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A Preliminary Study of the Fire Safety of Thermal Insulation for Use in Attics or Enclosed Spaces in Residential Housing

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U.S. DEPARTMENT OF COMMERCE

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A PRELIMINARY STUDY OF THE FIRE SAFETY OF THERMAL INSULATION FOR USE IN ATTICS OR ENCLOSED SPACES IN RESIDENTIAL HOUSING

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Abstract

An evaluation was made of the appropriateness of the flammability requirements in Federal specifications for loose-fill cellulosic and mineral fiber insulation and mineral fiber batts and blankets. This included an analysis of currently used standard test methods for measuring insulation flammability or combustibility and their principle limitations. To provide for more meaningful evaluations, a review was made of fire statistics and of likely fire occurrences, particularly for retrofit insulation in attic and enclosed spaces of residential buildings. A series of laboratory tests was conducted using an attic floor radiant panel test and a cigarette smoldering test to simulate flaming and smoldering exposures. Mockup tests on attic floor sections were conducted to validate the extent of flame spread on attic insulation and the initiation of smoldering ignition from covered recessed light fixtures. Based on these tests, changes were recommended to Federal Specifications HH-I-515C, HH-I-521E and HH-I-1030A.

Key words: Attics; Federal specifications; fire test; flame spread; loose-fill; mineral fiber; residences; smoldering; thermal insulation.

1. INTRODUCTION

With the current increased use of thermal insulation, a number of questions about fire safety have been raised. This has been due to reported fire incidents involving thermal insulation and an awareness of the possible consequences of using increasing quantities of insulation in attics, walls, crawl spaces and particularly around heat sources such as heaters and electrical devices. This concern was highlighted at the August 22, 1977, public meeting called by the Consumer Product Safety Commission (CPSC) in response to a petition from the Attorney General's Office of Denver, Colorado, regarding the potential fire hazards of certain types of thermal insulation.

At that meeting, there were requests that the Consumer Product Safety Commission use existing Federal specifications as a basis for nationwide mandatory or voluntary standards for flammability of insulation. Federal specifications for construction materials are generally used (a) for Government purchase of materials for use in Federal buildings and (b) by others in private or in federally supported housing. Consideration is also being given to the use of Federal specifications for acceptance of insulation materials in the event of enactment of tax credit legislation.

The position expressed by a number of speakers at the CPSC meeting encompassed the following thought: "If it's Government policy to conserve energy, it should be Government policy to insure use of safe products." The discussion implied a thesis that the addition of insulation should not increase the normal and expected level of fire risk to the resident.

The methods used to install insulation are extremely important from the standpoint of fire. Good installation practice, e.g., as specified in the National Electrical Code [1][1], and the Manual on Clearance for Heat-Producing Appliances [2], would provide physical separations between heat appliances, electrical fixtures, etc. and the thermal insulation. From a realistic standpoint, however, it can be anticipated that batt, blanket, and loose-fill insulation will be placed in contact with such appliances and fixtures, particularly with do-it-yourself and retrofit insulation projects in single family homes. Indeed, there may be no practical way to isolate a recessed light fixture which is located near the eave of an attic.

With the above philosophy in mind, the National Bureau of Standards (NBS) Center for Fire Research (CFR) evaluation presented here was focused primarily on the appropriateness of the flammability requirements of the three Federal specifications listed below. Although limited to the flammability portions of these three specifications, it is felt that the conclusions of this study would be applicable to other types of insulation used in a similar manner.

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[1] Numbers in brackets refer to the literature references listed at the end of this paper.

The three specifications reviewed are:

HH-I-515C	Insulation Thermal (Loose Fill for Pneumatic or Poured Application): Cellulosic Wood Fiber
HH-I-521E	Insulation Blankets, Thermal (Mineral Fiber, for Ambient Temperatures)
HH-I-1030A	Insulation, Thermal (Mineral Fiber, for Pneumatic or Poured Application)[2]

The requirements of the HH-I-515C and HH-I-521E specifications are based on a flame spread classification of 25 (or 50) and a smoke developed classification of 50 according to a prescribed standard flame spread test [3], while the HH-I-1030A specification provides for classification in terms of a maximum weight loss on ignition of either 1 percent or 12 percent.

The evaluation was based on a review of fire statistics, a statement of the perceived problem, a review of current test methods, and the performance of the insulation in laboratory fire testing. This report provides a brief summary of the more important information, findings and conclusions, including suggested changes to the specifications.

2. FIRE STATISTICS

Extensive data on the contribution of thermal insulation to fires are not available. We have reports of fire incidents in Denver, in Oklahoma City, in the state of Michigan, and in other locations. For example, the Departments of Public Safety and Public Health in Michigan have assembled data on fire incidents involving "paper insulation" as the first material ignited. There were 158 cases reported in 1975 and 1976 and 49 cases through part of 1977. Between 45 and 55 percent of all these cases involved treated paper insulation. The Oklahoma City Fire Department listed 24 cases in an 8-month period, involving recessed light and heater fixtures and flue and vent pipes covered with cellulose and mineral wool insulation.

On a nationwide basis fire data are collected in the Field Incident Data Organization (FIDO) system of the National Fire Protection Association and the National Fire Incident Reporting System (NFIRS) data system of the National Fire Prevention and Control Administration. These data are summarized in appendix A. The NFIRS data total 496 incidents in two states.

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[2] Available from Business Service Centers at the General Services Administration Regional Offices in Boston; New York; Philadelphia; Washington, D.C.; Atlanta; Chicago; Kansas City, Mo; Fort Worth; Houston; Denver; San Francisco; Los Angeles; and Seattle, Wa.

These data files code the first material ignited only and not the materials which contribute to fire spread. When thermal insulation was the first material ignited, its composition was generally cellulosic. Noncellulosic insulation materials accounted for only about 25 percent of the fires classified by specified materials. The intent of this review of fire incidence statistics was not to measure or estimate the magnitude of the problem, inasmuch as the data are uneven in quality, are not statistically representative, and do not reflect the potential future problems associated with retrofit insulation. They are useful, however, in providing an indication of possible patterns of ignition types and sources.

The two most commonly cited ignition sources were "electrical equipment, including short circuits," and "propane torches." These data illustrate the two most significant potential fire scenarios for insulation:

(1) a covered electrical (or heating) device, or a wiring hot spot, may cause smoldering ignition of insulation or ignition of a flammable vapor barrier;

(2) open flame from a plumber's torch, a match, or a spark from an appliance may cause ignition of exposed insulation.

3. RATIONALE AND PROBLEM OUTLINE

A need exists for a meaningful standardized fire test for evaluating attic insulation. The same test should be applicable to all types of insulation used for the same purpose.

Current specifications generally use a surface flame spread test. The rationale for this is not completely clear but probably is based partly on the convenience of using the same standard ASTM E-84 Flame Spread Test [3], which is referenced in most codes for interior wall and ceiling finish; and partly because of a lack of a suitable standard test method for flaming and smoldering ignition, even though ignition is always the first step in the chain of events leading to a major fire.

The fire properties of a material which determine its potential contribution to the start or spread of fire and which may ultimately result in life loss, injury, or property damage are, in estimated order of importance: (a) heat contribution, (b) ignitability (flaming or smoldering), (c) surface flame spread, (d) smoke production, and (e) toxic combustion products. In general, these properties are sensitive to insulation density and to test configuration since they are affected by the airflow patterns and the overall heat transfer.

Thermal insulation comes in several types and forms: boards, blocks, sheets, blankets, batts, felts, loose fill, foamed-in-place or prefoamed sheets. Insulation may be fibrous, closed or open cell, or in composite form to yield high thermal resistance; and it may be used in many places in many types of buildings. For this study we were concerned mainly with its use in the attics of residential dwellings.

In many applications, thermal insulation is left uncovered, where it may be directly exposed to a potential flame or heat source. Typical examples include insulation placed between the ceiling joists or roof rafters in an attic, in crawl spaces, in basement and utility spaces, or on walls or ceilings as a decorative finish. Alternately, thermal insulation may be enclosed in stud wall spaces, in floor or ceiling spaces or in other wall or roof cavities, where it is not likely to be exposed to flame sources, but could be in contact with sources of heat and electricity. In addition, thermal insulation may be temporarily exposed, such as during construction or repair.

In order of priorities, the fire incidence patterns suggest the most likely hazards are: (1) smoldering ignition of insulation in the attic; (2) flame spread along the surface of attic insulation; and (3) ignition plus flame spread along blanket insulation on the walls and ceilings in the basement area. Based on this, the primary emphasis of this evaluation was placed on insulation used in attics.

4. CURRENT TEST METHODS

4.1 Steiner Tunnel Test — ASTM E-84

This test, which is used in Federal Specifications HH-I-515C and HH-I-521E, utilizes a prescribed wire screen to retain loose fill insulation, and steel rods to hold batts and blankets in a ceiling position. The specimen is mounted on the ceiling of a long narrow tunnel and exposed to burner flames at one end, with a prescribed airflow. The flame spread classification (FSC), or rating, is based on the observed extent and speed of flame travel within the 25-ft (7.62 m) long tunnel in comparison to asbestos-cement board (FSC = 0) and red oak lumber (FSC = 100)[3].

The testing laboratory may apply a "correction" to the test result in an effort to account for the presence of the wire screen. The correction is not now a test requirement of ASTM E-84 and not all laboratories use it. Questions and problems which arise in the use of this test method for insulation materials include:

(1) Is the flame spread classification a reasonable comparison tool for all densities and material forms, so that a classification of 100 means the same for a low density cellulosic insulation as for a dense solid wood?

[3] This Standard uses values expressed in U.S. customary units. In this report, U.S. customary units are used where specified and where commonly used.

(2) Does a classification of 25 apply equally to such materials?

(3) The test has been shown to be invalid for low density fire-retardant treated plastic foams, in terms of measuring their contribution to fire growth[4]. Its applicability to and appropriateness for other low-density insulation materials may also be seriously questioned.

(4) Is it valid to test a material in the ceiling of the tunnel to represent its use on the attic floor, particularly when we know that the flame spread phenomenon is different for each position?

(5) Does the correction applied for the wire screen have any validity in relation to the real performance of the insulation?

Finally, neither this test nor any of the other current test methods provides for measurement of smoldering combustion characteristics.

4.2 Floor Mounted Tunnel Test

The inappropriate use of the tunnel test associated with testing a flooring material on the ceiling has been recognized by the Fire Research Section, National Research Council, Ottawa, Canada. Based on their tests, a modification of the E-84 test for loose fill cellulosic insulation has been adopted by the Canadian Standards Association [4]. It is also used for carpeting and other floor coverings. No wire screen is needed to hold the specimen in place. However, this test uses the same 5000 Btu per minute (108 kW) burner with 4-1/2 foot (1.37 m) flame exposure and 240 fpm (73.2 m/min) induced draft within the narrow tunnel apparatus and there is a question as to whether this is applicable to a reasonable fire scenario in an attic.

4.3 "Two Foot" Tunnel Test

This is not a standard fire test method. It is referenced in ASTM C739 [5] and is intended to serve as a low cost screening or quality control test to examine the effects of high temperature and humidity conditioning on cellulosic loose fill insulation.

4.4 Noncombustibility Test — ASTM E-136 [6]

This is a pass/fail test, which does not provide a quantitative or numerical measure of combustibility. It is used in some building codes for defining "noncombustible" materials for use in certain classes of buildings.

[4] Parker, W. J., National Bureau of Standards, private communication.

4.5 Loss of Ignition Test (Sec. 4.4.6 of HH-I-1030A)

This is a pyrolysis and weighing test used for estimating organic content. In HH-I-1030A the exposure pyrolysis temperature is 800°F (427°C), although temperatures as high as 1652°F (900°C) are more commonly used in other specifications.

5. NBS LABORATORY TEST STUDIES

A number of insulation materials meeting the three referenced Federal specifications were obtained from Government and commercial sources. In addition, a few insulation materials which were not identified with any particular specification were also obtained. The materials are listed in table 1. This list was not intended to be extensive or complete and no chemical analyses or other tests were conducted. A fairly extensive review and analysis of loose fill cellulosic insulation was recently published by the Energy Research and Development Administration (ERDA) (now Department of Energy) [7].

5.1 Attic Floor Radiant Panel Test

This test is essentially identical to Federal Test Method No. 372 [8] and to NFPA Standard Test Method No. 253 used for flooring evaluation. The conditions of this test simulate the configuration and the radiant heat exposure which may be experienced by insulation laid on or between attic floor joists, and subjected to a small open flame ignition.

The proposed test, described in appendix B, measures the imposed heat flux at which a fire will no longer propagate flame on the surface of the insulation under the test condition. This is called the critical radiant flux and is a quantitative measure of the ease with which flame propagation may occur on the surface of the test material in the given configuration when subjected to radiation from a heated overhead surface, in this case the attic roof.

The results with the Radiant Panel Test are summarized in table 2. Clearly there is a wide range in test results ranging from no ignition and no flame propagation to extensive flame propagation along the full length of the one meter long specimen. In between there is a gradation in the measured flame travel distances, and for five typical cellulosic loose fill insulations, the values ranged from 49 to >100 cm. These distances correspond to 0.34 to <0.11 W/cm^2, respectively.

The test method has been thoroughly examined for repeatability and reproducibility during its examination for carpets and other floor coverings [9,10]. To further check the reproducibility of the test method when applied

Table 1. Test materials

Designation	Description	Label information	
		Specification	ASTM E-84
G-1	Glass fiber blanket, unfaced R-19, 6 in thick	HH-I-521D Type I	
G-2	Glass fiber blanket, foil faced R-11, 3.5 in thick	HH-I-521E Type III	
G-3	Glass fiber blanket, unfaced "friction fit," 3.5 in thick	HH-I-521D Type I	FSC 20 SD 15 FC 20
G-4	Glass fiber pouring wool		
G-5	Glass fiber blanket, Kraft paper faced, R-30, 9 in thick	HH-I-521E Type II	
G-6	Glass fiber blanket, Kraft paper faced, R-30, 9 in thick	HH-I-521E Type II	
G-7	Glass fiber blanket, Kraft paper faced, R-30, 9 in thick	HH-I-521E Type II	
M-1	Mineral wool, high density pouring wool, minimum density 1.9 lb/ft^2	HH-I-1030A Type I	
P-1	Isocyanurate foam		FSC 25
P-2	Polystyrene foam		
P-3	Polyurethane foam		FSC 30
P-4	Polyurethane foam		
C-1	Cellulosic loose fill, FR		
C-2	Cellulosic loose fill, FR, density 2.2 lb/ft^3, R factor 3.7/in	HH-I-515C	
C-3	Cellulosic loose fill, FR		FSC 35
C-4	Cellulosic loose fill, same as above but 0.5% less FR		FSC 37
C-5	Cellulosic loose fill, untreated		
C-6	Cellulosic loose fill, FR density 2.1 lb/ft^3 R factor 3.8/in	HH-I-515B	FSC 25 SD 0 FC 25
C-7	Cellulosic loose fill, FR, density 2.5 lb/ft^3 R factor 5.0/in	HH-I-515B	
C-8	Cellulosic loose fill, FR, density 2.1 lb/ft^3 R factor 3.7/in	HH-I-515C	FSC 25 SD 0 FC 25
C-9	Cellulosic loose fill, FR,		
C-10	Cellulosic loose fill, untreated		
C-11	Cellulosic loose fill, FR	HH-I-515C	
C-12	Cellulosic loose fill, FR	HH-I-515B	
C-13	Cellulosic loose fill, FR	HH-I-515C Class 25	
C-14	Cellulosic loose fill, FR	HH-I-515C Type I	FSC 20 SD 10 FC 0
C-15	Cellulosic loose fill, FR	ASTM C739-73	

Table 2. Attic floor radiant panel test results

Insulation Designation	Density (lb/ft^3)	Distance Burned (cm)	Critical Radiant Flux (W/cm^2)	Remarks
<u>Glass Fiber</u>				
G-1	0.9	0	>1.0	DNI†
G-2	0.7	0	>1.0	DNI - foil face up
G-3	0.7	0	>1.0	DNI
G-4	1.8	0	>1.0	DNI
G-5	0.8	100*	<0.1*	Paper face up
G-5	0.8	100*	<0.1*	Paper face up - longitudinal slit
G-6		100*	<0.1*	Paper face up
G-6		100*	<0.1*	Paper face up - longitudinal slit
G-7		100*	<0.1*	Paper face up
G-7		100*	<0.1*	Paper face up - longitudinal slit
<u>Mineral Wool</u>				
M-1	3.0	0	>1.0	DNI
<u>Cellular Plastic</u>				
P-1	2.1	0	>1.0	DNI
P-2	1.9	0	>1.0	DNI, melted away from pilot flame
P-3	2.3	48	0.35	
P-4	1.8	54	0.27	
<u>Cellulose Loose-fill</u>				
C-1	3.5	61	0.21	
C-1	3.7	58	0.24	
C-1	5.6	53	0.29	
C-1	7.4	57	0.24	Tamped down to high density
C-1	2.4	58	0.23	Conditioned 22 hrs at 70°F and 65% rh
C-1	3.8	67	0.18	Dried 27 hrs at 180°F
C-2	3.6	60	0.22	
C-2	4.1	54	0.27	
C-2	4.2	61	0.21	Dried 24 hrs at 180°F
C-2	4.7	60	0.22	Dried 24 hrs at 180°F
C-3	3.2	80	0.13	
C-4	3.2	83	0.12	
C-5	2.9	100	<0.1	
C-6	2.2	95	<0.11	
C-6	2.3	94	<0.11	
C-6	2.3	97	<0.11	
C-6	2.5	100	<0.1	Blown in by machine
C-7	2.1	100	<0.1	
C-7	2.9	100	<0.1	
C-7	3.0	100	<0.1	
C-7	3.1	100	<0.1	
C-7	4.4	100	<0.1	
C-8	4.0	68	0.18	
C-8	4.8	57	0.28	
C-9	---	49	0.34	
C-11	3.7	100	<0.1	
C-11	3.8	96	<0.1	
C-12	3.3	100	<0.1	
C-12	3.5	100	<0.1	
C-13	3.0	98	<0.1	
C-13	3.0	100	<0.1	
C-13	3.0	93	<0.11	

† DNI - Did not ignite.

* Represents same results in each of three identical tests.

to cellulose insulation, a commercial test laboratory at our request ran two selected samples of cellulosic insulation in their apparatus, following the recommended procedure. Their results were within 5 percent of the NBS values.

In order to provide a reasonable assurance that flames will not propagate extensively on the insulation as installed in an attic floor, a critical radiant flux level of 0.12 W/cm^2 is suggested. The basis for this choice is given below. The test as carried out on flooring materials provides a distributed radiant heat flux ranging from 0.11 W/cm^2 to 1.1 W/cm^2. In initial studies on insulation materials, the radiant panel test was changed to operate a range of heat flux from 0.03 to 0.35 W/cm^2. Using this heat flux range, the uncertainty in making measurements at or near the proposed critical radiant flux level of 0.12 W/cm^2 may be less. However in the present design it was decided to use the test under the standard flux range now recommended for conventional flooring materials, since this permits operation at a single heat input setting and a single calibration. The possibility of operating the apparatus at an alternate heat flux range in the future may be examined.

Under solar exposure the temperature likely to be reached on the underside of the attic roof, during summer conditions in certain areas of the U.S., ranges up to 71°C (160°F), equivalent to a blackbody irradiance of 0.08 W/cm^2. Taking into account the probability of other heat sources in the attic and the added energy released if a fire starts, a 50 percent safety factor was added. This means that a fire should not propagate in the attic insulation, if the energy delivered to the insulation is less than 0.12 W/cm^2.

It may be noted that for the loose fill cellulosic insulations for which the ASTM E-84 flame spread classifications (FSC) were available from the labels, there was no apparent correlation with the attic floor radiant panel test results. In fact, at least two FSC 25-labeled insulations had a measured critical radiant flux of less than 0.11 W/cm^2.

5.2 Cigarette Smoldering Test

The basic problem was to devise a test method which would (a) provide a reliable index of smolder tendency and permit ratings of all types of (loose fill) insulation over a wide spectrum, (b) involve a minimum of equipment, and (c) be simple and expeditious.

A cigarette was used to initiate smoldering since it is a reasonably uniform and reproducible ignition source. Using one cigarette placed on top of cellulose loose fill insulation or two cigarettes — one on top and one embedded below the surface — it was found that one sample of untreated cellulosic loose fill insulation smoldered and resulted in a significant weight loss (18 percent). One fire retardant treated cellulose loose fill material smoldered considerably more than the untreated paper, giving a weight loss of 41 percent.

Various test parameters were explored. The size of the metal box specimen holder, specimen packing density, and cigarette placement were all found to influence the results. Positioning the cigarette vertically and having it burn downward was found advantageous, being a simpler procedure and yielding a moderately intense exposure with only a single cigarette. The test requires that the lighted cigarette end be placed so that it maintains contact with the insulation. As used, the cigarette is a slowly moving heat source that heats the material under test at an appropriately slow rate for the initiation of smolder. It is not designed to simulate any particular smoldering ignition source, but is rather used as a means for inducing smoldering and evaluating the tendency of the material to continue to smolder. The cigarette might be envisioned as a very small electrical heater of about 3 or 4 watts power with a surface area of about 1 sq cm at a temperature of 600°C to 700°C.

The cigarette smoldering test is described in detail in appendix C. Test results are summarized in table 3. These results indicate that where limited smoldering occurred, it was confined to the area in close proximity to the cigarette and did not result in weight losses in excess of 15 percent; on the other hand, appreciable smoldering resulted in weight losses ranging from 16 percent to over 75 percent. This formed the basis for the recommendation that a weight loss in excess of 15 percent provides a reasonable criteria of appreciable smoldering.

These results also suggest that the smoldering tendency generally increases with increasing density. Since the density of loose fill insulation may increase with vibration and elevated relative humidity, testing should be done at a "settled" density (see section 5.2 of appendix C).

The temperature and humidity conditioning specified (21°C, 50 percent rh) corresponds to standardized laboratory preconditioning of samples. Since this may not account for dehydration or other effects at the elevated temperatures and low humidities possible in attics, further studies appear desirable.

5.3 Mockup Flame Spread Tests

A large mockup of a home attic space was constructed to examine the extent to which flame propagation would occur when the material was mounted in a larger scale simulation and exposed to a small flaming ignition at one end. A 9 ft 4 in by 12 ft (2.84 by 3.66 m) attic floor was constructed of nominal 2 by 6 inch hemlock joists 16 inches on centers. The bottom was covered with a nominal 5/8 inch thick gypsum board "ceiling." This arrangement provided seven parallel floor joist spaces approximately 12 ft (3.66 m) long. A peaked roof section of nominal 3/8 inch plywood sheathing, nominal

Table 3. Smoldering combustion test results

Designation	Density	Weight loss %	Remarks
C-1	2.2	26	
	2.2	18	
	2.2	24	
C-2	2.2	1	
	2.3	1	
	2.3	< 1	
	2.4	< 1	
	2.3*	< 1*	8 mm hole
	2.3	< 1	12 mm hole
	2.3	2	12 mm hole
	2.3*	< 1*	16 mm hole
	2.3*	< 1*	Tapered hole
	1.8	4	
	1.8	16	
	1.8	2	
	2.0	< 1	
	2.0	56	
	2.0	4	
	3.0	28	
	3.0	3	
	3.0	16	
	3.0	45	
	3.0	62	
	3.0	62	
	3.0	3	
	3.0	42	
	3.0	24	
	3.0	34	
	4.0	70	
	4.0	66	
	4.0	68	
C-3	2.1	66	
	2.1	59	
C-5	1.7	42	
C-6	2.1	53	
	2.1	54	
	2.2	53	
	2.2	54	
	3.0	31	
	3.0	28	
	3.0	29	
C-7	2.2	65	
	2.2	65	
C-8	2.1	0	
	2.1	0	
	2.2	< 1	
	2.2	< 1	
	3.0	37	
	3.0	26	
	3.0	38	
	3.0	40	
C-9	2.2	36	
	2.2	47	
C-10	1.7	60	
	1.8	60	
C-11	2.5	52	
	2.5	43	
	2.5	48	
C-12	1.8	65	
	1.8	65	
	1.8	66	
	2.0	68	
	2.0	65	
	2.0	70	
	3.0	75	
	3.0	75	
	3.0	74	
	4.0	77	
	4.0	78	
	4.0	77	
	2.6	56	8 mm hole
	2.6	61	8 mm hole
	2.6	61	8 mm hole
	2.6	58	12 mm hole
	2.6	57	12 mm hole
	2.6	42	12 mm hole
	2.6	1	16 mm hole
	2.6	57	16 mm hole
	2.6	58	16 mm hole
	2.6	58	Tapered hole
	2.6	59	Tapered hole
	2.6	57	Tapered hole
C-13	3.0	60	
	3.0	65	
	3.0	60	
C-14	4.5	64	
	3.0	42	
G-5 paper faced	1.0	0	
P-2	1.8	0	
P-4	1.8	0	

* Represents same results in each of three identical tests.

2 by 6 inch roof rafters, and mineral wool blanket insulation between the rafters was built as a removable subassembly which could be placed to fit over the attic floor assembly. Electrical heating coils were mounted along the top, inside the roof, to generate elevated attic air temperatures, controllable up to 82°C (180°F). A series of five propane burner tips connected through a common manifold was mounted so that the assembly could provide a simultaneous flaming ignition source at the end of each of the five central floor joist spaces. The outer two floor joist spaces were not used.

In one test, the attic air temperature was raised to and maintained at 71°C (160°F), corresponding to an estimated heat flux level of 0.08 W/cm^2 at the top of the joists. The following materials were placed in the joist spaces flush with the top of the joists: G-5 paper exposed, G-5 glass fiber exposed, C-6, C-10 and C-11, cellulosic insulation (see table 1 for descriptions). The cellulosic loose fill materials were applied at a nominal density of 2.5 lb/ft^3 (40 kg/m^3). The glass fiber blanket was tested with the paper facing exposed as well as unexposed since it has been reported that mineral wool blankets are sometimes installed with the facing exposed.

Upon exposure to the flames from the propane burner, there was rapid and extensive spread of flame along the untreated cellulose (C-10) involving flames extending vertically approximately 6 to 12 inches (15 to 30 cm); there was a slow and continuous propagation of short flames along the entire upper surface of C-11. There was a slight flaming involvement and spread away from the burner on the surface of C-6, but the flames did not extend more than 12 in (30 cm) from the burner. The paper-exposed glass fiber ignited and produced 8 to 12 in (20 to 30 cm) tall flames which propagated slowly away from the burner but did not travel the complete joist space. There was very little propagation along the glass-fiber exposed insulation.

In a second test, the same procedure was repeated (with materials C-6, C-10 and C-11, but not material C-5), except the attic air temperature was raised and maintained at 82°C (180°F), corresponding to a heat flux of 0.12 W/cm^2 at the top joist surface level. In this test, the C-10 and C-11 materials propagated flames in a similar manner (but slightly more rapidly), and the C-6 material also propagated flames at a slow rate the full length of the insulated portion of the joist space.

In a third test, the three center joist spaces contained three types of paper-faced glass fiber insulation with the paper facing exposed on top and cut lengthwise in the center to simulate tears in the paper. The attic air temperature was maintained at 71°C (160°F). Upon exposure to the pilot burner flames, there was immediate involvement of the paper facing and flames progressed steadily, primarily along the cut edges. Within 4 minutes, the entire attic space was enveloped in flames.

These tests were conducted with no forced or induced air motion (no vent openings were provided and the roof-air mounted smoke exhaust fan was not actuated). However, it is apparent that propagation of flames along the upper surface of certain loose fill and exposed paper-faced blanket insulation placed in attic floor joists will occur at elevated temperatures and in the presence of a small pilot flame. These tests are a validation of the experimental arrangement and test conditions selected for measuring surface flame propagation in the attic floor radiant panel test.

5.4 Mockup Smoldering Tests

A smaller mockup of a home attic space, consisting of three joist spaces in a 48 by 48 inch (120 by 120 cm) box, was constructed and used for trial and error testing of several possible fire scenarios. The major ones contemplated were:

- Recessed light fixture covered with insulation.
- Other electrical devices (motors, ballasts, junction boxes), heated flue pipes, chimneys, etc. surrounded by insulation.

An initial series of tests confirmed that an overlamped recessed light fixture covered with a sample of R-35 cellulosic loose fill insulation could produce a self-propagating smoldering fire. A sample of glass fiber insulation (R-35) did not produce a smoldering fire in or near the fixture. Tests were also conducted to see if fires would be initiated with thermally insulated, electrically overloaded plastic-jacketed wiring with excessive current overloads. Smoldering fires were initiated at overloads corresponding to 190 to 200 percent of rated current. Further tests were not conducted since the practical limit of overload in a fused circuit is 35 percent.

A second series of tests was conducted using a recessed light fixture centrally located in a 16-inch joist space and covered with insulation. The insulation materials included most of the materials previously subjected to the cigarette smoldering test. The material was blown into the joist spaces using a commercial blowing machine. The results are shown in table 4. It should be noted that the smoldering reaction is slow and generally requires several hours before the reaction reaches the stage where considerable smoke is generated and where the heating of the joists starts to take place. Using a 150-W bulb in a fixture rated for 100 W produced smoldering ignition of seven of the eight materials tested. Using a 100-W bulb with 9-1/4 inches (23.5 cm) of cellulosic loose fill insulation did not produce smoldering ignition. The cigarette smoldering test produced extensive smoldering (more than 15% weight loss) in five of the eight materials tested. Thus, these results indicate a strong likelihood that smoldering ignitions will occur

Table 4. Mockup smoldering combustion tests

Material	Cigarette test			Recessed light fixture					
				150 W bulb			100 W bulb		
	Density (lb/ft^3)	Weight loss (%)	Result P=Pass F=Fail	Density (lb/ft^3)	R value	Result	Density (lb/ft^3)	R value	Result
C-1	2.2	23	F	2.9	56	F			
C-2	2.3	1	P	2.2	34	F	2.2	34	P
C-3	2.1	62	F	2.5	50	F			
C-5	1.7	42	F						
C-6	2.1	54	F	2.3	55	F	2.2	35	P
C-7	2.2	65	F				2.2	46	P
C-8	2.1	0	P	2.3 3.3	34 45	F F			
C-9	2.2	42	F						
C-10	1.7	60	F	2.0	54	F			
C-11	2.0	68	F	3.1	55	F	2.2	36	P
C-15	2.2	0	P	2.2	36	P			

Note: "P" indicates less than 15% weight loss in cigarette test and no extensive smoldering in light fixture test.
"F" indicates a weight loss of 15% or more in cigarette test and extensive smoldering in light fixture test.

where cellulose loose fill insulation is applied directly over overlamped recessed light fixtures. Also the simple cigarette smoldering test will screen out many, but probably not all, materials which will permit the propagation of smoldering in a recessed light fixture scenario which might be encountered in residential use.

6. SUMMARY AND CONCLUSIONS

6.1 Insulation intended for use in residential applications should be tested and rated for those properties which measure its tendency to be a principal source or contributor to fire. As a minimum, insulation intended for use in attics should be tested for tendency to smolder, and tendency to propagate open flaming under radiant heat exposure.

6.2 The complete insulation assembly should be tested in the form in which it is intended to be used or in which it may reasonably be expected to be used. Based on the results in section 5.3, it is suggested that HH-I-521E be revised to remove the current exclusion on testing of the membrane covering on the insulation blanket in view of known experience with the insulation being used with the paper face exposed, unless adequate measures can be devised to guarantee against this application.

6.3 Tests have shown that attic floor insulation materials which propagate flames over the entire length of the specimen surface in the attic flooring radiant panel test will also result in surface flame propagation in an attic floor construction assembly under conditions simulated by the test. Likewise, materials which permit the propagation of smoldering in the simple cigarette smoldering test will result in the propagation of smoldering in insulation applied directly over a typical (but overlamped) recessed light fixture, a condition which may reasonably be expected to be encountered in residential use.

6.4 Federal specifications for the three types of materials should be revised to incorporate more appropriate heat and flame exposure tests. For the three particular specifications under discussion, the recommended test methods are the Attic Floor Radiant Panel Test and a cigarette smoldering test.

> To allow for the elevated temperatures likely to be reached in attics and the presence of flaming ignition sources, a critical radiant flux of 0.12 W/cm^2 measured in the Attic Floor Radiant Panel Test is the minimum suggested level.

In the Smoldering Combustion Test, it is suggested that a suitable criterion is a weight loss of less than 15 percent of the initial weight with no evidence of flaming combustion.

In addition, all insulation should be labeled to indicate (a) conformance with the specifications and (b) cautions about fire dangers if applied improperly.

7. ACKNOWLEDGMENTS

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R. McCarter	-	Cigarette Smoldering Test
B. Buchbinder	-	Fire Statistics
W. H. Bailey D. Evans T. Prather J. S. Steel	-	Assembling Apparatus, Preparation of Specimens, Conducting Fire Tests

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[3] Standard Test Method for Surface Burning Characteristics of Building Materials, ASTM E-84-77, American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pa. 19103.

[4] Standard method of test for surface burning characteristics of flooring, Floor Covering and Miscellaneous Materials, ULC-S102.2-1977, Underwriters' Laboratories of Canada, 7 Crouse Rd., Scarborough, Ontario.

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APPENDIX A. FIRE INCIDENT DATA ON THERMAL INSULATION

A review and analysis was made of available data on fire incidents involving thermal insulation for two principal reasons: first, to get some feeling for the magnitude of the current home insulation fire problem and second, to describe the typical scenarios for fires involving insulation. Although this review was made, we were aware that the current retrofit movement is new, and particularly the home-owner application, so that existing statistics would be inadequate to reflect what might be a new and serious problem.

There are the following limitations on what can be learned from the data:

1. Current data do not at all reflect the potential problems from retrofit of extra amounts of insulation in homes. This might bring flammable insulation closer to potential ignition sources, reduce available air for cooling of fixtures and wiring, etc.

2. The data bases available to us are the National Fire Protection and Control Administration (NFPCA) National Fire Incident Reporting System (NFIRS) and the NFPA Field Incident Data Organization (FIDO). Both of these data bases identify only the first material ignited. We get no information on fires wherein insulation may play a significant role in fire growth, although another material is ignited first.

3. NFIRS is not yet national, and the data cover one year (1975) for California and five quarters (1976 and 1st quarter 1977) for Ohio.

The data available include a listing of 496 incidents from NFIRS, and 28 incidents from FIDO. The NFIRS data covers all incidents reported in residential occupancies (NFPA 901 codes in 400 series of fixed property) where "thermal, acoustical insulation within wall, partition, or floor/ ceiling space" (code 18 for form of material ignited) was the first material ignited (FMI). The 28 incidents from FIDO cover five years of reports on "serious fires." The FIDO system is heavily biased toward large loss or fatal fires.

The typical fires reported may be described by looking at the composition of the insulation and the ignition source. Each of these factors is represented by two data elements in NFIRS. The "first material ignited (FMI)" is described. In addition to the FMI, there is a data element entitled "type of material ignited (TMI)." The TMI for these insulation cases is tabulated in table A1. We see that fiberboard is identified 18 percent of the time, with other cellulosic categories heavily represented. These materials include most of the cellulose-based insulations. Note that the wood/paper total (code 69) should be added to the totals for the more specific categories such as 63, 65 and 67. We see that cellulose-base materials (e.g. wood, paper) play a significant role as the first material ignited.

The ignition source is defined by two data elements, "equipment involved in ignition" and "form of heat of ignition (FHI)." The distribution of the FHI code for our NFIRS cases is shown in table A2. Short circuits, at 27 percent, is the single largest category. When combined with the remainder of the "heat from electrical equipment" category, the 20-29 group of codes accounts for 37 percent of the total.

"Torches and open flames" (codes 40-49) represent 23 percent of the cases. Within this category, torches alone total 82 cases (18%), with plumber's torches comprising 69 of these (15%). Some other subtotals of interest include 21 "electric lamp or bulb" cases (5%), 16 "properly operating electrical equipment" cases (3%), seven cases for matches, and seven cases for lightning.

The 28 FIDO cases encompassed mobile property (mobile homes, travel trailers) in addition to the 400 code series for fixed property. Plumber's torches (13) and short circuits (9) were the only FHI codes to appear more than once. For TMI, 10 of the cases had either "fiberglass," "paper on fiberglass," or "paper on insulation" listed. Four cases listed fiberboard. There were only three other cases with TMI listed, two were "straw," one was "plastic."

In terms of occupancy, the FIDO cases were classified as follows:

Mobile homes	-	9
Apartments	-	6
Travel trailers	-	5
Single family dwellings	-	4
Hotel	-	1
Dormitory	-	1
Motor home	-	1
Recreational vehicle	-	1

Table A1. Distribution of NFIRS insulation by type of material ignited

Form of material	Codes	Cases: Number	Cases: Percentage
Fiberboard	66	86	18
Wood	63,65	72	15
Untreated paper	67	43	9
Fabric (man made fiber)	71	39	8
Wood/paper	69	37	8
Plastic	45,59	26	5
Rubber	51	21	4
Treated paper	83	17	3
Other	--	60	12
Unclassified	--	90	18
Total		491	100

Table A2. Distribution of NFIRS insulation incidents by form of heat of ignition

Form of heat of ignition	Codes	Cases: Number	Cases: Percentage
Short circuit	21-24	125	27
Torches and open flames	40-49	105	23
Sparks and heat from gas, liquid and solid fueled equipments	10-19	86	19
Heat from hot object	50-59	75	16
Heat from electrical equipment, excluding short circuits	20,25-29	48	10
Other	---	24	5
Total		463	100

APPENDIX B.

STANDARD METHOD OF TEST FOR CRITICAL RADIANT FLUX OF EXPOSED ATTIC FLOOR INSULATION USING A RADIANT HEAT ENERGY SOURCE

1. Scope

1.1 This method of test describes a procedure for measuring the critical radiant flux of exposed attic floor insulation subjected to a flaming ignition source in a graded radiant heat energy environment, in a test chamber. The test specimen may consist of loose-fill insulation, insulation batts, foam board insulation, or other form intended for the purpose.

1.2 This method measures the critical radiant flux at flame-out. It provides a basis for estimating one aspect of fire exposure behavior for attic floor insulation. The imposed radiant flux embraces the thermal radiation levels likely to impinge on the floor of an attic whose upper surfaces are heated by solar radiation and exposed to an open flame.

2. Summary of Method

2.1 The basic elements of the test chamber (figure B1) are: 1) an air-gas fueled radiant heat energy panel inclined at 30° and directed at 2) a horizontally-mounted attic floor insulation specimen (figure B2). The radiant panel generates a radiant energy flux distribution ranging along the 100-cm length of the test specimen from a nominal maximum of 1.0 W/cm^2 to a minimum of 0.1 W/cm^2. The test is initiated by open flame ignition from a pilot burner. The distance burned to flame-out is converted to W/cm^2 from the flux profile graph (figure B8) and reported as <u>critical radiant flux</u>, W/cm^2.

3. Significance

3.1 This method of test is designed to provide a basis for estimating one aspect of the fire exposure behavior of an attic floor insulation in a building attic. The test environment is intended to simulate conditions that have been observed and defined in full-scale attic experiments.

3.2 The test is intended to be suitable for regulatory purposes, specification acceptance, design purposes, or development and research.

3.3 The fundamental assumption inherent in the test is that "critical radiant flux" is one measure of the sensitivity to flame spread of attic floor insulation installed in a building attic.

3.4 The test is applicable to attic floor insulation specimens installed by acceptable installation practice.

4. Definition of Terms

4.1 <u>Critical Radiant Flux</u> is the level of incident radiant heat energy on the attic floor insulation system at the most distant flame-out point. It is reported in W/cm^2.

4.2 <u>Flux Profile</u> is the curve relating incident radiant heat energy on the specimen plane to distance from the point of initiation of flaming ignition, i.e., 0 cm.

4.3 <u>Total Flux Meter</u> is the instrument used to measure the level of radiant heat energy incident on the specimen plane at any point.

4.4 Black Body Temperature is the temperature of a perfect radiator - a surface with an emissivity of unity and, therefore, a reflectivity of zero.

5. Radiant Panel Test Chamber - Construction and Instrumentation

5.1 The radiant panel test chamber employed for this test shall be located in a draft-protected laboratory.

5.1.1 The radiant panel test chamber, figures B3 and B4, shall consist of an enclosure 140 cm (55 in) long by 50 cm (19-1/2 in) deep by 71 cm (28 in) above the test specimen. The sides, ends and top shall be of 1.3 cm (1/2 in) calcium silicate board, such as Marinite XL, 0.74 g/cm^3 (46 lbs/ft^3) nominal density, with a thermal conductivity @ 93°C (200°F) of 0.0011 W/cm °C (0.77 Btu-in/hr ft^2 °F). One side shall be provided with an approximately 10 cm x 110 cm (4 x 44 in) draft tight fire resistance glass window so that the entire length of the test specimen may be observed from outside the fire test chamber. On the same side and below the observation window is a door which, when open, allows the specimen platform to be moved out for mounting or removal of test specimens. A draft tight fire resistant observation window may be installed at the low flux end of the chamber.

5.1.2 The bottom of the test chamber shall consist of a sliding steel platform which has provisions for rigidly securing the test specimen holder in a fixed and level position. The free, or air access, area around the platform shall be in the range of 1950-3550 cm^2 (300-500 sq in).

5.1.3 The top of the chamber shall have an exhaust stack with interior dimensions of 12.5 cm (5 in) wide by 38 cm (15 in) deep by 30 cm (12 in) high at the opposite end of the chamber from the radiant energy source.

5.2 The radiant heat energy source shall be a panel of porous refractory material mounted in a cast iron frame, with a radiation surface of 30.5 x 45.7 cm (12 by 18 in). It shall be capable of operating at temperatures up to 816°C (1500°F). The panel fuel system shall consist of a venturi-type aspirator for mixing gas and air at approximately atmospheric pressure, a clean dry air supply capable of providing 28.3 NTP m^3 per hr (1000 Standard Cubic Feet per Hour) at 7.6 cm (3.0 in) of water, and suitable instrumentation for monitoring and controlling the flow of fuel to the panel.

5.2.1 The radiant heat energy panel is mounted in the chamber at 30° to the horizontal specimen plane. The horizontal distance from the 0 mark on the specimen fixture to the bottom edge (projected) of the radiating surface of the panel is 8.9 cm (3-1/2 in). The panel to specimen vertical distance is 14 cm (5-1/2 in) (see figure B3). The angle and dimensions given above are critical in order to obtain the required radiant flux.

5.2.2 The radiation pyrometer for standardizing the thermal output of the panel shall be suitable for viewing a circular area 25.4 cm (10 in) in diameter at a range of about 1.37 m (54 in). It shall be calibrated over the black body temperature range of 490-510°C (914-950°F) in accordance with the procedure described in appendix A.

5.2.3 A high impedance potentiometer with a suitable millivolt range shall be used to monitor the output of the radiation pyrometer described in 5.2.2.

5.3 The dummy holder (see figure B5), is constructed from heat-resistant stainless steel[1] having overall dimension of 115 cm (45 in) by 32 cm (12-3/4 in) with a specimen opening of 20 cm (7.9 in) x 100 cm (40 in). Six slots are cut in the flange on either side of the holder to reduce warping. The holder is fastened to the platform with two stud bolts at each end.

[1] AISI Type 300 (UNA-N08330) or equivalent, thickness 0.198 cm (0.078 in).

5.4 The specimen tray (see figure B6) is constructed from heat-resistant stainless steel[1] having overall dimensions of 110 cm (43.3 in) by 27.3 cm (10.8 in); the depth of the tray is 5 cm (2 in). The flanges of the specimen tray are drilled to accommodate two stud bolts at each end; the bottom surface of the flange is 2.1 cm (0.83 in) below the top edge of the specimen tray.

5.5 The pilot burner, used to ignite the specimen, is a commercial propane venturi torch[2] with an axially symmetric burner tip having a propane supply tube with an orifice diameter of 0.0076 cm (0.003 in). In operation, the propane flow is adjusted to give a pencil flame blue inner cone length of 1.3 cm (1/2 in). The pilot burner is positioned so that the flame generated will impinge on the centerline of the specimen at the 0 distance burned point at right angles to the specimen length (see figures B3 and B4). The burner shall be capable of being swung out of the ignition position so that the flame is horizontal and at least 5 cm (2 in) above the specimen plane.

5.6 Two 0.32 cm (1/8 in) stainless steel sheathed grounded junction chromel alumel thermocouples[3] are located in the Flooring Radiant Panel Test Chamber (see figures B3 and B4). The chamber thermocouple is located in the longitudinal central vertical plane of the chamber 2.5 cm (1 in) down from the top and 10 cm (4 in) back from the inside of the exhaust stack. The exhaust stack thermocouple is centrally located 15.2 cm (6 in) from the top.

5.6.1 An indicating potentiometer with a range of 100-500°C (212-932°F) may be used to determine the chamber temperatures prior to a test.

5.7 An exhaust duct with a capacity of 28.3-85 NTP m^3 per minute (1000-3000 SCFM) decoupled from the chamber stack by at least 7.6 cm (3 in) on all sides and with an effective area of the canopy slightly larger than the plane area of the chamber with the specimen platform in the out position is used to remove combustion products from the chamber. With the panel turned on and the dummy specimen in place, there should be no measurable difference in air flow through the chamber stack with the exhaust on or off.

5.8 The dummy specimen which is used in the flux profile determination shall be made of 1.9 cm (3/4 in) inorganic 0.74 g/cm^3 (46 lbs/ft^3) nominal density calcium silicate board, such as Marinite XL (see figure B5). It is 25 cm (10 in) wide by 107 cm (42 in) long with 2.7 cm (1-1/16 in) diameter holes centered on and along the centerline at the 10,20,30, ..., 90 cm locations, measured from the maximum flux end of the specimen.

5.8.1 The total heat flux transducer used to determine the flux profile of the chamber in conjunction with the dummy specimen should be of the Schmidt-Boelter[4] type, have a range of 0-1.5 W/cm^2 (0-1.32 Btu/ft^2 s), and shall be calibrated over the operating flux level range of 0.10 to 1.5 W/cm^2 in accordance with the procedure outlined in Annex A. A source of 15-25°C cooling water shall be provided for this instrument.

5.8.2 A high impedance or potentiometric voltmeter with a range of 0-10 m.v. and reading to 0.01 m.v. shall be used to measure the output of the total heat flux transducer during the flux profile determination.

5.9 A timer shall be conveniently mounted on the chamber for measuring preheat and pilot contract time.

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[1]ANSI Type 300 (UNA-N08330) or equivalent, thickness 0.198 cm (0.078 in).

[2]BERNZ-O-MATIC TX 101 or equivalent.

[3]Thermocouples should be kept clean to insure accuracy of readout.

[4]Medtherm 64-2-20 will meet this requirement.

6. Safety Procedures

6.1 The possibility of a gas-air fuel explosion in the test chamber should be recognized. Suitable safeguards consistent with sound engineering practice should be installed in the panel fuel supply system. These may include one or more of the following: (1) a gas feed cut-off activated when the air supply fails, 2) a fire sensor directed at the panel surface that stops fuel flow when the panel flame goes out, 3) a commercial gas water heater or gas-fired furnace pilot burner control thermostatic shut-off which is activated when the gas supply fails or other suitable and approved device. Manual reset is a requirement of any safeguard system used.

6.2 In view of the potential hazard from products of combustion, the exhaust system must be so designed and operated that the laboratory environment is protected from smoke and gas. The operator should be instructed to minimize his exposure to combustion products by following sound safety practice, e.g., insure exhaust system is working properly, wear appropriate clothing including gloves, et al.

7. Sampling

7.1 The samples selected for testing shall be representative of the product.

7.2 Standard ASTM sampling practice shall be followed where applicable, see ASTM Method E-122.

8. Test Specimens

8.1 The test specimen shall be attic floor insulation of sufficient size to fill the specimen tray to a depth of 5 cm (2 in).

8.2 Insofar as possible, the attic floor insulation specimen should simulate actual installation practice. Typical examples follow:

8.2.1 Loose-fill insulation blown in to fill the tray, then carefully screeded to provide a depth of 5 cm in the tray.

8.2.2 Loose-fill insulation poured in to fill the tray, then carefully screeded to provide a depth of 5 cm in the tray.

8.2.3 Insulation batts sliced to a depth of 5 cm and cut to fit into the tray.

8.2.4 Foam board insulation cut to fit into the tray to a depth of 5 cm.

8.3 A minimum of three specimens per sample shall be tested.

8.4 The density of the specimen tested shall be determined by weighing the specimen tray just prior to testing.

9. Radiant Heat Energy Flux Profile Standardization

9.1 In a continuing program of tests, the flux profile shall be determined not less than once a week. Where the time interval between tests is greater than one week, the flux profile shall be determined at the start of the test series.

9.2 Mount the dummy specimen in the mounting frame and attach the assembly to the sliding platform.

9.3 With the sliding platform out of the chamber, ignite the radiant panel. Allow the unit to heat for one hour. The pilot burner is off during this determination. Adjust the fuel mixture to give an air-rich flame. Make fuel flow settings to bring the panel to an apparent black body temperature as measured by the radiation pyrometer, of about 500°C (932°F), and the chamber temperature to about 180°C (356°F). When equilibrium has been established, move the specimen platform into the chamber.

9.4 Allow 0.5 hours for the closed chamber to equilibrate.

9.5 Measure the radiant heat energy flux level at the 40 cm point with the total flux meter instrumentation. This is done by inserting the flux meter in the opening so that its detecting plane is 0.16-0.32 cm (1/16-1/8 in) above and parallel to the plane of the dummy specimen and reading its output after 30 $\pm$ 10 seconds. If the level is within the limits specified in 9.6 the flux profile determination is started. If it is not, make the necessary adjustments in panel fuel flow. A suggested flux profile data log format is shown in figure B7.

9.6 The test shall be run under chamber operating conditions which give a flux profile as shown in figure B8. The radiant heat energy incident on the dummy specimen shall be between 0.87 and 0.95 W/cm^2 (0.77 and 0.83 Btu/ft^2 sec) at the 20 cm point, between 0.48 and 0.52 W/cm^2 (0.42 and 0.46 Btu/ft^2 sec) at the 40 cm point and between 0.22 and 0.26 W/cm^2 (0.19 and 0.23 Btu/ft^2 sec) at the 60 cm point.

9.7 Insert the flux meter in the 10 cm opening following the procedure given in 9.5 above. Read the m.v. output at 30 $\pm$ 10 seconds and proceed to the 20 cm point. Repeat the 10 cm procedure. The 30 - 90 cm flux levels are determined in the same manner. Following the 90 cm measurement, make a check reading at 40 cm. If this is within the limits set forth in 9.6, the test chamber is in calibration and the profile determination is completed. If not, carefully adjust fuel flow, allow 0.5 hours for equilibrium and repeat the procedure.

9.8 Plot the radiant heat energy flux data as a function of distance along the specimen plane on rectangular coordinate graph paper. Carefully, draw the best smooth curve through the data points. This curve will hereafter be referred to as the flux profile curve.

9.9 Determine the open chamber apparent black body and chamber temperatures that are identified with the standard flux profile by opening the door and moving the specimen platform out. Allow 0.5 hours for the chamber to equilibrate. Read the radiation pyrometer output and record the apparent black body temperature in °C. This is the temperature setting that can be used in subsequent test work in lieu of measuring the radiant flux at 20 cm, 40 cm, and 60 cm using the dummy specimen. The chamber temperature also should be determined again after 0.5 hours and is an added check on operating conditions.

10. Conditioning

10.1 Test specimens are to be conditioned to equilibrium or a minimum of 48 hours, whichever is greater, at 21 ± 3°C (69.8 ± 5.4°F) and a relative humidity of 50 ± 5 percent immediately prior to testing.

11. Test Procedure

11.1 With the sliding platform out of the chamber, ignite the radiant panel. Allow the unit to heat for one hour[5]. Read the panel apparent black body temperature and the chamber temperature. If these temperatures are in agreement to within ±5°C with those determined in accordance with 9.9 above, the chamber is ready for use.

11.2 Mount the specimen tray on the sliding platform and position with stud bolts (see figure B9).

11.3 Ignite the pilot burner, move the specimen into the chamber, and close the door. Start the timer. After 2 minutes preheat, with the pilot burner on and set so that the flame is horizontal and 5 cm above the specimen, bring the pilot burner flame into contact with the center of the specimen at the 0 cm mark. Leave the pilot burner flame in contact with the specimen for 5 minutes, then remove to a position 5 cm above the specimen and leave burning until the test is terminated.

11.4 If the specimen does not ignite within 5 minutes following pilot burner flame application, the test is terminated by extinguishing the pilot burner flame. For specimens that do ignite, the test is continued until the flame goes out. Observe and record significant phenomena, such as discoloration, charring, smoldering, etc.

11.5 When the test is completed, the door is opened, the specimen platform is pulled out.

11.6 Measure the distance burned, i.e., the point of farthest advance of the flame front, to the nearest 0.1 cm. From the flux profile curve, convert the distance to W/cm^2 critical radiant heat flux at flame out. Read to two significant figures. A suggested data log format is shown in figure B10.

11.7 Remove the specimen tray from the moveable platform.

11.8 The succeeding test can begin as soon as the panel apparent black body temperature and chamber temperature are verified (see 11.1). The specimen tray should be at room temperature prior to insertion of the next specimen.

12. Report

12.1 The report include the following:

12.1.1 Description of the attic floor insulation.

12.1.2 Description of the procedure used to prepare the floor insulation specimen.

---

[5]It is recommended that a sheet of inorganic millboard be used to cover the opening when the hinged portion of the front panel is open and the specimen platform is moved out of the chamber. The millboard is used to prevent heating of the specimen and to protect the operator.

12.1.3 Number of specimens tested, including critical radiant flux and density for each specimen as tested.

12.1.4 Observations of the burning characteristics of the specimen, such as discoloration, charring, smoldering, etc.

ANNEX A

PROCEDURE FOR CALIBRATION OF RADIATION INSTRUMENTATION

A1. Radiation Pyrometer

A1.1 Calibrate the radiation pyrometer by means of a conventional black body enclosure placed within a furnace and maintained at uniform temperatures of 490, 500, and 510°C (914, 932, 950°F). The black body enclosure may consist of a closed chromel metal cylinder with a small sight hole in one end. Sight the radiation pyrometer upon the opposite end of the cylinder where a thermocouple indicates the black body temperature. Place the thermocouple within a drilled hole and in good thermal contact with the black body. When the black body enclosure has reached the appropriate temperature equilibrium, read the output of the radiation pyrometer. Repeat for each temperature.

A2. Total Heat Flux Meter

A2.1 The total flux meter shall be calibrated by the National Bureau of Standards[1], or alternatively, its calibration shall be developed by transfer calibration methods with an NBS calibrated flux meter. This latter calibration shall make use of the radiant panel tester as the heat source. Measurements shall be made at each of the nine dummy specimen positions and the mean value of these results shall constitute the final calibration.

A2.2 It is recommended that each laboratory maintain a dedicated calibrated reference flux meter against which one or more working flux meters can be compared as needed. The working flux meters should be calibrated according to the procedure of A2.1 at least once per year.

---

[1] Direct requests for such calibration services to the: Optical Radiation Section, 232.04, National Bureau of Standards, Washington, D.C. 20234.

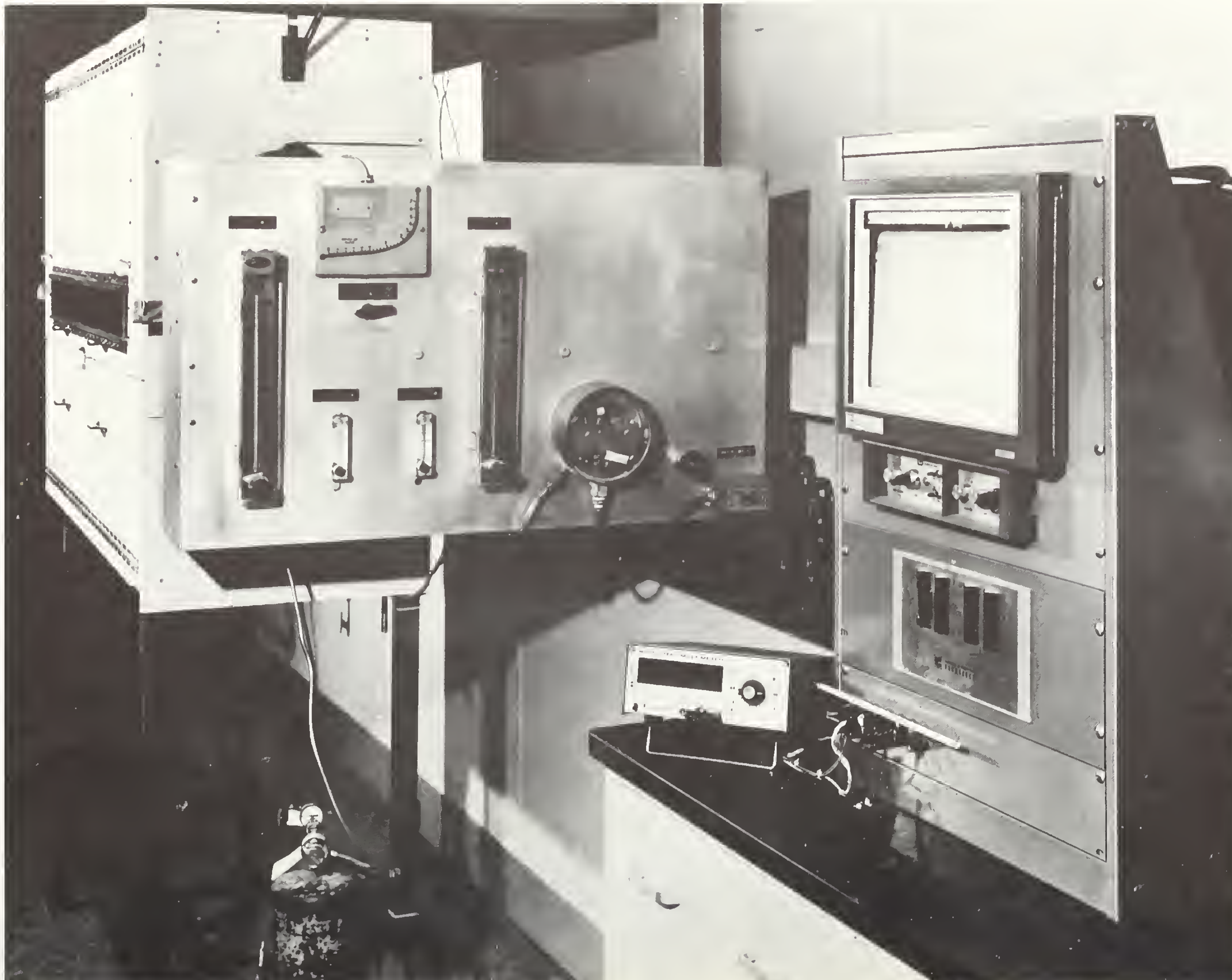

Figure B1. Radiant panel test chamber

Figure B2. Horizontally-mounted attic floor insulation specimen

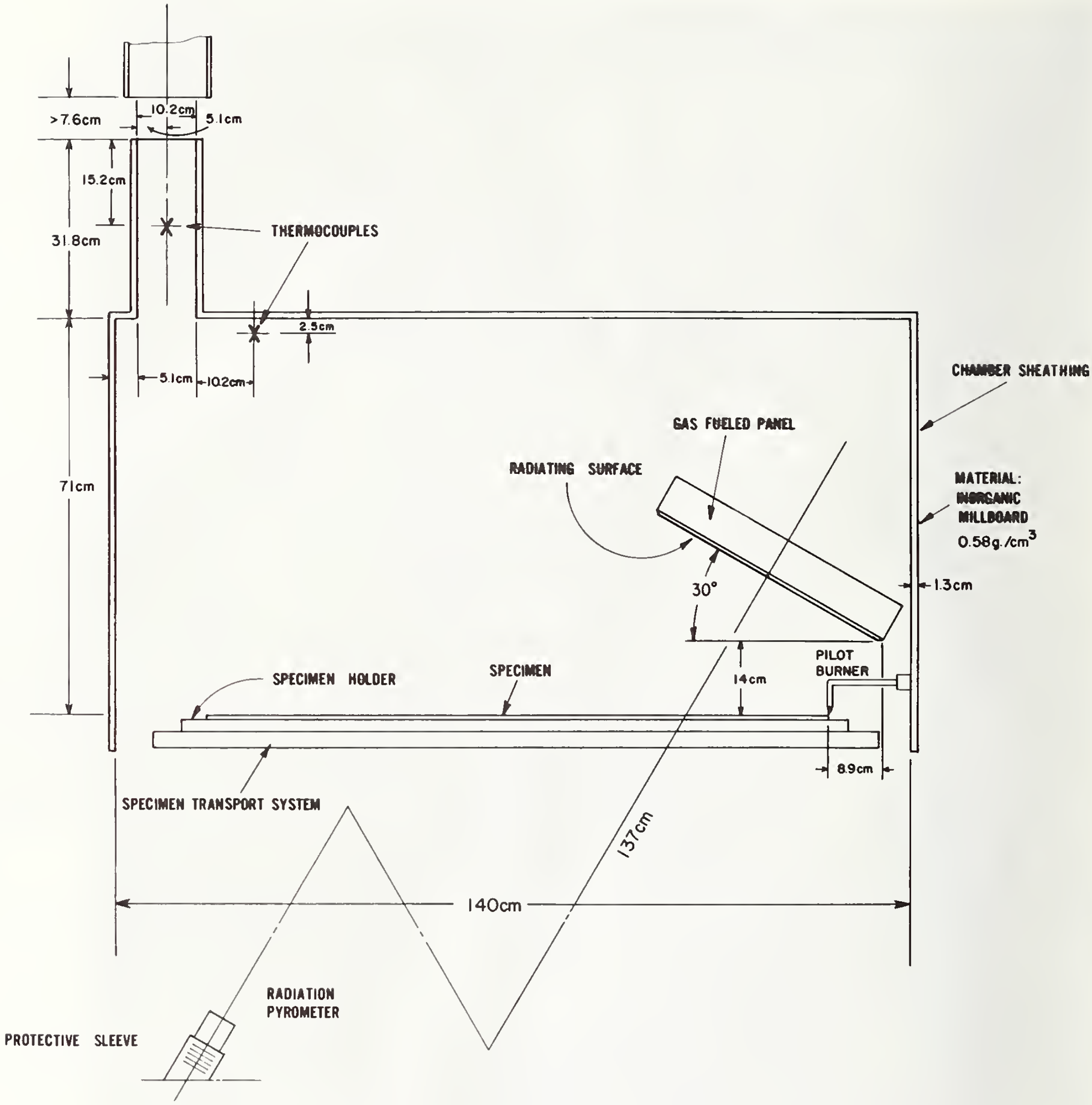

Figure B3. Flooring radiant panel tester schematic - side elevation

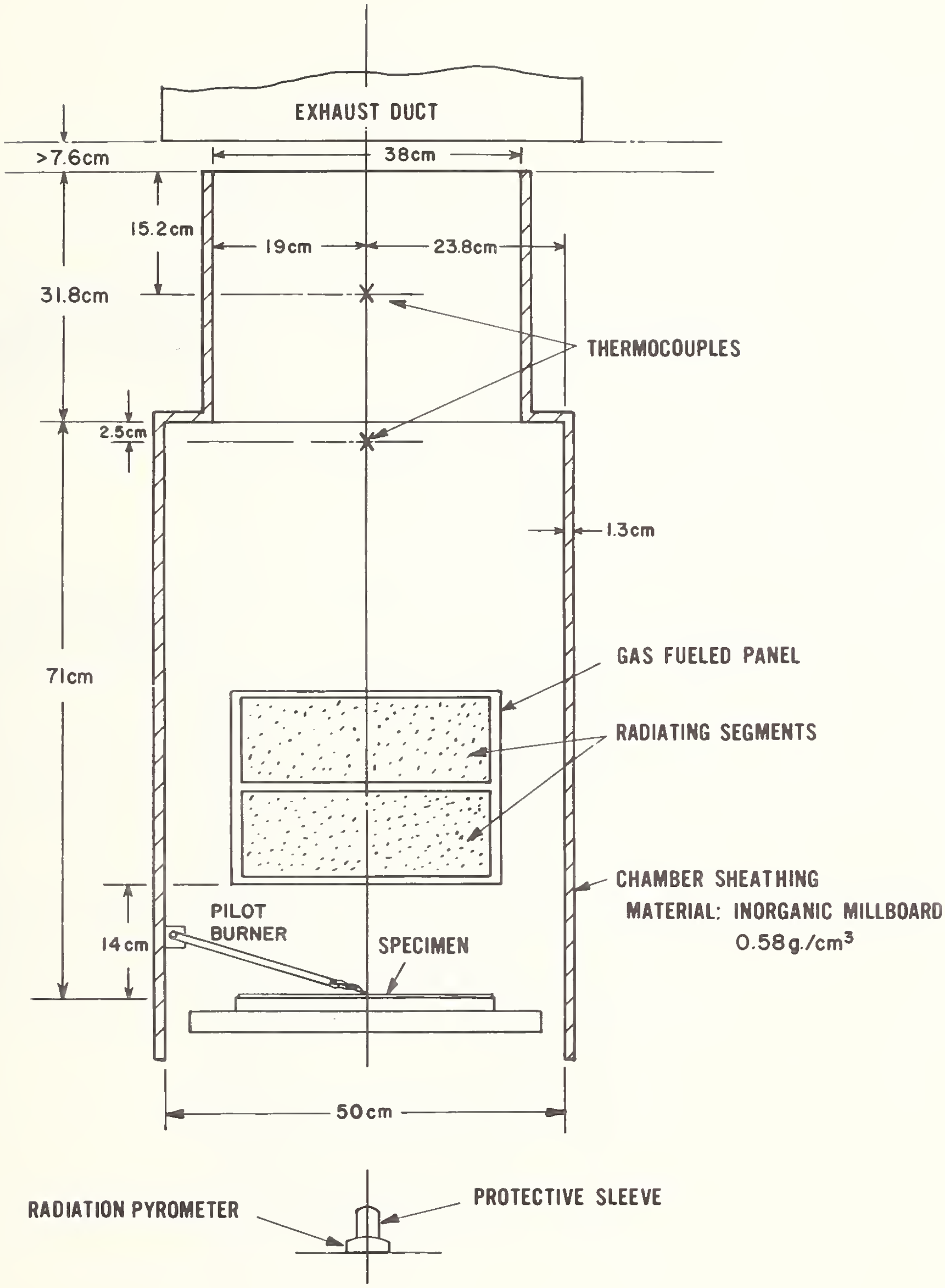

Figure B4. Flooring radiant panel tester schematic - low flux end, elevation

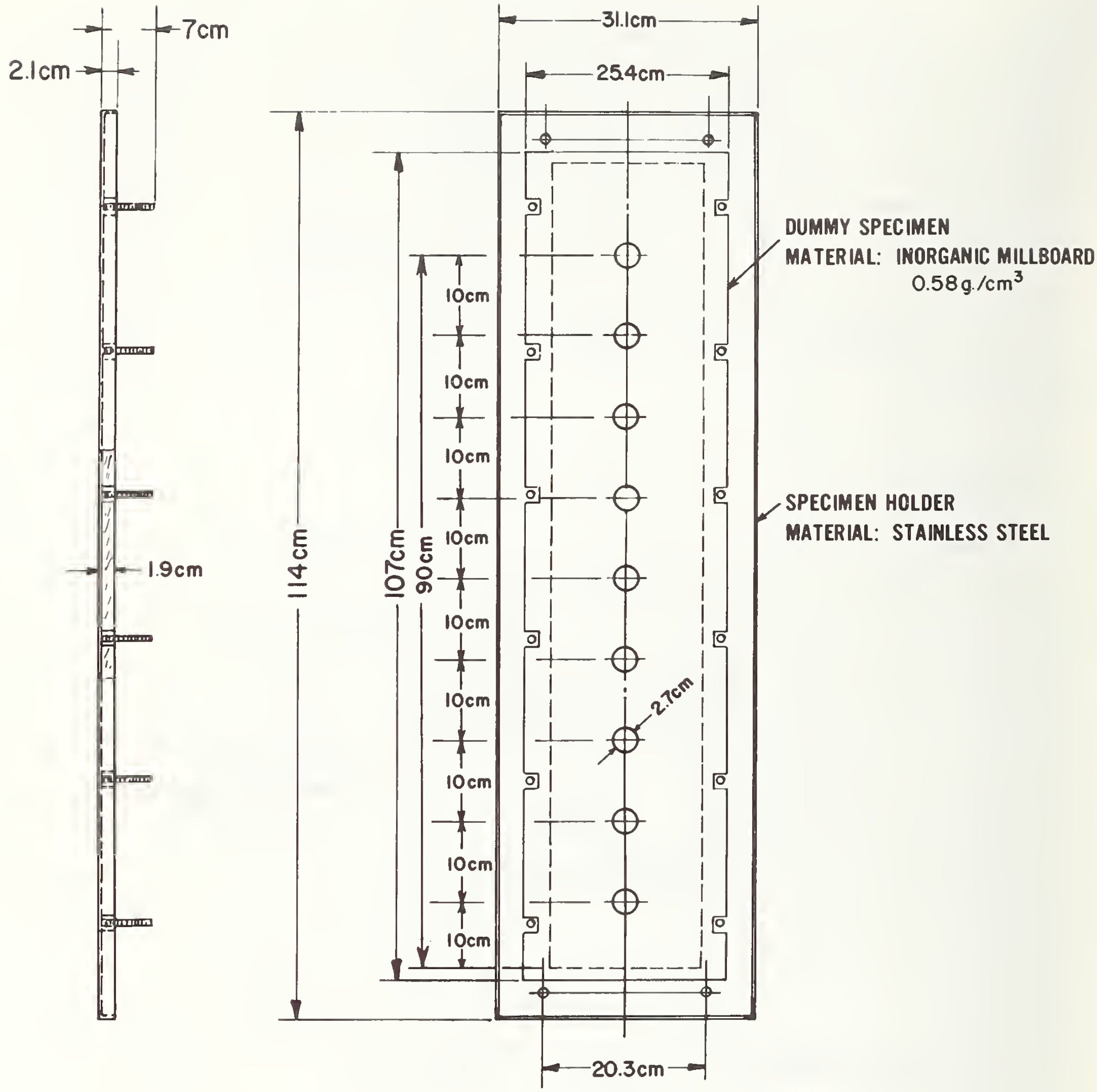

Figure B5. Dummy specimen holder

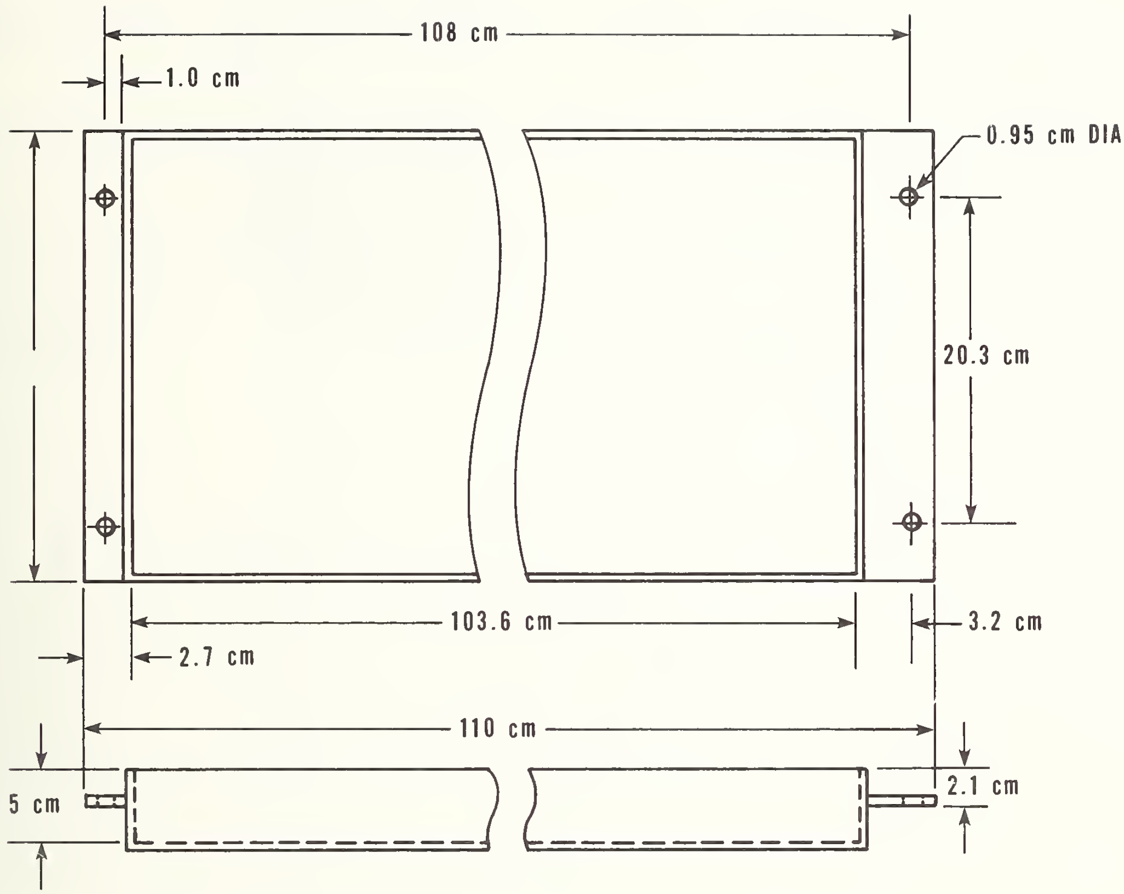

Figure B6. Specimen tray

RADIANT FLUX PROFILE

Date____________________

Black Body Temperature _______________m.v.   _______________°C (°F)

Gas Flow______________NTPm^{3}H (SCFH)   Air Flow______________NTPm^{3}H (SCFH)

Room Temperature________________°C (°F)

Air Pressure____________________   Gas________________cm (in) of H_2O

Flux Meter   Conversion Factor________________

Radiometer No.____________________   from Calibration on_______________

Distance (cm)	MV	Watts/cm^2
10	________	________
20	________	________
30	________	________
40	________	________
50	________	________
60	________	________
70	________	________
80	________	________
90	________	________

Signed_________________________________

Figure B7. Flux profile data log format

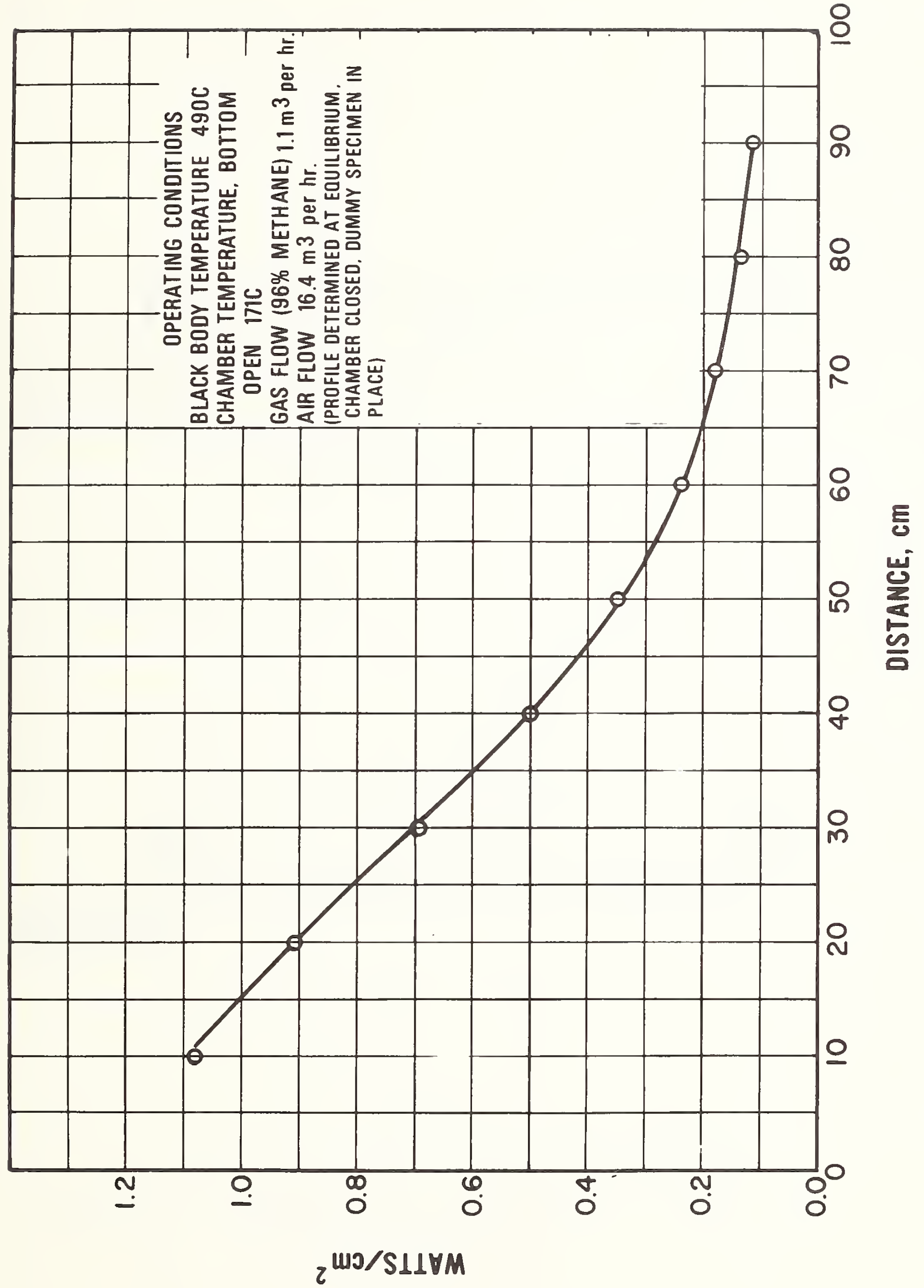
OPERATING CONDITIONS
BLACK BODY TEMPERATURE 490C
CHAMBER TEMPERATURE, BOTTOM OPEN 171C
GAS FLOW (96% METHANE) 1.1 m3 per hr.
AIR FLOW 16.4 m3 per hr.
(PROFILE DETERMINED AT EQUILIBRIUM, CHAMBER CLOSED, DUMMY SPECIMEN IN PLACE)
WATTS/cm2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
DISTANCE, cm
0
10
20
30
40
50
60
70
80
90
100

Figure B8. Standard radiant heat energy flux profile

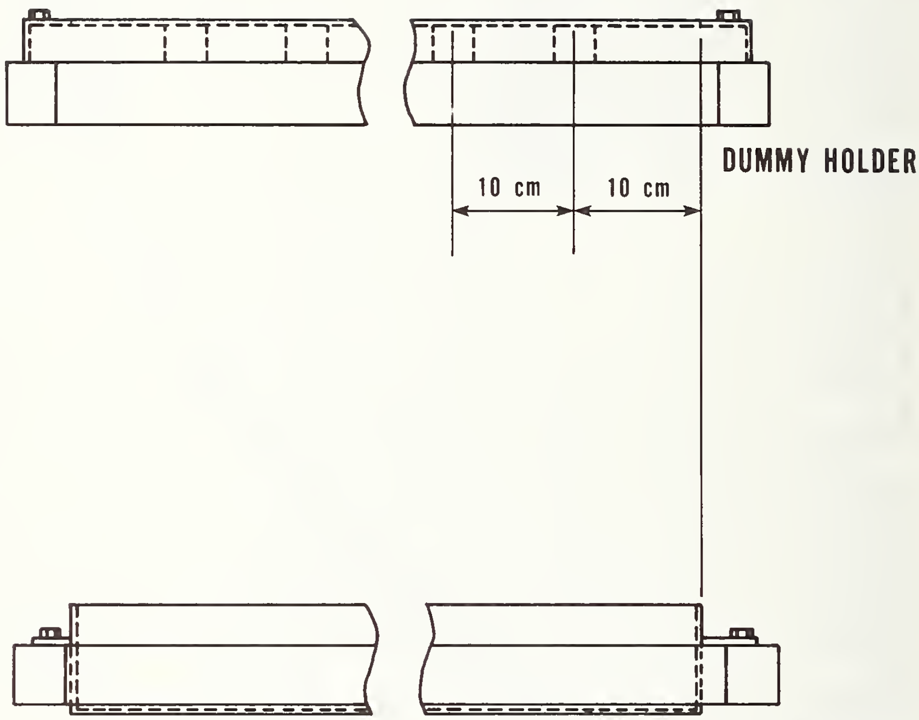

Figure B9. Specimen tray mounting position

Test Number ______________________ Date ____________________ Time _____________

Laboratory ________________________________

Specimen Identification/Code No. _____________________________________

Test Assembly: ____

Panel: Angle ________________° Temperature __________________°C (°F)

Flow: Gas _____________ NTPm^{3}H (SCFH) Air __________________ NTPm^{3}H

Pressure, cm (in) H_2O: Initial, Air ________________ Gas ____________

Chamber Temperature (Initial) __________________°C (°F)

Room: Temperature ____________°C (°F) Hood Draft ________________cm (in) water

Flame Front Out __________________ min.

All Flame Out ____________________ min.

Total Burn Length ______________________________________ cm (in)

Critical Radiant Flux watts/cm^2 ____________________________________

Flux Profile Reference ____

Observations:

Signed ____________________

Figure B10. Insulation radiant panel test data log format

APPENDIX C

STANDARD METHOD OF TEST FOR SMOLDERING COMBUSTION CHARACTERISTICS OF MATERIALS USED FOR THERMAL INSULATION

1. Scope

1.1 This method evaluates the tendency of thermal insulation in the form of loose fill, batts or blankets to support smoldering combustion. It is applicable to any insulation that is capable of being installed in the specimen holder at the density and in the physical state of the material in its intended use.

1.2 The purpose of this test is to determine the tendency of the material under test to support and propagate smoldering combustion subsequent to exposure to a standard ignition source.

2. Summary of Method

2.1 This method measures the extent and progression of smoldering from a lighted cigarette inserted vertically, with the lit end upward, into the center of an insulation material sample.

2.2 The extent of damage to the test specimen, as indicated by percent of specimen weight loss and by the extent of charring, are recorded in this test, as well as any other observable combustion behavior, such as progression to flaming combustion.

3. Significance

3.1 This method of test is designed to provide a basis for evaluating the tendency of insulation to support smoldering combustion when subjected to a small ignition source. The lighted cigarette represents a typical ignition source which may make contact with insulation installed in residential buildings.

4. Apparatus

4.1 Specimen Holder

4.1.1 The specimen holder shall be an open-top 20 $\pm$ 0.2 cm square box, 10 $\pm$ 0.2 cm in height, fabricated from a single piece of 0.61 $\pm$ 0.08 mm thick (24 U.S. Standard gauge) stainless steel sheet with the vertical edges of the box overlapped, not to exceed 7 mm in seam width, and soldered so as to be watertight.

4.1.2 The specimen holder during test use shall rest upon a pad of inert insulation, such as of glass or ceramic fibers, of at least 2.5 cm in thickness and approximating the dimensions of the bottom of the specimen holder. The density of the insulation shall be 40 ± 8 kg/m^3. (Glass fiber-board which meets Federal Specification HH-I-558B, Form A, Class 1, plain faced, is suitable for this purpose.)

4.2 Ignition Source

4.2.1 The ignition source shall be a cigarette without filter tip made from natural tobacco, 85 ± 2 mm long with a tobacco packing density of 0.270 ± 0.020 g/cm^3 and a total weight of 1.1 ± 0.1 gm.

4.3 Balance

4.3.1 A balance of 1 kg capacity, accurate at least to 0.1 g, and provided with a suitable scale pan is required.

4.4 Test Area

4.4.1 The test area shall be draft-protected and equipped with a suitable system for exhausting smoke and/or noxious gases produced by testing. Air velocities as measured by a hot wire anemometor in the vicinity of the surface of the sample shall not exceed 0.5 m/sec.

4.4.2 The test area shall be maintained at 21 ± 3°C (70 ± 5°F) and 50 ± 5 percent relative humidity.

4.3 Sampling

4.3.1 At least three samples shall be prepared of any material undergoing test. Samples shall be taken in a manner to encompass possible variations in material composition (for example, from the top, middle, and bottom of bagged insulation).

4.3.2 Samples of material to be tested shall be selected, prepared, and handled in a manner to avoid differences in the composition and condition of the sample from that of the sampled material in its intended use.

5. Test Procedure

5.1 Samples and cigarettes shall be conditioned in air at a temperature of 21 ± 3°C (70 ± 5°F) and a relative humidity of 50 ± 5 percent for at least 48 hours prior to test. Samples and cigarettes shall be removed from any packaging and exposed in a suitable manner to permit free movement of air around them during conditioning.

5.2 Sample material shall be loaded into specimen holders to fill the holders level and flush to the top edges of the holders. Specimen weight shall be measured, at least to the nearest 0.2 g, by weighing the holder before and after filling. The holder shall be tapped onto a solid surface to induce settling and additional insulation shall be added and screeded flush to the top edges of the holder to achieve the desired density. The density of the specimen contained in a holder (volume 4000 cm^3, 0.14 ft^3) shall be calculated and shall be tested at the settled density (Sec. 4.8.1 of HH-I-515D).

5.3 With the sample in the holder and placed on the insulated pad, a rod of 8 mm diameter with a pointed end shall be inserted vertically into the center of the material being tested and withdrawn to form an appropriate 85 mm long cavity for the ignition source. A well lit cigarette, burned not more than 8 mm (0.3 in), shall be inserted in the formed cavity, with the lit end upward and flush with the sample surface.

5.4 Burning of the cigarette and specimen shall be allowed to proceed undisturbed in the test area for at least 2 hours or until the smoldering is no longer progressing.

5.5 After completion of burning and after the holder has cooled down to 25°C, the specimen holder with its material residue shall be weighed, at least to the nearest 0.2 g, and the percent weight loss of the original specimen calculated.[1]

5.6 After completion of burning, the minimum distance of charring or smoldering of the material from the edge of the holder shall be measured. In cases where the material tested has smoldered to some extent, the material residue shall be carefully removed by layers and the closest proximity of charred material to the vertical sides of the specimen holder determined to the nearest 0.5 cm.

6. Criteria

6.1 Materials tested by this method shall be judged in terms of the following criteria:

6.1.1 Weight loss of each specimen expressed as a percent of its initial weight.

6.1.2 Evidence of flaming combustion of the specimen during testing.

7. Report

7.1 The report shall include the following:

7.1.1 Identification and/or description of the material being tested.

7.1.2 The original weight of specimens tested and their calculated density.

7.1.3 The final weight of specimens tested and the percent weight loss they have experienced during testing.

7.1.4 Any observations of the burning characteristics of the specimens that could be pertinent to the material's performance in its intended use.

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[1] The weight of the cigarette residue is ignored in this exercise and may, in some cases, result in a slight gain in sample weight.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

An evaluation was made of the appropriateness of the flammability requirements in Federal specifications for loose-fill cellulosic and mineral fiber insulation and mineral fiber batts and blankets. This included an analysis of currently used standard test methods for measuring insulation flammability or combustibility and their principle limitations. To provide for more meaningful evaluations, a review was made of fire statistics and of likely fire occurrences, particularly for retrofit insulation in attic and enclosed spaces of residential buildings. A series of laboratory tests was conducted using an attic floor radiant panel test and a cigarette smoldering test to simulate flaming and smoldering exposures. Mockup tests on attic floor sections were conducted to validate the extent of flame spread on attic insulation and the initiation of smoldering ignition from covered recessed light fixtures. Based on these tests, changes were recommended to Federal Specifications HH-I-515C, HH-I-521E and HH-I-1030A.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)* Attics; Federal specifications; fire test; flame spread; loose-fill; mineral fiber; residences; smoldering; thermal insulation.

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