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EVALUATION OF THERMAL BARRIERS FOR FOAM PLASTICS INSULATION

by

W. Taylor

PREFACE

This report describes a series of tests of the effectiveness of a range of thermal barriers for preventing the involvement of plastic foam insulation in the propagation of fires in wall cavities. It was carried out under the joint DBR/Industry Fellowship Program. The Division wishes to express to the Society of the Plastics Industry its appreciation for the Society's interest in and support of this program.

Ottawa
August 1981

C.B. Crawford
Director, DBR/NRC

NATIONAL RESEARCH COUNCIL OF CANADA

DIVISION OF BUILDING RESEARCH

DBR INTERNAL REPORT NO.

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by W. Taylor

Checked by: T.Z.H. **Approved by:** L.W.G. **Date:** August 1981

Prepared for: General Information

Concern that the flammability of plastic foam insulations can result in accelerated fire growth in the event of an accidental fire, has led to the requirement that all plastic foams in buildings be protected by a thermal barrier capable of preventing excessive transfer of heat from a heat source (fire) to the foam during a specified time. For low buildings of non-combustible construction, the National Building Code requires a barrier of 12.7 mm gypsum board or equivalent that, when tested by ULC-S101 (1), will not result in a temperature rise in excess of 140°C on the unexposed face of the thermal barrier up to a period of 10 minutes. In the case of tall buildings (>18 m in height) a much more stringent requirement of the fire barrier is specified: viz, a protective time period of 45 minutes is quoted and the suggested composition of the barrier is two layers of 15.9 mm thick fire resistant gypsum board or 75 mm of masonry or concrete.

The rationale for this requirement is to prevent the contribution of foam plastic insulation to the spread of fire in tall buildings from floor to floor via broken windows for at least 45 minutes, at which time it is reasoned, other combustibles in the fire compartment will have burnt out.

There is some evidence to suggest that, in a well ventilated compartment, the duration of a fully developed fire, during which the bulk of heat evolution takes place, is likely to be shorter than 45 minutes. Based on mathematical modelling of the characteristics of fully developed compartment fires (2), periods as short as 20 minutes have been suggested for the duration of fully developed compartment fires containing typical amounts of cellulosic fuel (Figure 1) while in Europe some full-scale experiments indicated that temperatures in the fire compartment had peaked within 30 minutes and decay of the fire was well underway in 35 minutes (3).

In a more recent full-scale fire test, carried out in California, ordinary core 12.7 mm gypsum sheathing failed after about 22 minutes in a compartment fire using a fire load of about 50 kg/m^2 and the fire temperature peaked at 28 to 30 minutes (4). Thus it appears that the requirement for a 45-minute fire barrier is somewhat excessive if the purpose is to minimize the upward progression of a fire via the windows.

It is of interest to note that many of the high-rise building fires that led to this concern about external fire spread (e.g., Sao Paulo 1972, 1974, New Orleans 1972, London 1980) occurred in structures of reinforced concrete without any plastic insulation. Thus the regulation is unlikely to prevent the sequence of events it is designed to guard against, even in the event that it is justified.

To determine what type of barrier is necessary to safeguard against contribution by foam insulation to fire spread via windows, and to evaluate the protective value of the required two layers of 15.9 mm gypsum board and possibly other, less expensive barriers, two series of tests have been conducted, one with the aid of a small-scale fire test furnace, and the other with the aid of a corner wall test facility.

A. FURNACE TESTS

Test Facility

The test furnace used is shown in Figure 2. It was built mainly from insulating fire brick and high temperature mortar, and was heated electrically using twelve 19 mm diameter "Globar" silicon carbide heating elements placed behind an Inconel plate. The furnace chamber was 760 mm high, 790 mm wide and 210 mm deep. Six ports cut into two opposite sides of the furnace made observation of the whole exposed surface of the specimens under test possible. The outer (narrow) ends of the ports were closed with mica sheets. (A more detailed description of the test furnace is given in reference 5).

Test Procedure

The heat input to the test furnace was controlled in such a way that the average temperature in the furnace chamber closely followed the standard temperature versus time curve stipulated in ASTM E119 and ULC-S101. The temperature of the furnace was measured by five B & S gauge 16, Chomel-Alumel Ceramo-type thermocouples with Inconel sheath. The hot junction of each thermocouple was kept in contact with the Inconel protecting plate on the specimen side by clips welded to the plate. All of the five temperatures, as well as their average were recorded on a potentiometric multipoint recorder, the average being taken as the temperature of the furnace.

The test specimens, which were attached vertically to the opening of the furnace, consisted of a sheet of the foamed plastic 790 × 840 mm in size, covered on one side by the protective thermal barrier to be tested, and on the other side by 12.7 mm thick regular gypsum wallboard that served as a back support. The whole assembly fitted into a welded angle iron frame and the protective barrier was mechanically fastened to this frame to simulate the mechanical attachment prescribed in the code requirements.

During the test, temperatures were measured at five locations at the interface between the foam and the protective material (one in the centre and the other four in the centre of each quarter section of the interface) and at two locations on the back surface of the foam (i.e., between the foam and the back support). These temperatures were recorded at one-minute intervals throughout the tests on a Monitor Lab Model 9300 Data Logger, which provided a digital print-out as the test proceeded. The progress of the test was also observed visually by means of the ports in the furnace wall.

The failure criterion in ULC-S101 is defined as a tempereature rise of 140°C at the interface between the protected and protecting material. A secondary end point considered in these experiments was the development of flaming in the furnace chamber resulting from a crack or failure point in the protecting layer.

Test Results

The materials tested in this series of experiments are listed in Table I and the results obtained summarized in Table II. As Table I shows, two kinds of protective barrier were used: regular gypsum board and fire resistant gypsum board.

In all cases some flaming of the exposed paper surface of the gypsum board was observed in the furnace chamber about three to four minutes into the test. The flaming stopped within one minute, and was not considered as a failure of the protective barrier.

Protective Barrier: Regular Gypsum Board

When 12.7 mm regular gypsum board was used as the protective barrier, an average rise in temperature of 140°C was recorded by the five interface thermocouples at 15 to 16 minutes into the test, regardless of the nature of the foam insulation. Cracks had developed in the gypsum board, and about three to four minutes afterwards flames were observed emanating from these cracks. The furnace temperature at this point was about 800°C. The average temperature at the interface was 550°C and the temperature on the back face of the insulation 200°C in the case of polystyrene foam, but only 100°C in the case of polyurethane foam.

The results with regular gypsum board indicate that foam insulation might be expected to contribute some fuel to a compartment fire after a period of about 18 to 20 minutes exposure to a fully developed fire (i.e., in a shorter time period than the expected duration of a fully-developed compartment fire) and on this basis 12.7 mm regular gypsum board may be considered unsatisfactory as a thermal barrier for high-rise buildings.

Protective Barrier: Fire Resistant Gypsum Board (Type X)

Two sets of tests were done with this material. In the first, the recommended thermal barrier listed in the 1980 National Building Code, i.e., two layers of 15.9 mm thick Fire Resistant Gypsum Board (Type X), was used with a range of polystyrene and polyurethane foam insulations. In these tests, the time required for the average interface temperature to rise by 140°C was between 58 and 60 minutes regardless of the type of foam. At this time the furnace temperature was 925°C and the temperature on the back face of the insulation was typically 30 to 35°C - a rise of less than 10°C during the course of the one-hour test. This failure time was well in excess of both the 45-minute period stipulated by the building code and the expected duration of a well-ventilated compartment fire. As the exposed gypsum board was observed to be intact and free of any cracks at this stage, the tests were allowed to continue for a further 15 minutes before termination. At this time there was still no evidence of physical failure of the barrier or the development of flames in the furnace, although the temperature at the interface between the thermal barrier and the insulation had reached 500°C.

Some decomposition of the polyurethane foams was evident during the extension period, as indicated by the evolution of light fumes, but no ignition occurred. At the end of the test the foam showed charring to a depth of about half the original thickness. The back face of the foam was unaffected and the maximum temperature registered at that surface was only 50°C.

In the polystyrene foam tests no fumes were evolved during the extension period, but the temperatures recorded by the two thermocouples located at the back face of the insulation rose more rapidly than with polyurethane, and had reached a level of 250°C when the test was terminated. This behaviour was evidently due to melting and shrinkage of the polystyrene foam, leaving an air space behind the Gypsum X protective layers that tended to equalize the temperatures throughout, as the test progressed. After the test, the only polystyrene remaining was a thin film around the edges of the assembly.

In view of the wide margin of safety inherent in the recommended thermal barrier, as attested to by the foregoing results, the second series of similar tests were carried out with a single protective layer of 15.9 mm Fire Resistant Gypsum Board (Type X). In this series, the average temperature rise of 140°C at the interface between the protective layer of Gypsum X and the foam insulation was recorded at 22 to 23 minutes, and at that time the temperature on the back side of the foam sample was 25 to 30°C. Since visual observation showed no obvious damage to the gypsum barrier and no flaming in the furnace chamber, the test was continued for a further 10 to 15 minutes to determine if the gypsum board would still continue to act as a barrier. When removed from the furnace at termination of the test, the gypsum barrier was examined for any evidence of cracking or flaking; none was found.

The pattern of temperature increase in the insulated cavity during the 10- to 15-minute period after the initial failure point was reached was similar to that noted with the double layer of gypsum, and the condition of the foam insulation was also comparable, i.e., the urethane specimens charred to a depth of about 10 mm on the surface facing the furnace, and the polystyrene was reduced to a thin film around the edges of the test assembly, leaving essentially an air space behind the protective gypsum barrier.

B. CORNER WALL TESTS

Test Facility and Procedure

The apparatus used in this series of tests is illustrated in Figure 3. It consists of a modified 1.2 m corner wall configuration and ignition source as described in ULC S127-1978 (6).

In the tests, the walls of the corner were lined with the insulation material and covered by the thermal barrier to be tested. The thermal barrier was mechanically fastened to the outer shell of the corner through the insulation. An air space of 38 mm was maintained by wood spacer studs between the insulation and the outer shell of the apparatus (Figure 4). The 38 mm air space was installed to provide a configuration in which flames can spread rapidly if the foam insulation is ignited during the test. The ceiling of the corner was formed by asbestos boards and insulated from above by 85 mm fibre glass batts to minimize loss of heat. The floor of the compartment was covered by a sheet of reflective aluminum foil to provide increased thermal feedback to the boundaries of the assembly.

The burner consisted of a horizontal sand bed, 220 mm in diameter, through which natural gas flowed to produce a diffusion flame. The fuel flow through the burner was maintained constant and at a level to produce a heat input of 45 kW for the duration of the test. In a real fire situation, the igniting source would probably be smaller, resulting in a considerably longer fire period before the maximum temperature is reached (Figure 5).

Thermocouples for the measurement of temperatures were located at several points below the ceiling and at the interface between the thermal barrier and the foam insulation as shown in Figure 6. Visual observation of the thermal barrier was made throughout the tests to check for the development of cracks or signs of physical failure. The air space behind the insulation was monitored through ventilation holes in the asbestos shell for any sign of ignition or flames.

Test Results

Two protective barriers were evaluated, one consisting of 12.7 mm regular gypsum boards and the other of 15.9 mm fire resistant boards, in combination with both polyurethane and polystyrene foam insulations. Appendix A includes a selection of photographs illustrating the appearance of the corner assembly following the tests.

Protective Barrier: Regular Gypsum Boards

Ignition of the paper facing on the gypsum board in the vicinity of the burner occurred about 3 minutes after the start of the test and burned off over an area that extended about 300 mm from the corner along each wall to the full height of the enclosure. An area of charring extended a further 100 mm over much of the height and 200 mm near the junction of walls and ceiling. Slight surface cracking in the corner was noted about 25 minutes into the test, but the barrier remained in place. No flaming developed at the cracks, nor did any ignition of the foam insulation in the cavity take place. The test was terminated after 30 minutes, at which time the gypsum barrier was still in place. The air temperature in the enclosure, as recorded by the three thermocouples at the ceiling, rose rapidly at the start of the test and reached 585°C within 4 minutes. Thereafter the temperature increased only slightly until the termination of the test. The temperature in the "doorway" also rose rapidly at the start. It reached 200°C within 4 minutes then increased more slowly to a maximum of 240°C.

When the insulation was polyurethane, the maximum temperature at the gypsum-insulation interface was 330°C, and was recorded by the thermocouple in the corner near the ceiling (No. 4 in Figure 6). The temperatures recorded by the other interface thermocouples reached a maximum of 140°C during the tests.

With polystyrene foam insulation, the interface temperatures recorded by thermocouples Nos. 4, 7 and 9 reached a maximum of 200°C while the remaining interface thermocouples reached only 100°C.

In neither case was any burning noted inside the cavity when viewed through the ventilation holes, nor was any heavy smoke, characteristic of burning polyurethane or polystyrene, observed. In the case of polyurethane, some light fumes evolved in the last 2 to 3 minutes of the test, due to incipient decomposition of the material as the interface temperature rose above 300°C. These fumes passed through the ventilation holes in the outer asbestos board shell and had not penetrated the compartment at the time when the test was terminated. No fumes evolved during the tests with polystyrene.

When the gypsum board was removed, the urethane insulation was found to have been charred in the corner in an area approximately equal to the area of char on the gypsum board. In the corner near ceiling level the charring extended to the full thickness of the foam; elsewhere only surface charring was visible. With polystyrene insulation, melting and shrinkage had occurred in the corner along the upper quarter of the two walls forming the corner, leaving this part of the cavity empty. No flow of the melted material through joints into the corner area was observed.

Protective Barrier: Fire Resistant Gypsum Boards

Ignition of the paper facing on the gypsum again occurred at 3 to 4 minutes into the test and the paper burned off in the corner over an area extending about 350 mm along each wall. In addition, over the upper third of the walls, charring extended to the full 1.2 m width at the conclusion of the tests, which was at 52 minutes for the urethanes and 60 minutes for the polystyrenes.

When the insulation was polystyrene, the temperature of the enclosure atmosphere, as yielded by the ceiling thermocouples, reached 500°C within 3 minutes; then it rose gradually to approximately 600°C after 30 minutes and remained at this temperature for the rest of the test. The temperature at the "doorway" in the canopy reached 200°C within 1 minute of the start of the test and increased to a maximum of 285°C after 50 minutes. Interface temperatures near the ceiling and close to the corner (thermocouples 4, 7 and 9) rose to about 250°C. The remaining interface thermocouples yielded peak temperatures of about 180°C.

During the 60-minute test period, no cracks developed in the gypsum board, no burning was observed inside the cavity, and no smoke or fumes evolved. When the gypsum barrier was removed, melting and shrinkage of the polystyrene in the corner and along the upper third of both walls were noted, as in the tests with regular gypsum board, and again there was no sign of ignition having taken place.

With polyurethane insulation, the temperature of the enclosure atmosphere was generally similar to that for polystyrene, although the initial temperature increase was more rapid and 500°C was reached within 1 minute from the start of the test. The temperatures recorded at the insulation-gypsum board interface reached between 140°C and 160°C after about 35 minutes and except for thermocouple No. 4, remained at this level for the rest of the test. The interface temperature in the corner near the ceiling, yielded by thermocouple 4, began to increase after about 44 minutes and reached a level of 350°C at the termination of the test. At about the same time as the temperature increase started, fumes began to evolve from the vent holes close to the location of thermocouple 4 and the rate of evolution increased as the test continued. After some 48 minutes the fumes began to penetrate into the compartment through the joints between the wall and the ceiling. After 50 minutes intermittent flaming was observed, as the fumes accumulated below the ceiling were ignited by the burner in the corner and at the 52-minute mark, the test was terminated. Examination of the gypsum board after the test revealed no cracks or failure, indicating that the leakage of decomposition fumes into the compartment was solely via the joints between walls and ceiling. During the test no ignition or flaming was observed in the air space between the insulation and the outer shell of the corner.

When the gypsum boards were removed the polyurethane in the corner was found to be severely charred, particularly near the ceiling. The remainder of the foam insulation was unaffected.

DISCUSSION

The results of the furnace tests carried out indicate that a 12.7 mm regular gypsum board protective barrier over foam plastics insulation may not be adequate to delay the ignition of insulation for the time required to evacuate the residents of a high-rise building in the event of a fire, or to ensure that the foam plastic does not contribute fuel to flames which may exit a broken window and spread to the floor above. On the other hand, two layers of 15.9 mm thick fire resistant gypsum board is excessive, even if the allowed temperature rise of 140°C at the interface is considered as the sole criterion of failure. In fact, it is known that fire rarely spreads by heat transmission through the compartment boundaries; spread usually occurs by heat fluxes emanating from the flames (7). If the integrity of the barrier is maintained, no ignition of the foam behind the barrier layer is likely to occur. The fire resistant gypsum board in all tests carried out in the furnace remained sound for a period significantly longer than the "failure" time measured by the presently defined 140°C temperature rise criterion. The conservatism incorporated into the temperature rise failure criterion can be understood in the light of the results of thermogravimetric analyses of the foam plastic insulation materials used in this study (Table III). At a temperature of 160°C, corresponding to the established failure criterion (20°C ambient + 140°C temperature rise) the weight loss is, in all cases, very small, and even at 260°C is still only 10 per cent or less. Thus the amount of heat that can be released by the combustion of the pyrolysis products of the foam into the room during the period the 160°C temperature level is reached is minor relative to the heat generated by the fire within the compartment.

The results of the corner wall tests corroborate those of the furnace tests and emphasize the conservative nature of the accepted failure criterion. Even with 12.7 mm of regular gypsum board protective barrier, a 30-minute protection was indicated by the tests, confirming results obtained by Lie (8). In the case of corner wall tests with 15.9 mm of fire resistant gypsum board protective barriers, no ignition of the foam in the cavity wall or contribution of fuel to the fire within the compartment was observed up to 60 minutes into the test in the case of polystyrene foam, and 48 minutes in the case of polyurethane foam.

On the basis of these experimental results, it is believed that a single layer of 15.9 mm thick fire resistant gypsum will provide an effective and realistic protection for foam plastics insulation in high-rise buildings. Such protection will allow sufficient time for evacuation of the fire area before the foam becomes involved and prevent it from contributing fuel to the fire and thus from promoting the spread of fire via broken windows to the upper stories.

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6. Standard Corner Wall Method of Test for Flammability Characteristics of Non-melting Building Material, ULC S127-1978.

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TABLE I

Test Materials

Protective Barriers

12.7 mm Gypsum wall board

15.9 mm Fire Resistant Gypsum

2 x 15.9 mm Fire Resistant Gypsum

Plastic Foams

Polyurethane/Isocyanurate Laminate
FSC ≃ 45

Polyurethane Laminate
FSC ≃ 450

Polystyrene Bead Board
Density 16 kg/m^3

Extruded Polystyrene Board
Density 32 kg/m^3

FSC = Flame Spread Classification

TABLE II

Furnace Test Results

Foam Material	Thermal Barrier	Time for 140°C Temp. Rise (min)		Flames observed (min)	
		Test 1	Test 2	Test 1	Test 2
Polyurethane Laminate FSC=≃ 450	12.7 mm Gypsum regular	15	15	18	18.5
Polystyrene Bead Board Density 16 kg/m^3	12.7 mm Gypsum regular	16	15	19	18.5
Polyurethane Laminate FSC ≃ 450	2 x 15.9 mm Gypsum Type X	58	58	>75	>75
Polyurethane/Isocyanurate Laminate FSC ≃ 45	2 x 15.9 mm Gypsum Type X	59	58	>75	>75
Polystyrene Bead Board Density 16 kg/m^3	2 x 15.9 mm Gypsum Type X	60	59	>75	>75
Extruded Polystyrene Board Density 32 kg/m^3	2 x 15.9 mm Gypsum Type X	58	58	>75	>75
Polyurethane Laminate FSC ≃ 450	15.9 mm Gypsum Type X	23	22	>35	>35
Polyurethane/Isocyanurate Laminate FSC ≃ 45	15.9 mm Gypsum Type X	22	22	>35	>35
Polystyrene Bead Board Density 16 kg/m^3	15.9 mm Gypsum Type X	22	23	>35	>35
Extruded Polystyrene Board Density 32 kg/m^3	15.9 mm Gypsum Type X	22	22	>35	>35
-	15.9 mm Gypsum Type X	25	-	-	-
-	2 x 15.9 mm Gypsum Type X	60	-	-	-

TABLE III

Results of Thermogravimetric Analyses of Plastic Foams

Foam Material	Wt. Loss (%) at 160°C	Wt. Loss (%) at 260°C	Density kg/m^3	FSC S102 or S102.2
Polyurethane	0	9	32	450
Polyurethane/Isocyanurate	4	10	32	45
Polystyrene Bead Board	0	1	16	230
Extruded Polystyrene	1	2.5	32	210

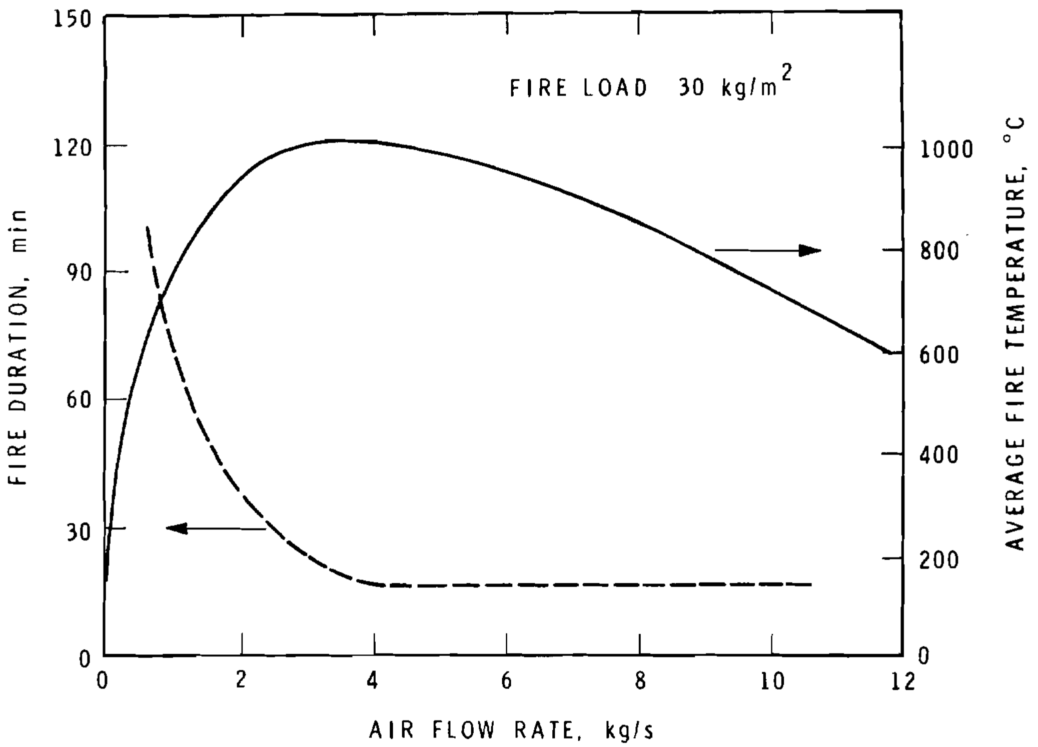


FIGURE 1

FIRE TEMPERATURE AND DURATION

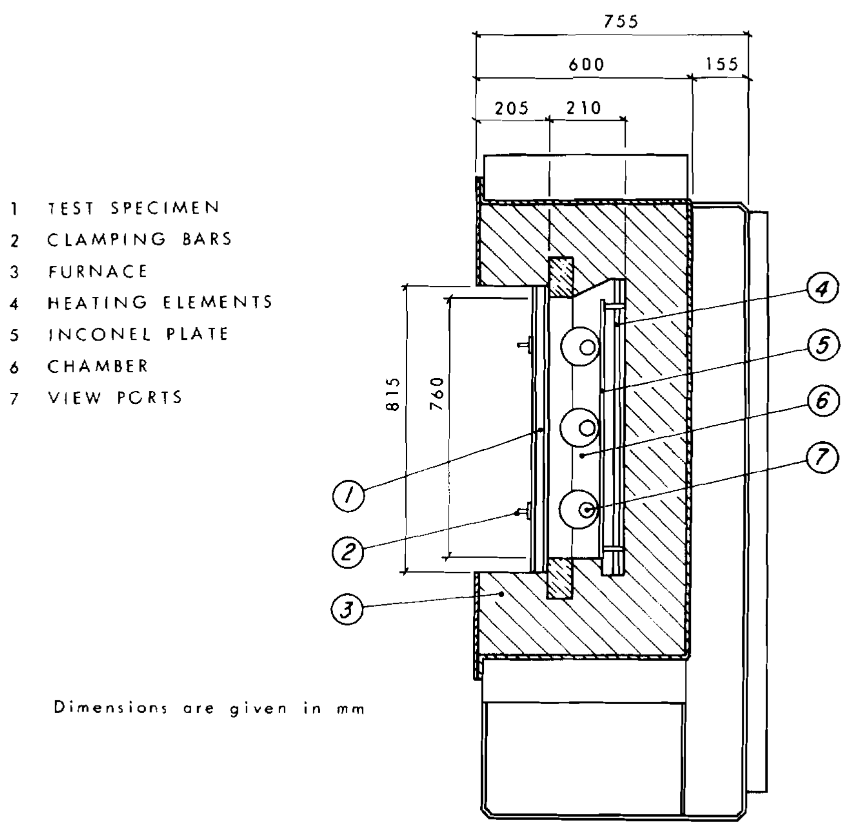


FIGURE 2

CROSS-SECTION OF TEST FURNACE

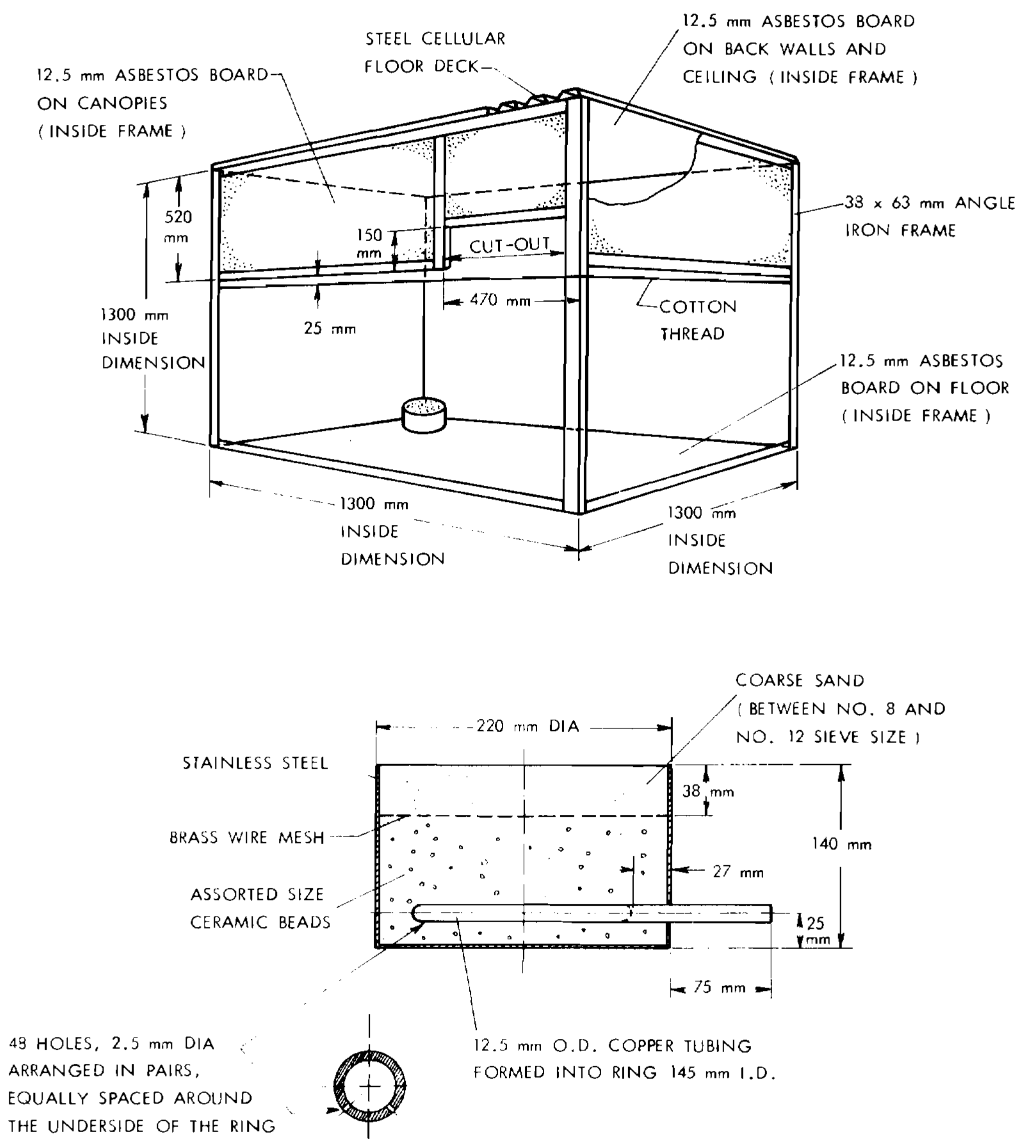


FIGURE 3

1.2 m CORNER WALL TEST COMPARTMENT AND IGNITION SOURCE

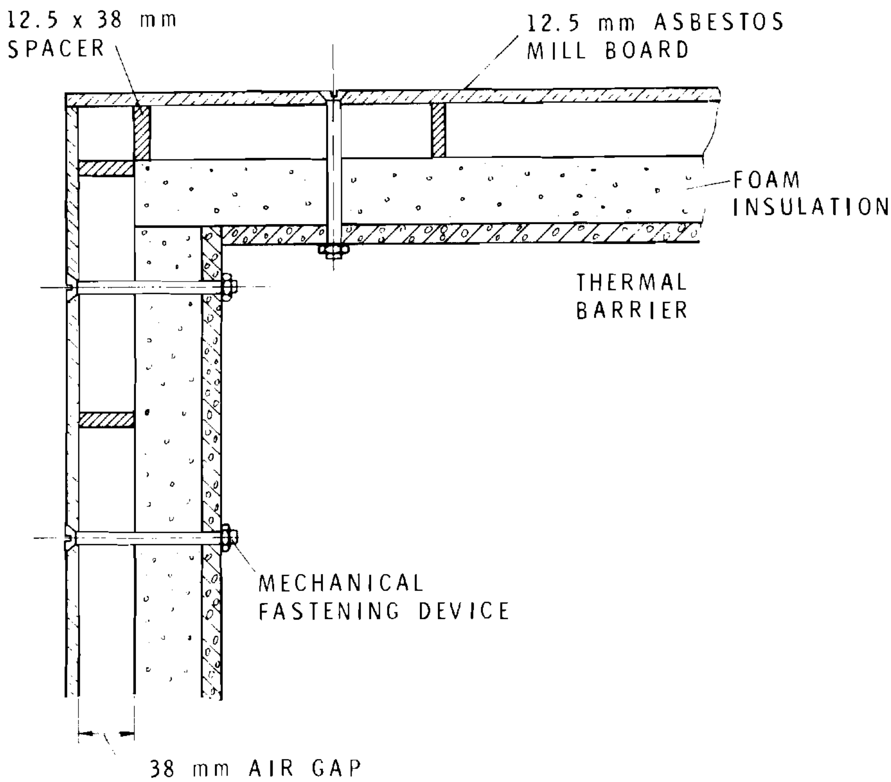


FIGURE 4

CORNER WALL CONSTRUCTION

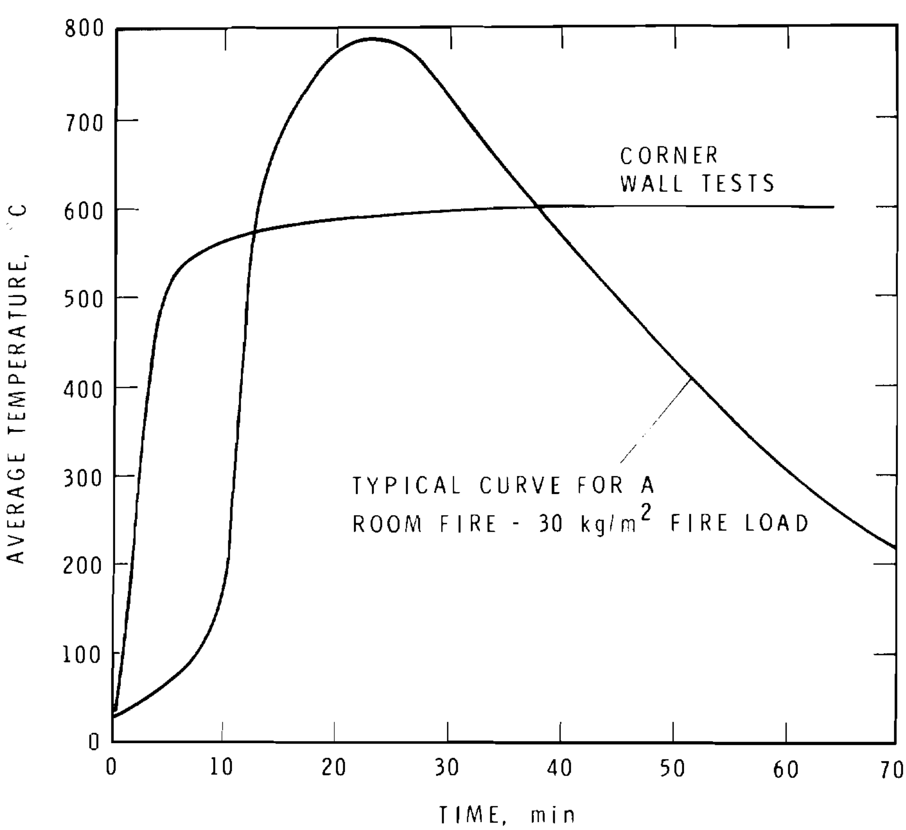


FIGURE 5

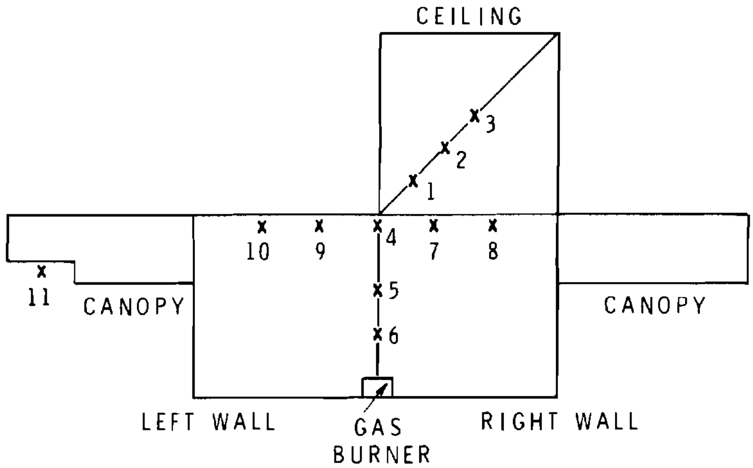


FIGURE 6

THERMOCOUPLE LOCATIONS

THERMOCOUPLES 1, 2 AND 3 MEASURE TEMPERATURES 25 mm BELOW CEILING. THERMOCOUPLE 11 MEASURES TEMPERATURE 25 mm BELOW DOORWAY. REMAINDER MEASURE BARRIER/INSULATION INTERFACE TEMPERATURES

APPENDIX A

A Selection of Photographs Showing the Appearance of Specimens After 1.2 m Corner Wall Tests

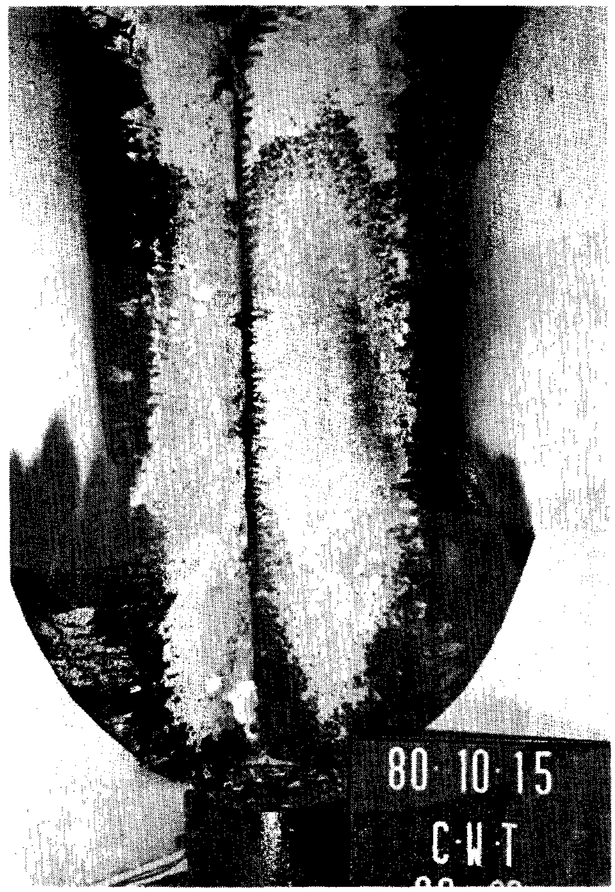
FIGURE A1

Protective Barrier: 12.7 mm Regular Gypsum Board

Insulation: Polyurethane/Isocyanurate Laminate

Duration of Test: 30 minutes

Appearance of Protective Barrier After Test.



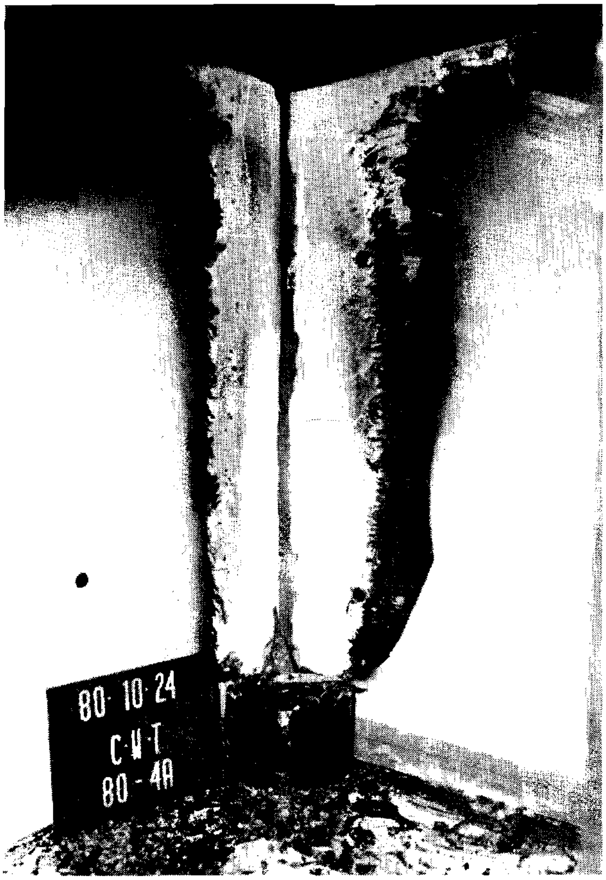
Protective Barrier Removed. Appearance of Insulation.

FIGURE A2

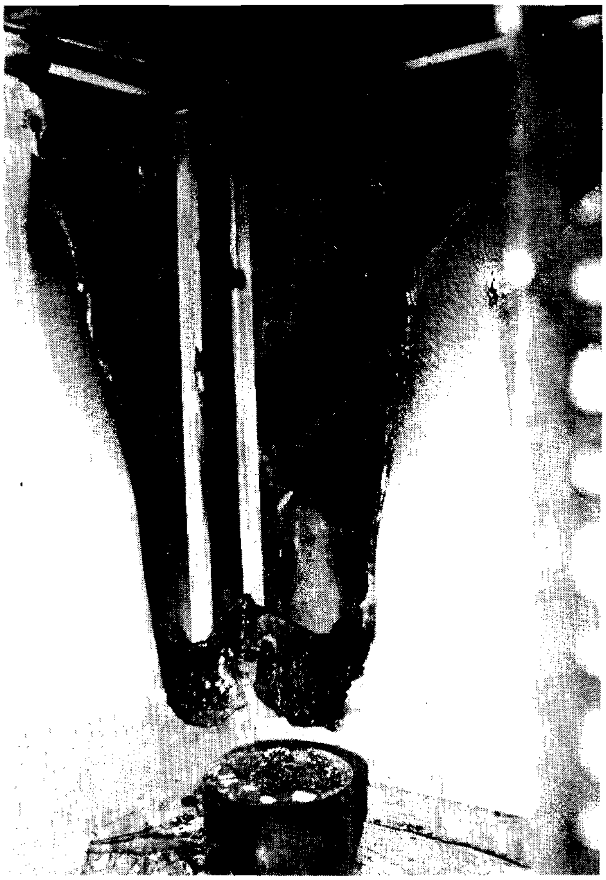
Protective Barrier: 12.7 mm Regular Gypsum Board

Insulation: Extruded Polystyrene Foam

Duration of Test: 30 Minutes



Appearance of Protective Barrier After Test.



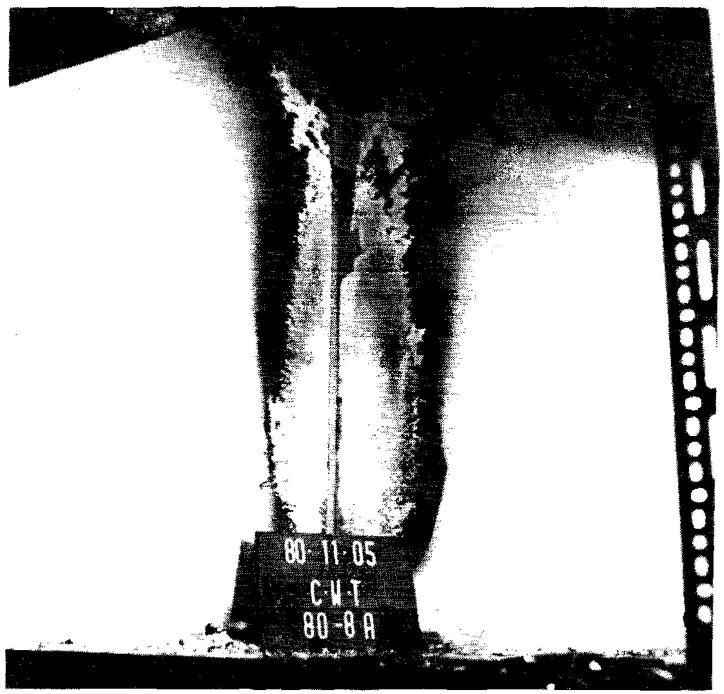
Protective Barrier Removed. Appearance of Insulation.

FIGURE A3

Protective Barrier: 15.9 mm Fire Resistant Gypsum Board

Insulation: Polystyrene Bead Board

Duration of Test: 60 Minutes



Appearance of Protective Barrier After Test.

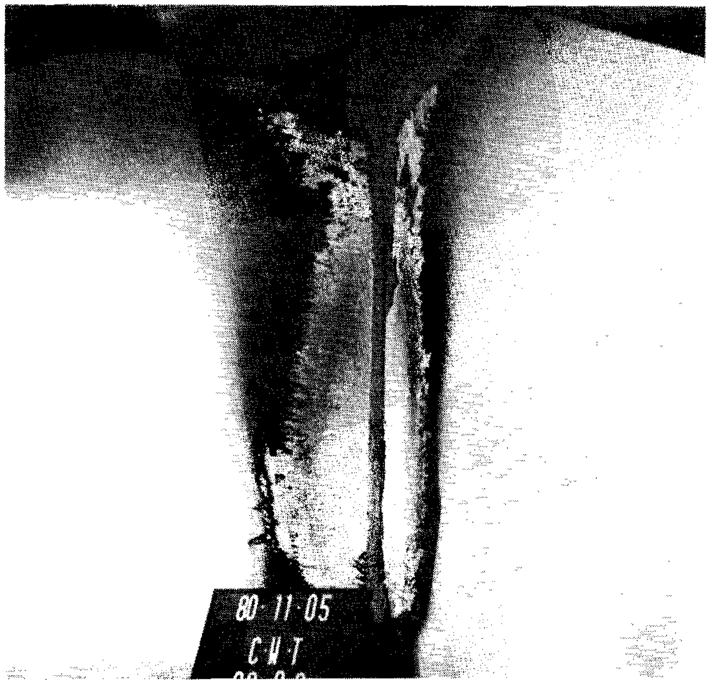
Protective Barrier Removed. Appearance of Insulation.

FIGURE A4

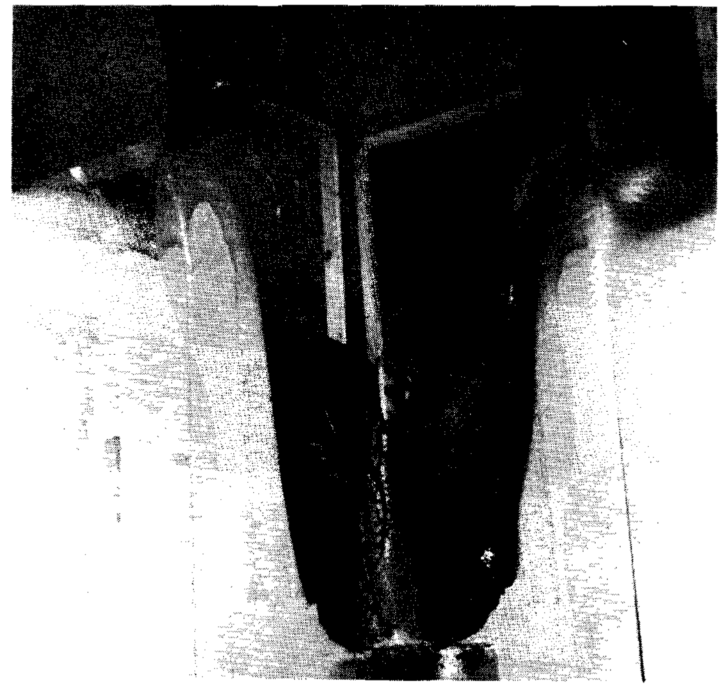
<u>Protective Barrier</u>: 15.9 mm Fire Resistant Gypsum Board

<u>Insulation</u>: Extruded Polystyrene Foam

<u>Duration of Test</u>: 60 Minutes



Appearance of Protective Barrier After Test.



Protective Barrier Removed. Appearance of Insulation.

FIGURE A5

Protective Barrier: 15.9 mm Fire Resistant Gypsum Board

Insulation: Polyurethane Laminate

Duration of Test: 52 Minutes

Appearance of Protective Barrier After Test.

Protective Barrier Removed. Appearance of Insulation.

Aluminum Foil Facing Removed From Insulation.