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SPREAD OF FIRE IN VERTICAL CONCEALED SPACES  
CONTAINING FOAMED-PLASTICS INSULATION  
PART I. POLYURETHANES AND POLYISOCYANURATES  
by W. Taylor

Private copy for: T. Z. HARMATHY

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by

W. Taylor

PREFACE

Rigid foam plastics are used for insulating purposes. Because they are combustible, it is essential to establish the fire hazard that may be associated with this application. The fire behaviour of polyurethanes and polyisocyanurates was investigated under an Industrial Fellowship program sponsored jointly by the Society of the Plastics Industry of Canada and the National Research Council of Canada. The result of this cooperative work is presented in this report. The author, Dr. William Taylor, held the position of DBR Plastics Research Fellow from 1979 to 1981. Other reports prepared by Dr. Taylor during his stay with the Division are:

- Evaluation of thermal barriers for foam plastics insulation (Internal Report No. 466)
- Spread of fire in vertical concealed spaces containing foamed-plastics insulation: Part II. Expanded Polystyrenes (Internal Report No. 469)
- Evaluation of the effectiveness of fire barriers in preventing fire spread in concealed spaces (Internal Report No. 470)
- Spread of fire in residential-type wood-frame construction (Internal Report No. 471)

The Division of Building Research greatly appreciates the interest and support of the Society of the Plastics Industry in this program.

Ottawa  
November 1981

C.B. Crawford  
Director DBR/NRC

**NATIONAL RESEARCH COUNCIL OF CANADA**

**DIVISION OF BUILDING RESEARCH**

**DBR INTERNAL REPORT NO. 468**

SPREAD OF FIRE IN VERTICAL CONCEALED SPACES  
CONTAINING FOAMED PLASTICS INSULATION.  
PART I. POLYURETHANES AND POLYISOCYANURATES

by W. Taylor

**Checked by:** T.Z.H.

**Approved by:** L.W.G.

**Date:** November 1981

**Prepared for:** Record purposes

The spread of fire within concealed spaces in buildings has presented problems to fire-fighters and has been cited as a factor in a number of fires such as those at Summerland, Isle of Man (1970), Fairfield Nursing Home in England (1974) and One New York Plaza, New York City (1970). The National Building Code of Canada (NBCC) places some limits on the area of concealed spaces between fire stops where combustible materials are involved, but the fire stops specified in the code appear to have been selected with wood frame construction in mind and, in some cases, may not be effective as thermal barriers.

Experimental work related to fire spread in concealed spaces, in which foamed plastics insulation is installed, is limited. Some tests with polyurethane foams indicated that such insulation, used in a vertical position between two layers of concrete, with no internal air space, was unlikely to contribute to fire propagation within the assembly, regardless of the flame spread rating of the polyurethane (1). If there was an air space, somewhat more extensive fire spread was reported and therefore a limitation in flame spread rating of 25, as measured by ASTM E-84 (2), was suggested for the insulation to limit

the spread of fire in the cavity. Later tests with a vertical cavity enclosed by asbestos cement board gave generally similar results (3).

The NBCC limits the use of foamed plastics in non-combustible construction to those with flame spread ratings of 25 or less, as measured by the test method described in ULC S102-1978 (4). This method, by using a procedure for calculating flame spread ratings that is different from ASTM E-84, results in some materials, apparently judged satisfactory by the tests described in references 1 and 3, being eliminated from use in certain areas.

It is evident that more information is required concerning the fire performance in concealed spaces of foamed plastics insulations, in relation to both the flame spread ratings as currently measured and construction variables such as width of air space, before conditions can be defined under which foamed plastics will not cause continuing spread of flames from a fire that penetrates a concealed space within a vertical assembly. Where conditions for limiting the spread of fire are not met, the effectiveness of the fire barriers allowed by the code in preventing movement of fire from storey to storey within a concealed space also requires investigation.

The series of tests described in this paper addresses these concerns in relation to vertical concealed spaces, such as cavity walls, in assemblies of non-combustible construction.

#### TEST FACILITIES AND PROCEDURE

The test rig, used to simulate wall designs typical of buildings of non-combustible construction, is illustrated in Figure 1. It comprises a vertical, rectangular duct, measuring 5 m high  $\times$  1.25 m wide, bounded on the back side by marinite boards lined with the insulating material under test and on the front side by 13 mm gypsum boards. Three sides of the rig are fixed rigidly to a framework, while the front face is adjustable to allow various cavity air gaps. A number of Vycor-covered viewing ports are set in the front panel to allow visual observation of the progression of the fire during a test. In addition thermocouples are located at intervals along both front and rear interior faces of the cavity for temperature measurements during the course of the test. Smoke evolution is measured by the obscuration of a light beam from a tungsten source that passes across the top of the cavity to a selenium cell filtered to represent eye sensitivity. A horizontal slot 25 mm wide is left at the bottom of the cavity for the entrance of flames.

The fire source for the tests is a natural gas burner that consists of a 25 mm diameter pipe with a series of 24 radial holes, 4.75 mm in diameter, set at 50 mm intervals along its length. Gas flow to the burner is adjusted to provide a series of flamelets with a total energy output of 25 kW. This source was found capable of producing a mean compartment entrance temperature of 820 C in blank runs (i.e., no insulation installed) with an air space of 25 mm; the temperature in the

upper part of the compartment (4 m above the bottom of the cavity) reached approximately 220 C. These conditions in the cavity correspond closely with those developed in tests described in Reference 3, which also used a gas burner as a fire source.

In the test program, attention was focussed on determining whether the fire would spread within the cavity and into vertically adjacent cavities. The source flames were applied through the orifice at the base of the cavity for a period of 10 minutes. After that time the burner was cut off and any continued combustion within the cavity was monitored until natural extinction took place. The selection of 10 minutes for the application of the gas burner flames was made on the assumption that, in a well ventilated room with normal furnishings the duration of a fully developed fire (i.e., the period during which the bulk of the heat evolution takes place) is usually less than 30 minutes (5) and the foamed plastic within the cavity wall will be prevented from igniting during the first 20 minutes of this time by a protective thermal barrier which the NBCC specifies must cover all foamed plastics insulation installed in buildings of non-combustible construction.

#### TEST MATERIALS

Table I lists particulars of the materials and the tests performed.

Materials 1 and 2 were in the form of 2500 mm × 1250 mm × 50 mm boards. Material 1 was faced with aluminum foil while Material 2 had a layer of Kraft paper topped by aluminum foil as facing.

Materials 3 and 4 were spray foamed to an approximate thickness of 85 mm in suitably sized moulds which were lined with polyethylene film to ensure release. The foams were allowed to age for at least a week prior to testing. Owing to the irregularity of the surface of the sprayed foam samples, a constant air gap in the test assembly could not be achieved. It was learned from spray foam applicators that in practice an irregular air space, which varied from zero to a maximum of 10 mm, between the upper surface of the foam and the facing material, was normal. For the tests carried out in this program, the minimum air space was set at 5 mm and the maximum at 15 mm, thus providing a somewhat more severe condition than might be expected in practice. A few experiments were also carried out with zero air space. In preparing specimens for these experiments, the mould used in forming the insulation was provided with a 13 mm thick gypsum board base to which the foam adhered and which served as the front face of the assembly during the test. The two arrangements for the sprayed foams are illustrated schematically in Figure 2.

#### TEST RESULTS

A selection of photographs comprising Appendix A illustrates the tests described in this section.

1. No air gap

With all the materials tested in this configuration, burning of the foam was confined to the immediate vicinity of the burner flames. Burning continued for several minutes after the source flames were extinguished but did not spread beyond the area initially involved. Examinations following the test revealed that surface charring of the foam had extended into the cavity and, in the case of the board materials (Materials 1 and 2), had reached a maximum height of 1 m. For the sprayed foams (Materials 3 and 4) the area of surface char was much less extensive, and was limited to about 0.15 m above the burner. This was probably due to the good adhesion of the sprayed foam to the gypsum boundary of the assembly and the complete exclusion of air from the interface. With the board samples, in the nominal zero air space configuration, complete exclusion of air from the interface was not possible.

Smoke evolution was moderate to heavy throughout each of the tests and continued for some time after the flames were extinguished. Typically the light transmission through the smoke at the top of the assembly was reduced to about 30 per cent when smoke density reached its maximum.

2. Air gaps up to 25 mm

Increases in the air gap between the insulation and the boundary walls resulted in more involvement of the insulation and greater spread of flames in the cavity.

The behaviour of the two board materials (Materials 1 and 2) was again similar for equivalent air gaps. At an air gap of 12.5 mm the foam in the lower 1 m of the cavity was burned to a friable char and, above this, an area of surface char extended a further 0.75 m. Some discolouration of the foil coating was evident in a plume above the damaged area but the foam beneath the foil was unaffected.

Increasing the air gap to 25 mm resulted in an increase in the amount of foam involved in the fire and more flaming was observed in the viewing ports than was the case with a 12.5 mm air gap. The foam in the lower 1.25 m of the cavity was essentially consumed in the fire and an area of moderate char extended a further 0.75 m. The foil coating was discoloured above this height but flames did not extend beyond the lower 2 m of the test cavity and the foam beneath the discoloured facing was unaffected.

Smoke evolution was heavy during these tests and, within 2 to 3 minutes of the start, light transmission through the smoke at the top of the cavity was reduced to zero.

For the two sprayed urethane foams, with an irregular air space varying from 5 mm to a maximum of 15 mm, Material 3, which had a flame

spread rating of 475, burned in the immediate vicinity of the source flames and burning and smouldering continued for some 20 minutes after the source burner was removed. At the conclusion of the test, heavy charring of the foam to a depth of about 70 mm was noted in the lower 0.5 m of the cavity and surface char extended a further 0.75 m in areas where the maximum air space was available.

With Material 4 (FSC 1100) burning was more prolonged and, 40 minutes after the removal of the source burner, the flame front had progressed to a maximum distance of 1.25 m into the cavity along a path where the maximum air space was available, leaving severely charred material behind. The rate of advance of the flame front was slow, apparently being limited by oxygen availability. However, continued steady progress of the fire appeared probable as cracks developing in the front face of the assembly allowed access to additional oxygen. The test was terminated after about an hour.

Smoke evolution in the tests with sprayed foams was moderate during the first 10 minutes with light transmission reduced to 35 per cent. Later, when foam inside the cavity continued to smoulder, smoke evolution increased and light transmission was zero after 12 to 15 minutes.

### 3. Air gaps greater than 25 mm

Only the board materials were included in this series and only Material 1 was tested with air spaces of both 38 mm and 50 mm; tests on Material 2 were restricted to a 38 mm air space due to operational difficulties experienced with the larger gap. The strong, burner driven updraft in the 50 mm air space reduced flame impingement on the specimen and caused some flamelets to lift from the burner. Adjustments to the burner setting offered little improvement so it was decided not to carry out further tests with the larger gap.

In the one successful test carried out on Material 1 with a 50 mm air gap, complete involvement of the foam insulation in the fire occurred very rapidly and flames were observed at the top of the assembly within about 7 minutes. After 10 minutes, almost all the material in the cavity was consumed and burning stopped within one minute of the source burner being removed. Smoke evolution during this test was extremely heavy and was sufficient to completely fill the 12 m x 12 m x 12 m burn hall in which the tests were conducted. Light transmission readings at the top of the assembly were reduced to zero in less than one minute.

For the two board materials and a 38 mm air space, the spread of flame extended up to the upper regions of the test assembly. With Material 1 (FSC 45) flames were visible at the top of the cavity after 20 minutes and continued to burn there until the test ended after about 30 minutes; at that time essentially all the foam material in the cavity had been consumed. Material 2 (FSC 450) burned more slowly and,

while flames did not appear at the top, burning inside the cavity continued until the test was terminated after 50 minutes. At this time most of the foam in the lower 2.5 m of the assembly was consumed and severe charring was observed at higher levels, but the charred area did not reach to the full 5 m height of the test assembly. Had the test been allowed to continue, it is probable that the foam insulation remaining in the cavity would eventually have been consumed by the advancing flame front.

Very heavy smoke evolution again characterized both these tests. Light transmission through the smoke at the top of the assembly was reduced to zero in a little over one minute.

#### 4. Evaluation of fire barriers

In evaluating the effectiveness of barriers designed to prevent the excessive movement of fire within a concealed space, a configuration is required that determines the performance of the barrier rather than the foam. For this reason, based on the results just described, an air space of 38 mm was selected and Material 1 was used as the insulation.

Three arrangements, shown in Figure 3, have been tested. In arrangement A, the fire stop provides a complete closure across the air space, limiting the ventilation but not the drainage of the cavity. In arrangements B and C full ventilation and drainage of the cavity are allowed by means of 25 mm slots above and below the fire barrier. In B the barrier projects in front of the cavity face, while in C it ends flush with the front face.

Three fire stop materials approved for use by the National Building Code of Canada have been evaluated - 12.5 mm asbestos board, 18-gauge sheet steel and 38 mm solid lumber.

Results were generally similar for asbestos board and sheet steel fire barriers except that somewhat higher temperatures developed in the cavity above the fire stop when sheet steel was used.

With arrangements B and C, the progress of events in the cavity below the fire stop closely followed that observed in earlier tests with a 38 mm unstopped air gap. Heavy smoke evolved from the ventilation slot below the fire stop and flames emerged after 5 to 10 minutes. The flames were long enough to reach above the fire barrier and curl in towards the slot at the base of the upper cavity. With the barrier projecting 75 mm (arrangement B) no involvement of the foam in the upper cavity was noted when examined at the end of the test, although smoke had caused discolouration of the foil coating. Limited involvement of the foam above the fire stop was observed when the projection was absent (arrangement C) and surface charring extended a maximum distance of 1 m above the barrier, while the foil covering was blackened throughout.

When the ventilation slot was closed (arrangement A) the burning of the insulation in the lower cavity was less extensive. The air space below the fire stop rapidly filled with smoke, which was then forced back out of the lower slot around the burner and prevented free access of oxygen into the cavity. The lack of ventilation limited the fire spread to a triangular segment of foam.

A wood fire stop with a 50 mm projection was evaluated in a test with arrangement B only. The early part of this test paralleled the tests just described; flames were playing on the barrier in less than 10 minutes and the fire stop began to smoulder. Five minutes later it burst into flames and continued to burn during the remainder of the test. Ignition of the foam insulation above the fire stop occurred two to three minutes after the fire stop ignited. Fairly rapid spread of fire took place in the upper cavity. Flames emerged from the top of the structure approximately 25 minutes from the start of the test and burning continued until the test was terminated after 30 minutes.

#### DISCUSSION

The test results just described indicate that, when a vertical concealed space in a wall assembly that contains urethane foam insulation is subject to a fire, consideration of the flame spread rating of the foam, as determined by the procedure described in ULC-S102-1978 (4), does not allow prediction of the spread of the fire within the space. Urethane foams which differed in flame spread rating by a factor of 10 behaved similarly in the tests under comparable conditions.

Of much greater significance was the air space between the insulation and the boundary of the cavity wall. In assemblies where this air space was less than 25 mm wide, foam polyurethane insulations with flame spread ratings as high as 450 were involved in burning to a limited extent only, and indicated that spread of fire from storey to storey in a concealed space with this arrangement would be unlikely to occur. Only when a foam with a flame spread rating over 1000 was used did significant spread of fire seem probable and even then at a relatively slow rate. Increasing the air space above 25 mm resulted in more extensive involvement of the foam with rapid spread of flames throughout much of the 5 m height of the test rig, even when the flame spread rating of the foam was as low as 45. Here the effect of the facing material on the foam appeared to be significant since, under comparable conditions, the involvement of Material 2 (flame spread 450, facing-aluminum foil over Kraft paper) in the fire was slower and less extensive than Material 1 (flame spread 45, facing aluminum foil only). The reverse might have been expected if the surface flame spread rating of the foams was a significant variable.

The incorporation of an asbestos board or a sheet steel fire barrier in assemblies with an air space greater than 25 mm was effective in limiting the spread of fire in a concealed space beyond the immediate

area of origin. A barrier that permits drainage but not ventilation of the space proved very effective. With barriers that allow full ventilation of the cavity, the fire consumed all the insulation in the cavity of fire origin and, in the absence of any projection of the barrier beyond the face of the assembly, caused a limited amount of damage to the foam immediately above the barrier. Under the conditions used in this investigation, the involvement in burning of foam in the upper cavity was eliminated when the fire barrier projected 75 mm in front of the assembly.

The use of a wood fire barrier in a ventilated cavity appears to have a negligible effect on the spread of fire. In the test the wood fire barrier ignited after 14 minutes and fire spread to the top of the upper cavity in about 25 minutes. This compares with a time of about 20 minutes for flames to reach the top of a similar unstopped cavity when subjected to the same initial ignition source.

#### CONCLUSIONS

1. Polyurethane foam insulation used in a vertical position between two layers of non-combustible material with an intervening air space of 25 mm or less is not likely to contribute to fire propagation if its flame spread rating is less than 500.
2. Without an intervening air space fire propagation may not occur even if the flame spread rating is substantially higher than 500.
3. Fire stops of asbestos or steel are effective in controlling spread of fire in vertical concealed spaces where the air space is greater than 25 mm but wood fire stops are relatively ineffective.
4. Smoke evolution appears to be potentially more hazardous to life safety than the excessive spread of fire from storey to storey within a concealed space lined with polyurethane.

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1. Lie, T.T. Contribution of insulation in cavity walls to propagation of fire. National Research Council of Canada, Division of Building Research, Fire Study No. 29, November 1972. (NRCC 12878).
2. Standard Test Method for Surface Burning Characteristics of Building Materials, ASTM Designation E84-80, 1980 Annual Book of ASTM Standards, Part 18, p. 795.
3. D'Souza, M.V. Fire propagation tests with foamed plastics insulation within a cavity wall. National Research Council of Canada, Division of Building Research, Internal Report No. 424, February 1976.
4. Standard Method of Test for Surface Burning Characteristics of Building Materials, Underwriters' Laboratories of Canada, ULC-S102-1978.
5. Harmathy, T.Z. Design of Buildings for Fire Safety - Part I, Fire Technology, 12, 95-108 (1976).

TABLE 1  
MATERIALS AND TEST GEOMETRIES

No.	Material Type	Thickness mm	FSC* S-102-1978	Density kg/m	Air Gap, mm <sup>†</sup>					
					0	12.5	15**	25	38	50
1	Polyurethane/ Isocyanurate Laminate	50	45	32	x	x		x	x	x
2	Polyurethane Laminate	50	450	32	x	x		x	x	
3	Polyurethane Sprayed Foam	85	475	40	x		x			
4	Polyurethane Sprayed Foam	85	1100	40	x		x			

\* FSC - Flame Spread Classification

\*\* Irregular air space - 15 mm represents maximum

† x indicates arrangements tested

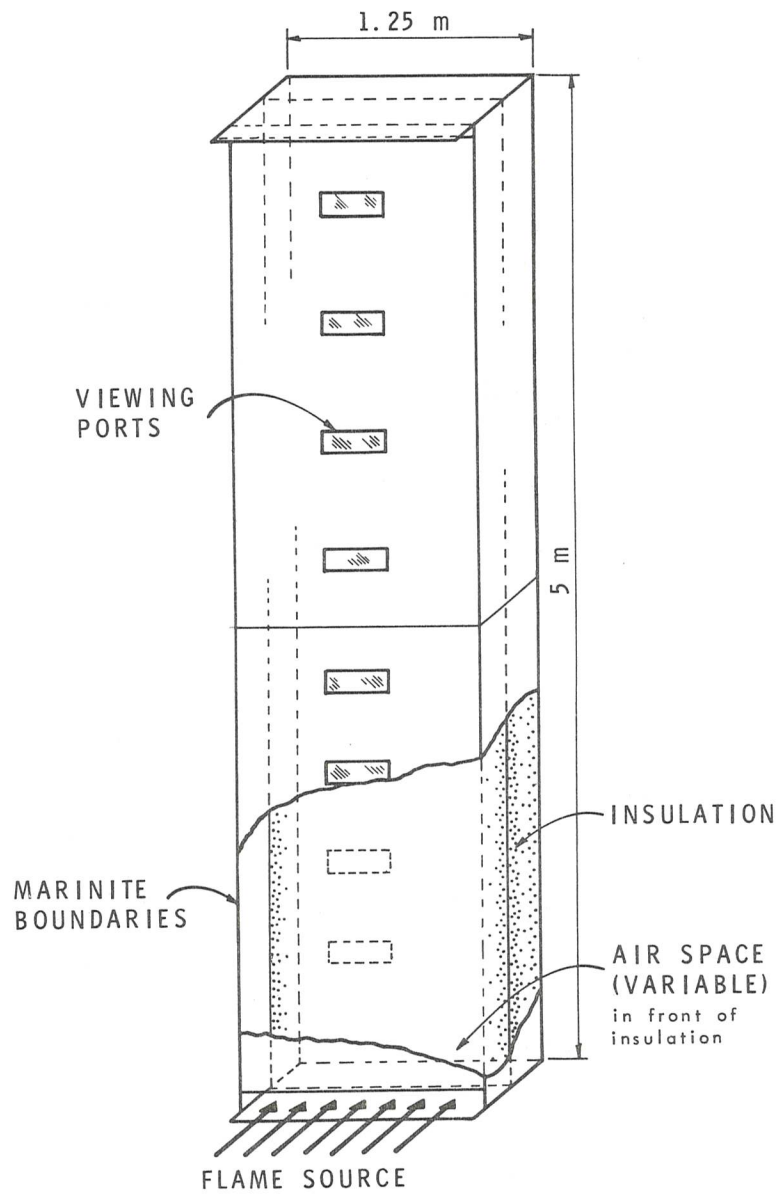


FIGURE 1  
CAVITY WALL TEST RIG

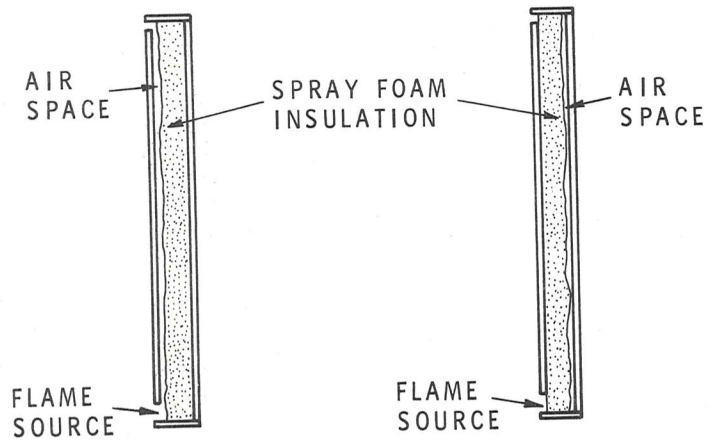
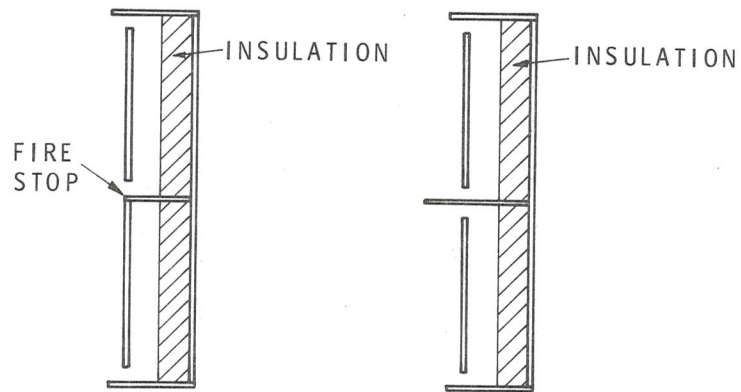
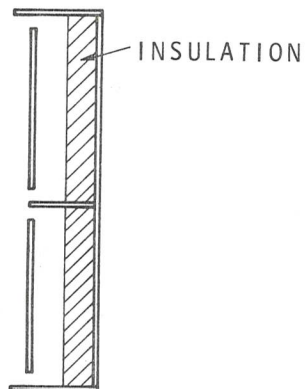


FIGURE 2  
SCHEMATIC OF TEST RIG FOR SPRAY FOAM  
EVALUATIONS



(a) NO VENTILATION,  
FULL DRAINAGE

(b) FULL VENTILATION,  
FULL DRAINAGE,  
75 mm PROJECTION OF STOP



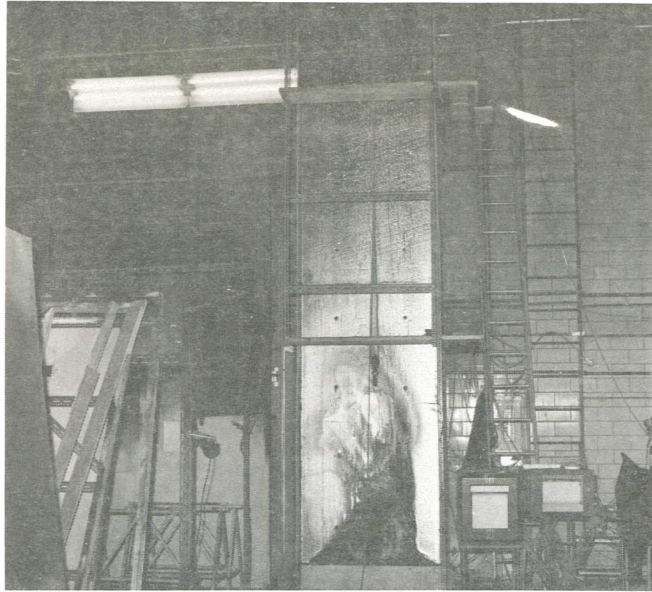
(c) FULL VENTILATION,  
FULL DRAINAGE,  
NO PROJECTION OF STOP

FIGURE 3  
ARRANGEMENTS FOR FIRE STOPPING OF VERTICAL  
FLAME SPREAD

APPENDIX A

A SELECTION OF PHOTOGRAPHS, WITH TEST RIG  
FRONT PANEL REMOVED, SHOWING APPEARANCE  
OF INSULATION AFTER THE CAVITY WALL TESTS

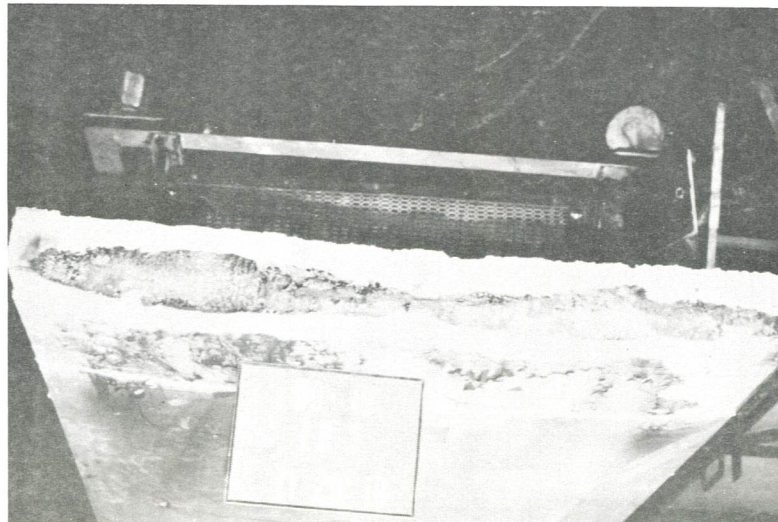
Figure A1 Tests with zero air gap



Material 1 F.S.C. 45



Material 2 F.S.C. 450



Material 4 F.S.C. 1100

Figure A2  
Tests with 12.5 mm air gap



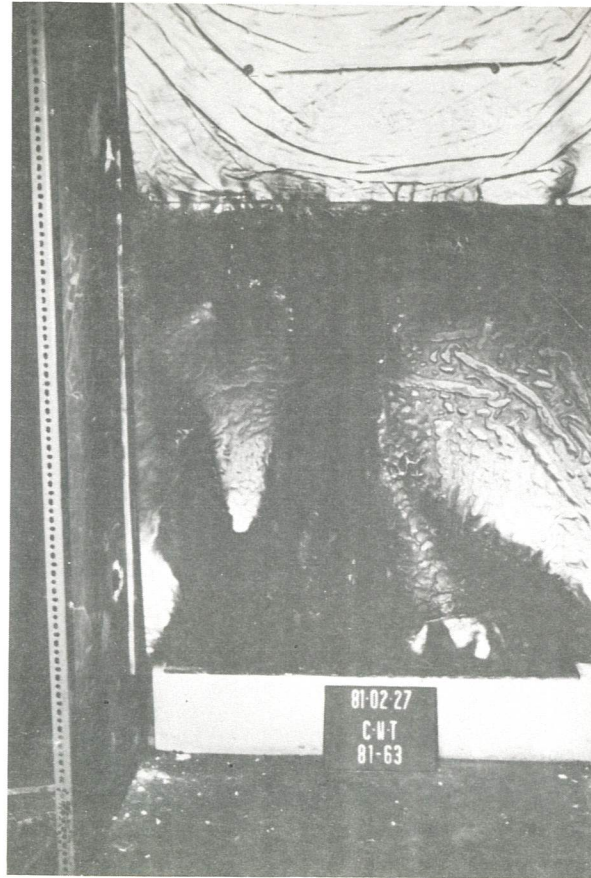
Material 1 F.S.C. 45



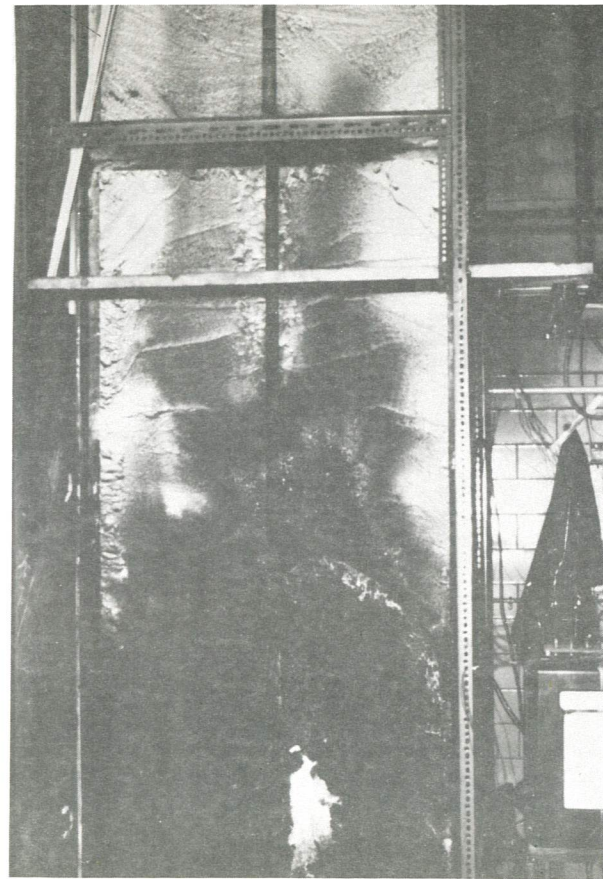
Material 2 F.S.C. 450

Figure A3

Tests with 15 mm air gap



Material 3 F.S.C. 475



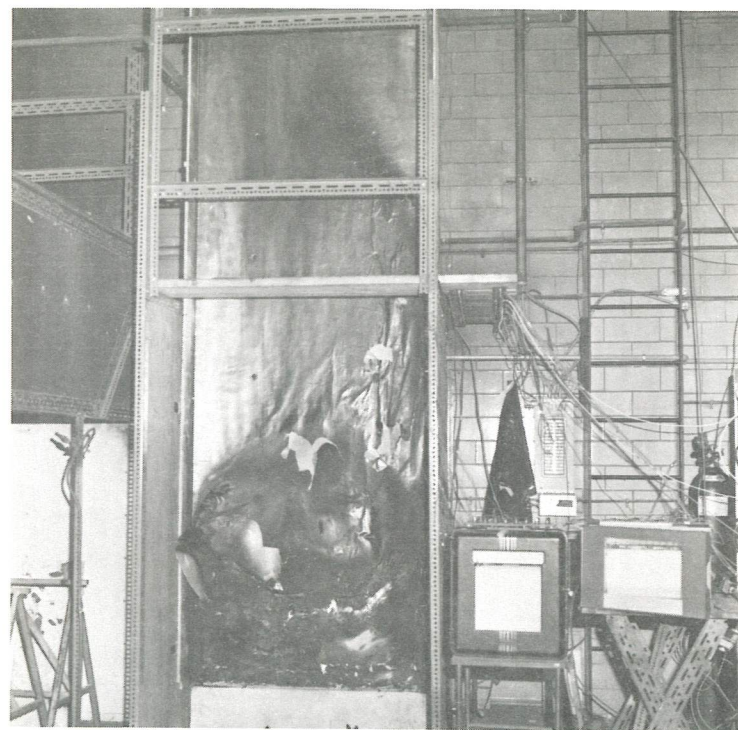
Material 4 F.S.C. 1100

Figure A4

Tests with 25 mm air gap



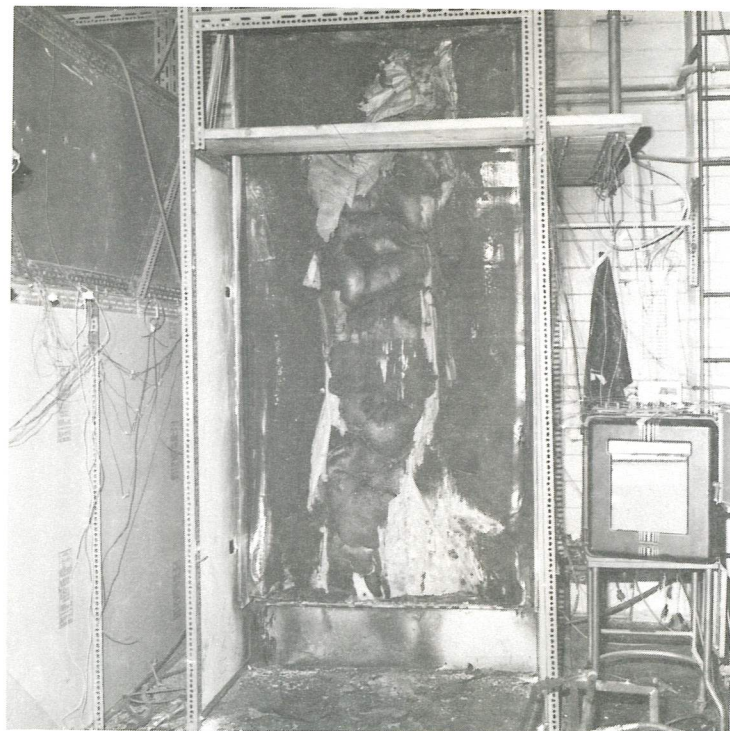
Material 1 F.S.C. 45



Material 2 F.S.C. 450

Figure A5

Tests with 38 mm air gap



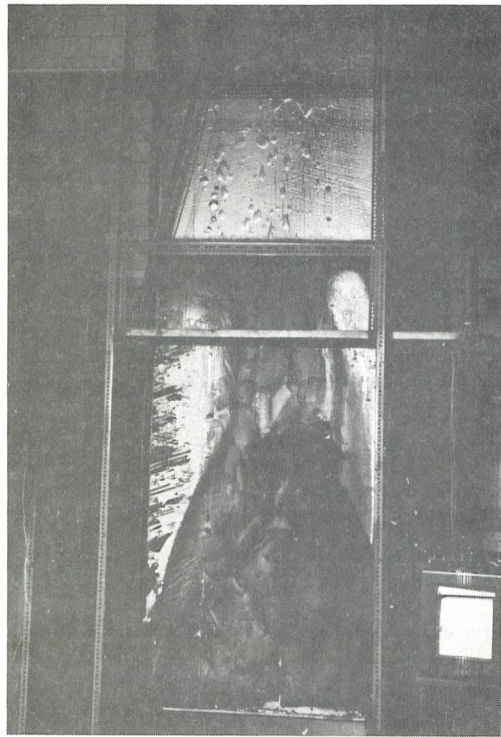
Material 1 F.S.C. 45



Material 2 F.S.C. 450

Figure A6

Tests with fire stop of asbestos board or sheet steel



Fire stop - Configuration A



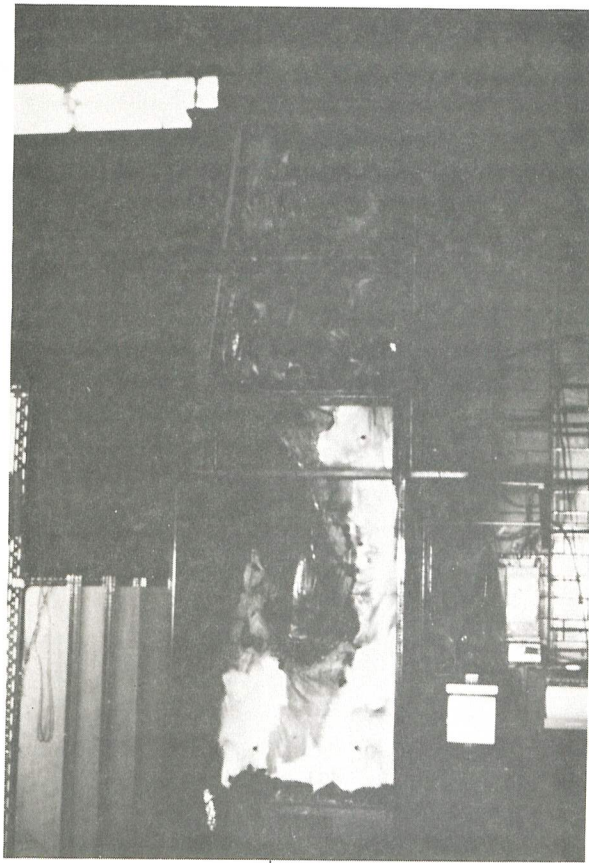
Fire stop - Configuration B



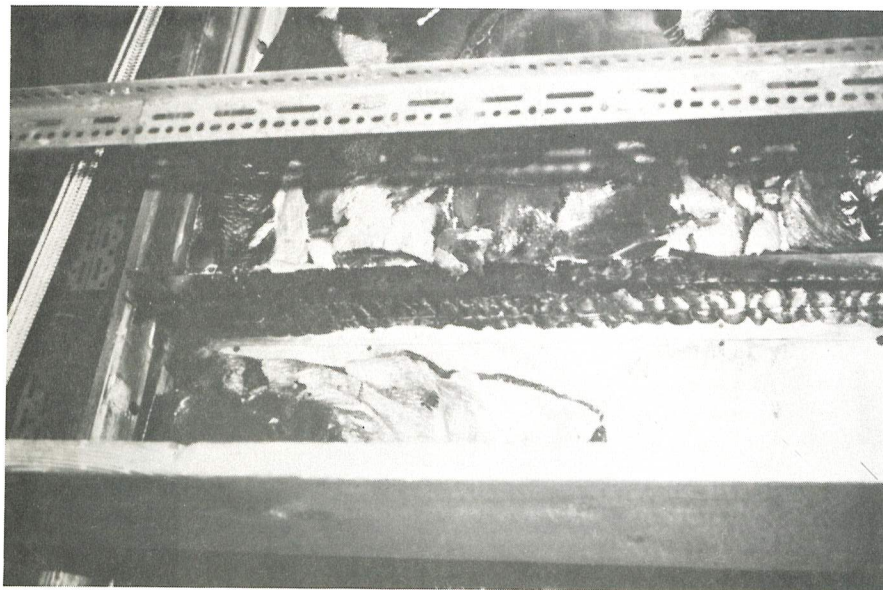
Fire stop - Configuration C

Figure A7

Test with fire stop of wood



Fire stop - Configuration B



Close-up of fire stop after test terminated at 30 minutes

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1. Lie, T.T. Contribution of insulation in cavity walls to propagation of fire. National Research Council of Canada, Division of Building Research, Fire Study No. 29, November 1972. (NRCC 12878).
2. Standard Test Method for Surface Burning Characteristics of Building Materials, ASTM Designation E84-80, 1980 Annual Book of ASTM Standards, Part 18, p. 795.
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5. Harmathy, T.Z. Design of Buildings for Fire Safety - Part I, Fire Technology, 12, 95-108 (1976).