Designation: F 2133 – 01

An American National Standard

Standard Test Methods for Determining Effects of Large Hydrocarbon Pool Fires on Insulated Marine Bulkheads and Decks, Constructed of Steel[1]

This standard is issued under the fixed designation F 2133; 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.

1. Scope

1.1 These test methods described in this fire-test response standard are used for determining the fire-test response of insulated marine steel bulkheads and decks. The insulation is either homogeneous or composite construction.

1.2 It is the intent that tests conducted in accordance with these test methods will indicate whether bulkheads and decks will continue to perform their intended function during the period of fire exposure. These test methods shall not be construed as implying suitability for use after fire exposure.

1.3 These test methods prescribe a standard fire exposure for comparing the relative performance of different bulkhead and deck assemblies under controlled laboratory conditions. The application of these test results to predict the performance of actual assemblies when exposed to large pool fires requires a careful engineering evaluation.

1.4 *Limitations*—These test methods do not provide the following:

1.4.1 Full information on the performance of assemblies constructed with components or of dimensions other than those tested.

1.4.2 An evaluation of the degree to which the assembly contributes to the fire hazard through the generation of smoke, toxic gases, or other products of combustion.

1.4.3 Measurement of flame spread over the surface of the test assembly.

1.4.4 The erosive effect that the velocities or turbulence, or both, generated in large pool fires has on some fire protection materials.

1.4.5 Full information on the performance of assemblies at times less than 5 min because the rise time called out in Section 6 is longer than that of a real fire.

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

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

1.7 This test method is based on the fire exposure as defined in Test Methods E 1529 (issued by the Committee on Fire Standards, E05).

1.8 *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 prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 119 Test Methods for Fire Tests of Building Construction and Materials[2]

E 176 Terminology of Fire Standards[2]

E 511 Test Method for Measuring Heat Flux Using a Copper-Constantan Circular Foil, Heat-Flux Gage[3]

E 1529 Test Methods for Determining Effects of Large Hydrocarbon Pool Fires on Structural Members and Assemblies[2]

3. Terminology

3.1 *Definitions of Terms Specific to These Test Methods*—Refer to Terminology E 176 for definitions of terms associated with fire issues used in these test methods.

4. Summary of Test Methods

4.1 The fire environment within the furnace shall develop a total heat flux of 204 ± 16 kW/m^2 (65 000 ± 5000 Btu/ft^2-h) and an average temperature of 1093 ± 111°C (2000 ± 200°F) within 5 min from the start of the test. The fire environment shall be controlled by reproducing the furnace temperatures recorded during the furnace calibration method specified in Section 7. This temperature shall be maintained throughout the remainder of the fire test as shown in Fig. 1.

4.2 Performance is defined as the time period during which bulkheads and decks will continue to perform their intended

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[1] These test methods are under the jurisdiction of ASTM Committee F25 on Ships and Marine Technology and are the direct responsibility of Subcommittee F25.02 on Insulation/Processes.

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[2] *Annual Book of ASTM Standards*, Vol 04.07.

[3] *Annual Book of ASTM Standards*, Vol 15.03.

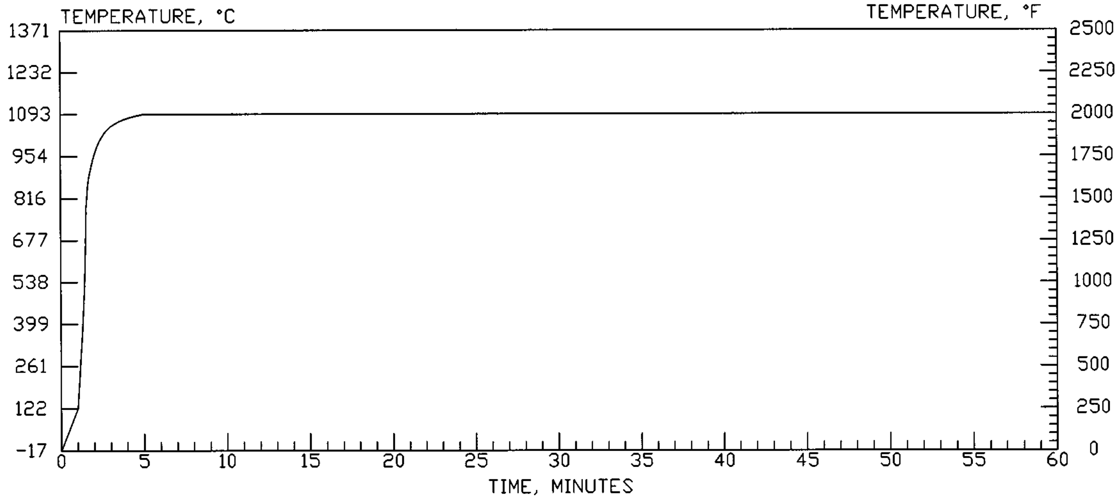


FIG. 1 Time-Temperature Curve

function when subjected to fire exposure. The results are reported in terms of time increments such as 15, 30, 60, 90, and 120 min.

5. Significance and Use

5.1 These test methods are intended to provide a basis for evaluating the time period during which bulkheads and decks will continue to perform its intended function when subjected to a controlled, standardized fire exposure.

5.1.1 In particular, the selected standard exposure condition simulates the condition of total continuous engulfment of a member or assembly in the luminous flame (fire plume) area of a large free-burning fluid hydrocarbon pool fire. The standard fire exposure is basically defined in terms of the total flux incident on the test specimen together with appropriate temperature conditions.

5.1.2 It is recognized that the thermodynamic properties of free-burning, hydrocarbon fluid pool fires have not been completely characterized and are variable depending on the conditions, the physical relationship of the structural member to the exposing fire, and other factors. As a result, the exposure specified in these test methods is not necessarily representative of all the conditions that exist in large hydrocarbon pool fires. The specified standard exposure is based upon the best available information and testing technology. It provides a basis for comparing the relative performance of different assemblies under controlled conditions.

5.1.3 It is feasible that substantial changes in the fire performance characteristics of the assembly will result from any variation from the construction or conditions (that is, size, method of assembly, and materials) that are tested.

5.2 The structural assemblies that will be evaluated in accordance with these test methods will be located on a ship.

6. Furnace Control

6.1 The fire environment within the furnace shall develop a total heat flux of 204 ± 16 kW/m^2 (65 000 ± 5 000 Btu/ft^2-h) and an average temperature of 1093 ± 111°C (2000 ± 200°F) within 5 min from the start of the test. The fire environment shall be controlled by reproducing the furnace temperatures recorded during the furnace calibration method specified in Section 7. This temperature shall be maintained throughout the remainder of the fire test as shown in Fig. 1.

6.2 The furnace shall be controlled to maintain the area under the time-temperature curve to within 10 % of the corresponding area under the standard time-temperature curve shown in Fig. 1 for fire tests of 60-min or less duration; to within 7.5 % for test longer than 60 min but not longer than 120 min: and to within 5 % for tests exceeding 120 min in duration. The area under the time-temperature curve shall be obtained by averaging the results of thermocouple readings.

6.3 A correction will be applied for variation of the furnace exposure from the prescribed, where such variation will affect the test results, by multiplying the indicated time period by two thirds of the value obtained by dividing the difference in area between the curve of average furnace temperature and the standard curve for the first three fourths of the period by the area between the standard curve above a baseline of 20°C (68°F) for the same part of the indicated period during the first part of the test. For fire exposure times longer than standard, it is feasible that the indicated rating period will be increased by the amount of the correction, and for fire exposure times less than standard, the indicated rating period may be similarly decreased. The correction will be expressed by the following formula:

$$C = \frac{2I\,(A - A_s)}{3\,(A_s)} \tag{1}$$

where:

C = correction in the same units as I,
I = indicated fire-resistance period,
A = area under the curve of indicated average furnace temperature for the first three fourths of the indicated period, and
A_s = area under the standard furnace curve for the same part of the indicated period.

6.4 The temperature fixed by the furnace calibration (see Section 7) shall be the average temperature obtained from the readings of five thermocouples symmetrically disposed and distributed within the test furnace to show the temperature near all parts of the assembly.

6.5 The thermocouples shall be fabricated by fusion-welding the twisted ends of (0.064-in.) diameter (No. 14 B & S gage) chromel-alumel wires having a time constant of 2 min or less, and mounting the wires in porcelain insulators. The thermocouple assembly shall be inserted through a standard weight, nominal 13-mm (½-in.) iron, steel, or inconel pipe, and the end of the pipe from which the welded junction protrudes is to be open. The thermocouple junction shall protrude 13 mm (½ in.) from the open end of the pipe.

6.6 The junction of the thermocouples shall be placed 102 mm (4 in.) away from the exposed face of the test specimen and located at the ⅓ and ⅔ heights of the test specimen.

6.7 Each thermocouple within the furnace shall be recorded at intervals not exceeding 1 min.

7. Calibration of Furnace

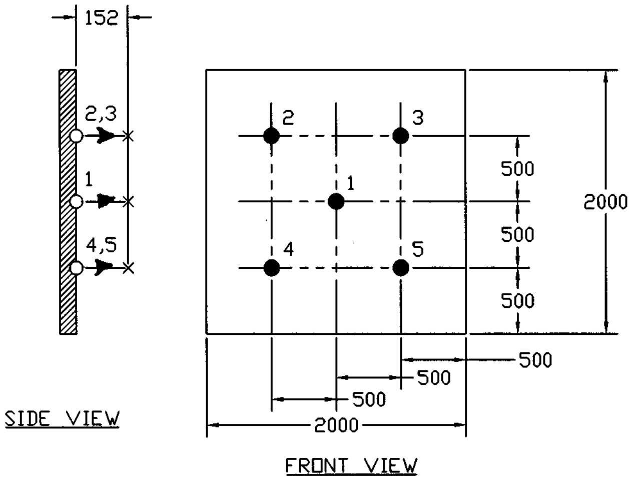
7.1 A furnace calibration record shall be maintained and the furnace shall be recalibrated after completion of any repair that could alter the heat generation, retention, or flow characteristics of the furnace.

7.2 The temperature of the furnace shall be measured by five thermocouples. They shall be located as shown in Fig. 2.

7.3 The measured values of all thermocouples and calorimeters shall be recorded at intervals not exceeding 1 min.

7.4 The thermocouples used to measure the temperatures on the face of the calibration wall shall be No. 28 gage, Type K inconel sheathed thermocouples having a time constant of 0.5 s or less. The thermocouple junction shall be located 6.3 mm (¼ in.) from the face of the calibration wall.

7.5 The thermocouples used to measure the temperatures within the furnace shall be constructed as described in 6.5.



NOTE 1— • denotes site of heat flux measurement, X a gas temperature sensor.

NOTE 2—Arrow denotes viewing direction of heat flux sensor.

NOTE 3—All dimensions are in mm.

NOTE 4—Calibration assembly is to be fabricated from noncombustible materials.

FIG. 2 Calibration Assembly for Fire-Containment Walls

7.6 The calorimeters shall have a minimum range from 315 kW/m^2 (100 000 Btu/ft^2-h) and a 180° view angle. They shall be located as shown in Fig. 2.

7.7 The fire environment during the calibration test shall comply with the requirements of 6.1. The length of the calibration test shall be 60 min.

7.8 Individual total heat flux measurements shall lie within the limits shown in Fig. 3.

7.9 The average furnace temperature shall be determined by averaging the temperatures recorded by the five thermocouples placed 102 mm (4 in.) from the specimen. The average shall be 1093 ± 111°C (2000 ± 200°F) and individual temperatures are to be 1093 ± 219°C (2000 ± 400°F) 5 min after the start of the test and until the end of the test.

7.10 The average furnace temperature curve shall be reproduced to maintain the furnace control described in Furnace Control, Section 6.

7.11 A record of the temperatures measured near the face of the wall and the oxygen content shall be retained by the testing laboratory on file for a period of ten years.

8. Furnace Pressure

8.1 A linear pressure gradient exists over the height of furnace, and although the gradient will vary slightly as a function of the furnace temperature, a mean value of 8 Pa/m height shall be assumed in assessing the furnace pressure conditions. The value of the furnace pressure shall be the nominal mean value, disregarding rapid fluctuation of pressure outside the furnace at the same height. It shall be monitored and controlled continuously and by 5 min from the commencement of the test shall be achieved within ±3 Pa, see Fig. 4 for design of the T-shaped sensor.

8.2 For vertically orientated specimens, the furnace should be operated such that a pressure of zero is established at a height of 500 mm above the notional floor level to the test specimen. However, for specimens with a height greater than 3 m, the pressure at the top of the test specimen shall not be greater than 20 Pa, and the height of the neutral pressure axis shall be adjusted accordingly.

8.3 For horizontally orientated specimens, the furnace shall be operated such that a pressure of 20 Pa is established at a position 100 mm below the underside of the specimen.

9. Test Specimen

9.1 *Bulkheads*:

9.1.1 *Dimensions*:

9.1.1.1 The minimum overall dimensions for the test specimen including the perimeter details at the top, bottom, and vertical edges, are 2440-mm width and 2500-mm height.

9.1.1.2 The overall dimensions of the structural core shall be 20 mm less in both the width and the height than the overall dimensions of the specimen, and the other dimensions of the structural core shall be as follows:

Thickness of plating: steel	4.5 ± 0.5 mm
Stiffeners spaced: steel at 600 mm	65 ± 5 × 65 ± 5 × 6 ± 1 mm

9.1.1.3 The width of the structural core shall be greater than the specified dimensions providing that the additional width is in increments of 600 mm to maintain the stiffener centers and the relationship between the stiffeners and the perimeter detail.

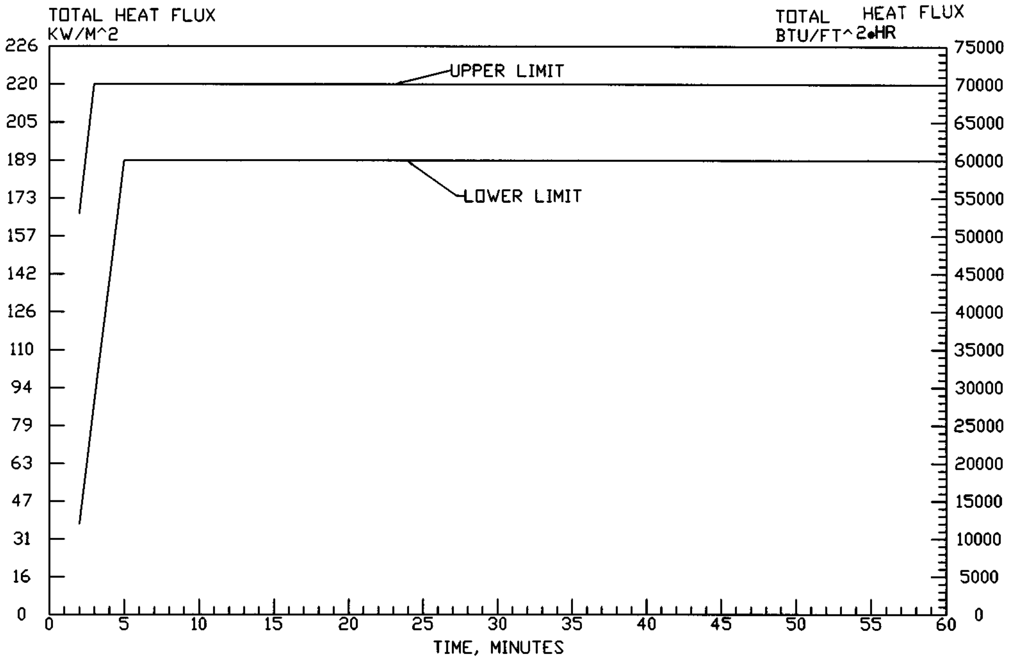


FIG. 3 Time-Total Heat Flux Curve

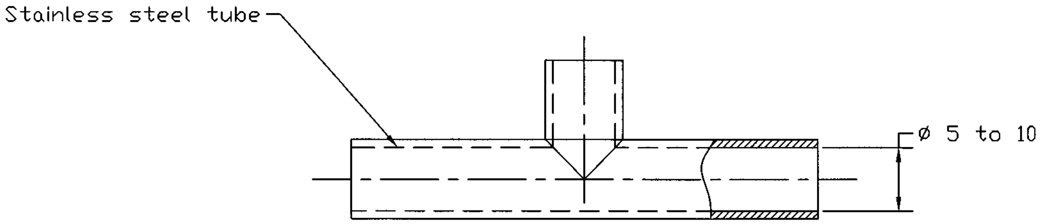


FIG. 4 T-Shaped Sensor

9.1.1.4 Any joints in the plating shall be full-welded, at least from one side.

9.1.1.5 The construction of a structural steel core having the recommended dimensions is shown in Fig. 5; the thickness of the plating and dimensions of the stiffeners shown are nominal dimensions. Irrespective of the dimensions of the structural core and the material of manufacture, the details around the perimeter shall be as illustrated in Fig. 6.

9.2 *Decks*:

9.2.1 *Dimensions*:

9.2.1.1 The minimum overall dimensions for the test specimen including the perimeter details at all edges are 2440 mm in width and 3040 mm in length.

9.2.1.2 The overall dimensions of the structural core shall be 20 mm less in both the width and length than the overall dimensions of the specimen, and the other dimensions of the structural core shall be as follows:

Thickness of plating: steel	4.5 ± 0.5 mm
Stiffeners spaced: steel at 600 mm	100 ± 5 × 70 ± 5 × 8 ± 1 mm

9.2.1.3 The width of the structural core shall be greater than the specified dimensions providing that the additional width is in increments of 600 mm to maintain the stiffener center and the relationship between the stiffeners and the perimeter detail.

9.2.1.4 Any joints in the plating shall be full welded, at least from one side.

9.2.1.5 The construction of a structural steel core having the recommended dimensions is shown in Fig. 2; the thickness of the plating and dimensions of the stiffeners shown are nominal dimensions. Irrespective of the dimensions of the structural core and the material of manufacture, the details around the perimeter shall be as illustrated in Fig. 7.

10. Mounting of the Test Specimens

10.1 *Restraint and Support Frames*:

10.1.1 All test specimens shall be mounted within substantial concrete, or concrete or masonry-lined frames, which are capable of providing a high degree of restraint to the expansion forces generated during the test. The concrete or the masonry shall have a density between 1600 and 2400 kg/m^3. The concrete or masonry lining to a steel frame shall have a thickness of at least 50 mm.

10.1.2 The rigidity of the restraint frames shall be evaluated by applying an expansion force of 100 kN within the frame at mid-width between two opposite members of the frame, and measuring the increase in the internal dimensions at these position. This evaluation shall be conducted in the direction of the bulkhead or deck stiffeners, and the increase of the internal dimension shall not exceed 2 mm.

10.2 *Bulkheads and Decks*:

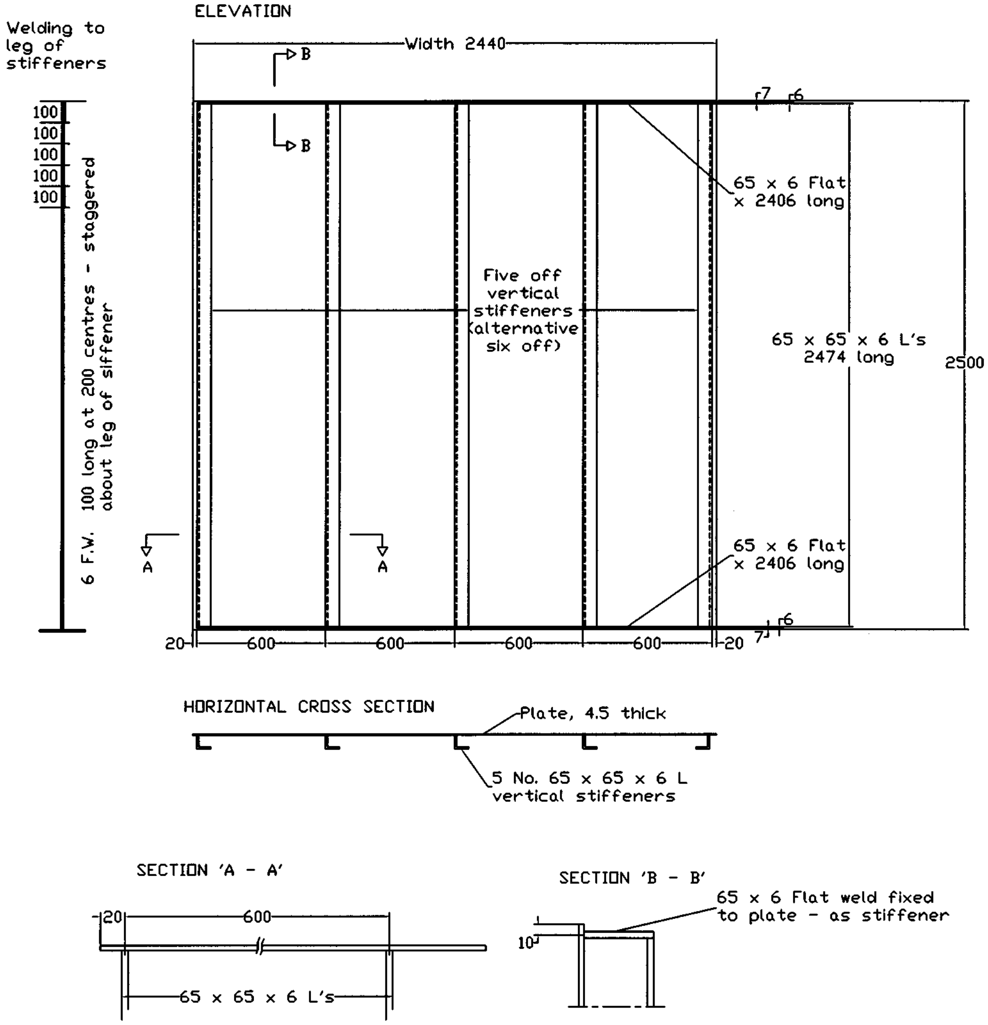


FIG. 5 Bulkhead

10.2.1 The structural core to bulkheads and decks shall be fixed into the restraint frame and sealed around its perimeter as shown in Fig. 6. It is feasible that steel spacers, with an approximate thickness of 5 mm, will be inserted between the fixing cleats and the restraint frame if the laboratory finds this necessary.

10.2.2 When the structural core of a bulkhead or a deck is to be exposed to the heating conditions of the test, that is, when the fixing cleats are on the exposed side of the structural core, then a 100-mm-wide perimeter margin adjacent to the restraint frame shall be insulated such that the fixing cleats and the edges of the structural core are protected from direct exposure to the heating condition. In no other situations, irrespective of the type of test specimen, shall the perimeter edges be protected from direct exposure to the heating conditions.

11. Insulating the Test Specimen

11.1 Decks shall be insulated from below on the stiffener side. Insulation shall be on the exposed side.

11.2 For unrestricted use, bulkhead insulation shall be installed on the unexposed side.

11.3 If the insulation is installed on the unstiffened or stiffened exposed side, the use shall be restricted.

11.4 If the insulation is installed on both sides in identical details then the use shall be unrestricted. The unexposed face shall be the stiffened side of the test specimen.

11.5 If different insulation details are installed on both sides of the bulkhead, then the bulkhead shall be tested from both sides for unrestricted use.

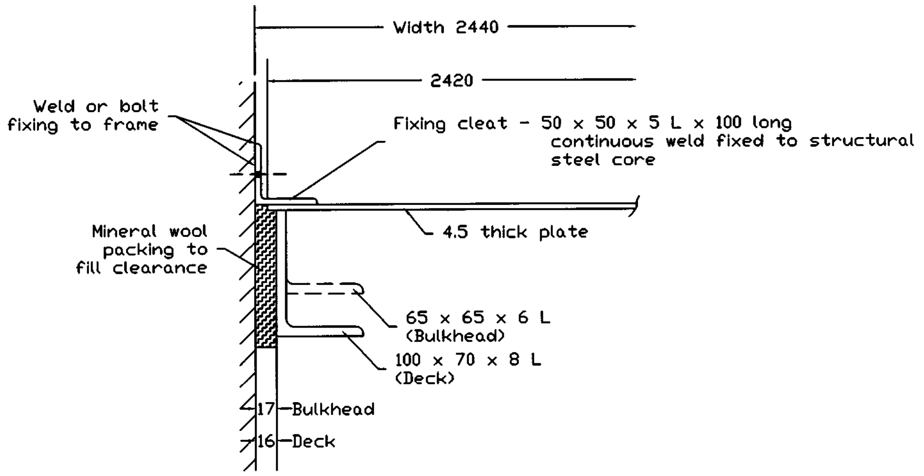
12. Conditioning

12.1 *General*:

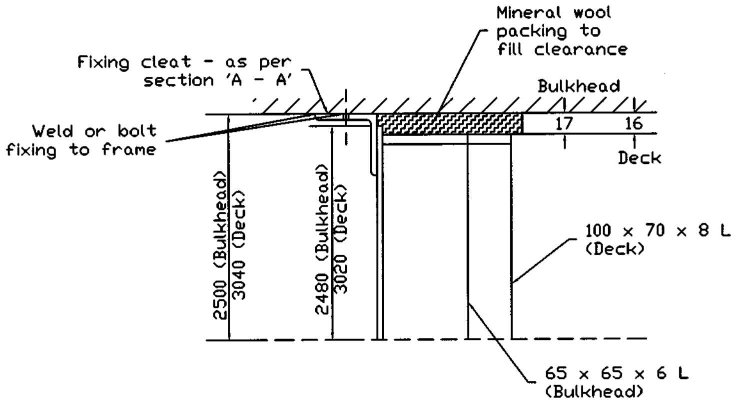
12.1.1 The test specimen shall not be tested until it has reached an air-dry condition. This condition is defined as an equilibrium (constant weight) with an ambient atmosphere of 50 % relative humidity at 23°C (73°F).

12.1.2 Accelerated conditioning is permissible provided the test method does not alter the properties of component materials. In general, high-temperature conditioning shall be below temperatures critical for the materials.

12.2 *Verification*—The condition of the test specimen shall be monitored and verified by use of special samples for the determination that shall be so constructed as to materials, as appropriate. These samples shall be so constructed as to represent the loss of water vapor from the specimen by having



SECTION 'B - B' (see figures 5 and 7)



NOTE 1—Section ′A—A′ (see Fig. 5 and Fig. 7).

NOTE 2—Section ′B—B′ (see Fig. 5 and Fig. 7).

FIG. 6 Section Details

similar thicknesses and exposed faces. They shall have minimum linear dimensions of 300 by 300 mm (12 by 12 in.) and a minimum mass of 100 g. Constant weight shall be considered to be reached when two successive weighing operations, carried out at an interval of 24 h, do not differ by more than 0.3 % of the mass of the reference specimen or 0.3 g, whichever is the greater.

12.3 *Encapsulated Materials*—When the test specimen incorporates encapsulated materials, it is important to ensure that these materials have reached an equilibrium moisture content prior to assembly, and special arrangements shall be made with the applicant for the test to ensure that this is so.

13. Unexposed Face Temperature Thermocouples

13.1 *Design*—The temperature of the unexposed surface shall be measured by means of disk thermocouples of the type shown in Fig. 8. Thermocouple wires, 0.5-mm-thick noncombustible insulating pad. The pad material shall have a density of 900 ± 100 kg/m^3.

13.2 *Connection*—Connection to the recording instrument shall be by wires of similar or appropriate compensating type.

13.3 *Preparation of Surfaces to Receive Thermocouples*:

13.3.1 *Steel*—Surface finishes shall be removed and the surface cleaned with a solvent. Loose rust and scale shall be removed by a wire brush.

13.3.2 *Irregular Surfaces*—A smooth surface not greater than 2500 mm^2, to provide adequate adhesive bond, shall be made for each thermocouple by smoothing the existing surface with a suitable abrasive paper. The material removed shall be the minimum to provide adequate bonding surface. Where the surface cannot be smoother, fillings shall be used of minimum quantity to provide a suitable surface. The filling shall comprise a ceramic cement, and when the filled surface is dry, it shall be smoothed, if necessary, with abrasive paper.

13.4 *Fixing of Thermocouples*:

13.4.1 *Steel*—The insulating pad with the thermocouple fitted shall be bonded to the cleaned surface of the steel using a water-based ceramic cement produced by integrating the components to form a high-temperature resistant adhesive. The adhesive shall be of such a consistency that no mechanical aid is necessary for retention purposes during the drying process, but where difficulty in bonding is experienced, it is feasible that

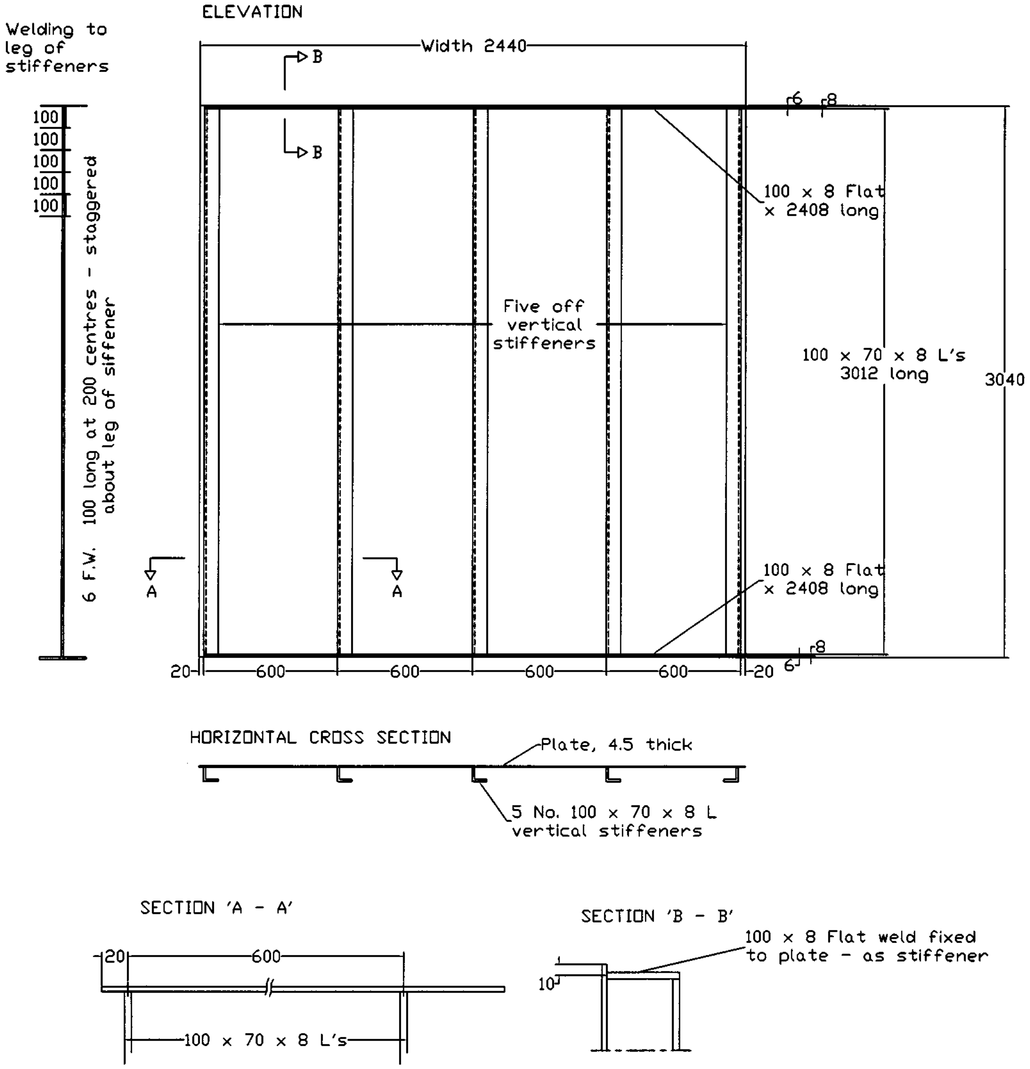


FIG. 7 Deck

retention by adhesive tape will be used provided that the tape is removed sufficiently long in advance of removal of the tape to ensure that the insulating pad is not damaged. If the thermocouple pad is damaged when the tape is removed, then the thermocouple should be replaced.

13.4.2 *Mineral Wool*—The thermocouples with insulating pads fitted should be arranged in such a way that if a surface wire mesh is present it may aid retention, and, in all cases, the bond to the fibrous surface should be made using a contact adhesive. The nature of the adhesive necessitates a drying time before mating surfaces are put together, thus, obviating the need for external pressure.

13.4.3 *Mineral Fiber Spray*—Thermocouples should not be fitted until the insulation has reached a stable moisture condition. In all cases, the bonding technique for steel should be used, and, where a surface wire mesh is present, the thermocouples should be affixed to the insulation in such a way that the wire mesh aids retention.

13.4.4 *Vermiculite/Cement-Type Spray*—The technique specified for mineral fiber spray shall be employed.

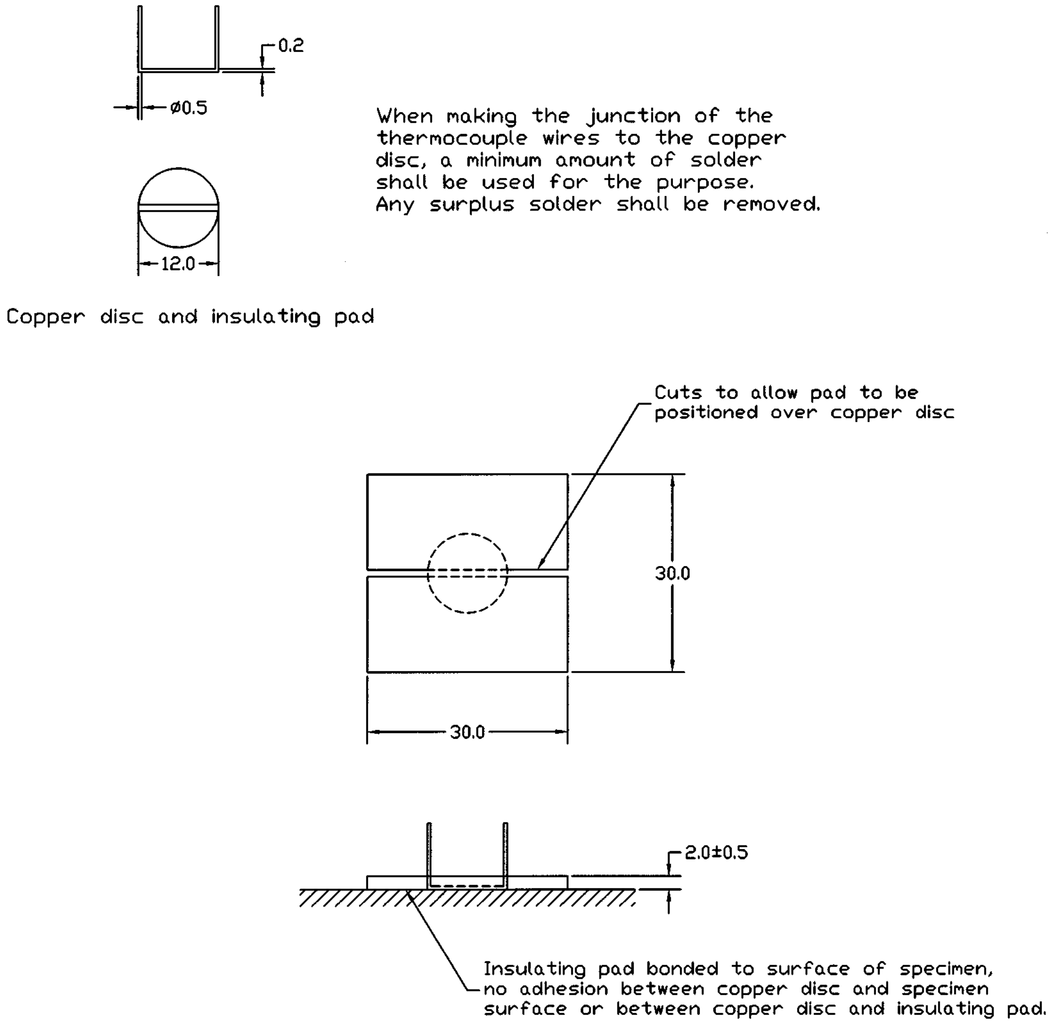
13.4.5 *Boards of Fibrous or Mineral Aggregate Composition*—The bonding technique for steel shall be used.

13.4.5.1 In all cases of adhesive bonding, the adhesive shall be applied in a thin film sufficient to give an adequate bond, and there should be a sufficient lapse of time between the bonding of the thermocouples and the test for stable moisture conditions to be attained in the case of the ceramic adhesive and evaporation of the solvent in the case of the contact adhesive.

13.5 *Positioning of Thermocouples on the Specimen*:

13.5.1 *Bulkheads and Decks*—The surface temperatures on the unexposed face of the test specimen shall be measured by thermocouples located as shown in Figs. 9 and 10:

13.5.1.1 Five thermocouples, one at the center of the test specimen and one at the center of each of the four quarters, all positioned no closer than 100 mm away from the nearest part of any joints welds or pins to any stiffeners;



When making the junction of the thermocouple wires to the copper disc, a minimum amount of solder shall be used for the purpose. Any surplus solder shall be removed.

Copper disc and insulating pad

Cuts to allow pad to be positioned over copper disc

Insulating pad bonded to surface of specimen, no adhesion between copper disc and specimen surface or between copper disc and insulating pad.

FIG. 8 Unexposed Surface Thermocouple Junction and Insulation Pad

13.5.1.2 Two thermocouples, one placed over each of the central stiffeners and positioned for a bulkhead at 0.75 height of the specimen, and positioned for a deck at mid-length of the deck;

13.5.1.3 Two thermocouples, each placed over a vertical (longitudinal) joint, if any, in the insulation system and positioned for a bulkhead at 0.75 height of the specimen and positioned for a deck at mid-length of the deck;

13.5.1.4 When a construction has two differently orientated joint details, for example normal to each other, then two thermocouples additional to those already described in 13.5.1.3 shall be used, one on each of two intersections;

13.5.1.5 When a construction has two different types of joint detail, then two thermocouples shall be used for each type of joint;

13.5.1.6 Additional thermocouples, at the discretion of the testing laboratory, shall be fixed over special features or specific construction details if it is considered that temperatures higher than those measured by the thermocouples previously listed are possible; and

13.5.1.7 The thermocouples specified in 13.5.1.4-13.5.1.6 for measurements on bulkheads, for example, over different joint types or over joint intersections, shall, where possible, be positioned in the upper half of the specimen.

14. Measurements and Observations on the Test Specimen During Test

14.1 *Temperature*:

14.1.1 The ambient air temperature at the beginning of the test shall be within the range from 10 to 32°C (50 to 90°F).

14.1.2 All temperature measurements shall be recorded at intervals not exceeding 1 min.

14.1.3 When calculating temperature rise on the unexposed surface of the test specimen, this shall be done on an individual thermocouple-by-thermocouple basis. The average temperature rise of the unexposed surface shall be calculated as the average of the rises recorded by the individual thermocouple used to determine the average temperature.

14.1.4 For bulkheads and decks, the average temperature rise on the unexposed face of the specimen shall be calculated from the thermocouples specified in 13.5.1.1 only.

14.2 *Deformation*—The maximum deflection of specimen shall be recorded during the test. These deflections and displacements shall be measured with an accuracy of ±2 mm.

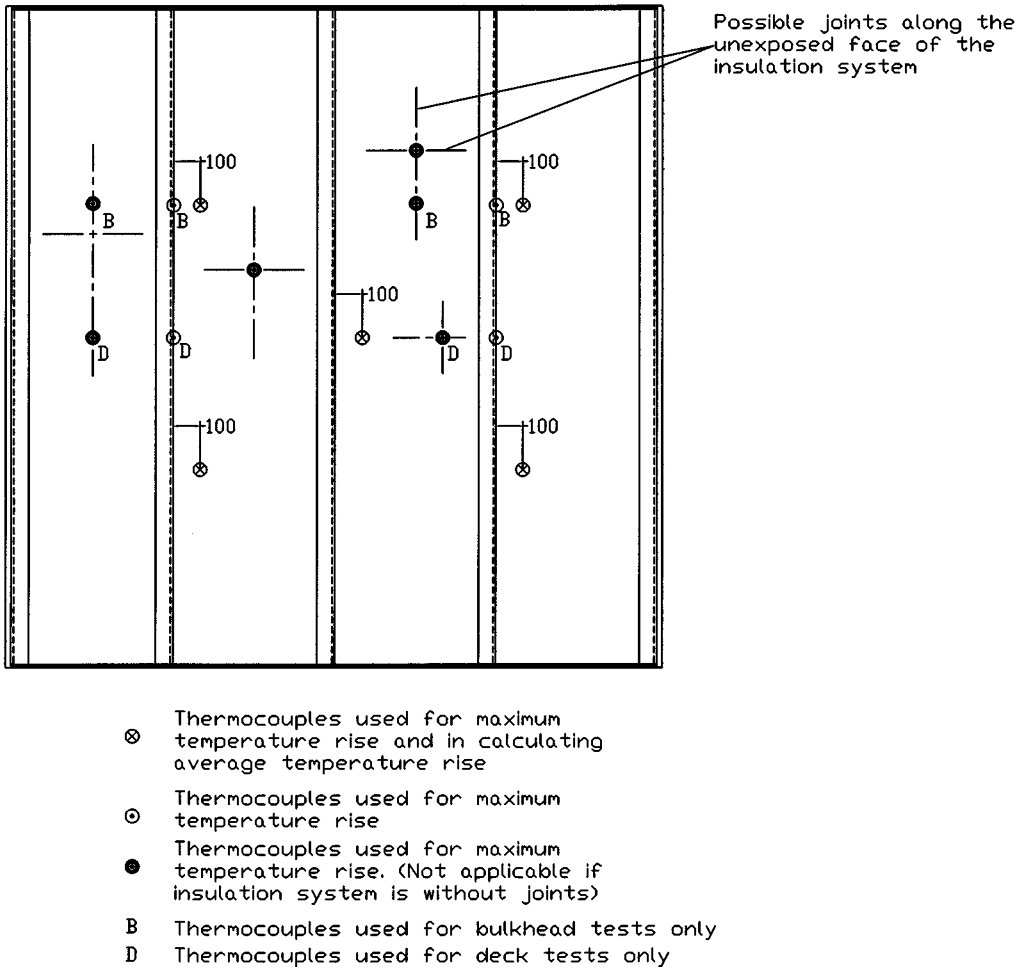


FIG. 9 Position of Unexposed Face Thermocouples for Bulkhead or Deck: Insulated Face to the Laboratory

14.3 *General Behavior*—Observations shall be made of the general behavior of the specimen during the course of the test and notes concerning the phenomena such as cracking, melting or softening of the materials, spalling or charring, and so forth, of materials of construction of the test specimen shall be made. If quantities of smoke are emitted from the unexposed face, this shall be noted in the report. However, the test is not designed to indicate the possible extent of hazard due to these factors.

15. Performance Criteria

15.1 The average unexposed face temperature rise as determined by averaging the five thermocouples as described in 13.5.1.1 shall not be more than 140°C (250°F), and the temperature recorded by any of the individual unexposed face thermocouples shall not be more that 180°C (325°F), during the following periods for each classification:

Class H-120	120 min
Class H-60	60 min
Class H-30	30 min
Class H-15	15 min

16. Report

16.1 Report all important information relevant to the test specimen and the fire test including the following specific items:

16.1.1 The name of the testing laboratory and the test date.

16.1.2 The name of the applicant for the test.

16.1.3 The name of the manufacturer of the test specimen and of the products and components used in the construction, together with identification marks and trade names.

16.1.4 The constructional details of the test specimen, including description and drawing and principal details of components. All the details of the specimen shall be give. The description and the drawings, which are included in the test report, shall, as far as practicable, be based on information derived from a survey of the test specimen.

16.1.5 All the properties of materials used that have a bearing on the fire performance of the test specimen together with measurements of thickness, density and, where applicable, the moisture or binder content, or both, of the insulation material(s) as determined by the test laboratory.

16.1.6 A statement that the test has been conducted in accordance with the requirements of these test methods (and if any deviations have been made to the prescribed procedures and a witness and their affiliation) and a clear statement of the deviations.

16.1.7 The name of the witness and their affiliation present at the test; when a test is not witnessed by a certifying authority, a note to this effect shall be made in the report.

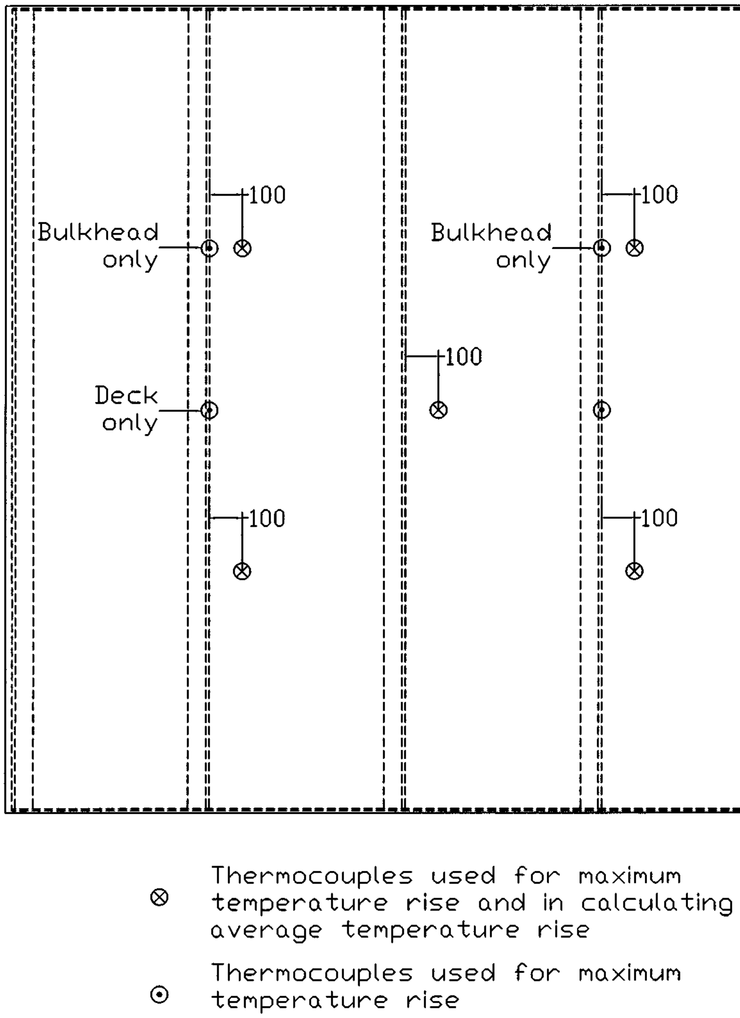


FIG. 10 Position of Unexposed Face Thermocouples for Bulkhead or Deck: Flat Face of Structural Steel Core to the Laboratory

16.1.8 Information concerning the location of all thermocouples fixed to the specimen, together with tabulated data obtained from each thermocouple during the test. Additionally a graphical depiction of the data obtained shall be included. A drawing shall be included which clearly illustrates the positions of the various thermocouples and identifies them relative to the temperature/time data.

16.1.9 The average and the maximum temperature rises, recorded at the end of the period of time appropriate to the insulation performance criteria for the relevant classification of insulation. If the test is terminated due to the insulation criteria having been exceeded, the times at which limiting temperatures were exceeded.

16.1.10 The individual unexposed thermocouple readings at each time interval. The average, as described in 14.1.2, and maximum thermocouple at each time interval.

16.1.11 The individual furnace thermocouple reading at each time interval. The average furnace thermocouple reading at each time interval.

16.1.12 Observations of significant behavior of the test specimen during the test and photographs or video recordings or both.

17. Precision and Bias

17.1 The precision and bias of these test methods have not yet been determined.

18. Keywords

18.1 bulkhead, deck; fire test response; hydrocarbon pool fire; restricted, unrestricted, insulation; temperature, heat flux

ANNEX

(Mandatory Information)

A1. TOTAL HEAT FLUX SENSOR ("CALORIMETER")

A1.1 *General Description*—For measurement of total heat flux, a water-cooled circular foil "Gardon Gage" heat flux sensor shall be used. A general description of this type of gage is given in Test Method E 511, which was developed by ASTM Subcommittee E21.08. While it is used to make total heat flux measurements, this device is designed for making radiative heat flux measurements. Caution must be exercised when using this gage to make measurements with a large convective fraction as a result of calibration constant changes. Additional information is contained in the literature **(1-4)**.[4] This rapid-response sensor derives its output from a differential thermocouple circuit that measures the temperature difference between the center and periphery of the active sensing area (which is the water-cooled circular foil). This millivolt area output is self-generating and is directly proportional to the total heat flux.

A1.2 *Specifications:*

A1.2.1 *View Angle*—180°.
A1.2.2 *Accuracy*—±3 % of reading (radiative fluxes only).
A1.2.3 *Linearity*—±2 % of full range.
A1.2.4 *Repeatability*—±½ %.
A1.2.5 *Response Time*—0.5 s or less.
A1.2.6 *Surface Coating Absorptivity*—To be specified by the manufacturer for a 2500°R (139K) blackbody radiation spectrum.

A1.3 *Calibration:*

A1.3.1 Each instrument shall have a certified calibration for the range of intended use, directly traceable to the National Institute for Standards and Technology (NIST). The instrument shall have a certified recalibration, for the range of intended use, directly traceable to the NIST range if intended use, directly traceable to the NIST whenever there is reason to suspect that recalibration is required (for example, if there is a change in the appearance of the sensor coating); or at least once per year, or after 25 testing hours, whichever comes first.

A1.3.2 Before each use, each instrument should have a recalibration performed by the testing laboratory that is either directly or indirectly traceable to NIST.

A1.4 *Operation*—Because condensation on the surface of the sensor can cause faulty readings, the temperature of the sensor shall be kept above 120°F (50°C) or above the dew point of the local environment, whichever is greater.

A1.5 *Mounting and Use*—Sensors shall be mounted in the calibration fixtures. The sensors shall be mounted where there is no direct flame or high-velocity jet impingement. The water-cooling must be capable of maintaining foil edge temperature less than 300°F (150°C).

A1.6 *Acceptable Sensors*—Several sensors have been verified by their manufacturers to meet the requirements of A1.1 through A1.2.

A1.7 *Radiometers and Calibrations*—Radiant heat flux measurements are not required in the test method. If radiant heat flux measurements are desired, radiometers based on the designs of the total heat flux sensors are available. If the radiometer uses a window, calibration of the sensors shall be performed with the window in place and use a thermal source with a radiation spectrum similar to that present in a furnace at 2500°R (139K).

APPENDIXES

(Nonmandatory Information)

X1. COMMENTARY

X1.1 *Introduction*—This commentary has been prepared to provide the user of these test methods with background information and rationale on the development of these test methods and the selected standard test condition. These test methods are primarily intended for evaluation of materials used for fire protection of structures in the hydrocarbon processing industry (HPI) (such as oil refineries, petrochemical plants, offshore oil-production platforms, and so forth), and other structures that can be exposed to large, free-burning, fluid hydrocarbon-fueled, pool fires. No attempt has been made to incorporate all the available information on pool fires in this commentary.

X1.2 *Basic Differences in Large Pool Fire Test Versus Test Methods E 119*—Before the development of these test methods, Test Methods E 119 were the only standardized tests available

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[4] The boldface numbers in parentheses refer to the list of references at the end of the standard.

for evaluation of the thermal response of structural members and assemblies to fires. These test methods differ from Test Methods E 119 in two major ways:

X1.2.1 When a furnace is used to produce the thermal exposure, the primary control for these test methods is based on a calibration procedure that develops a time-temperature curve to produce a specified heat flux incident upon the test specimen.

X1.2.2 These test methods get hotter faster than in Test Methods E 119, which consequently subjects the test specimens to a strong thermal shock. Specifically, these test methods specify a cold wall heat flux of 204 kW/m^2(65 000 Btu/ft-h^2) upon the test specimen within 5 min of test initiation. This compares to values measured in a major Test Methods E 119 furnace of 35 kW/m^2 (11 100 Btu/ft^2-h) at 5 min and 18 kW/m^2 (37 400 Btu/ft^2-h) at 60 min **(5)**.

X1.2.3 *Need to Control Heat Flux*—The heat flux incident upon an object is defined as energy per unit area per unit time (for example, Btu/ft^2-h (kW/m^2). During the initial stages of the fire, the thermal response of an object to the fire is a direct function of the heat flux to which the object is exposed **(5-9)**. While temperature is an important driving force for heat flux, temperature alone does not sufficiently define a fire environment. For example, both a match and a large pool fire (for example, 50 ft in diameter) burn in a roughly similar temperature regime (from 871 to 1093°C (1600 to 2000°F)), but clearly a person can safely get within a few inches of a match. The reason is, that the size of the pool fire results in a much higher incident heat flux. Therefore, it is temperature as well as other factors, such as fire size, flame thickness, and so forth, that cause heat flux. One study of Test Methods E 119 concluded:

> Exposure severity is given indirectly and incompletely by specification of the furnace temperature. The true measure of severity is given by the heat flux. Our overriding conclusion is to recommend that future improvements of Test Methods E 119 focus more on the control, measurement, and specification of the heat flux condition rather than the ambient gas temperature history **(10)**.

Therefore, specifying a combination of the heat flux and the temperature for the control of these test methods represents an advance in fire technology, not a unique requirement for large pool fires as such.

X1.3 *Need for a Large Hydrocarbon Pool Fire Test:*

X1.3.1 A large pool fire is loosely defined as that resulting from hundreds (or thousands) of gallons of liquid hydrocarbon fuel burning over a large area (several hundred to several thousand square feet) with relatively unrestricted air flow to it and combustion products from it (for example, outdoors). A number of large pool fire experimentalists **(11-18)** have shown that high heat flux and temperature conditions are rapidly achieved in this fire (typically in less than 1 min.) This is in sharp contrast to the slow rate of buildup of thermal conditions in the Test Methods E 119 fire, which simulates a fire in which the fuel is solid and restrictions exist on air flow to (and combustion products from) the fire.

X1.3.2 The HPI facilities, which largely are located outdoors, handle large quantities of hydrocarbon fluids. Personnel responsible for safety and loss prevention in these facilities are concerned that when they have a fire of consequence, it is a large pool fire, not a Test Methods E 119 type fire, and that structures, assemblies, and fire protection materials should be designed based on ratings in a large pool fire, not the Test Methods E 119 fire **(19-22)**. Indeed, Norway now specifies firewalls on offshore platforms rated per a hydrocarbon fire **(23)**.

X1.3.3 The concern for materials and structural performance in large pool fires has led to the development of several different types of large pool fire simulation tests **(5, 6, 20, 24-27)** that have shown that materials can perform quite differently in Test Methods E 119 versus pool fire test. For example, one experimenter showed that 2 in. of a standard fireproofing material gave only 1 h in a pool fire simulation test versus a nominal 3-h Test Methods E 119 rating **(20)**.

X1.3.4 However, the existence of various simulation tests has sometimes led to confusing and conflicting results, and the lack of a standardized test has inhibited acceptance of ratings in accordance with this test method **(21)**. Therefore, the need was established for this standardized test method that simulates the effects of large pool fires on the types of structures and assemblies that are used in HPI facilities.

X1.4 *Rationale for the Specific Test Conditions:*

X1.4.1 *Need for a Single Set of Test Conditions*—To establish a standardized large pool fire simulation test, the issue becomes one of selection of the conditions to simulate. As demonstrated by the various large pool fire experimenters, a range of temperatures, velocities, heat fluxes, and chemical conditions exist, and they vary dramatically with time and spatial location **(12, 14)**. From a pragmatic viewpoint, selection of multiple test conditions would probably result in prohibitively high testing costs. Therefore, it becomes a case of whether engineering judgment can be exercised in selecting a single set of test conditions that represent a reasonable worst case for HPI facility design purposes.

NOTE X1.1—Reasonable worst case means, in essence, designing to withstand the most severe set of conditions that could be expected, within reason, to occur. Note that the design solution for a structure exposed to the reasonable worst case set of fire conditions selected does not necessarily have to be limited exclusively to passive fire protection, but can, and generally does, include a combination of passive plus active systems fixed and mobile.

X1.4.2 *Radiant Heat Flux and the Continuous Total Flame Engulfment Criterion*—There is a consensus that radiation is the dominant heat transfer mechanism to an object immersed in a large pool fire **(6, 9, 11, 12, 14, 17)**. Radiant heat transfer to an object is defined by the Stefan-Boltzmann equation as follows:

$$q = \sigma \epsilon F T^4 \quad \text{(X1.1)}$$

where:

q = radiant heat flux incident on the exposed time, kW/m^2 (Btu/ft^2-h);
σ = Stefan-Boltzmann constant, 5.67×10^{-11} $kW/m^2\ K^4$;

ϵ = emissivity of the fire as viewed from the exposed item (by definition $0 \leq \epsilon \leq 1$), the case in which $\epsilon = 1$ is given the name *blackbody radiation*;
F = view factor of the exposed item to the fire (by definition $0 \leq F \leq 1$); and
T = absolute temperature of the fire, *R or K.

Therefore, to determine a reasonable worst case radiation condition, consideration must be given to the view factor to the fire, fire emissivity, and time continuity, as well as fire temperature.

X1.4.2.1 *View Factor*—Only those surfaces of an object that are in a direct visual line to a fire can receive heat flux. Because an object located outside of, or on the periphery of, a fire has a view factor (to the fire) of 0.5 or less, it is clear that maximum radiation occurs when the object is fully engulfed in the fire and hence has a view factor of 1.0 (which is the theoretical maximum) and that this is a reasonable maximum.

X1.4.2.2 *Emissivity of a Fire*—By definition, emissivity ranges from zero (for example, no flames at all) to 1.0 (for example, flames so thick that they cannot be optically seen through). Experimenters are tending to believe that in a fire that has a large quantity of luminous soot particles (such as a liquid hydrocarbon fueled pool fire), flames only have to be 3 to 6 ft thick to be optically opaque **(15)**. Clearly, then, it is a reasonable maximum to have an emissivity of 1.0.

X1.4.2.3 *Time Continuity*—This is perhaps the most important factor. Consider an example of fire exposure of an individual structural member, such as a beam or column, centered in a pool fire on the order of 30 to 40 ft in diameter. It is clear that, at least at some times during the fire, an optically opaque fire can totally engulf the beam or column. Hence it is reasonable for the view factor and fire emissivity to be 1.0 at some times, with respect to the beam or column. The question then must be answered: For what percentage of the time duration of the fire (for example, if it is a 1-h fire) do these conditions prevail? Since these pool fire predominantly occur outdoors, and since even small winds can cause the fires to fluctuate greatly in a given space (Note X1.2) **(12, 15-18)**, this is a very difficult question to answer. Therefore, an assumption has to be made, and the reasonable worst case assumption made is that the total engulfment conditions prevail 100 % of the duration of the fire exposure. In other words, total continuous engulfment means that at no time during the fire does any part of the structural member ever see out (nor would an imaginary observer anywhere outside of the fire ever see in to the member). Because the performance of any individual member (for example, a column) can be critical, this total continuous engulfment criterion designs the member as if it were in the central portion of a large stationary fuel spill on a relatively windless day for the duration of the protection time desired (for example, 1.0 h).

NOTE X1.2—Indeed, virtually all large pool fire experimenters specifically wait for windless (or special prevailing wind) conditions to conduct their fires so they have a measure of control on their experiment.

X1.4.3 *Total Heat Flux*:

X1.4.3.1 The specified total heat flux is 204 kW/m^2-h (65 000 Btu/ft-h^2) within 5 min of fire initiation, and is a summation of the radiative plus convective components, with the radiative component being very dominant:

$$q_r = q_R = q_c \tag{X1.2}$$

where:
q_r = total heat flux, kW/m^2 or Btu/ft^2-h;
q_R = radiant heat flux, see Eq X1.1; and
q_c = convective heat flux, h($T_f - T_s$) (see Eq X1.3).

Therefore, total heat flux is a strong function of fire temperature(s), and the convective component is a function of the temperature and velocity of the gases in the fire. In X1.4.4 and X1.4.5, fire temperature and gas velocity are discussed.

X1.4.3.2 Measurement of heat flux in a fire is a difficult experimental task. However, it is surprising how much agreement there is between experimenters, given this experimental difficulty plus the fluctuation of conditions within a given fire, as well as the differences in types and sizes of fires and where and how the heat flux measurements are made and other variables (for example, wind).

(*1*) Bader of Sandia **(11)** measured heat fluxes in large pool fires by several methods and developed a simplified computer model to predict the response of an object immersed in the fire. Using slug (that is, solid metal) calorimeters, the maximum time-integrated measured heat flux in 5.5- by 5.5-m (18- by 18-ft) fires was 150 kW/m^2 (47 500 Btu/ft^2-h). For modeling of an object's response, he states:

> It was realized that both radiant and convective heat transfer played significant parts as energy transfer modes within a fire, but it was reasoned that at high temperature the radiant mode would be dominant, blackbody source temperature which would combine the effects of radiation and convection. A study of experimental temperature measurements was undertaken. After analyses, "It was decided that a good numerical representation of a large free-burning fire was possible using an 1850°F (1010°C) blackbody temperature as the input."

NOTE X1.3—This input began at –1 min after fire initiation. Blackbody radiation at 1850°F (1010°C) gives a heat flux of 48 800 Btu/ft^2-h (154 kW/m^2).

(*2*) Canfield and Russell of the U.S. Navy **(12)** mapped the temperature and radiant heat flux (using Gardon gages) at up to 32 points in the flame plume of a 16- by 8-ft (4.9- by 2.4-m) pool fire. The maximum means value of radiant heat flux was 51 000 Btu/ft^2-h (161 kW·m^2), this being in the (spatially) small hot core of the flames (measured from 1945 to 1974°F (1063 to 1079°C).

(*3*) NASA and Avco **(13)** measured total heat flux in a 48- by 54-ft (14.6- by 16.5-m) pool fire using a Gardon gage. The maximum total heat flux measured was 50 600 Btu/ft^2-h (160 kW/m^2).

(*4*) Brown of the FAA **(16)** also used Gardon gages to measure total heat flux at one point in a series of 20- by 20-ft (6.1- by 6.1-m) pool fires under various wind conditions. The result: "The heat flux to the . . . calorimeters averaged about 50 400 Btu/ft^2-h (159 kW/m^2) for calm wind or steady perpendicular wind (blowing fire toward calorimeter) tests." (The heat flux was about 18 000 Btu/ft^2-h (56.7 kW/m^2) for wind blowing away.) The heat flux reached quasisteady state values in less than 20 s.

(*5*) Mansfield of NASA **(14)** also used Gardon gages. The fires were 25 by 25 ft (7.6 by 7.6 m) and 30 by 80 ft (9.1 by 9.1 m). The average total heat flux of three points was 50 800 Btu/ft^2-h.

(*6*) In a series of tests at Sandia National Laboratories **(17, 18, 28)**, a variety of flat plate and cylindrical calorimeters have been used in 30- by 60-ft (9- by 18-m) pool fires to obtain hot wall heat fluxes to objects of different sizes and shapes. The maximum average value of the cold wall heat flux in these test methods was slightly less than 50 000 Btu/ft^2-h (158 kW/m^2).

X1.4.3.3 Therefore, the selected value of 50 000 Btu/ft^2-h (158 kW/m^2) is a reasonable average of the experimental values. This is assumed to be a reasonable worst-case exposure.

X1.4.4 *Convective Heat Flux and Gas Velocity*:

X1.4.4.1 While the convective heat flux is not called out separately in these test methods, on a vertical column it is expected to be approximately 10 % of the total heat flux or about 5000 Btu/ft^2-h (16 kW/m^2) (see X1.4.4.4).

X1.4.4.2 Convective heat flux to an object occurs as the result of the flow over the object of gases of higher temperature than the object. For an object of a given shape (for example, a 9-ft tall column), and gases of a given temperature and composition, the convective heat flux is then a function of the velocity of the gases and their orientation to the object. In the continuous engulfment portion (see X1.4.2) of a large pool fire, the prevalent (time-wise at any one spatial point) velocity of the combustion gases is vertical as a result of the buoyant forces of the flame plume (for example, in comparison to any wind conditions that could exist which would add horizontal component to the gas velocity, and to very sporadic cyclone-type whirling vortices). For the example of a 9-ft (2.7-mm) tall column, the flow is parallel to the 9-ft height and is turbulent and the convective heat flux can be quantified as follows:

$$q_c = h_{avg}(T_g - T_s) \tag{X1.3}$$

$$h = 0.0037 = (k/L) = (VL/v)^{0.8} = Pr^{0.33} \tag{X1.4}$$

where:

q_c = cold wall convective heat flux, Btu/ft^2-h; wall at 70°F;
h_{avg} = average heat transfer coefficient, Btu/ft^2-h °F;
T = average gas temperature, °F;
L = height of the column, ft;
k = thermal conductivity of the gases, Btu/ft^2-h °F;
v = kinematic viscosity of the gases, ft^2/h;
Pr = Prandtl number; and
V = average velocity of the gases, ft/h (m/h).

X1.4.4.3 Unfortunately, state-of-the-art heat transfer theory for buoyant plume velocities in large pool fires is corroboration. Theory **(9, 29-33)** states that maximum (vertical) velocity occurs at the centerline of a fire (under windless conditions), and increases with height (until a height is reached where lateral air entrainment/dilution effects cause the flame plume to become dissipated) (Note X1.3). Vertical velocity in general decreases with lateral distance from the fire centerline. Published data on velocity measurements is scarce. One published value of measured vertical plume velocity in a large pool fire is 38 ft/s (11.6 m/s) at a 20-ft (6.1-m) elevation at the exact centerline of a 50-ft (15.2-m) diameter fire **(17)**. Reference **(19)** provides average velocities at the centerline of a 9 by 18 m, and 9.5 m/s at 6.1 m; velocities measured during periods of low winds are up to 30 % higher. References **(18, 29-33)** provide theoretical analysis.

X1.4.4.4 Using Eq X1.3 and X1.4, and using $T = 2000°F$ (1093°C) and estimated properties (that is *k*, *v*, *PR*) for the combustion gases, *q* computes to slightly of 5000 Btu/ft^2 is total specified heat flux of 50 000 Btu/ft^2-h (159 kW/m^2). This agrees well with Mansfield's observation **(14)**. "This division of radiant and convective energy transfer is similar to a frequently accepted average or standard radiant/convective ratio of 9:1 for large pool fires."

X1.4.4.5 Although theory predicts higher velocities at higher elevations, common HPI design practice limits the major areas of fire protection concern to a maximum of 30 to 40 ft (9.1 to 12.2 m) above the fire source **(23)**. The 20-ft (6.1-m) height at which the 38-ft/s (11.6-m/s) value was reported **(17)** or the 41-ft/s (12.6-m/s) value reported in **(18)** during low winds are therefore at the approximate average height of HPI concern. Note that the data reported **(18)** show that the temperatures at this elevation are lower than at some elevations closer to the pool surface.

X1.4.4.6 As a counterpoint to the discussion of X1.4.4.4, the possibility exists that some fireproofing materials might be susceptible to erosive damage because of exposure to high-temperature gases with velocities representative of those measured in large pool fires. However, preliminary analysis of measurements made in large pool fires at Sandia National Laboratories, gives a shear stress estimate of less than 1 psf (50 Pa). As technology advances, this entire subject of gas velocity and its effects is one that could use further attention.

X1.4.4.7 As a pragmatic point, it is extremely difficult and expensive experimentally to generate high velocities of large quantities of hot gases and direct them in a highly controlled manner on a large test specimen. In fact, it is not clear if any existing test facility, other than an actual fire, has the capability of generating the representative velocities.

X1.4.5 *Fire Temperature*:

X1.4.5.1 The specified fire temperature (that is, the temperature of the environment that generates the heat fluxes of X1.4.3 and X1.4.4) is from 1850 to 2150°F (1010 to 1180°C). While this range is narrower than that seen in large pool fires **(15, 17, 18)**, it was selected for two reasons:

(*1*) As the discussion in X1.4.5 presents, fires do not burn at any one temperature, but rather consist of gases with a wide range of temperatures, depending on spatial and time position in the fire. The range from 1700 to 2300°F (927 to 1260°C) is typical of the luminous plume engulfment region of large pool fires **(12, 15, 17, 18)**. The selected range is in the middle of the broader range.

(*2*) The selected temperature range provides the experimenter/test facility with some flexibility and latitude in the means used to achieve the specified heat fluxes.

X1.4.5.2 As a reference point, using Eq X1.1 (the Stefan-Boltzmann equation for radiant energy transfer), if one is disposed to think of the fire at a single idealized temperature, then for the blackbody radiation case of emissivity –1 and view factor of $F = 1$, $T_f = 2000$°F (1093°C) gives an incident radiant heat flux of 63 770 Btu/ft^2-h (198 kW/m^2). Indeed, this concept of a single fire temperature is quite useful if an enclosed furnace is used as the test simulation facility. The heat flux of 65 000 Btu/ft^2-h called out in this test method would require a surface absorptivity of 0.8.

X1.4.5.3 Temperature can be thought of as the driving potential for the heat flux. In actuality, the temperature in a luminous mass of combusting gases from a pool fire is not a constant but varies over a wide range, from about 1000 to 1200°F (538 to 649°C) at the air-entraining edge of the plume to a broad internal zone from 1200 to 1900°F (649 to 1038°C) to a small central hot core from about 1900 to 2200°F (1038 to 1204°C) **(12, 15)**. One set of data for a spatially fixed grid of up to 50 thermocouples in the vertical cylindrical space over a 50-ft (15.2-m) diameter pool fire on a windless day gave the following time-averaged volumetric distribution **(31)**:

Less than 1200°F (649°C)—66 %
1200 to 1900°F (649 to 1038°C)—23 %
1900 to 2200°F (1038 to 1204°C)—11 %

Given the fluctuating nature of a pool fire, and therefore the probability that at some times the member will see out through the fire, thus counterbalancing exposures to higher temperatures, the specified range appears to meet the criterion of a reasonable worst case.

X1.4.6 *Gas Chemistry and Oxygen Content*:

X1.4.6.1 While the chemistry of the gases adjacent to the test specimen are not specified in these test methods, some discussion of these topics was considered appropriate for commentary.

X1.4.6.2 The chemistry in the fire plume of a pool fire is, like temperature, not a constant, but dynamic with time and spatial position. On the one hand, the chemistry is complex such as CO, CO_2, HO, O, N, H, and C_nH_m (for example, various hydrocarbons), soot particles, and so forth. On the other hand, the chemistry is relatively straightforward—that of a fluid hydrocarbon reacting with air. Therefore, the range of chemical species present are relatively well known.

X1.4.6.3 The most extensive measurement of chemistry in a pool fire is given by Ref **(15)**, where up to 23 spatial points were sampled periodically in the cylindrical area over a 50-ft (15.2-m) diameter pool fire. One analysis of this data led to the statement: "The overall conclusion form the data presented is that in the JP-4 fuel fire there is very little oxygen at the center of the fire up to a height of 1.5 fire radius. That is, combustion is still taking place" **(30)**. For the 50-ft diameter fire cited, a height of 1.5 fire radius is about 38 ft (11.6 m), approximately the normal maximum height of primary interest for fire protection (in accordance with the HPI; see X1.4.4.4).

X2. USE OF FURNACE TYPE FACILITIES

X2.1 While these test methods do not restrict the technique used to achieve the test conditions specified in Section 6 for the purposes stated in Section 1, there is strong interest in the use of traditional fire test facilities. The use of enclosed furnaces to simulate the thermal effects of a hydrocarbon fire is discussed.

X2.2 Traditionally, enclosed furnace-type facilities have been used for testing of structural response of materials (for example, for Test Methods E 119 testing). These furnaces normally are fueled by a clean burning gas such as natural gas or propane. Experimental experience to date indicates that gas-fired enclosed furnaces are in concept also usable to simulate the pool fire conditions specified in Section 6 for the purposes specified in Section 1. The reason that an enclosed furnace type facility appears applicable to simulating the pool fire can be understood by referring to the discussion in X1.4.2, which explained that the 50 000-Btu/ft^2-h heat flux condition simulates total engulfment in the luminous portion of the flame plume. That is, the view factor F and emissivity are at the maximum value of 1.0. In addition, the fire is conceptualized as being at a uniform temperature of 1865°F (1018°C), as explained in X1.4.5.2. Consider a 2.7-m (9-ft) column in an enclosed furnace with optically opaque walls at 1865°F (1018°C) and with optically transparent gases in the furnace also at 1865°F (1018°C). The view factor of the column to the walls of the furnace is 1.0. If the walls of the furnace and the surface of the column are at a uniform temperature, the effective emissivity of the walls is 1.0 (Note Note X2.1). The radiant heat flux to the specimen in accordance with Eq X1.1 is the specified 65 000 Btu/ft^2-h. As long as the temperatures are uniform throughout the furnace, the same discussion for radiant heat fluxes holds true even if the gases in the furnace are not transparent.

NOTE X2.1—For the case of a fully enclosed furnace with optically opaque walls and at a uniform temperature, the radiosity (that is, the sum of the emitted and reflected radiation) of the walls is constant and equal to that of a blackbody at the same temperature, regardless of the materials of construction of the furnace **(34)**. The walls have an effective emissivity of 1.0, regardless of the actual emissivity of the wall material. If the test specimen is at a temperature lower than that of the furnace walls, the heat flux to the specimen will drop below the blackbody flux based on the wall temperature. The size of the effect depends on the size of the test specimen relative to the furnace volume, the temperature difference, and the radiative properties of the test specimen and the furnace materials **(35)**.

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