American National Standard for Cleanroom Materials Flammability Test Protocol ANSI/FM Approvals 4910

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Foreword

NOTE: This foreword is introductory only and is not part of American National Standard FM 4910.

This standard is intended to verify that the product as described will meet minimum specific stated conditions of performance, safety and quality, useful in determining the potential suitability for end-use conditions of these products. It describes minimum performance requirements for materials that are intended for use in cleanroom facilities by evaluating the ability of the materials and, in turn, the system components, to limit fire spread and smoke damage resulting from a fire in the cleanroom environment.

This American National Standard has been developed according to the essential requirements of due process for standards development of the American National Standards Institute (ANSI). FM Approvals is an ANSI accredited standards developer (ASD).

ANSI/FM 4910 was originally published in 2004 and revised in 2013. This draft contains editorial corrections in 2.2.1 and 2.4.1 to make references to SDI consistent.

Approval of an American National Standard requires verification by ANSI that the principles of openness and due process have been followed and that a consensus of those directly and materially affected by the standard has been achieved. Consensus requires that all views and objections be considered, and that a concerted effort be made toward their resolution. Consensus is established when, in the judgment of the ANSI Board of Standards Review, substantial agreement has been reached.

The American National Standards Institute does not develop standards nor will it in any circumstances give an interpretation of any American National Standard. Requests for interpretations of this test standard should be addressed to FM Approvals.

ANSI regulations require that this American National Standard shall be revised, reaffirmed or withdrawn within five years of the date of publication.

FM Approvals
1151 Boston-Providence Turnpike
P. O. Box 9102
Norwood, MA 02062
U. S. A.

Phone: 781-762-4300
Fax: 781-762-9375
E-mail: information@fmapprovals.com

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1. INTRODUCTION

1.1 PURPOSE

This test standard states test requirements and procedures for the evaluation of materials used in cleanroom occupancies mainly for, but not restricted to, use in the semiconductor industry. The test evaluates the materials' fire propagation behavior, expressed as Fire Propagation Index (FPI), and potential for smoke contamination, expressed as Smoke Damage Index (SDI).

1.2 SCOPE

1.2.1 This test standard describes minimum performance requirements for materials which are intended for use in cleanroom facilities. This standard evaluates the ability of the materials to limit fire spread and smoke damage. All requirements in the standard must be met for materials to be acceptable.

1.2.2 This standard is intended to verify that the materials, as described, will meet minimum specific stated conditions of performance, safety and quality useful in determining the potential suitability for end-use conditions of these materials.

1.3 BASIS FOR REQUIREMENTS

1.3.1 The requirements of this test standard are based on experience, research and testing, and/or the standards of other organizations. The advice of manufacturers, users, trade associations, jurisdictions and/or loss control specialists was also considered.

1.4 APPLICABLE DOCUMENTS

The following standards, test method descriptions and practices are related to this standard:

1. Tewarson, A., ‘‘Generation of Heat and Chemical Compounds in Fires’’, Chapter 4, Section 3, pp. 3-82 to 3-161. The SFPE Handbook of Fire Protection Engineering, 3rd Edition. The National Fire Protection Association Press, Quincy, MA, June 2002.

2. Tewarson, A., ‘‘Flammability’’, Chapter 42, pp. 577-604. Physical Properties of Polymers Handbook (J.E. Mark, Editor). American Institute of Physics, Woodbury, NY, 1996.

3. ASTM E2058 ‘‘Standard Test Methods for Measurement of Synthetic Polymer Material Flammability Using a Fire Propagation Apparatus (FPA),’’American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

4. NFPA 287 ‘‘Standard Test Methods for Measurement of Flammability of Materials in Cleanrooms Using a Fire Propagation Apparatus (FPA)”, National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02269.

1.5 DEFINITIONS

For purposes of this test standard, the following terms apply:

Chemical Heat Release Rate (Q_{ch}): energy actually released by chemical reactions during a test

Critical Heat Flux (CHF): the maximum heat flux at, or below, which there is no ignition.

Fire Propagation Index (FPI): an index representing the propensity of a material to support fire propagation.
Flame Height: elevation of the tip of the contiguous flame region averaged over a 5-second interval

Ignition Zone: the area of the surface of a material heated by an outside source, resulting in ignition.

Smoke Damage Index (SDI): smoke yield multiplied by FPI. It is an indicator of the smoke contamination of the environment during fire propagation.

Smoke yield (y_s) ratio of the total mass of smoke released to the total mass of the material vaporized.

Thermally Thick Behavior: when a material is heated on one side and exhibits a negligible temperature rise above ambient on the unexposed face of the material.

Thermally Thin Behavior: when a material is heated on one side and there is a uniform temperature rise across the thickness of a material.

Thermal Response Parameter (TRP)): indicator of the ignition resistance of a material.

2. GENERAL INFORMATION

2.1 CLEANROOMS

Due to the sensitivity of cleanroom environments, the high cost of construction and the high value of equipment and products produced and stored in them, significant damage can be caused by the presence of small amounts of contamination. As a result, it is useful to evaluate the ability of a material to limit fire propagation and restrict emission of particulates in the form of smoke. The criteria for the selection of materials for use in cleanrooms are based on tests conducted using the Fire Propagation Apparatus (FPA) described in ASTM E2058 (for determining FPI and SDI) or the 8 ft (2.4 m) Parallel Panel Test (when the FPI and SDI results are uncertain or where the thickness is less than 0.25 in (6 mm)). The criteria used to assess cleanroom materials deal with limiting fire propagation beyond the ignition zone and limiting contamination of the cleanroom environment due to smoke.

2.2 FPI AND SDI

Materials examined using the Fire Propagation Apparatus are evaluated based on the following two criteria:

2.2.1 The Fire Propagation Index (FPI) is used as a criterion for fire propagation beyond the ignition zone. The criterion is based on the maximum value of FPI for a 15 second running average of the data during the entire test duration. A value of FPI ≤ 6 $(m/s^{1/2})/(kW/m)^{2/3}$ has been assigned for materials intended for use in cleanrooms.

2.2.2 The Smoke Damage Index (SDI) is used as a criterion for significantly limiting smoke concentration for non propagating fires beyond the ignition zone. A value of SDI ≤ 0.40 $[(m/s^{1/2})/(kW/m)^{2/3}][g/g]$ has been assigned for materials intended for use in cleanrooms.

2.3 REQUIRED TESTS

2.3.1 The FPI and SDI indices shall be quantified in the Fire Propagation Apparatus. In order to do so, three types of tests shall be performed: 1) ignition; 2) fire propagation; and 3) combustion.

2.3.2The purpose of the ignition test is to determine the Thermal Response Parameter (TRP). The fire propagation test is conducted to quantify the chemical heat release rate during fire propagation. The chemical heat release rate and the TRP value are utilized to calculate the FPI value. The combustion test is conducted in order to quantify the yield of smoke. The yield of smoke shall be multiplied by the FPI value to calculate the SDI value.

2.3.3 The reported test data shall be rounded such that the FPI is rounded to the nearest integer whole number (1, 2, etc.). The SDI shall be rounded to the nearest tenth (0.1, 0.2, etc.).

2.4 UNCERTAINTY RANGES OF FPI AND SDI

2.4.1 Experience has shown that an uncertainty range of FPI and SDI exists. These ranges encompass FPI values between 6 and 7 $(m/s^{1/2})/(kW/m)^{2/3}$ and SDI values between 0.4 and 0.5 $[(m/s^{1/2})/(kW/m)^{2/3}][g/g]$. When the FPI and/or SDI value falls within these ranges, the material can exhibit fire propagation and smoke damage characteristics undesirable of materials utilized in cleanroom environments. In these cases, the 8 ft (2.4 m) Parallel Panel Test shall be conducted in order to determine the material's suitability.

2.4.2 The Parallel Panel Test shall be permitted to be used as an alternate to the Fire Propagation Apparatus regardless of a material's FPI or SDI. In cases where the FPI and SDI have been determined and a Parallel Panel Test has been conducted, the results of the Parallel Panel Test shall govern.

2.5 MATERIALS THINNER THAN 0.25 IN. (6 MM)

Materials whose thickness is less than 0.25 in. (6 mm) cannot be tested in accordance with ASTM E2058 on the FPA. These thin materials must be tested utilizing the Parallel Panel Test.

3. FIRE PROPAGATION APPARATUS TESTS

3.1 TEST SAMPLES

3.1.1 Ignition and combustion tests samples of planar materials shall be 4 by 4 in. (± 0.125 in.) [100 by 100 mm (± 3 mm)] square with a minimum thickness of 0.25 in. (6 mm) and a maximum thickness of 1 in. (25 mm).[1] 3. 1.2 Fire propagation tests samples of planar materials shall be 12 in. ± 0.125 in. long by 4 in. ± 0.125 in. wide [305 mm (±3 mm) long by 102 mm wide (± 3 mm)] with a minimum thickness of 0.25 in. (6 mm) and a maximum thickness of 1 in. (25 mm).

3.2 SAMPLE PREPARATION AND PLACEMENT IN THE APPARATUS

3.2.1 Ignition and combustion tests **-** the samples shall be wrapped in heavy duty aluminum foil, 0.002 in. (0.05 mm) thick, to tightly cover the edges and back of the sample. For the ignition test, the sample surface shall be coated with a thin layer of fine graphite powder or Thermo-lux Solar Collective black paint to compensate for surface absorptivity differences. The wrapped sample shall be placed horizontally, exposed surface up, in the Fire Propagation Apparatus at the locations shown in Figure 3 and Figure 5. For the ignition test, the quartz tube shall not be used. For the combustion test, the sample shall be located inside the quartz tube.

[1] A maximum thickness of 1 in. (25mm) is the limit that can readily be tested on the FPA apparatus.

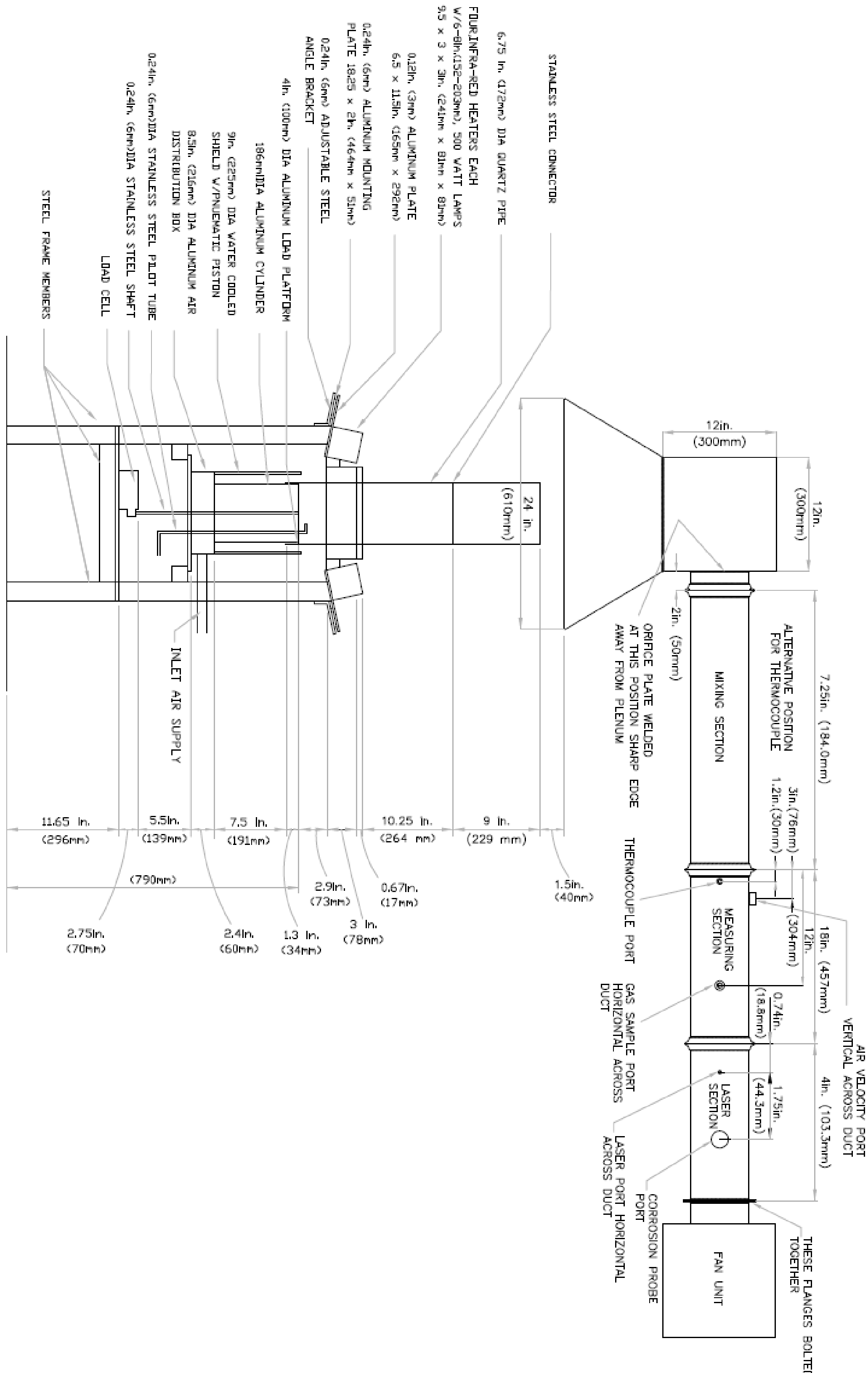

Figure 1 Fire Propagation Apparatus and Ventilation Arrangement

3.2.2 Fire propagation test – the sides and back surface of the sample shall be covered with 0.125 in. (3.2 mm) thick ceramic paper and the sides and back of the sample shall be wrapped tightly with heavy duty aluminum sheet. The sample shall be attached to a 12 in. ± 0.25 in. [300 mm ± 6 mm] long by 4 in. ± 0.25 in. [100 mm ± 6 mm] wide vertical steel ladder by three #24 gage nichrome wires and placed inside the quartz tube in the Fire Propagation Apparatus.

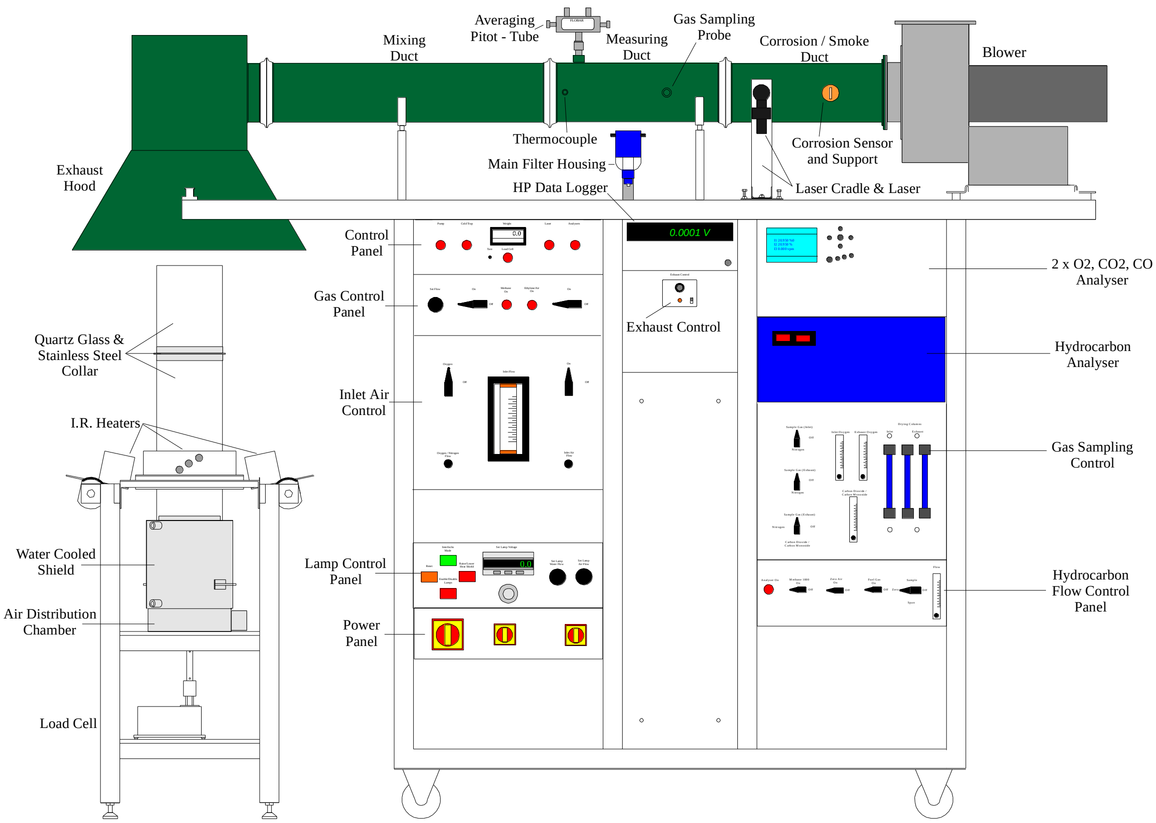

Figure 2 Fire Propagation Apparatus and Control Panel

3.3 IGNITION TEST

3.3.1 The ignition test shall be performed in accordance with ASTM E2058 under natural airflow. The pilot ignition tube burner consists of a vertical 0.25 in. ± 0.0625 in. [6 mm ± 1.6 mm]) diameter copper tube with perforated ceramic tip bent at a right angle to be horizontal near the sample surface. The position of the burner shall be adjusted such that the tip of the burner shall be 0.4 in. ± 0.06 in. [10 mm ± 1.6 mm] above the sample surface and 0.4 in. ± 0.06 in. [10 mm ±1.6 mm] from the perimeter of the sample, toward the centerline. A premixed ethylene-air mixture flowing through the burner shall be used as the combustible gas mixture for the pilot flame. The gas mixture that flows through the burner shall be adjusted such that the flame shall be blue and average 0.4 in. (10 mm) in length. Figure 3 shows the ignition test configuration.

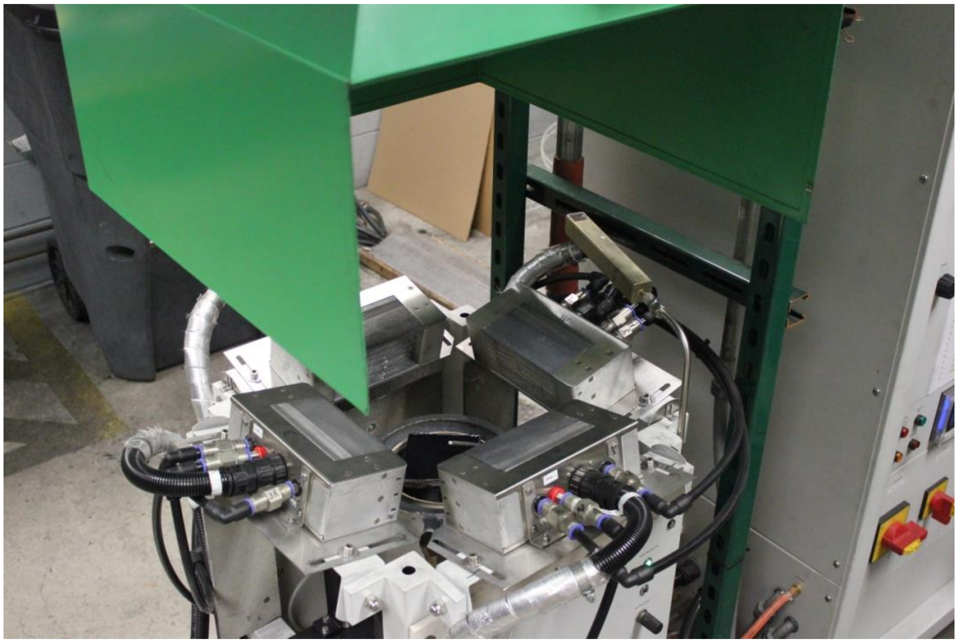

Figure 3 Ignition Test Configuration

3.3.2 In the ignition tests, sample surfaces shall be exposed to various external heat flux values. The heat flux value shall be fixed in each test with a tolerance of ±5%. Both time to vapor formation and time to sustained ignition shall be measured visually . A minimum of four tests at different heat fluxes shall be performed until no ignition is observed within 15 minutes. The data shall be used to calculate the *Critical Heat Flux (CHF)* and *Thermal Response Parameter (TRP)* using the *Ignition Test Data Calculation Procedure* described in Section 5.1.

3.4 FIRE PROPAGATION TEST

3.4.1 The fire propagation test shall be performed in the Fire Propagation Apparatus shown in Figure 2 in accordance with ASTM E2058 with a co-flowing oxygen-air mixture having 40 ± 1% oxygen concentration[2]. The mixture enters the apparatus at the bottom and flows through a series of inlet tubes and screens such that the mixture velocity across the quartz tube, near the sample, shall be uniform within 5%. The mixture flow used in the test shall be set at 7 ± 0.35 cfm (0.00333 ± 0.0002 m^3/s).

3.4.2 In the Fire Propagation test, the bottom 4 ± 0.125 in. (100 ± 3 mm) of the 12 in. (300 mm) long and 4 in. (100 mm) wide vertical sample depicted in Figure 4, shall be exposed to 50 kW/m^2 of external heat fluxin the presence of a pilot flame. Above this bottom 4 in. (100 mm) area, defined as the ignition zone, the fire may propagate by itself, supported mainly by the heat flux from its own flame. The ignition zone shall be preheated by the external flux for one minute. If ignition and fire propagation has not occurred during this preheating period, the premixed ethylene-air pilot flame shall be moved into contact with the sample surface at a position 3 ± 0.25 in. (75 ± 6 mm) from the bottom of the sample. Once ignition and fire propagation have been initiated, the pilot flame shall then be moved away from the sample.

[2] 40% oxygen is used to simulate flame radiation typical of large-scale fires [1, 2]

Figure 4 Propagation Test Sample Holder

3.4.3 The fire propagation test shall be continued until there are no visible flames and no material vapors are issuing from the front, sides, or back of the sample. The test shall be aborted if the sample starts to melt sufficiently to form a liquid pool and/or burns very intensely such that flames enter the sampling duct.
When this situation occurs, the FPI shall be assigned a value > 6.

3.4.4 In the test, measurements shall be made for flame height and the generation rates of CO and CO_2. Data on CO_2 and CO generation rates shall be used to calculate the Fire Propagation Index (FPI) following the *Fire Propagation Test Data Calculation Procedure* described in Section 5.3.

3.5 COMBUSTION TEST

3.5.1The combustion test shall be performed in accordance with ASTM E2058 in co-flowing normal air in the Fire Propagation Apparatus (Figure 1). Air enters the apparatus at the bottom and flows through a series of inlet tubes and screens such that the air velocity across the quartz tube, near the sample, shall be uniform. The air flow used in the test shall be set at 7 ± 0.35 cfm (0.00333 ± 0.0002 m^3/s). Figure 5 shows the Combustion Test configuration.

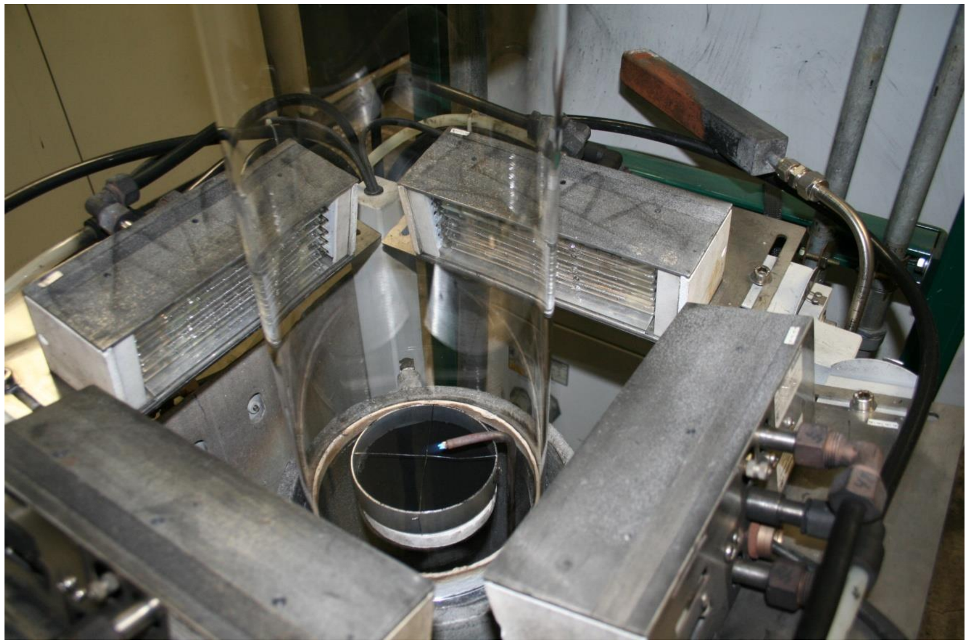

Figure 5 Combustion Test Configuration

3.5.2 In the combustion test, the sample surface shall be exposed to 50 kW/m^2 of external heat flux. Measurements shall be made for: 1) times to vaporization and sustained ignition, 2) flame height, 3) release rates of material vapors (sample mass loss rate), convective energy, CO, CO_2, total hydrocarbons, and smoke. The data shall be used to calculate chemical and convective heat release rates, the heat of combustion and yield of smoke by using the *Combustion Test Data Calculation Procedure* described in Section 5.4.

4. PARALLEL PANEL FIRE TEST

4.1 PURPOSE

The 8 ft (2.4 m) Parallel Panel Test shall be performed when the FPI and/or SDI values obtained from the Fire Propagation Apparatus fall into the uncertain range or if the material is less than 0. 25 in (6 mm) thick [see Sections 2.4 and 2.5].

4.2 PARALLEL PANEL TEST ARRANGEMENT

4.2.1 The Parallel Panel test shall be performed under the Fire Products Collector, which is a minimum 5 MW heat release rate calorimeter running with the optimal air flow for the size of the calorimeter. For details, see the Parallel Panel Test arrangement shown in Figure 6 and the Fire Products Collector in Figure 7.

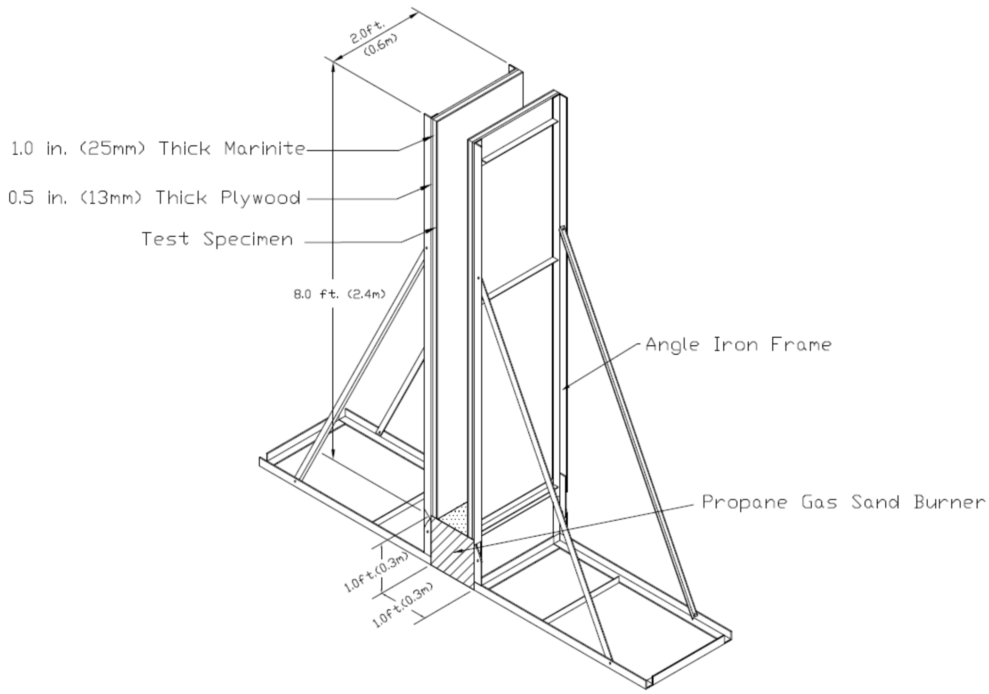

Figure 6 Parallel Panel Test Arrangement

4.2.2 Two vertical parallel panels shall be constructed. Each panel shall be 8 ft ± 0.5 in. (2.4 m ± 13 mm) long by 2 ft ± 0.5 in. (0.61 m ± 13 mm) wide. The sample thickness shall be a maximum of 1 in. (25 mm). This minimum sample thickness shall be achieved without the use of multiple material layers held together by fasteners or adhesives that are not a normal component of the sample material. The outer layer of each panel shall be a layer of minimum 0.5 in. (13 mm) thick rigid plywood. The inner layer of each panel shall be a layer of minimum 1 in. (25 mm) thick calcium silicate insulation board[3].

[3] One inch thick calcium silicate board shall be used to prevent heat damage to the plywood layer, regardless of the sample thickness.

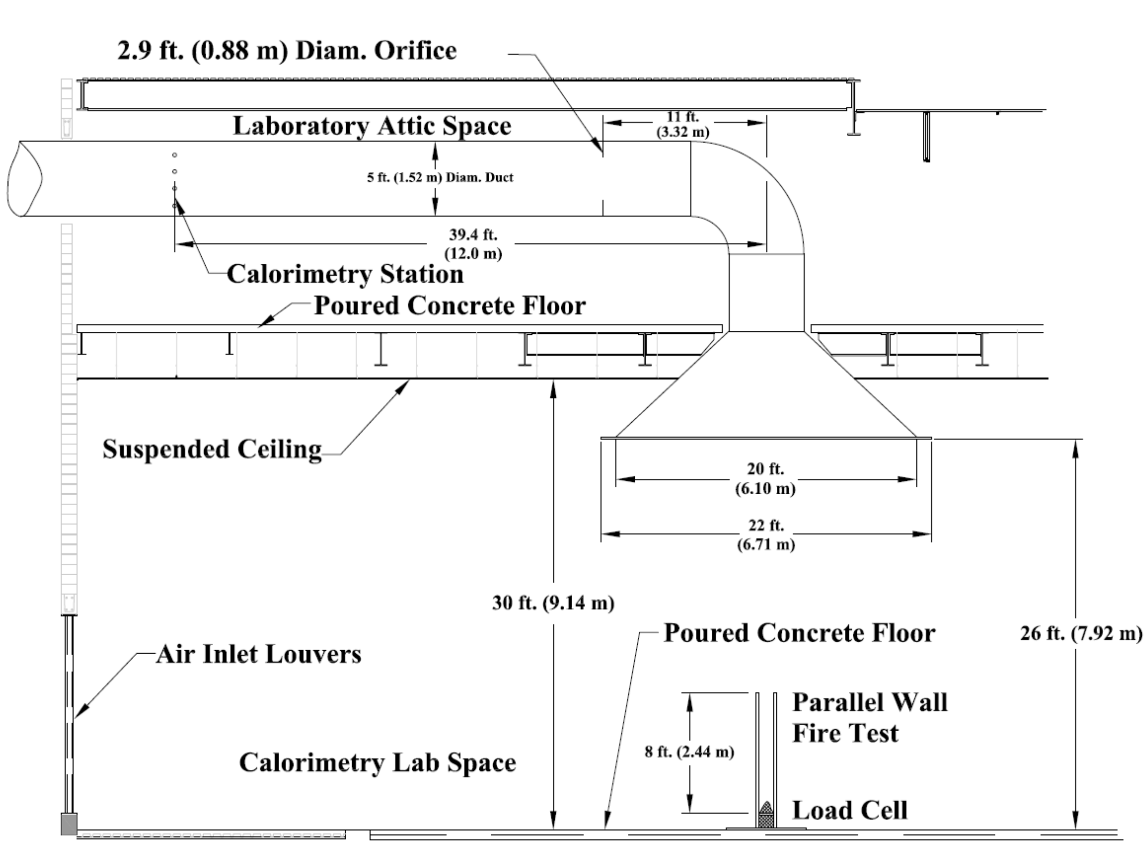

Figure 7 Fire Products Collector Used for Large Scale Tests in the Parallel Panel Fire Test

4.2.3 Each sample sheet shall be in thermal contact with the insulation board side of the panel through the use of eight fasteners and a nominal 1 in. (25 mm) angle iron clamped along the two 8 ft ± 0.5 in. (2.4 m ± 13 mm) long edges of the sample[4]. The ignition source, a nominal 2 ft ± 0.5 in. (0.61 m ± 13 mm) long by 1 ft ± 0.25 in. (0.31 m ± 6 mm) wide by 1 ft ± 0.25 in. (0.31 m ± 6 mm) high propane sand burner, shall be located between the assembled panels to provide a 1 ft ± 0.25 in. (305 mm ± 6 mm) separation between sample sheets. The panel assembly shall be positioned such that the top surface of the burner is in contact with the bottom edge of the vertical sample material. To further insure that the sample separation distance is 1 ft ± 0.25 in. (305 mm ± 6 mm) throughout the test, two threaded rods shall be installed to connect the panels together at the top of each long edge of the assembly.

4.2.4 A heat flux gauge, Gardon Type Model *GTW-10SB-8-36-40-484, 0-200 kW/m²* shall be installed on the vertical centerline [± 0.25 in. (± 6 mm)] of one panel at a height of 4 ft ± 0.25 in. (1220 ± 6 mm). Propane gas flow to the burner shall be adjusted to provide a heat release rate of 60 ± 2 kW and a heat flux of at least 40 ± 2 kW/m² measured by the gauge at the 1 ft ± 0.25 in. (305 mm ± 6 mm) height when no sample material is present. The panel/burner assembly shall be placed on top of a load cell transducer.

4.3 CONDUCT OF TEST

4.3.1 The test duration shall be 12 minutes (+ 0.1 min, -0) consisting of propane sand burner operation at the prescribed 60 ± 2 kW heat release rate for the first 10 minutes (+ 0.1 min, -0), followed by 2 minutes (+ 0.1 min, -0) without burner operation. If flaming of the sample, including fingers of flame above the average height,

[4] Angle iron clamping along the top is not necessary since if heat sufficient to cause warpage there, the material will have failed. Clamping along the bottoms would interfere with the flame exposure to the test panels.

is observed above the top of the panels while the burner is operating, propane flow to the burner shall cease. A hose stream shall be applied to the panels and the test terminated thirty seconds after stopping propane flow to the burner if flame height continues to increase above the top of the panels. The test shall also be terminated and a hose stream applied if the panels do not stay intact for any reason (i.e., the melting material obstructs the top of the sand burner)[5].

4.3.2 During the test, measurements shall be made for the release rates of material vapors (mass loss rate, *m*), heat flux to the panel at the three gauge locations, flame height and heat and smoke release rates using the Fire Products Collector instrument section shown in Figure 7. Following the test, data on fire burn patterns shall also be recorded.

5. PROCEDURES TO CALCULATE FLAMMABILITY DATA

5.1 IGNITION TEST DATA CALCULATION PROCEDURE

During the ignition tests, time-to-ignition shall be measured at various external heat flux values. The time-to-ignition follows the thermally thick material relationship:

5.1.1 Thermally Thick Material Relationship at External Heat Flux Values Much Greater than the Critical Flux for Ignition:

At an applied heat flux much greater than the critical flux for ignition, materials which exhibit thermally thick behavior demonstrate the following:

$$\sqrt{\frac{1}{t_{ig}}} \propto \sqrt{\frac{4}{\pi}\frac{\dot{q}_e^{"}}{TRP_{thick}}}$$

Equation 1

where t_{ig} is time-to-ignition(s), q_e is the externally imposed heat flux (kW/m^2), q_{loss} is the heat loss from unit exposed sample area, and *TRP* is the *Thermal Response Parameter (kW-s/½m2).*

5.1.2 Data for the inverse of square root of time-to-ignition versus external heat flux shall be examined. Figure 8 shows that the data are linear at higher external heat flux values, between 15 and 60 kW/m^2. A linear regression analysis of these data shall be performed and TRP value shall be the inverse of the slope of the resulting linear fit, using Equation 1.

5.1.3 The maximum heat flux at, or below, which there is no ignition, defined as *Critical Heat Flux (CHF)* shall be determined from the intercept on the x-axis of the line obtained from the measured inverse of times to- ignition versus external heat flux values[6]. The inverse of ignition time equals zero when the externally applied heat flux equals the heat flux loss. Higher CHF and TRP values represent higher resistance to ignition and fire propagation.

[5] Trained firefighting personnel should use a heavy mist rather than a jet of water from the hose to terminate the test.
[6] This is not to be confused with the inverse of the square root of the time to ignition vs. external heat flux plot used to determine TRP.

5.2 CHEMICAL HEAT RELEASE RATE CALCULATION

5.2.1 Fire propagation and combustion tests in the Fire Propagation Apparatus and Parallel Panel Tests under the Fire Products Collector require that chemical heat release and smoke generation rates be measured in a measurement duct where the flow is well-mixed.

5.2.1.1 The chemical heat release rate shall be determined from the following equation:

$$\dot{Q}_{ch} = 13,300\left(\dot{G}_{CO2} - \dot{G}^{0}_{CO2}\right) + 11,100\left(\dot{G}_{CO} - \dot{G}^{0}_{CO}\right)$$

Equation 2

where $\dot{G}_{CO2}$ is the mass flow rate (kg/s) of CO_2 and $\dot{G}_{CO}$ is the mass flow rate (kg/s) of CO in the measurement duct of the Fire Propagation Apparatus or the Fire Products Collector and is the corresponding mass flow rate (kg/s) before specimen ignition. The coefficients 13,300 kJ/kg and 11,100 kJ/kg in Equation 2 shall be replaced by coefficients recommended in Equation 1 if the composition of the specimen is known.

5.2.1.2 The mass flow rates of CO_2 and CO shall be determined from the following equations:

$$\dot{G}_{CO2} = A_d K\sqrt{P_{atm}/101{,}000}\sqrt{2 \times 353\Delta p_m/T_d} \times 1.52X_{CO2}$$

Equation 3

$$\dot{G}_{CO} = A_d K\sqrt{P_{atm}/101{,}000}\sqrt{2 \times 353\Delta p_m/T_d} \times 0.966X_{CO}$$

Equation 4

where A_d (m^2) is the cross sectional area of the sampling duct and T_d the gas temperature for flow in the appropriate measurement duct, K (-) is the flow coefficient and Δp_m (Pa) the differential pressure output corresponding to the device sensing gas velocity in the measurement duct, P_{atm} (Pa) is actual atmospheric pressure during the measurement, X is the mole fraction of CO_2 or CO measured in the duct and 353 (kg K/m^3) is the product of air density and temperature at normal atmospheric pressure.

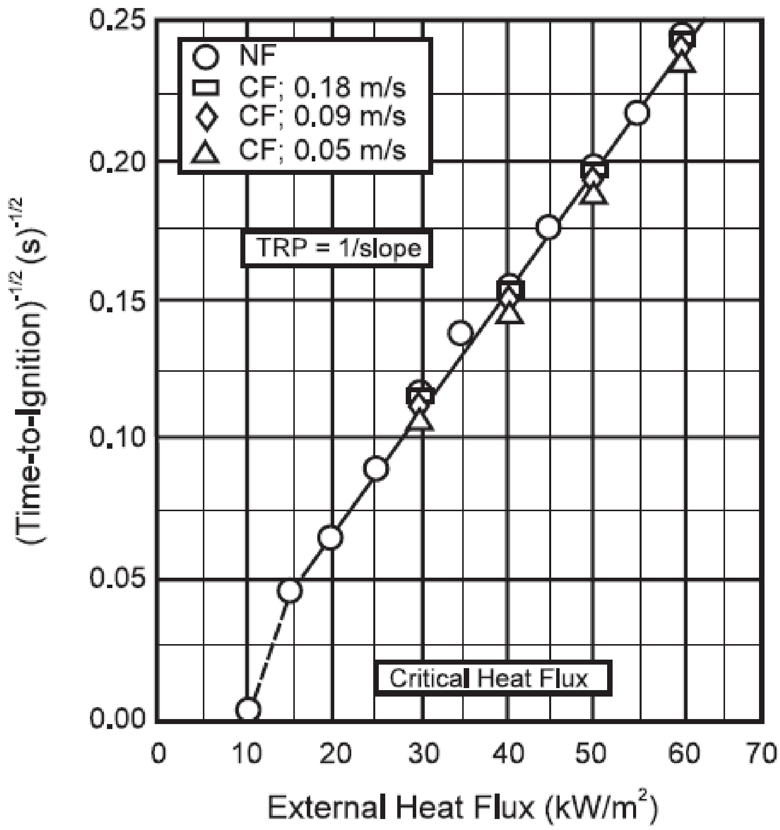

Figure 8 Example of Time to Ignition Heat Flux Data from the Flammability Apparatus

[*NF = Natural Air Flow; CF = Cp Air Flow;*

Numbers are Air Flow Velocities]

5.2.2 Smoke generation rate, S_s, shall be determined from the following equation :

$$\dot{G}_s = 0.157\lambda D\dot{v}$$

Equation 5

where λ is the wavelength of light (which shall be in the range 0.6328 to 0.6348) used to measure the extinction coefficient, *D* (m^{-1}) in the measurement duct and *v* (m^3/s) is the total volumetric flow rate in the measurement duct.

5.2.3 The volumetric flow rate shall be determined from the following equation:

$$\dot{v} = A_d K \frac{\sqrt{2\Delta p_m T_d / 353}}{\sqrt{P_{atm}/101{,}000}}$$

Equation 6

where all parameters have been defined above.

5.2.4 The extinction coefficient in the measurement duct shall be determined from the following equation:

$$D = \frac{ln\left(^{I_a}/_{I}\right)}{L}$$

Equation 7

where I_a/I is the ratio of the average measured light intensity before the test to that during the test and L is the path length in the duct for the measurement of this light intensity.

5.3 FIRE PROPAGATION TEST DATA CALCULATION PROCEDURE

5.3.1 The chemical heat release rate during a fire propagation test shall be calculated from the equations in Section 5.2 and the calculated heat release rate shall be used in the following equation to calculate the Fire Propagation Index (FPI) from the peak chemical heat release rate during the time duration of the test:

$$FPI = \frac{750\left(\dot{Q}_{ch}/w\right)^{1/3}}{TRP}$$

Equation 8

where FPI is the *Fire Propagation Index,* Q_{ch} is the chemical heat release rate per unit width or circumference in the case of cables (kW/m) and *TRP* is the Thermal Response Parameter for the material *(kW-s* $^{1/2}$ *m*^{2}*)* (see Equation 1).

5.4 COMBUSTION TEST DATA CALCULATION PROCEDURE

5.4.1 The chemical heat release rate and smoke generation rate during the combustion test shall be calculated from the expressions in Section 5.2. Release rates of chemical heat and material vapors (mass loss rate, *m*) and the generation rate of smoke shall be integrated to calculate the total amount of chemical energy, material vapors and smoke that are released. These integrated quantities shall be used to calculate:

5.4.1.1 Average chemical heat of combustion: calculated from the ratio of the total chemical energy to the total amount of material vapors released, as follows:

$$\frac{\int \dot{Q}_{ch}dt}{\int \dot{m}dt}$$

Equation 9

5.4.1.2 Average smoke yield: calculated from the ratio of the total amount of smoke released to the total amount of material vapors released, as follows:

$$y_s = \frac{\int \dot{G}_s dt}{\int \dot{m}dt}$$

Equation 10

5.5 SMOKE DAMAGE INDEX (SDI) CALCULATION

5.5.1 Smoke Damage Index *(SDI)* shall be calculated as:

$$SDI = y_s \times FPI$$

Equation 11

6. CONDITIONS OF ACCEPTANCE

6.1 FIRE PROPAGATION APPARATUS TESTS

When the Fire Propagation Apparatus is used to evaluate a material's suitability for use in cleanroom applications, materials shall meet both of the following conditions of acceptance:

$$FPI \leq 6 \qquad SDI \leq 0.4$$

6.2 PARALLEL PANEL FIRE TESTS

When the Parallel Panel Fire Test is used to evaluate a material's suitability for use in cleanroom applications, materials shall meet all five of the following conditions of acceptance:

1) The test shall not be terminated for any reason before the end of the normal 12 minute test duration.

2) Two minutes after the burner is turned off, the measured heat release rate shall drop to 25% of the maximum rate that is determined within 10 seconds before the burner is turned off.

3) Maximum observed average flame height shall be less than, or equal to, 6 ft (1.83 m).

4) Maximum measured heat flux at 4 ft (1.22 m) above the sand burner shall be less than, or equal to, 40kW/m^2.

5) The maximum measured smoke generation rate shall be less than, or equal to, 0.23 g/s during the 10 minute burn period. The measured smoke generation rate at the end of the 12 minute test duration shall be less than, or equal to, 0.07 g/s. The smoke generation rated integrated over the total 12 minute test time shall be less than 60 g.