the area under a concentration-time curve.

3.2.3.1 *Discussion*—Values expressed using this unit are numerically equal to those using the previously cited unit, ppm, a term whose use is discouraged.

3.2.4 *fractional exposure dose (FED), n*—the ratio of the integrated area under the concentration-time curve for a gaseous toxicant or the sum of all combustion products produced in a given test to that integrated $C(t)$ area which has been determined statistically from independent experimental data to produce lethality in 50 % of test animals within a specified exposure and postexposure time.

3.2.4.1 *Discussion*—When C is nearly constant over time, the time values in this ratio numerically cancel, and the FED is simply the ratio of the average concentration of a gaseous toxicant to its LC_{50} value for the same exposure time. When only a single measurement of C is made during a test, the accuracy of this simplification is not known. When not used with reference to a specific toxicant, the term FED represents the summation of FEDs for individual toxicants in a combustion atmosphere.

3.2.5 *LC_{50}, n*—a measure of lethal toxic potency; the concentration of gas or smoke calculated statistically from concentration-response data to produce lethality in 50 % of test animals within a specified exposure and postexposure time, expressed in µL/L.

3.2.5.1 *Discussion*—Values expressed using this unit are numerically equal to those using the previously cited unit, ppm, a term whose use is discouraged.

3.2.6 *mass loss concentration, n*—the mass loss of a test specimen per unit exposure chamber volume in $g \cdot m^{-3}$.

3.2.7 *post-flashover, n and adj*—referring to the state of a fire after flashover.

4. Summary of Test Method

4.1 In this test method, a test specimen is subjected to ignition while it is exposed for 15 min to a radiant heat flux of 50 kW/m^2. (See X1.2.2.) The smoke produced is collected for 30 min within a 200-L chamber communicating with the combustion assembly through a connecting chimney. Concentrations of the major gaseous toxicants are monitored over the 30-min period, with Ct products for each being determined from integration of the areas under the respective concentration-time plots. The Ct product data, along with the mass loss of the test specimen during the test, are then used in calculations to predict the 30-min LC_{50} of the test specimen.

4.2 The predicted LC_{50} is then confirmed in comparable tests by exposing six rats, restrained for head-only exposure,

for 30 min to the smoke produced from that mass of the test specimen whose mass loss concentration during the 30-min period is approximately (±10 %) equivalent to 70 % and to 130 % of its estimated LC_{50}. If no more than one rat dies during the 30-min exposure, or within 14-days postexposure to the mass loss concentration corresponding to 70 % of the LC_{50}, and at least five rats die during the 30-min exposure, or within 14-days postexposure to the mass loss concentration corresponding to 130 % of the LC_{50}, the predicted LC_{50} is considered to be confirmed. Confirmation ensures that the monitored toxicants account for the observed toxic effects.

4.3 An animal test result that does not confirm the prediction indicates the presence of one or more additional toxicants or toxicological antagonists, and the degree of disagreement indicates the importance of the unmeasured factors.

4.4 For calculation of hazard from pre-flashover, flaming fires, the toxicant gas yields and LC_{50} values are to be used as experimentally determined. For calculation of hazard from post-flashover fires, the yields of carbon monoxide are augmented to reflect the higher yields produced in such fires. The experimental LC_{50} values are then adjusted using a specified calculation to produce LC_{50} (post-flashover) values.

5. Significance and Use

5.1 This test method has been designed to provide data for the mathematical modeling of fire hazard as a means for the evaluation of materials and products and to assist in their research and development.

5.1.1 Test Method E1678–15 is functionally equivalent to NFPA 269–2012.

5.2 This test method is used to predict, and subsequently confirm, the lethal toxic potency of smoke produced upon the exposure of a material or product to specific fire test conditions. Confirmation determines whether certain major gaseous toxicants account for the observed toxic effects and lethal toxic potency. If a predicted lethal toxic potency value is not confirmed adequately, indicating a potential for unusual or unexplained toxicity, the lethal toxic potency will need to be investigated using other methodology, such as conducting an experimental determination of the LC_{50} using the apparatus described. (See X1.3.1 and X1.3.2.)

5.3 This test method produces lethal toxic potency values that are appropriate for use in the modeling of both pre-flashover and post-flashover fires. Most fire deaths due to smoke inhalation in the U.S. occur in areas other than the room of fire origin and are caused by fires that have proceeded beyond the room of fire origin. It is assumed that these are flashover fires. Therefore, the principal emphasis is placed on evaluating toxic hazard under these conditions. In post-flashover fires, large concentrations of carbon monoxide results from reduced air supply to the fire plume and other room-scale factors. Bench-scale tests do not have the capacity to simulate these phenomena. The lethal toxic potency values determined in this test method are obtained from fuel/air ratios more representative of pre-flashover, rather than post-flashover conditions. In cases where a pre-flashover fire representation is desired in fire hazard modeling, these LC_{50} values are appropriate. Lethal toxic potency and carbon monoxide yield values

determined in this test method require adjustment for use in modeling of the hazard from post-flashover conditions. (See X1.4.1.)

5.4 The lethal toxic potency values determined in this test method have a level of uncertainty in their accuracy when used to predict real-scale toxic potencies. (See X1.4.2.)

5.4.1 The accuracy of the bench-scale data for pre-flashover fires has not been established experimentally. The combustion conditions in the apparatus are quite similar to real pre-flashover fires, although the mass burning rate may be higher at the 50 kW/m^2 irradiance of the test method.

5.4.2 Comparison of the toxicant yields and LC$_{50}$ (post-flashover) values obtained using this method have been shown in limited tests (1) to reproduce the LC$_{50}$ values from real-scale, post-flashover fires to within an accuracy of approximately a factor of three. Therefore, LC$_{50}$ (post-flashover) values differing by less than a factor of three are indistinguishable from each other. (See X1.4.2.)

5.5 This test method does not attempt to address the toxicological significance of changes in particulate and aerosol size, smoke transport, distribution, or deposition or changes in the concentration of any smoke constituent as a function of time as may occur in a real fire.

5.6 The propensity for smoke from any material to have the same effects on humans in fire situations can be inferred only to the extent that the rat is correlated with humans as a biological system. (See X1.2.5.)

5.7 This test method does not assess incapacitation. Incapacitation must be inferred from lethal toxic potency values.

5.8 The effects of sensory irritation are not addressed by this test method.

6. Apparatus

6.1 *Animal Exposure Chamber*—Shown in Figs. 1 and 2, a transparent polycarbonate or polymethylmethacrylate chamber with a nominal volume of 0.2 m^3 (200 L). (See X1.2.6.) Its inside dimensions are 1220 by 370 by 450 mm (48 by 14½ by 17¾ in.). The six animal ports, intended for head-only

exposure, are located in a horizontal row, approximately half way from the bottom to the top of the chamber, in the front wall. A plastic bag with an approximate volume of 0.05 m^3 (50 L or approximately 13 gal) is attached to the port at the end of the chamber during a test to provide for gas expansion. The exposure box is equipped with a gas sampling port at the animal nose level in the geometric center of the exposure chamber and with a port for returning gases in the end wall closest to the gas analyzers. A thermocouple shall be provided to monitor the temperature at the level of the animal ports. There are two doors in the exposure chamber, in the front wall near the connection to the combustion cell and in the end wall nearest the animal ports. The purpose of the doors is to allow for cleaning and maintenance of the chamber, chimney, and smoke shutter and to provide fresh air during calibration of the heat lamps and immediately prior to testing.

6.2 *Smoke Shutter,* made of stainless steel plate and situated inside the animal exposure chamber. It is positioned so that it will close over the chimney opening. It is hinged and provided with a positive locking mechanism. The purpose of the shutter is to seal the combustion chamber and chimney from the exposure chamber at the end of irradiation. A wire attached to the shutter and a simple push rod are provided for gentle closing of the shutter. A wire attached to a clamp locks the shutter in place. To produce a gas-tight seal, the underside of the shutter is covered with a 12-mm (0.5-in.) thick blanket of low-density ceramic fiber insulation (approximately 65 kg/m^3), which is further covered with stainless steel foil.

6.3 *Chimney* (Fig. 3)—A stainless steel assembly approximately 30 by 300 mm (1¼ by 11¾ in.), inside dimensions, and 300 mm (11¾ in.) wide. It connects the combustion cell to the animal exposure chamber. The chimney is divided into three channels by stainless steel dividers. The center channel is approximately 150 mm (6 in.) wide. The purpose of the dividers is to induce smoke to travel up through the center portion of the chimney, while air from the animal exposure chamber is drawn down through the outside channels to provide air to the combustion cell. The chimney is connected to the underside of the animal exposure chamber by clamps, permitting its removal for cleaning. It is sealed to the animal chamber by low-density ceramic fiber insulation (approximately 65 kg/m^3). The other end of the chimney is sealed to the combustion cell by an H-shaped trough with a small quantity of the same fiber insulation in the trough.

6.4 *Combustion Cell*—Shown in Figs. 4-6, a horizontal quartz tube with a 127-mm (5-in.) inside diameter and approximately 320 mm (12½ in.) long. It is sealed at one end and has a large standard taper outer joint at the other end. A sealed inner joint serves as a removable plug for the open end (Fig. 6). The combustion cell has a rectangular opening on the top parallel to the axis of the cylinder with a "collar" that allows it to fit securely into the chimney. The bottom of the cell has a hole for the rod connecting the specimen support platform and load cell. The sealed end of the combustion cell is fitted with a glass collar to accommodate the electric sparker.

6.4.1 The combustion cell is supported by a metal frame that also holds the load cell (Figs. 4 and 5). This entire frame is supported by a laboratory jack that holds the combustion cell
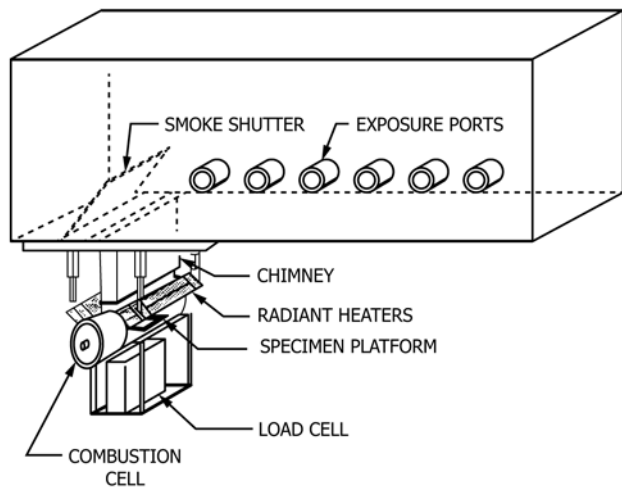

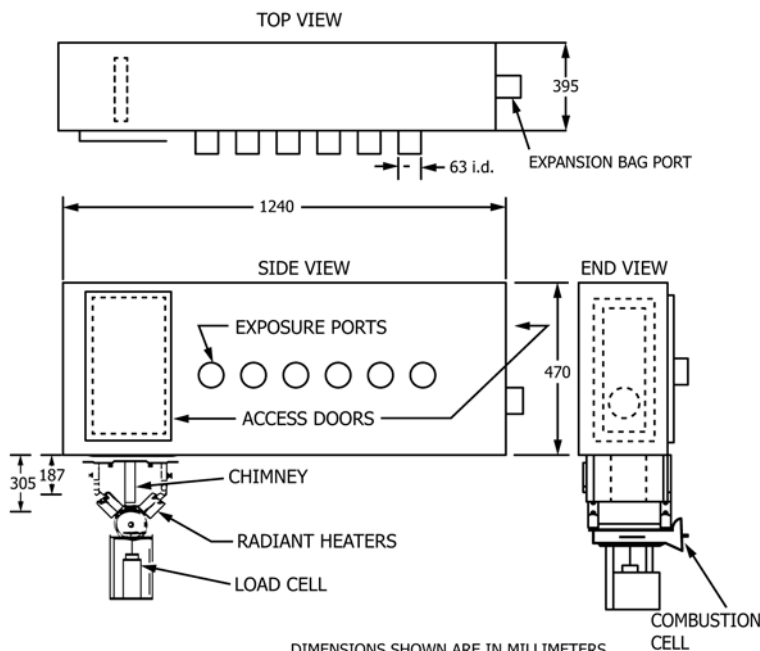
FIG. 1 Overall View of the Apparatus

FIG. 2 Schematic Drawing of the Apparatus

NOTES:
DIMENSIONS IN MILLIMETERS, INSIDE MEASURE
WHERE APPLICABLE
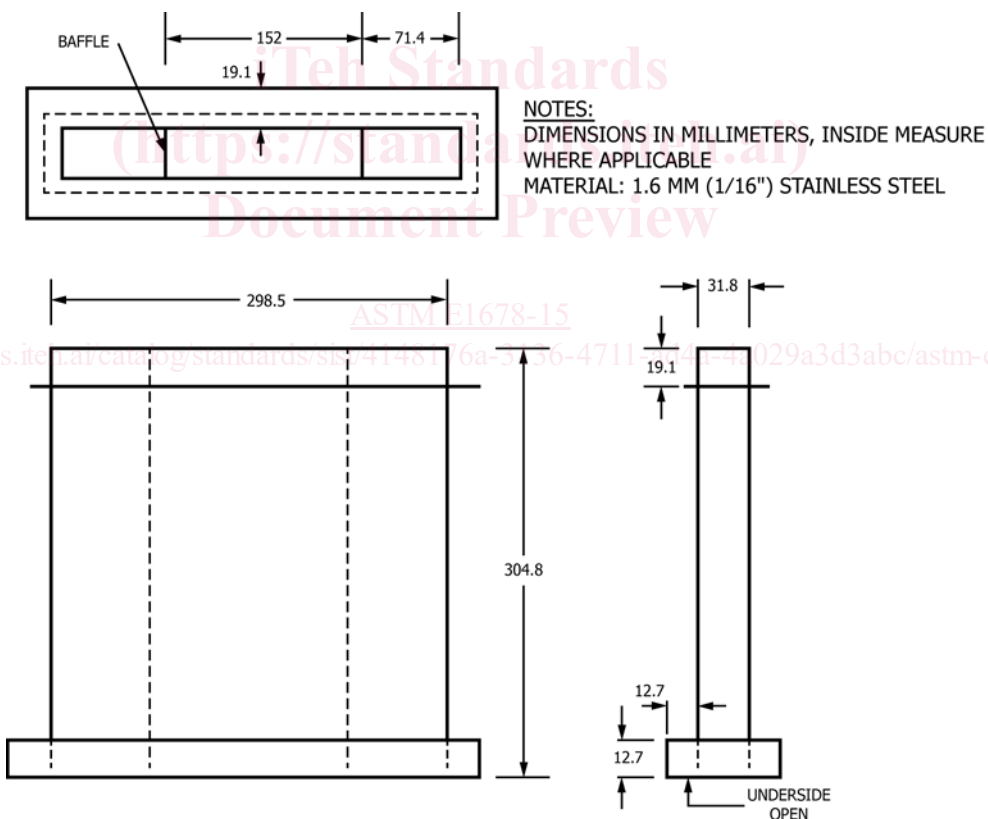MATERIAL: 1.6 MM (1/16") STAINLESS STEEL

FIG. 3 Stainless Steel Chimney

tightly to the chimney during experimentation and allows the cell to be lowered for removal and cleaning. The load cell is always at a fixed distance from the combustion cell.

6.5 *Radiant Heaters:*

6.5.1 The active element of the heater consists of four quartz infrared lamps (with tungsten filaments), rated at 2000 W at 240 V. The lamps (two on each side) are encased in water-cooled holders with parabolic reflectors. These holders (Fig. 4)
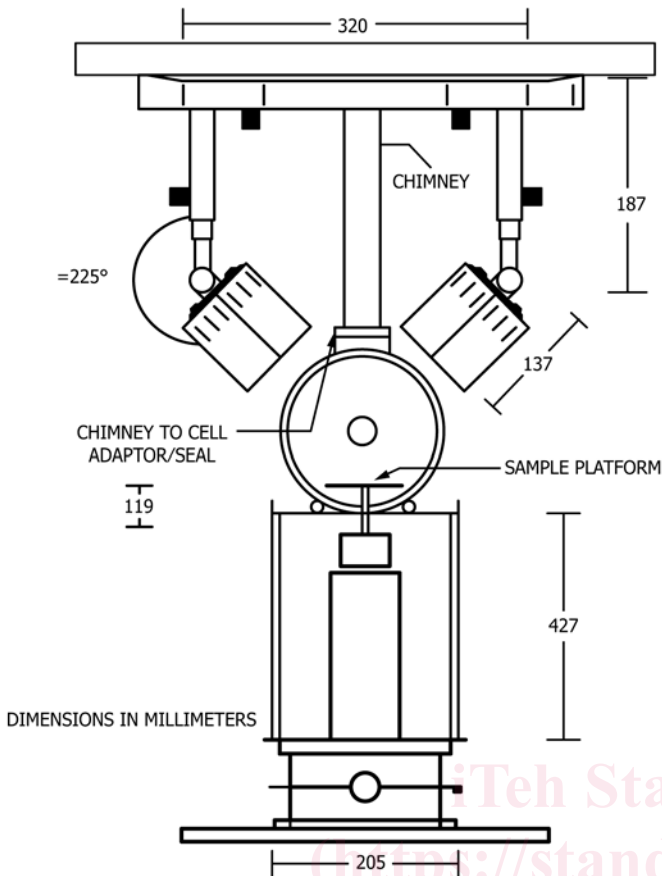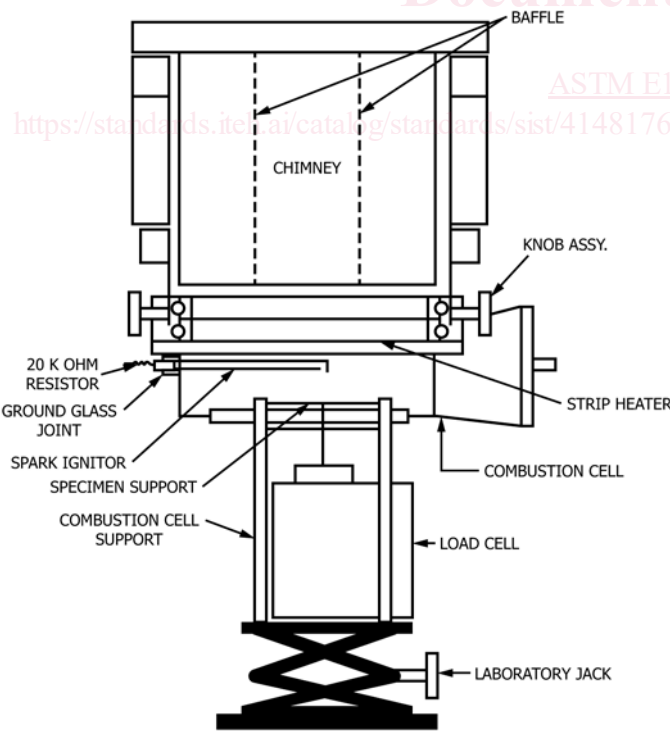
FIG. 4 Front View of the Combustion Zone
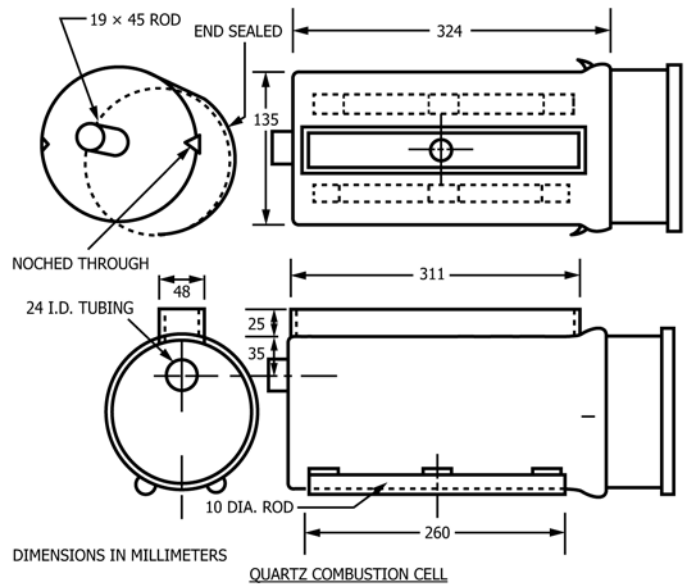

FIG. 6 Combustion Cell

FIG. 5 Side View of the Combustion Zone

to be moved vertically and laterally and rotated in such a way as to provide a uniform flux field across the sample surface. Cooling water must be circulated through the lamps' respective holders to keep them from overheating. The lamps must not be operated without the cooling water.

6.5.2 The irradiance of the lamps must be held at a preset level. One method entails a temperature controller and two thermocouples (Type K) that are placed between the lamps and the combustion cell and wired in parallel.

6.5.3 The irradiance from the lamps shall be uniform within the central area of the specimen holder to within ±10 %. Fig. 7 shows the calibration holder to be used when determining the uniformity of the radiant field from the lamps. The lampholders must be repositioned, as necessary, if the field is found not to be adequately uniform.
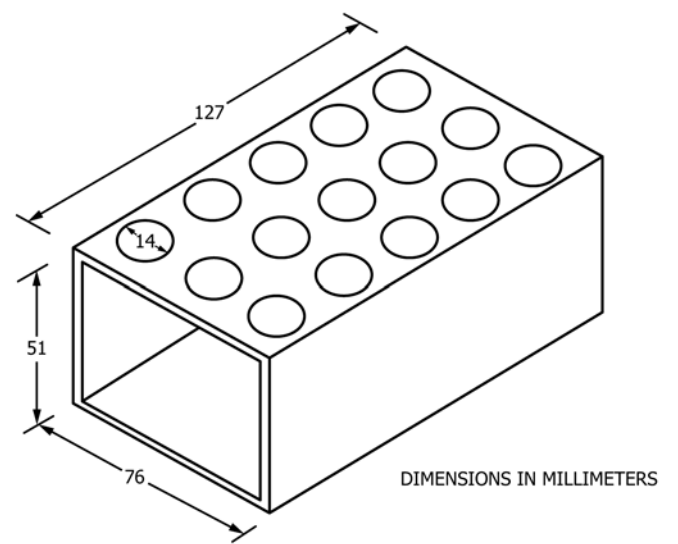
are attached to adjustable metal frames, which allow the lamps

FIG. 7 Calibration Jig

6.6 *Temperature Controller* (Optional)—When a temperature controller is used for maintaining the required radiant flux, the quartz lamp output is controlled by a thermocouple signal to the temperature controller. The outputs from the two Type K thermocouples are averaged by means of a parallel-wired connection, and this averaged value is used as the input to the controller. The temperature controller must be a three-term type and must provide an output signal suitable for driving the power controller. The temperature controller must also incorporate a means for setting the maximum output to prevent the power controller from being driven wide-open, if needed. The power controller is selected to be compatible with the radiant heat lamps used.

6.7 *Heat Flux Meter:*

6.7.1 The total heat flux meter shall be of the Schmidt-Boelter (thermopile) type or equivalent, with a design range of at least 75 kW/m^2. The target receiving radiation shall be flat, circular, approximately 12.5 mm in diameter, and coated with durable matt-black finish. The target shall be water cooled. The flux meter shall have an accuracy of within ±3 % and a repeatability within 0.5 %.

6.7.2 The calibration of the heat flux meter must be checked periodically. This is accomplished most readily by having two flux meters, one used for routine testing and another used only for calibration purposes.

6.7.3 The flux meter shall be used to calibrate the radiant heater temperature controller. It shall be positioned in a rigid support device to ensure repeatable readings. The surface of the heat flux meter must be located at a position equivalent to the center of the specimen face. Fig. 7 indicates a calibration bracket suitable for this purpose.

6.8 *Ignitor*—A spark ignitor is constructed of two 3.2-mm (0.125-in.) stainless steel rods. One of these two rods is bent at 90°, flattened on the end, and positioned to have the appearance of the tip of an automotive spark plug. The gap between the two rods shall be 2 ± 0.5 mm. The two rods are connected to the high-voltage spark system, which uses a 10-kV transformer (Fig. 8). A20 000-Ω, 5-W resistor is connected in series with one of the electrodes to reduce the propagation of radio frequency interference into the instrumentation. The spark gap is positioned approximately 25 mm (1 in.) above the center of the top surface of the specimen, inside the combustion cell. In one operation method, the rods comprising the spark igniter pass through a 29/42 male ground glass stopper, forming a gas-tight seal with a mating joint in place of the collar on the combustion cell (Fig. 6). Otherwise, the electrical leads shall be sealed in the glass collar in a gas-tight manner.

6.9 *Specimen Holder*—A stainless steel assembly approximately 76 by 127 mm (3 by 5 in.), inside dimensions, and 50 mm (2 in.) deep (Fig. 9). The specimen is backed by a layer of ceramic fiber blanket of nominal 65-kg·m^{-3} density. The specimen holder is positioned for testing on the specimen platform, inside the combustion cell.

6.10 *Load Cell*—The general arrangement of the load cell and specimen holder is illustrated in Fig. 5. The load cell is

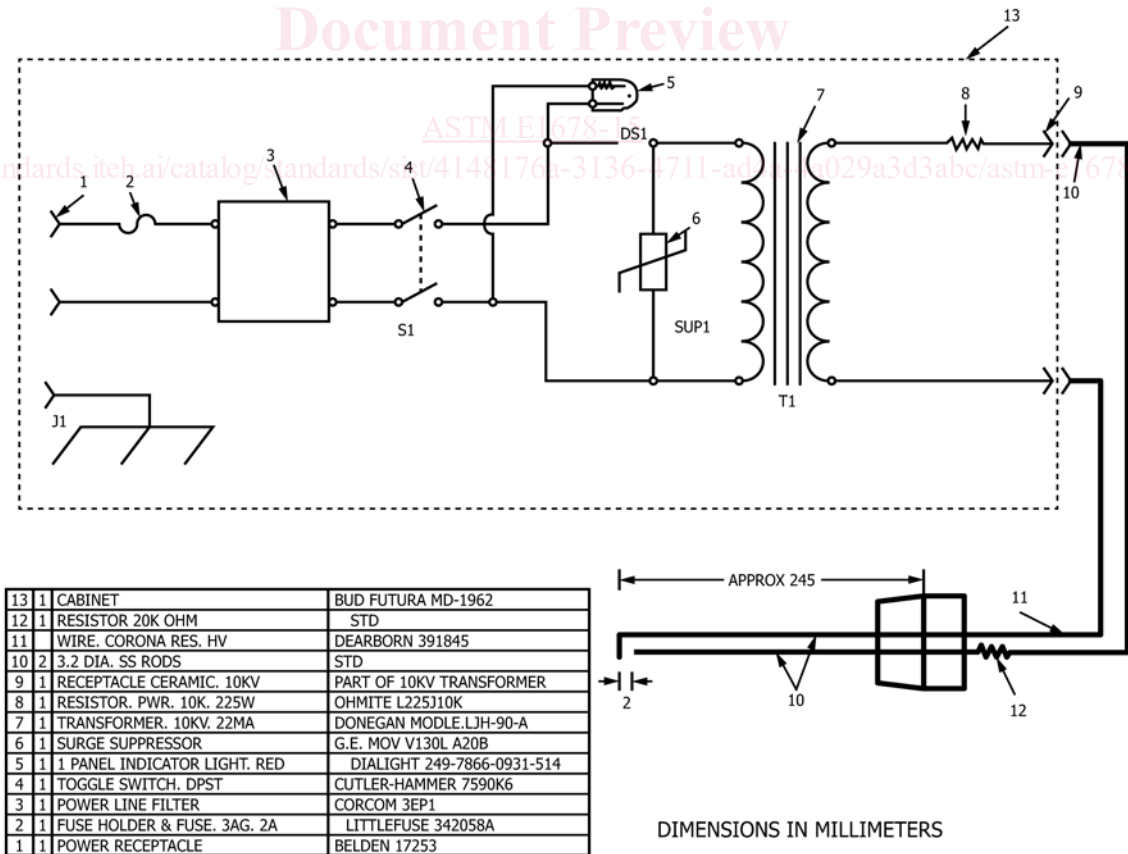| 13	1	CABINET	BUD FUTURA MD-1962
12	1	RESISTOR 20K OHM	STD
11	1	WIRE. CORONA RES. HV	DEARBORN 391845
10	2	3.2 DIA. SS RODS	STD
9	1	RECEPTACLE CERAMIC. 10KV	PART OF 10KV TRANSFORMER
8	1	RESISTOR. PWR. 10K. 225W	OHMITE L225J10K
7	1	TRANSFORMER. 10KV. 22MA	DONEGAN MODLE.LJH-90-A
6	1	SURGE SUPPRESSOR	G.E. MOV V130L A20B
5	1	1 PANEL INDICATOR LIGHT. RED	DIALIGHT 249-7866-0931-514
4	1	TOGGLE SWITCH. DPST	CUTLER-HAMMER 7590K6
3	1	POWER LINE FILTER	CORCOM 3EP1
2	1	FUSE HOLDER & FUSE. 3AG. 2A	LITTLEFUSE 342058A
1	1	POWER RECEPTACLE	BELDEN 17253

DIMENSIONS IN MILLIMETERS

FIG. 8 Spark Igniter System