STUDY REPORT

No. 144 (2005)

Flame Barriers For Foamed Plastics

P.C.R. Collier

The work reported here was jointly funded by Building Research Levy, and the Department for Building and Housing

FUNDED BY THE BUILDING RESEARCH LEVY

ISSN: 0113-3675

Preface

This is a report prepared describing research into the establishment of a viable testing method for the fire performance of flame barriers for foamed plastic construction materials as a means of demonstrating that the requirements of Acceptable Solution C/AS1 have been met.

Acknowledgements

This work was jointly funded by the Building Research Levy and the Department of Building and Housing.

Valuable advice and assistance from Bondor NZ, in particular Wren Bracegirdle and Antony Cook and also James Firestone of the New Zealand Fire Service, is gratefully acknowledged.

Note

This report is intended for:

- The Department of Building and Housing as a technical basis for reviewing and/or updating provisions contained within their Approved Documents.
- Manufacturers and designers who specify foamed plastics so they will have greater confidence in the safe application and use of the product.
- Insurance providers so they will also have a better basis for understanding the risk involved in covering buildings constructed from foamed plastics.

FLAME BARRIERS FOR FOAMED PLASTICS

BRANZ Study Report SR 144
P.C.R. Collier

REFERENCE

Collier, P.C.R. (2005). *Flame Barriers for Foamed Plastics*. BRANZ Study Report SR 144, BRANZ Ltd, Judgeford, Porirua City.

ABSTRACT

This study has demonstrated the effectiveness of the ISO 9705 room corner fire test method in evaluating the reaction to fire performance of polystyrene insulated panels (PIP) and differentiating the influence of various construction details used to join the panels on that fire performance. The results of the measurement of heat release rate (HRR) and smoke production rate (SPR) are a direct indicator of the opening (failure) of panel joints that expose the foam core to fire, allowing the escaping volatiles to contribute to the HRR and SPR. The recorded increases in the HRR and SPR were shown to be directly related to the opening of the panel joints which in turn was dependent on the jointing detail. So the stability of the construction details when subjected to fire exposure was demonstrated by the ISO 9705 test method to have a direct relationship to the fire performance achieved.

Keywords: polystyrene, insulating, panels, foamed plastics, fire, flame barriers, ISO 9705

Contents

Page

Figures

Page

Tables **Page**

1. INTRODUCTION

1.1 Background

A study jointly funded by the New Zealand Fire Service Commission, Plastics New Zealand and the Building Research Levy (NZFS, 2004) identified means of improving the fire performance of polystyrene insulated panel (PIP) in New Zealand. Joint detailing was identified as an area for attention in order to achieve further improvement in fire performance.

1.1.1 New Zealand test method

The current test method in New Zealand is specified in NZBC C/AS1 – Appendix C (DBH, 2005). The test method requires an assembly incorporating the flame barrier, and any proposed jointing methods in that barrier are subjected to the time-temperature conditions of AS1530 Part 4 (SA, 2005) for a period of at least 10 minutes. At the completion of the test, the exposed face of the flame barrier shall be inspected. The flame barrier shall pass the test if no cracks, openings or other fissures have developed which would permit vision through the flame barrier or joint. More details of the test method and evaluation of results are included in *Appendix 2 – Current flame barrier test method*. Evaluation of the test result is very subjective and joints may continue to move after the test has been terminated. In BRANZ's experience, the reported results show passes or failures with little relevance to the core involvement other than observations of production of smoke, flaming and the opening of the gaps on the basis of vision through the gaps at the conclusion of the test. BRANZ experience of this test method has highlighted difficulties and deficiencies in accurately determining a pass or fail. For example, a particular joint design may be included in two locations at opposite ends of a specimen; one is deemed to pass and the other to fail on the basis of the gaps formed. This problem may arise where the exposure conditions vary for different locations in a furnace, especially with the practical difficulties of ensuring the exposure is exactly to the prescribed fire exposure conditions in the first 10 minutes when conditions are unstable, and the combustion of the gases evolved from the pyrolysis of foamed plastics may be causing localised temperature excursions. Another practical issue is that while smoke is being cleared to permit the specimen to be examined, further movement of specimen joints occurs. It then becomes difficult to accurately assess the pass/fail criteria specified in the NZBC Acceptable Solution C/AS1.

1.1.2 New Zealand research into PIP

Analysis of the results of the testing in the BRANZ ISO 9705 room of 2.4 m (H) x 1.2 m (W) panel joint sections (NZFS, 2004) indicate that the performance of the joints can be resolved and are summarised in Table 1. The FIGRA index in the right hand column is the FIre GRowth RAte and is the ratio of peak heat output (after the 100 or 300 kW of the burner is subtracted) to the time in seconds at which it occurs. The trend indicates an improvement in the performance of the joints consistent with expectations as the rivet spacing is reduced and the difference between the aluminium and steel angles on the mitred corners.

Table 1: Performance of joints

Trial	Average, kW	Peak, kW	At time, secs	Total heat, MJ	Joint/rivets ctrs, mm	FIGRA
1	228	527	1065	296	Interlocking, 2400	0.213
2	227	469	933	273	Interlocking, 1200	0.181
3	212	325	1122	259	Interlocking, 600	0.0222
4	236	648	768	283	Mitre alum angle, 200	0.45
5	222	415	801	265	Mitre steel angle, 200	0.143

Smoke analysis of the above five trials indicated a similar trend, but was not reported as there were some gaps in the data due to malfunctioning of the equipment. In future the SMOke Growth RAte (SMOGRA) can be evaluated similarly to FIGRA.

Cone calorimeter testing to AS/NZS 3837 (SA, 1998) of 100 mm x 100 mm x 25 mm samples demonstrated (Table 2) the value of fire retarded EPS and the steel skins, and also the inclusion of a fibre-cement board between the steel and the EPS. The data from NZFS (NZFS, 2004) is compared on the basis of 50 kW/m^2 radiation exposure and evaluated. It is not considered appropriate to rely on such small scale testing of a metal clad EPS composite since, for a metal clad composite, the fire behaviour would be determined almost totally by the edge detailing and effects.

Table 2: Cone calorimeter testing of PIP

Specimen type*	FR-S	FR-N	NFR-S	NFR-N	FR-S-FC
Radiation, kW/m2	50	50	50	50	50
Time to ignition, sec	83	37	68	26	198
Peak heat release, kW/m^2	97	306	477	507	76
Total heat release, MJ/m^2	19	15	17	17	20
ABCB Group No.	1	2	2	3	1
SEA m^2/kg	1004	1394	977	1174	609

** Key to specimen types:*

FR = flame retardant treated EPS
NFR = non-flame retardant treated EPS
S = covered with steel skin
N = not covered with steel skin
FC = a layer of 4.5 mm fibre-cement board between the EPS and the steel skin

However, a sample of the cone calorimeter results for the five different samples were compared with the ABCB Specification A2.4-3 (ABCB, 2005) method for predicting a material's group number on the basis of a cone result instead of an ISO 9705 room result. The ABCB group number results are included in Table 2. For the purposes of ABCB, Specification C1.10a (ABCB, 2005) in turn specifies in what class of building such materials may be used in.

1.2 Project objectives

The objective of this project is to follow the outcomes of the earlier BRANZ research and identify, with possible further development, an appropriate test method that can be cited in C/AS1 as a means of testing the effectiveness of flame barriers for foamed plastics.

The key requirements of a test method are:

- test method can rank the performance of products and systems in accordance with prescribed levels in C/AS1
- primarily the system performance is evaluated rather than the material performance
- satisfactory performance can be recognised and quantified
- the test is practical and of reasonable cost
- rapid turnaround between tests
- wide acceptance internationally
- can be related to the expected building performance in fire
- delivers reproducible and consistent results.

2. LITERATURE REVIEW

The definition of flame barriers in C/AS1 (DBH, 2005) is: "a material or system applied or installed to protect another *building element* from flame contact. The protection shall be effective for no less than 10 minutes exposure in the *standard test* for *fire* resistance". The test requirements are explained in *Appendix 2 – Current flame barrier test method*. PIP is a manufactured composite product, whereby the steel skins provide the flame barrier function of protecting the foamed plastic panel core. The selection of PIP for this study was based on the knowledge that the product is produced under consistent conditions and would be capable of delivering repeatable results. Therefore any changes in the installations would be indicated by changes in the reaction to fire performance parameters measured and evaluated in the alternative test method used for the experimental phase.

The problem with panel cores, whether they are EPS or any other similarly flammable material as used in PIPs, is the risk of them becoming involved in a building fire and this is concisely described by Rakic (2003). If the facings are secured with no through fixings, early collapse can occur and accelerate the speed of flame spread. However, if the panel facings remain secured and the joints remain tight there should be no unexpectedly sudden spread of flame across a wall or ceiling. This was included in the conclusions of the previous BRANZ study (NZFS, 2004) and accepted as a most effective means of improving the fire performance of PIPs.

The objective of this literature review is to present a 'state of the art' approach to furthering the case of developing and recommending the most appropriate and effective test method to evaluate the performance in fire of construction/assembly details of PIP systems in fire. Such a test method will be able to replace product ranking tests by a newer reference scenario test where the end-use of the product is realistically represented (Wade, 2003).

2.1 Current test methods

In a literature survey by Baker (2002) the fire test methods currently in use are described and evaluated. Although no particular test method is recommended as a preferred test, the information provided serves as a starting point to justify selecting the most favourable test and develop it further.

From the range of test methods used worldwide a selection is listed in Table 3. The methods listed are evaluated on the basis of exposure intensity of the fire source, sample size, assessment and classification of results. Further comments assess the effectiveness of the various test methods.

Table 3: Test methods in current use

Test method	Juristiction	Exposure/fuel	Room/sample size	Assessment/classification criteria	Comments	Comments
AS ISO 9705	Australia	100/300 kW gas burner	3.6 x 2.4 x 2.4(H)	FCRC Group 1, 2, 3 or 4	Trial tests both within ISO room enclosure and free-standing have shown improved results consistent with improvements in fabrication techniques	Group 1 performance has been achieved using steel materials instead of aluminium for angles and rivets. SMOGRA can be evaluated too
ISO 9705	International	100/300 kW gas burner	3.6 x 2.4 x 2.4(H)	FIGRA, SMOGRA, Flashover > 1MW	Best chance of getting flashover. And subjecting specimen to a severe test. Quantitative	
ISO 9705	International	100/300 kW gas burner	3.6 x 2.4 x 2.4(H)	Eurific Class A, B, C, D, E and UC	Reference, Johansson and Van Hees, 2000	
ISO 13784-1	International	100/300 kW gas burner	3.6 x 2.4 x 2.4(H) free standing		More severe than ISO 9705 but representative of	Easier to erect and demolish specimens
SBI EN13823	Europe	30 kW for 20 mins gas burner		Euro Class A1, A2, B, C, D, E & F (FIGRA) and for smoke s1, s2, or s3 based on smoke produced	Latest calorimetry std (copy of ISO 9705)	Unlikely to be able to discriminate between different panel constructions (G. E. M. Cooke)
LPS 1181 (LPC corner test)	UK	Wood crib 1 MW peak - an ignition test	10 x 4.5 x 3 (H)	Qualitative post-test examination. No pass/fail criteria. Just reports the extent of damage to specimen on a percentage basis	Fire source creates a severe test of short duration (10 mins) and therefore may not simulate a) a small localised fire which continues to spread or b) a fully developed fire of greater thermal severity	Test rig is too big for practical purposes
LPS 1208	UK	Essentially a fire resistance test			Basically fire resistance test based on BS 476	Unsuitable
FM 4880	USA	1.5m (H) x 1.7 x 1.7 m (340kg wood pallet crib approx 4 MW	6.1 x 6.1 x 15.2 m(H) Corner test	Propagation of upward flame spread above 6 m.	Qualitative assessment. Too big. Unsuitable	FM state that the requirement of metal skins is to delay ignition of the plastic for 10 to 15 mins to allow sprinklers to control the fire.
NZBC C/AS1	NZ	ISO 874 furnace TT exposure for 10 mins	2.2 x 1 x 1.2m(H)		Qualitative assessment	Unsuitable

2.2 Current research into test methods

A study at the Swedish National Testing and Research Institute (Johansson and Van Hees, 2000) compares the fire performance of panel with four different cores. The fire test methods include ISO 9705 (ISO, 1993) room test and ISO 13784 Part 1 (a draft international standard under consideration, (ISO DIS, 2000)) that used the same fire exposure conditions as ISO 9705, except that the specimen itself forms a room as a free-standing construction under an exhaust extraction hood rather than being constructed inside the ISO 9705 room. The Single Burning Item (SBI) test method (EN13823, 2000) was included as a third test method in this evaluation.

The fire behaviour of these panels is acknowledged as a combination of material characteristics such as the core material and the mechanical behaviour of the panels such as joints, dilations (openings) etc.

It is further concluded that simulating the end-use conditions in a realistic way is very important when evaluating the burning of sandwich panels. Based on the results of a series of tests conducted both in free-standing rooms, the ISO 9705 room/corner test configuration and the SBI test protocol, a number of conclusions can be drawn (Johansson and Van Hees, 2000):

- Mounting technique and especially joint behaviour are important factors determining fire behaviour. Any test used for evaluation of the fire risk of sandwich panels should be able to include the so-called end-use conditions.
- A first comparison with the SBI test shows poor correlation with full-scale set-ups. The products behave in most cases much better in the intermediate scale SBI test. Use of the SBI method for sandwich panels is therefore questionable.
- The free-standing test set-up allows for correct mounting in end-use conditions of panels and allows easier mounting and dismounting.
- The free-standing test set-up used for the project allows for measurement of the HRR and SPR. This means that the procedure for HRR and SPR measurements as mentioned in ISO 13784 Part 1 was used.
- The free-standing test set-up is more severe than the ISO 9705 room tests.

Wade (2003) reports research indicating that large-scale testing is required to gain reliable results. Smaller scale tests (including cone and SBI) cannot evaluate the ability of the panel sheet and joints to prevent ignition of combustible cores. Although the provisions of ISO 9705 may be relevant, there are practical difficulties in achieving a representative installation and there is now a preference for fire testing a free-standing room. However, this requires large facilities only currently available at Fiskville, VUT, Australia. Use of the ISO 9705 might still be practical with innovative means of getting the specimen inside the room (test enclosure). Recent European research recommends that:

- tests should be carried out on a free-standing room and measurements taken of HRR and smoke production
- sandwich panels should not be tested using small-scale methods (e.g. cone, SBI).

A report prepared by the BRE (BRE, 2003) addresses the implications of European harmonisation for sandwich panels. The report supports the testing to ISO/FDIS 13784-1 as opposed to the ISO 9705 room as it provides the smallest realistic size for realistic construction of the end-use conditions for sandwich panel systems, which are the building envelope rather that linings within a building. It is also the worst case in terms of propensity for flashover and incorporates the measurement of HRR, SPR and fire spread performance through the panels. Although the experimental part of the programme did not test EPS panels (it tested modified phenolic, PIR, PUR and rock fibre) reference is made to a similar study (Johansson and van Hees, 2000) that tested EPS panels. Much the same conclusions are reached in each case.

The general tenor of the conclusions and recommendations are vague, and although the ISO/FDIS 13784-1 test standard is preferred over the SBI test, there are a number of practical problems with the draft test method concerned mainly with the structure for mounting of the specimen and the effect on burner location and flame behaviour.

Rakic (2003) reports that the ISO 9705 (ISO, 1993) full-scale test method may not in fact be the best method for testing of insulating (sandwich) panels, as the test does not allow fully for the mechanical behaviour of the panels, such as the important influence on performance by way of proprietary and relatively complex panel-to-panel joint systems, and the proprietary mechanical fastening of the panels. Recent developments include a ‘free-standing set-up’, ISO 13748 Part 1 (ISO, 2002). It is based on the principles of ISO 9705, but caters for the exacting requirements of testing insulated (sandwich) panel building systems.

Cooke (2000) in an assessment of the safety issues in general, states that there is no British Standard for the reaction to fire of sandwich panels in their composite form and that the performance of panel joints or other features are dependent on the size of the specimen under test. It is also considered unlikely that the SBI test will discriminate between different panel constructions and that ISO 9705 is more likely to be used for sandwich panels.

The International Association of Cold Storage Contractors (IACSC, 1999) acknowledge the need for a reaction to fire test that tests the products as they are intended to be used. This requires that sandwich panels be tested with joints and junctions such as in ISO 13784 Part 1 and 2 for intermediate and large-scale assemblies respectively.

2.3 Ignition characteristics of EPS

The ignition characteristics of EPS are likely to have a significant influence on the fire performance. It was considered in the course of the steering committee meetings for this project that it may actually be fairly difficult to initiate and maintain burning, and that molten polystyrene in a pool as it occurs at the bottom of wall cavities would generally self-extinguish in the absence of a significant heat flux impinging on it.

The ignition characteristics of styrene (a liquid at ambient temperature) were sourced from Babrauskas (2003) and are summarised as follows.

The flammability limits are LFL 1.1% and UFL 6.1%, and the minimum oxygen concentration for flame propagation in a predominantly nitrogen environment is 9%.

For polystyrene, a temperature of about 350^{o}C is required for the formation of ignitable gases, and ignition will occur when initiated with a pilot flame (for fire retardant treated polystyrene the ignition temperature rises to 430-445^{o}C). Without an ignition source the temperature of surrounding surfaces must rise to 500-600^{o}C, by which time the polystyrene most likely will have melted and flowed away from the hot surface in the case of a wall. In the case of a ceiling, a pool of polystyrene is likely to be sitting on the hot surface and it may therefore ignite if sufficient oxygen is present or it may flow through gaps into the heated room space below and ignite if sufficient oxygen is present.

In conclusion, to initiate and sustain combustion of the polystyrene core or the resultant molten formations at floor level, significant temperatures and heat flux are required. These conditions may not be met at the lower elevations of the ISO 9705 test room unless flashover has occurred, in which case the temperature and heat flux at floor level will be significantly higher.

3. SELECTION OF A TEST METHOD

The principal requirement in the selection of a test method for the experimental phase of the project is that it could successfully resolve the differences in the reaction to fire performance of the PIP constructions. Two candidates were considered, ISO 9705 and ISO 13748 Part 1, because it was expected they would deliver the most consistent results for variations in PIP construction. At BRANZ it was not possible to conduct tests strictly in accordance with ISO 13748 Part 1 due to limitations in the test apparatus preventing a free-standing construction. However the ISO 9705 test room does permit the construction of a free-standing specimen within the test room enclosure without attachment to the walls and ceiling, but with some limitations in the detailing of the outer skin.

3.1 ISO 9705 room

A typical ISO room layout is shown in Figure 1. The burner in the corner subjects the test specimen to an exposure of 100 kW for 10 minutes followed by 300 kW for 10 minutes. The exhaust gases are removed by the extraction hood and analysed to determine oxygen, carbon dioxide, carbon monoxide and optical density. The HRR is calculated by oxygen consumption calorimetry and the SPR is determined from the optical density and flow rate in the duct.

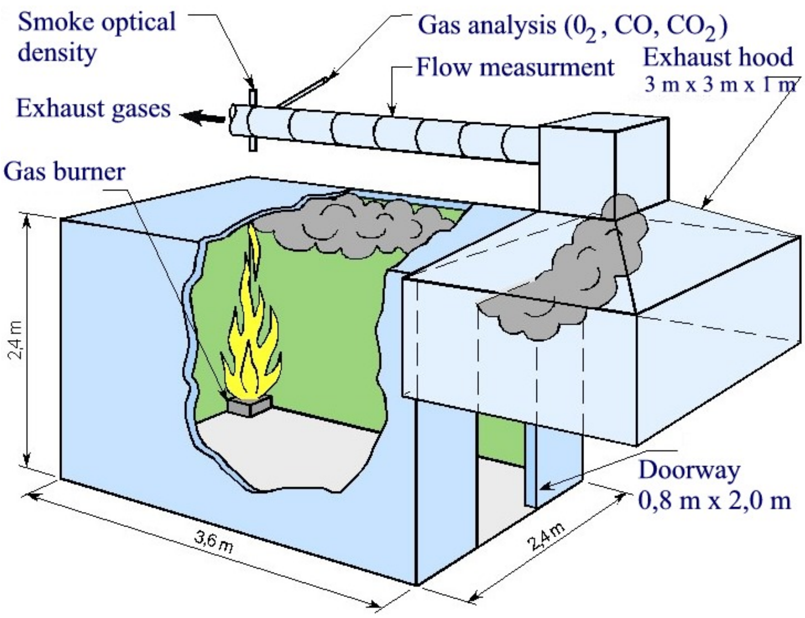

Figure 1: ISO 9705 room and extraction hood (diagram courtesy of SP Swedish National Testing and Research Institute)

Various options for using the ISO 9705 room to evaluate PIP assemblies were considered for the experimental trials in this project.

The construction of the BRANZ ISO 9705 room is from lightweight concrete panels nominally 100 mm thick and density 560 kg/m^3.

The floor is modified with the addition of 16 mm fire rated plasterboard over 12 mm plywood covering the floor. This provides a base for securing the bottom edge of the walls via aluminium angles to the floor, whereby the angles are riveted to the panels and screwed to the floor.

The panels are then assembled inside the room as a free-standing enclosure.

The disadvantages of this approach are highlighted by Johansson and van Hees (2001) such that:

1. The internal dimensions in the room (3600L x 2400W x 2400H mm) will limit the internal dimensions and volume of the system under test, especially as the thickness of the panels increase.

2. The joints are expected to have an important effect on the fire behaviour of the complete system. It is important that the test specimen is assembled in the same manner as it would be in an actual construction situation. The practicalities of assembly within an enclosure limit the access to all joints on the outside surface. Some sections can be pre-assembled before installation in the room enclosure, but one of the corner sections and the wall-to-ceiling junctions cannot be accessed on the outer surface. This means that the external angles cannot be attached to both skins resulting in an imperfect seal on the outer skin, which may be detrimental to the performance.

3. Because the test assembly is contained within an enclosure it is not possible to make observations of the outer surface. Such observations may include excessive smoke leakage, flaming and deformation.

It was also determined by Johansson and Van Hees (2001) that the free-standing assembly is (generally) a more severe test condition than if enclosed in a room as above.

On balance it was considered that by erecting a free-standing test assembly within the room any advantage to the performance of the specimens would be minimised and that free-standing conditions would be achieved as close as practicable to the provisions of the ISO 13784 Part 1 test.

So for the experimental phase free-standing specimens were erected within the ISO 9705 test room. Limitations due to practical difficulties such as fixing angles to external corners were accepted but, where possible, complete detailing was achieved in critical areas close to the burner corner. At locations remote from the burner some compromises were made without adversely affecting the test results. The envelope created by the ISO room enclosure contained the smoke and hot gas emitted from the specimen's outer surface and funnelled them to the hood for analysis along with the exhaust gases from inside the test specimen.

4. EXPERIMENTAL TRIALS – RESULTS AND ANALYSIS

The existing BRANZ ISO room with the addition of plasterboard over plywood on the floor was selected for the experimental phase. Four specimens were constructed to the general details illustrated below in Figure 2 and Figure 3 and more specific features of the individual specimens are recorded in Table 4.

The PIP lining was installed inside the lightweight concrete room as a free-standing assembly – there were no mechanical fixings between the panels and the test room other than at floor level. The lining material was nominally 100 mm thick fire retardant treated expanded polystyrene sandwiched between steel skins of 0.6 mm thickness. The density of the EPS was 16 kg/m^3. Panels were secured at 250 mm centres with 4.8 mm aluminium blind rivets on the bottom edges between 40 x 40 x 1.6 mm aluminium angles screwed to the floor. The mitred corners were joined with 40 x 40 x 1.6 mm (aluminium or colorsteel®) angle on the internal corners and 50 x 50 x 1.6 mm (aluminium or colorsteel®) angle on the external corners. In each case the angles were attached to the steel skins with 4.8 mm (aluminium or stainless steel) rivets at 250 mm centres.

The layout of the panels in the assembly was three 1200 mm wide panels on each 3600 mm long side wall with two slip (interlocking) joints. The 2400 mm long end wall comprised a 1200 mm wide panel in the centre interlocked with two 600 mm wide half-panels to the mitred corners. The ceiling comprised two panels of nominal dimensions (3600 x 1200 mm) with the interlocking joint running along the centre of the 3600 mm dimension of the ISO room.

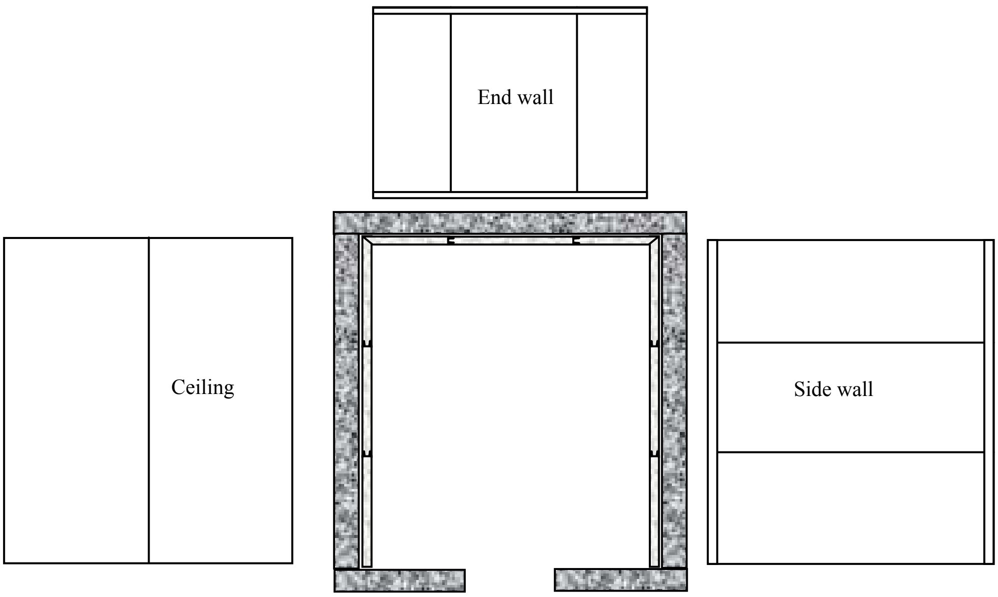

Figure 2: Assembly of test specimen, layout of panels

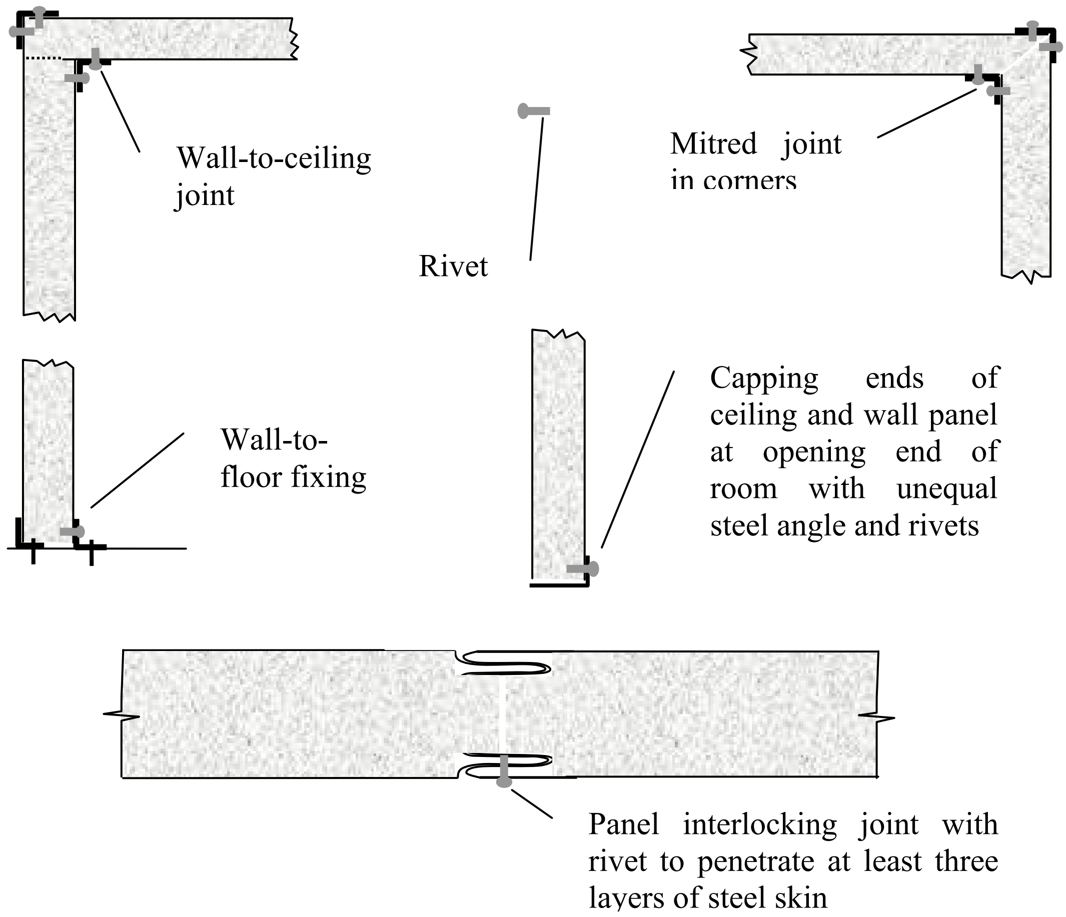

Figure 3: Panel assembly details

Table 4: Variations of individual test specimens

Test specimen number	PIP 1	PIP 2	PIP 3	PIP 4
Panel	100 mm EPS core plus 0.6 mm steel skin glued on each side			
Rivets	4.8 x 15 mm aluminium			4.8 x 14.3 mm stainless steel
Internal angle on wall-to-wall and wall-to-ceiling junctions	40 x 40 x 1.6 mm aluminium angle fixed with rivets at 200 mm ctrs		40 x 40 x 0.6 mm colorsteel® angle fixed with rivets at 200 mm ctrs	
External angle material (where fitted)	50 x 50 x 1.6 mm aluminium angle with rivets at 250 mm ctrs		50 x 50 x 1.6 mm colorsteel® angle with rivets at 250 mm ctrs	
Interlocking joints/rivets	No rivets	On ceiling at 1500 ctrs, but not at each end On walls at 2400 ctrs i.e. top and bottom	On ceiling at 1500 ctrs and at each end On walls at 2400 ctrs i.e. top and bottom	
Fixing bottom of panels to floor	40 x 40 x 1.6 mm aluminium angle on each side			
End capping on wall and ceiling panels at open end	100 x 40 x 2 mm mild steel angle fixed with rivets at 200 mm ctrs			

4.1 Analysis of test results

The results or the tests were processed in the format required by the test standard ISO 9705:1993(E) and an in-depth analysis of the tests, including comparisons of the influences of construction features, is included below.

A summary of results are presented on same basis of the Nordtest project (Johansson and Van Hees, 2001) in Table 5.

Table 5: Table of results evaluating PIP systems using ISO 9705 parameters

Parameter	PIP 1	PIP 2	PIP 3	PIP 4
Flashover Yes / No	Yes	Yes	Yes	No
Flashover time (time to 1000 kW (min:sec)	9:54	11:51	14:21	>20:00
Max HRR 0-2 min (kW) excl. burner	92.94	0***	11.70	2.47
Max HRR 0-10 min (kW) excl. burner	>900**	260.50	67.65	22.49
Max HRR 0-12 min (kW) excl. burner	>900**	>700**	67.65	43.76
Max HRR 0-20 min (kW) excl. burner	>900**	>700**	>700**	57.41
Max SPR 0-2 min (m^2/s)	0.00	0.49	0.32	0.53
Max SPR 0-10 min (m^2/s)	4.45	9.94	3.35	1.42
Max SPR 0-12 min (m^2/s)	**	**	3.35	2.29
Max SPR 0-20 min (m^2/s)	*	*	*	3.55
Average HRR 0-10 min (kW) excl. burner	126.92	52.37	12.18	-8.37
Average HRR 0-12 min (kW) excl. burner	*	*	7.99	-6.35
Average HRR 0-20 min (kW) excl. burner	*	*	*	1.39
Average SPR 0-10 min (m^2/s)	1.83	2.95	1.48	0.67
Average SPR 0-12 min (m^2/s)	*	*	1.42	0.78
Average SPR 0-20 min (m^2/s)	*	*	*	1.32
Group number according to BCA	**3**	**2**	**2**	**1**
Euroclass according to ISO 9705	E	D	C	A
FIGRA kW/s	1.85	1.00	0.83	0.07
SPR60 m^2/s (60 second average)	34.4	22.9	20.9	2.9
$SMOGRA_{RC}$ (m^2/s^2 x 1000) according to BCA	**58**	**32.2**	**24.3**	**3.8**

** Not appropriate due to flashover*
*** Flashover occurred during this period*
**** Calorimetry instrumentation recorded some negative HRR values, when adjusted for the burner contribution, indicating some suppression of combustion by the excessive smoke observed and indicated by max SPR in the same period.*

The HRR recorded in each of the four tests are compared in Figure 4. Once a heat release of 1 MW is exceeded indicating flashover the fires were extinguished with a standpipe mounted sprinkler at 1.2 m elevation in the centre of the room. Of particular significance is the margin of the HRR above that contributed by the burner (this equates to the contribution of the EPS in the panel core adding fuel to the fire). The magnitude of the peak is not particularly relevant as this is cut short by extinguishment of the fire once it is deemed that flashover has occurred. Of greater significance is the time period, and this is dependent on the rate that the EPS vapour escapes from the panel core and contributes to the HRR and whether 1 MW is exceeded. By comparing the jointing detail methods in Table 4 it is evident that there is a clear relationship between improving the security of the panel joints and a delay in the contribution of the EPS core and time to flashover.

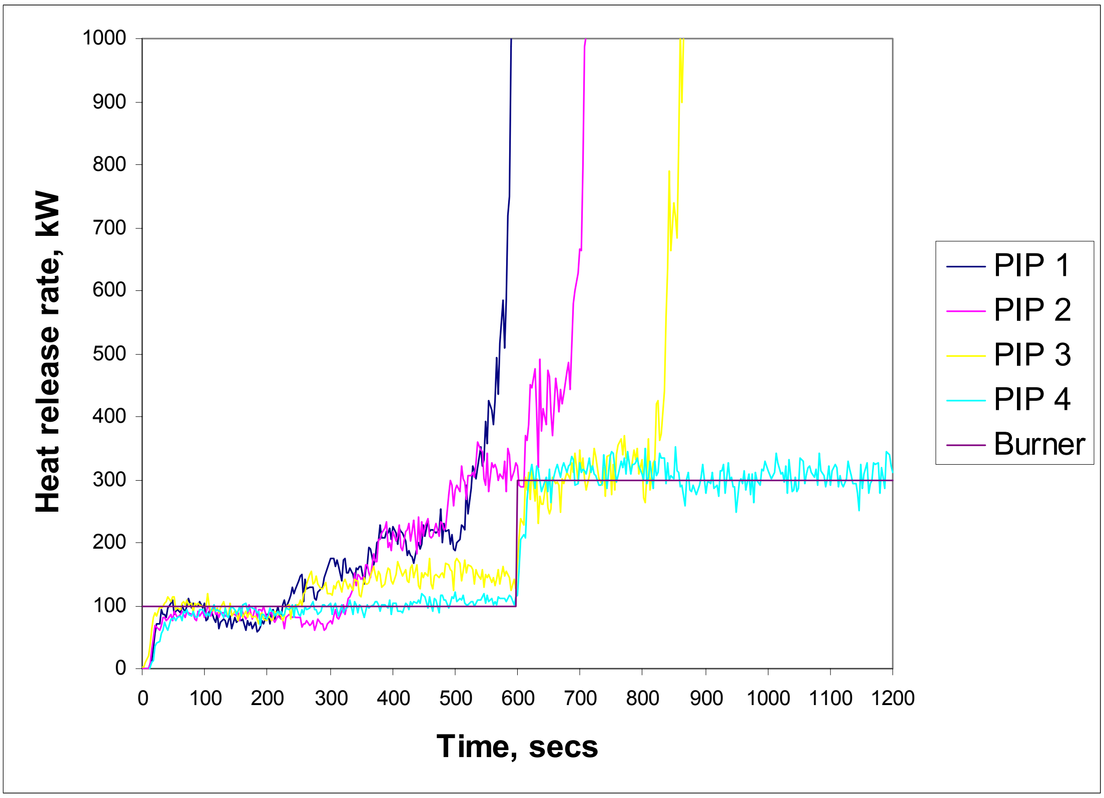

Figure 4: Heat release rates of each test

Similar comparisons can be made with the products of combustion such as the SPR, carbon monoxide (CO) and carbon dioxide (CO_2) where the delays in the increases are directly attributable to the performance of the joints as indicated in Figure 5, Figure 6 and Figure 7.

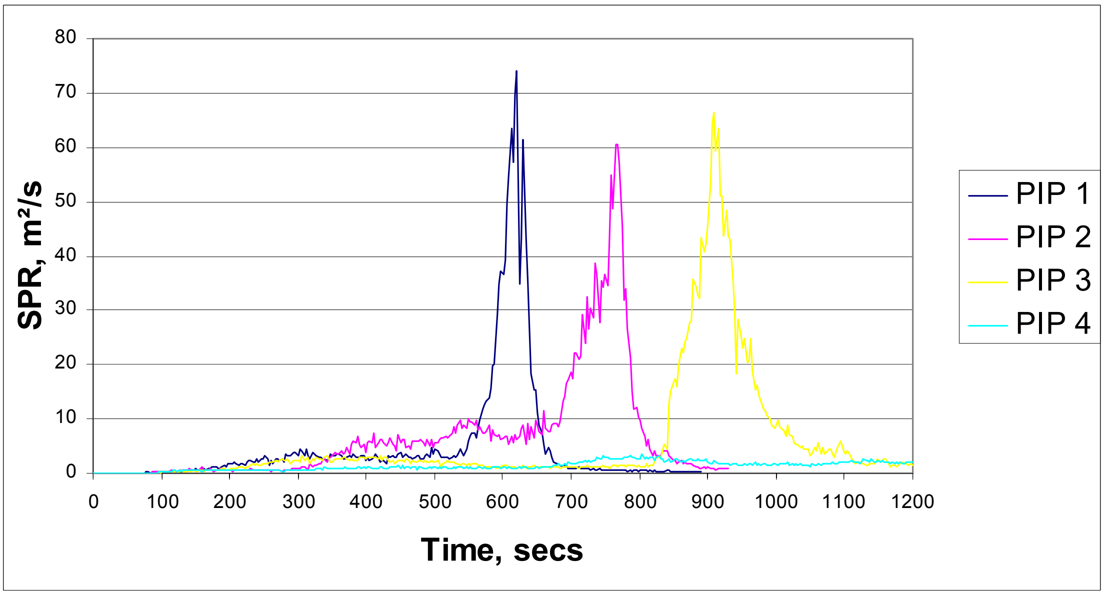

Figure 5: Smoke production rate

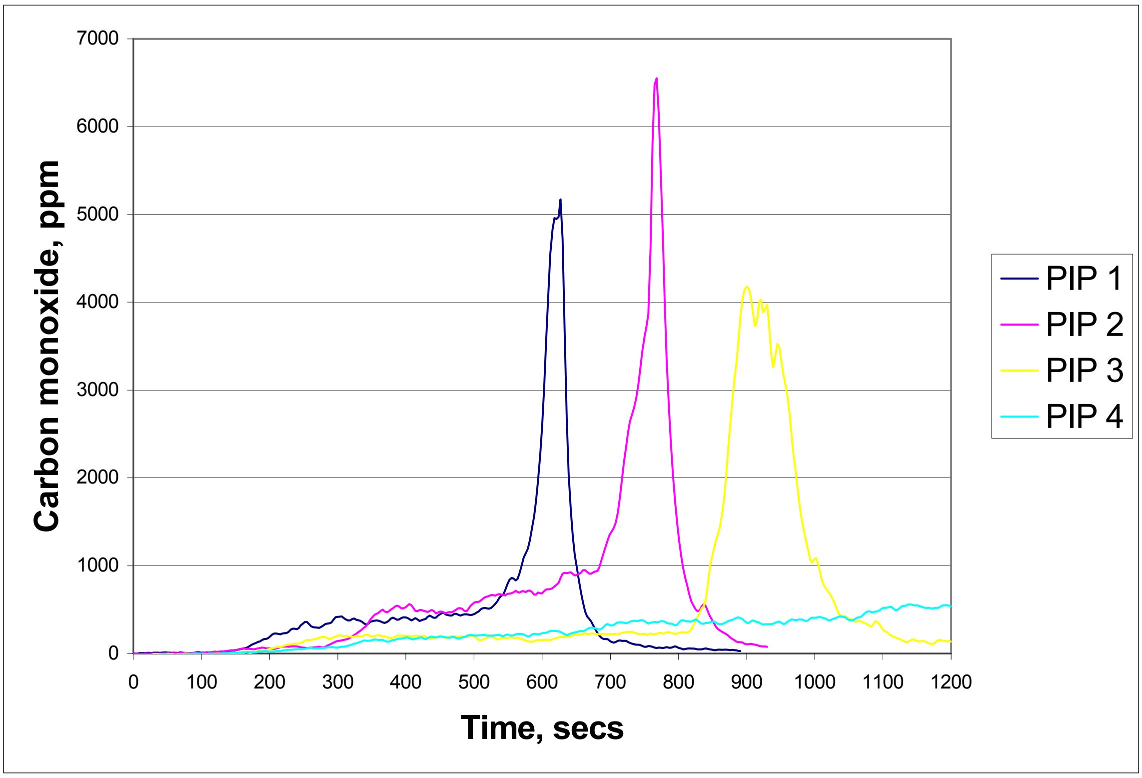

Figure 6: Carbon monoxide production

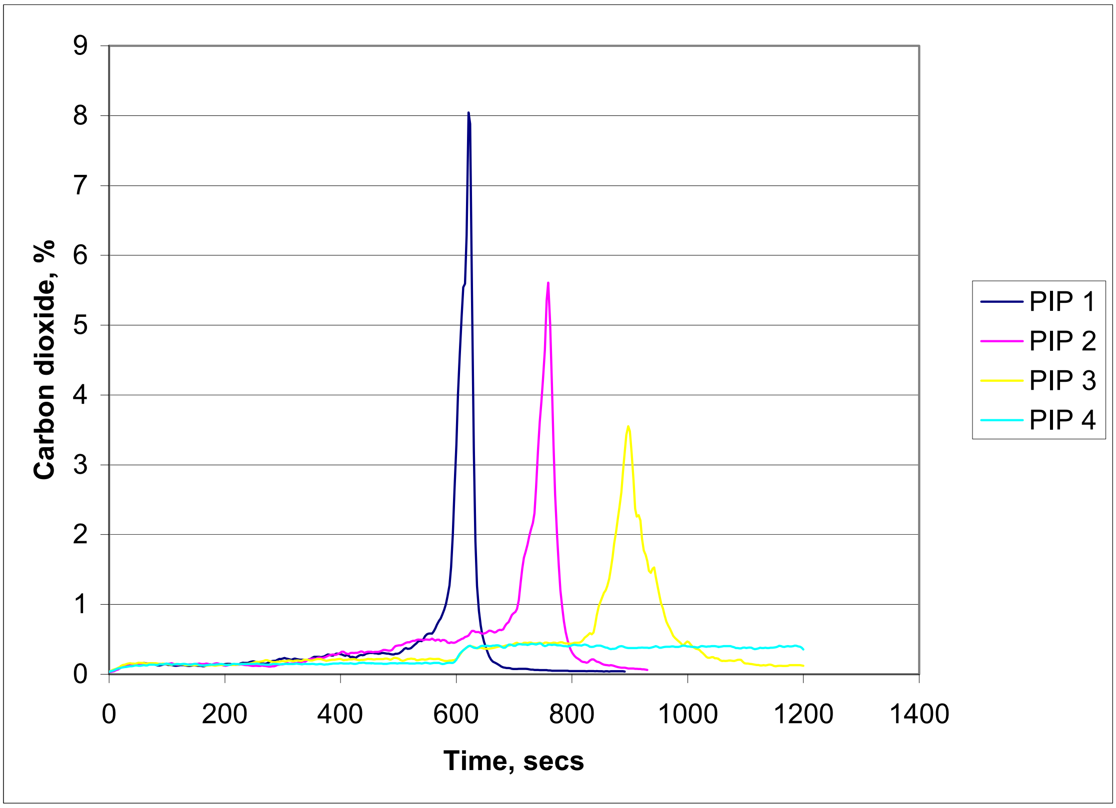

Figure 7: Carbon dioxide production

4.2 Behaviour of the panels in fire

Appendix 1 – Analysis of test data shows contours of the remaining depth of EPS measured at the end of each test. The temperature contour graphs were generated from cavity temperatures measured during the tests.

4.2.1 Depth of foam remaining in cavities at end of tests

The depth of foam remaining as shown in Figure 15 to Figure 18 gives an indication of the amount of foam remaining in the walls that had not melted or burnt. Little foam remained in the ceilings in any of the four tests. The burner was positioned in the corner at 6000 mm along the bottom axis (refer to Figures). The surface graphs give a visual representation of the remaining foam core for a more complete assessment of the loss of the foam core throughout the progress of the tests. An analysis of the core temperatures is presented below.

4.2.2 Temperature measurement in and analysis of panel cores

Measurements of the temperatures in the panel core at a depth of 50 mm were recorded on a data-logger with the objective of monitoring the loss of EPS firstly by melting and then possibly combustion. Thermocouples were installed in the walls in a 600 x 600 mm grid pattern up to 600 mm from the burner corner and then at 1200 mm centres. The ceiling was similarly instrumented along the centre joint at 600 mm centres, as shown in Figure 8.

Processing of the results included plotting the temperatures on a surface graph on which temperature contours were drawn (see Appendix 1). The 150^{o}C contour represented the boundary between solid and melted EPS and the 450^{o}C contour represented combustion of the EPS. Areas that had exceeded 150 or 450^{o}C could then be accumulated to determine a percentage (%) melted or burnt that is then used as a measure of the progression of the destruction of the panel's core so that comparisons could be made of the various fixing systems.

Graphs of the progression of the percentage melted for the walls and ceiling in Figure 9 and Figure 10 show the progressive improvement in performance of the various fixing systems from PIP 1 to PIP 4. When a graph line reaches a plateau, this is the indication that the test finished and the fire extinguished, halting any further melting of the core. Of particular significance is the percentage melted with respect to time. It is shown that more secure fixings delay the melting of the EPS core, whether it is by reducing heat entering the cavity or reducing the escape of flammable EPS vapours that would otherwise contribute to the heat release.

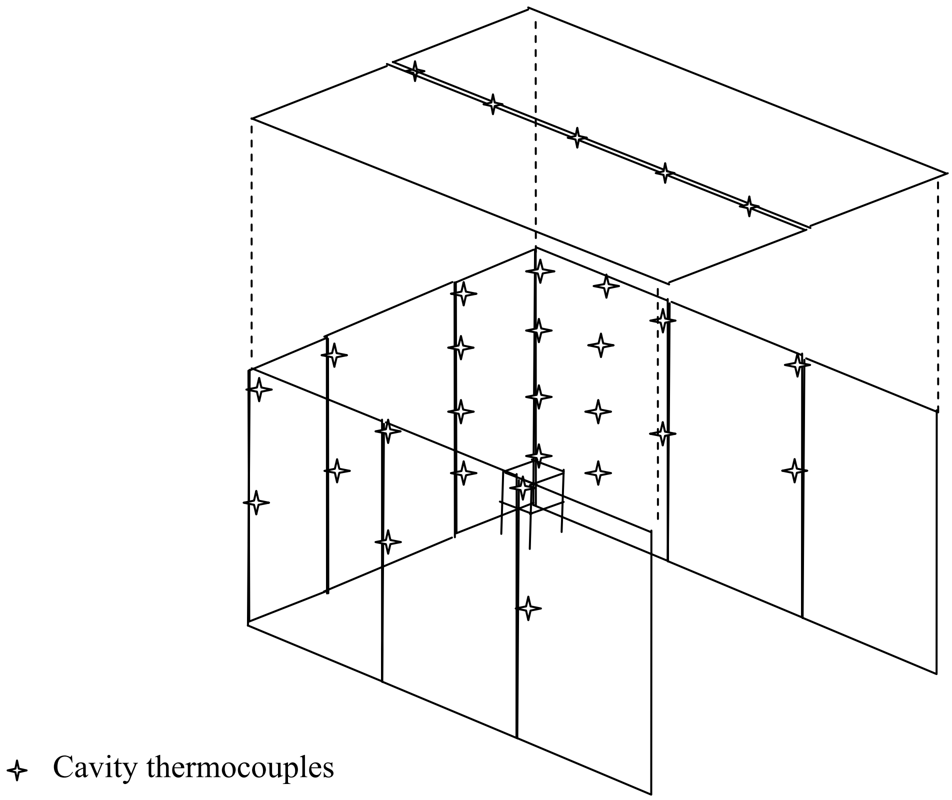

Figure 8: Cavity thermocouples

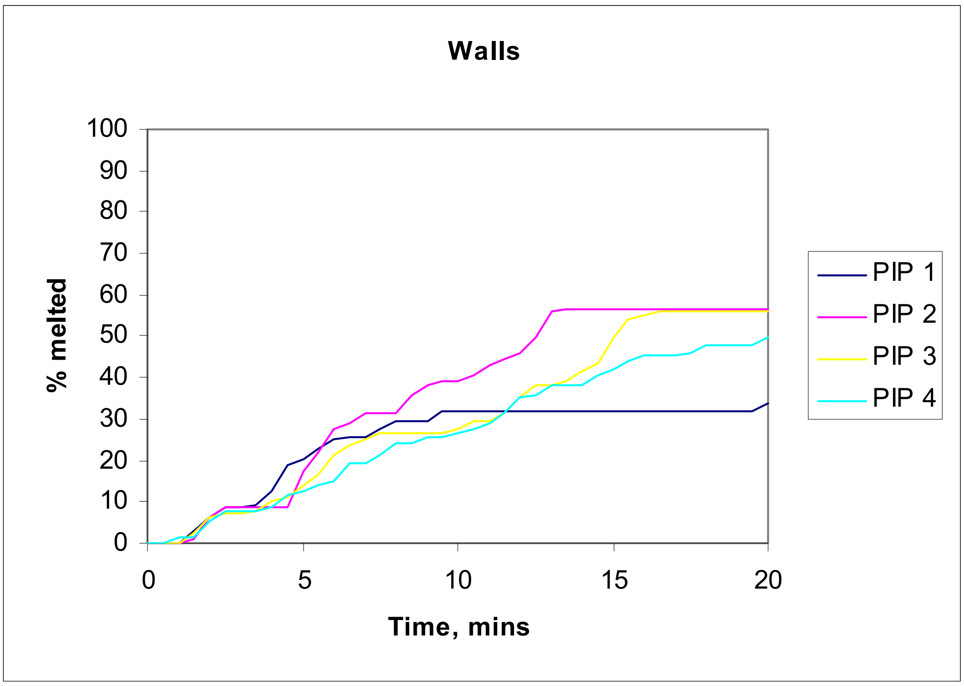

Figure 9: Percentage melted EPS in wall cavities

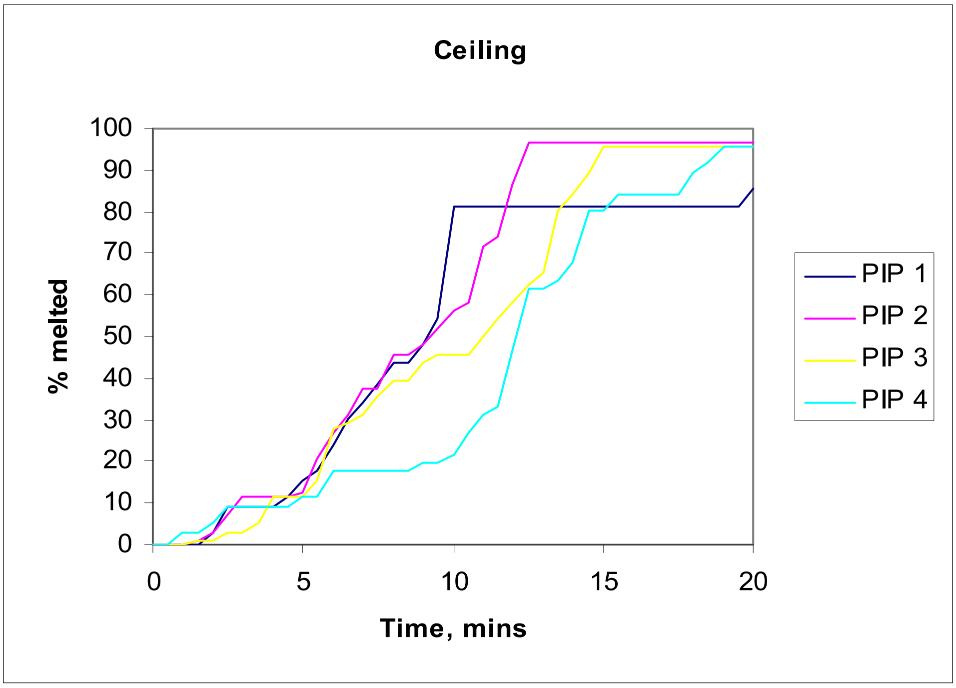

Figure 10: Percentage melted EPS in ceiling cavity

A similar trend is indicated in considering the combustion of the EPS indicated by the temperature exceeding 450°C. Improved security of fixing of the panels results in a delay of the burning of the core, although this is not strictly true considering that the core melts at ~150°C in the walls and it will have a tendency to flow towards the bottom of the cavity where the temperature is lower and therefore does not contribute to the heat release. Similarly in the ceiling, molten EPS will flow to the lower points of the sagging panel skin and either burn within the panel or flow from opened joints and burn within the compartment contributing to the heat release. Figure 11 and Figure 12 show the indicated % burnt for the walls and ceiling respectively. The plateaus reached seem low compared with the quantity of EPS core remaining when the specimens were dismantled, and this can be attributed to the melting and flowing of the core to the bottom of the panels confirmed by observations of pooling when the panels were dismantled as shown in Figure 13.

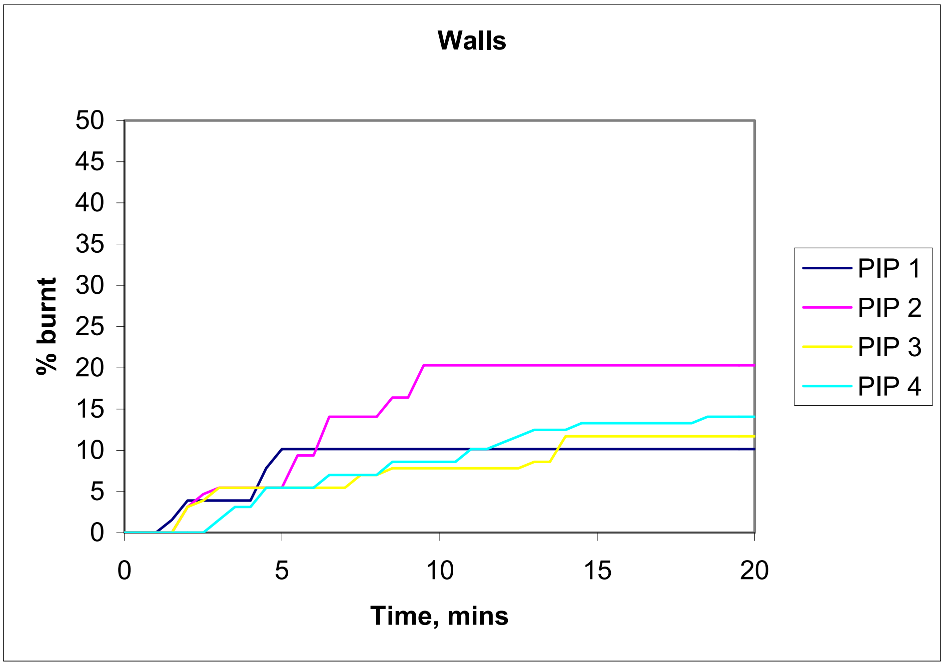

Figure 11: Percentage core burnt in walls

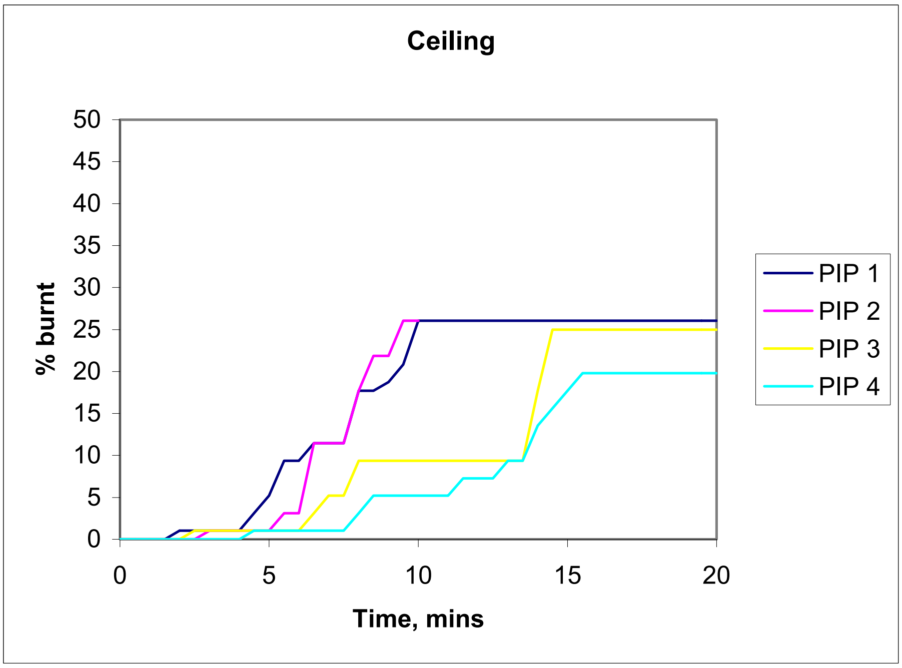

Figure 12: Percentage core burnt in ceiling

Figure 13: Ponding of molten EPS at the bottom of cavity

4.3 General observations of PIPs

During the fire testing of the PIPs, the sequence of events followed a similar pattern with the significant difference being the time-scale in which a particular event occurred for a particular method of construction.

Table 6 shows the sequence of events and times for the four tests conducted. The sequence of events was essentially the same for each test specimen with the major difference being a stretching of the time-scale as the security of the construction improves. This supports the trend in the quantitative observations of the HRR and the SPR reported earlier in this report.

Table 6: Typical observation at exposure times in minutes

Test number	PIP 1	PIP 2	PIP 3	PIP 4
Distortion of steel skins	1			
Smoke exiting from panels joints	1-2	2	2-3	2 (minor)
Loss of visibility	2-6 (nil visibility)	4-8 (almost total blackout)	5-6 (minor loss)	2 (minor loss)
Opening of corner joints	blackout -<6 not seen	4-5	NA*	NA
Flaming from joints	up to 6	4-5	10-12	10-12
Ceiling panels deflected downwards	10	9-11	12-14	15-17
Ceiling joints opening spilling flaming molten EPS	8-10	10-11	14	NA
Establishment of vent fires	10	12	15	NA

**NA – Not applicable (not observed) for duration of test.*

Significant events such as the occurrence of flashover in the first three tests corresponded with some of the events observed in

Table 6, in particular the ceiling dropping and the opening of the centre joint spilling flaming molten EPS. The molten EPS flamed vigorously as it fell thought the hot zone creating a fireball effect significantly increasing the HRR and temperatures leading to flashover. It was noticeable too that the molten EPS that reached floor level had a tendency to self-extinguish in the cooler lower layer, prior to flashover. Once flashover was deemed to have occurred the fire was extinguished by the 1.2 m upstand sprinkler, after which deposits of solidified EPS were found on the floor.

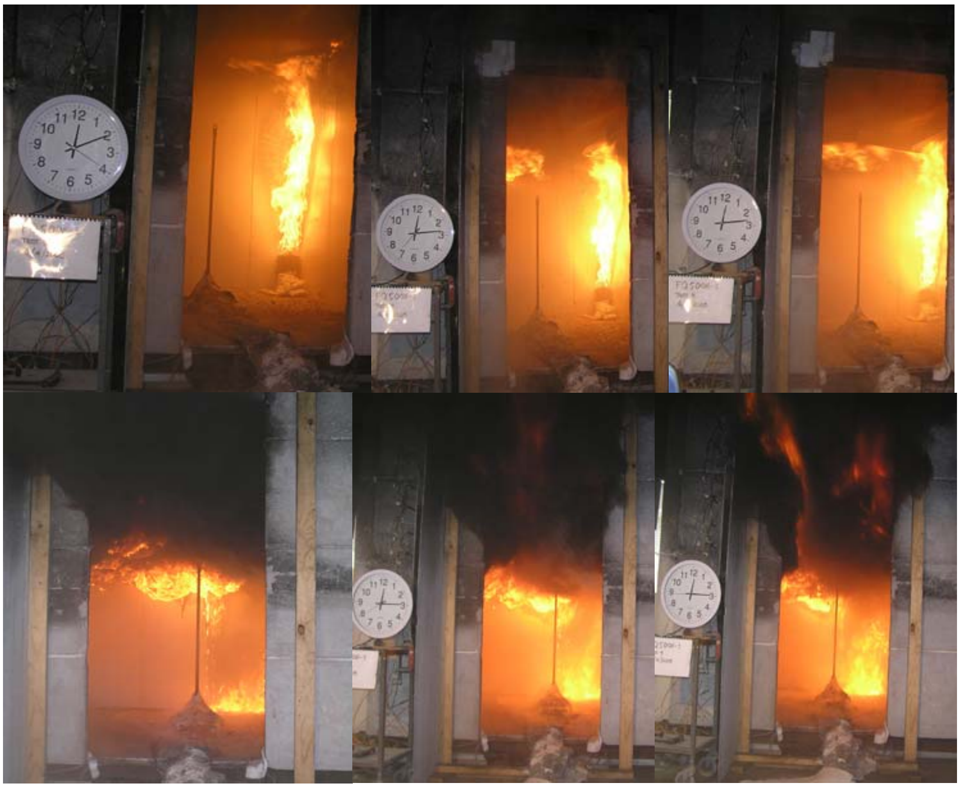

Figure 14: Events leading to flashover in trial PIP 3

The montage in Figure 14 shows the fire development just prior to flashover from 10:20 to 14:44 minutes. The centre joint in the ceiling has opened sufficiently at about 12 minutes to allow the molten and vaporised EPS to initiate some flaming just below the ceiling. The additional heat results in greater opening of the gap and more fuel in the form of EPS becoming involved, and this was seen to drop through the burning fireball just below the smoke layer and onto the floor forming a pool and continue to burn. The process continued to the extent that the burning gases in the hot layer grew to flashover conditions as evidenced by the vent fire in the doorway at about 14 minutes and 50 seconds and confirmed by the HRR exceeding 1 MW and the temperature in the room exceeding 500^{o}C. This scenario is confirmed in Figure 12 showing the percentage of the core in the ceiling that is burnt. At about 13 minutes a rapid increase occurs up to 15 minutes after the test was stopped, and this matches the photographic evidence of the fireball in the room.

None of the other three trials indicated such a rapid increase in the contribution of the panel core in the ceiling or walls. However, a calculation of the energy content of the EPS core in the panels (in Appendix 1) indicates that there is potential there for a sustained period of flashover conditions. The rate of EPS recession to sustain flashover conditions is marginally below 2 mm/minute, and at that rate and with 100 mm thickness of EPS available over the wall surface there is enough fuel for about 50 minutes of flashover burning at 1 MW (excluding the burner). Although this is an over-simplification of how the EPS would actually burn, it gives an indication of the potential of a fire and the importance of effectively separating the fuel from the fire. For the cases shown this has been done by providing effective joining of panels.

4.4 Evaluation of the ISO 9705 test method

The results of the four trial tests to ISO 9705 (using PIP panels as the interior lining based on an analysis of the gases and smoke collected from the lining when exposed to the fire conditions) indicated a clear distinction in performance consistent with the expected security of the fixing of the panels. These results were also supported by the temperature data recorded from within the panels.

All analysis shows that the ISO test method effectively discriminates between levels of performance and this is confirmed by temperature measurements within the panels. This confirms that the test method is suitable for ranking this product and the effectiveness of the installation methods.

5. CONCLUSIONS

Based on the results of the series of tests conducted in the ISO 9705 room/corner on 100 mm thick polystyrene insulated panel that included four different specifications for assembly of the panels, a number of conclusions can be drawn:

- There is a direct correlation between the timing of the opening/failure of the panel joints and the performance assessed by the ISO 9705 test method.
- Panel joints secured with stainless steel rivets and steel angle perform better than aluminium rivets and aluminium angle.
- Rapid increases in the measured HRR, CO, CO_2 and SPR due to the involvement of the panel core corresponded to the opening of joints in the walls and ceiling and were an indicator of impending compartment flashover.
- The performance of the unseen surface and joints against the enclosure can be qualitatively assessed by the smoke travelling in the gap and being entrained into the airstream drawn into the room through the lower portion of the doorway opening.
- A test result can be improved by delaying the contribution of the core material, which would otherwise provide fuel in addition to the burner output increasing the temperature causing yet more fuel to be available hastening the destruction of the specimen.
- The energy contribution in an ISO room lined with nominally 100 mm thick PIP is sufficient to maintain flashover conditions for a period in excess of 50 minutes should it all become available. So the security of the panel skins is critical to the overall performance.
- The ISO 9705 test method was shown to be able to accurately discriminate the changes in construction responsible for improvements in the reaction to fire performance.
- It is essential that the construction technique subjected to the test for evaluation of the reaction to fire performance should relate to the end-use conditions intended.

6. FURTHER WORK

While the ISO 9705 test method is suggested here as suitable for assessing the reaction to fire performance of PIP panels, performance criteria are still required for specific applications in buildings. This may be dependent on building use, its location within the building, the presence of any fire suppression system and the fire load.

The ISO 9705 fire test method was originally developed for the purpose of evaluating the fire hazard of interior walls and ceilings. The test method has already been adopted in Australia as one means of demonstrating acceptable fire properties for walls and ceilings. It is an opportune time now to review NZBC C/AS1 requirements for both internal linings and foamed plastics materials, including PIP panels, with a view towards developing consistent and technically robust requirements and criteria for regulatory use in New Zealand.

7. REFERENCES

Australian Building Codes Board. (2005). *Building Code of Australia: Specifications A2.4-3 and C1.10a-3*. Canberra, ACT.

Babrauskas, V. (2003). *Ignition Handbook*. Fire Science Publishers. A division of Fire Science and Technology Inc. Issaquah, WA 98027 USA. ISBN 0-9728111-3-3.

Baker, G.B. (2002). *Performance of Expanded Polystyrene Insulated Panel Exposed to Radiant Heat*. Fire Engineering Research Report 02/1, University of Canterbury, Christchurch.

BRE/FRS. (2003). *Final Report for Sector Group C – Sandwich Panels*. Report on Experimental Programme and Recommendations. PII Project Report Number 210725.

Cooke, G.M.E. (2000). *Sandwich Panels for External Cladding – Fire Safety Issues and Implications for the Risk Assessment Process*. Commissioned by Eurisol – UK Mineral Wool Association. Department of Civil Engineering, City University, London.

Department of Building and Housing. (2005). *Compliance Document for New Zealand Building Code Clauses C1, C2, C3, C4.* ISBN 0-477-01606-5.Wellington.

International Association of Cold Storage Contractors (European Division). (1999). *Guidelines for the Design, Specification, Construction, Maintenance and Fire Management of Insulated Envelopes for Temperature Controlled Environments*. IACSC, Bracknell.

ISO 9705:1993(E). (1993). *Fire Tests – Full-scale Room Tests for Surface Products.* Switzerland: International Standards Organisation.

ISO DIS 13784 Part 1. (2000). *Fire Tests – Reaction to Fire Part 1: Small-scale Room Tests for Sandwich Panel Products for Industrial Buildings.*

ISO 13784. (2002). *Reaction to Fire Tests for Sandwich Panel Building Systems – Part 1 Test Methods for Small Rooms*. First Edition, International Standards Organisation.

Johansson, P. and Van Hees, P. (2001). *Development of a Test Procedure for Sandwich Panels Using ISO 9705 Philosophy – Nordtest Project nr 1432-99*. Fire Technology SP Report 2000:26, Swedish National Testing and Research Institute, Borås.

NZFS. (2004). Collier, P.C.R. and Baker, G.B. (2004). *Improving the Fire Performance of Polystyrene Insulated Panel in New Zealand.* New Zealand Fire Service Commission Report Number 45. NZFCS. ISBN 1-877349-08-9. www.fire.org.nz/research/reports/reports/report_45.htm

prEN13823. (2000). *Reaction to Fire Tests of Building Products – Building Products Excluding Floorings – Exposed to the Thermal Attack by a Single Burning Item.* European Committee for Standardisation (CEN).

Rakic, J. (2003). 'Fire Rated Insulated (Sandwich) Panels'. Fire Protection Association Australia. *Fire Australia Journal* (May issue). ISSN 1032-6529.

Standards Australia. (1998). *Method of Test for Heat and Smoke Release for Materials and Products Using Oxygen Consumption Calorimetry*. AS3837. North Sydney.

Standards Australia. (2005). *Methods for Fire Tests on Building Material, Components and Structures – Fire Resistance Tests of Elements of Construction*. AS1530.4. North Sydney.

Wade, C.A. (2003). *Future Directions in Testing of Building Products*. 'Building for a Global Future' – Australia's Built Environment.

8. APPENDIX 1 – ANALYSIS OF TEST DATA

Some of the analyses presented in this report required some in-depth examination of the test data recorded. This additional analysis is presented in this Appendix and is based on some of the recommendations for additional data recording in test standard ISO 9705:1993(E) (ISO, 1993) and other calculations considered necessary to evaluate the building system under test.

The additional inspections were:

- foam remaining in panels at end of tests
- using temperatures in panel cores to assess the degradation of the foam
- compartment temperatures
- fuel load of foam core.

8.1 Depth of foam remaining in panels

At the conclusion of the test and after the specimens had been dismantled from the ISO room the depth of the EPS remaining was measured. This was done by measuring the depth of penetration of a screwdriver into the foam over a 600 mm rectangular grid pattern over the walls. No measurements were taken of the ceiling as the EPS had almost totally melted due to being exposed to the high temperature layer at ceiling level. As a result it had flowed to the lowest point and poured through openings onto the floor where it may or may not have burnt.

The results of the measurements are presented as surface graphs showing contours of the depth of EPS in Figure 15, Figure 16, Figure 17 and Figure 18 and apply to the exposure times at the point the fires were extinguished. The horizontal axis measurement of 6000 mm represents the burner corner and 3600 mm the left hand corner. The recession of the EPS core is dependent on the exposure conditions and also the extent of the opening up of the joints. The exposure conditions change at 10 minutes when the burner HRR is increased from 100 kW to 300 kW, and this results in a stepwise increase in the temperature that the ceiling and upper portions of the walls are subjected to. This is evident by greater melting in the upper regions and that leads to a combination of vaporisation and combustion or pooling of molten EPS in the lower regions. Generally no foam remained in the ceiling as it was the first to melt and either vaporise or flow through gaps towards the floor. As a result no measurement of the remaining foam depth in the ceiling was possible.

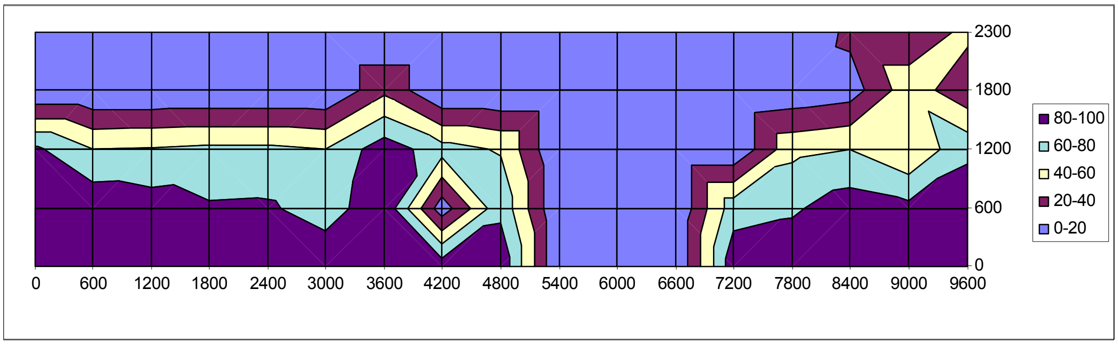

Figure 15: Depth of foam at end of test PIP 1 after 10 minutes

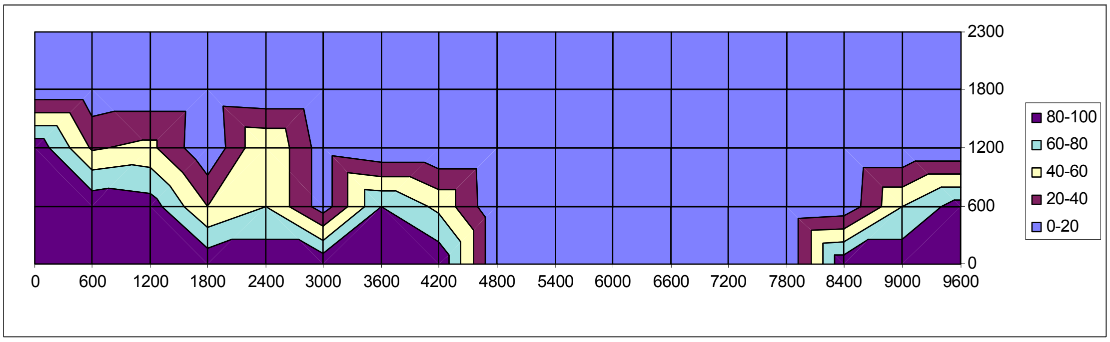

Figure 16: Depth of foam at end of test PIP 2 after 12 minutes

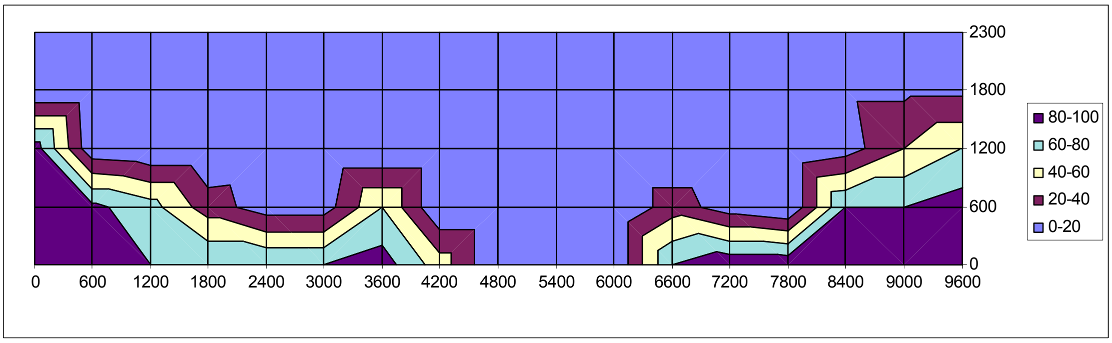

Figure 17: Depth of foam at end of test PIP 3 after 15 minutes

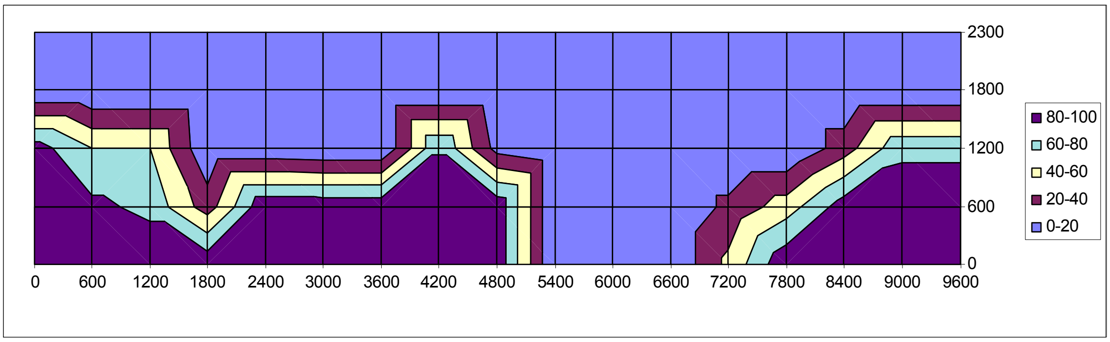

Figure 18: Depth of foam at end of test PIP 4 after 20 minutes

8.2 Temperature contours in panel cores

The panels were instrumented internally with thermocouples at a depth of approximately 50 mm at the locations indicated in Figure 8. The temperature data is plotted and the temperature contours interpolated on maps of the walls and ceiling (with photographic confirmation of the post-test condition) of the remaining cores in Figure 19 to Figure 40. The maps are presented at five minute intervals and also at the end of test time, if significantly different to the previous interval. There is a minor disagreement at the ends of the 3.6 m long walls at the opening end of the compartment – the thermocouples did not record any data in the last panel width of 1200 mm so no comparison is possible between the maps and photographs at the ends. The maps show unaffected EPS at the top corners but the photographs show it has actually melted.

Comparing the four tests, the same trend previously established where the improving security of the panel fixings from test 1 through to test 4 delays the melting and involvement of the core in the compartment fire. By summing the areas of the maps above 150°C and 450°C the percentage of the EPS core that had melted or burnt was determined for that time and the progression was plotted in the graphs in Figure 9 to Figure 12.

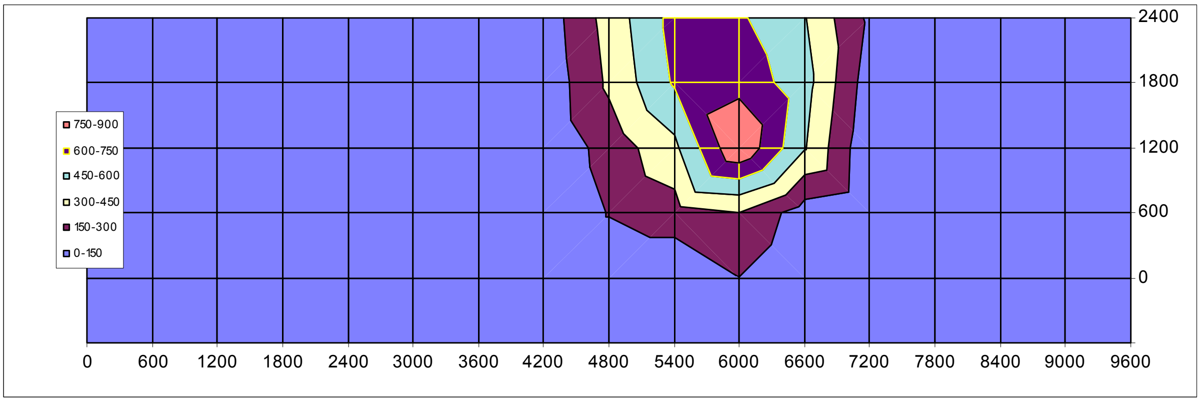

Figure 19: Temperature contours in walls of test PIP 1 at 5 minutes

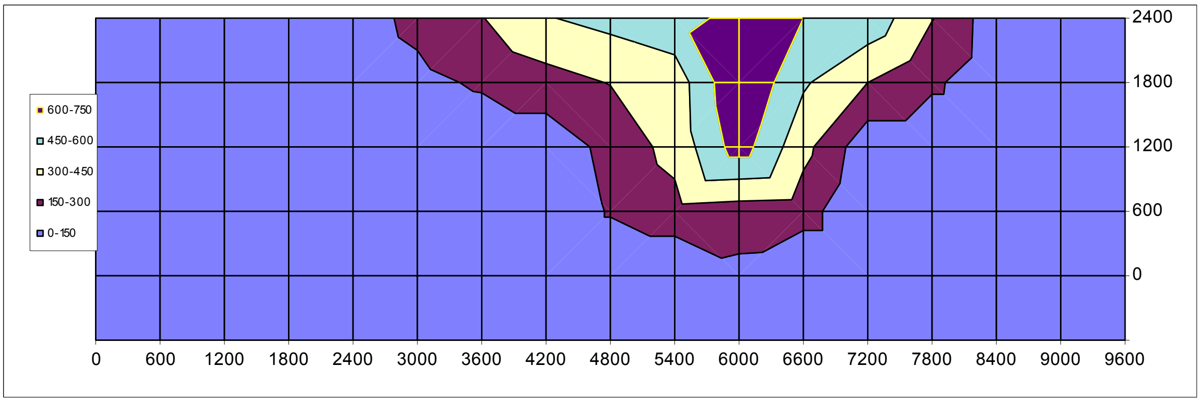

Figure 20: Temperature contours in walls of test PIP 1 at 10 minutes

Figure 21: EPS core remaining in the burner corner after test PIP 1, with exposed skins removed

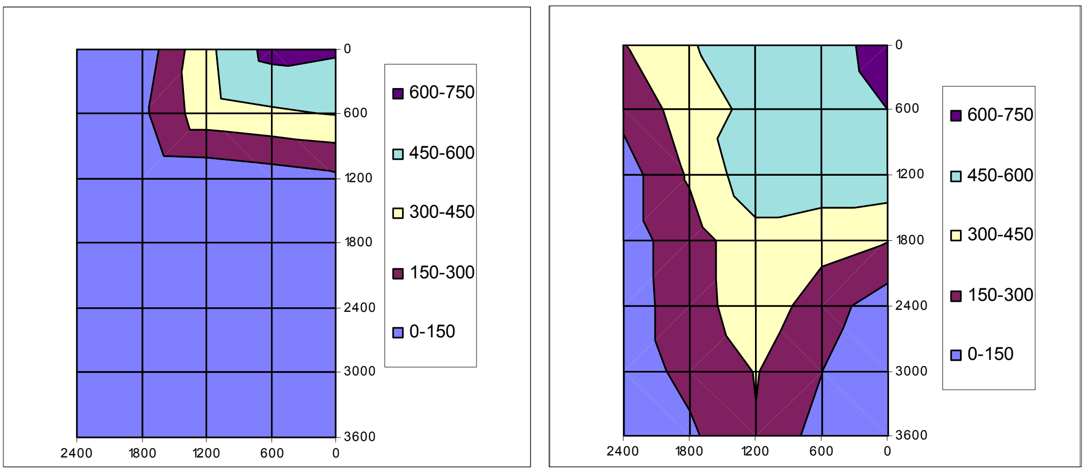

Figure 22: Temperature contours in ceiling of test PIP 1 at 5 and 10 minutes

Figure 23: EPS core remaining in the ceiling at end of test PIP 1, upper steel skins on left and lower fire exposed skins on right

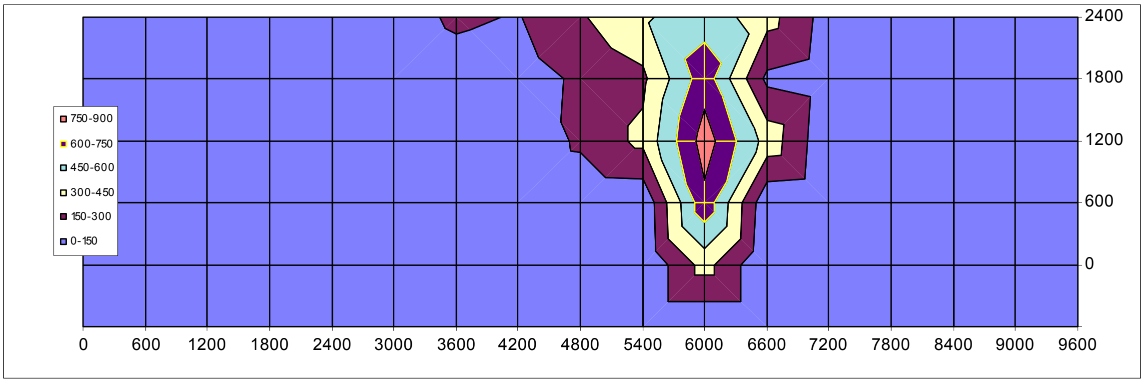

Figure 24: Temperature contours in walls of test PIP 2 at 5 minutes

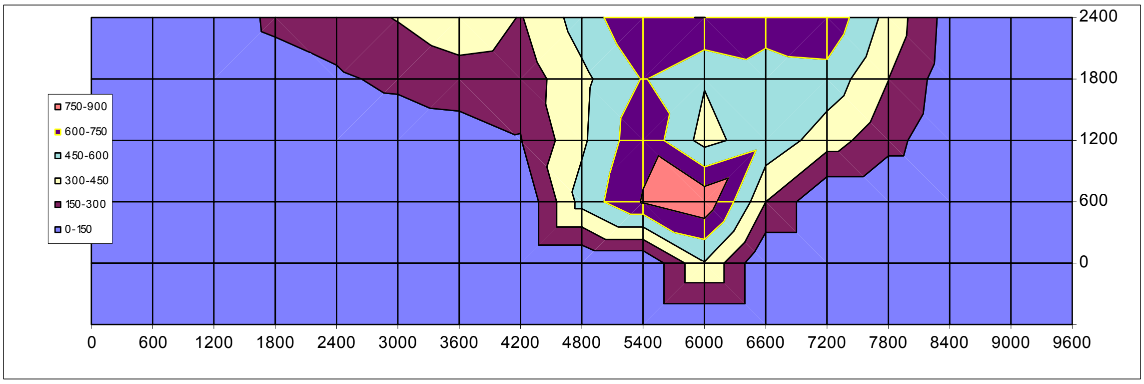

Figure 25: Temperature contours in walls of test PIP 2 at 10 minutes

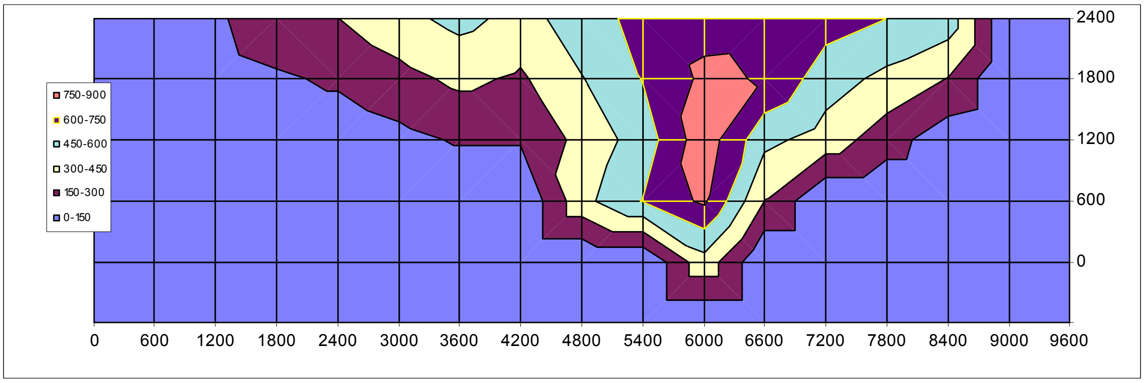

Figure 26: Temperature contours in walls of test PIP 2 at end of test 11:51

Figure 27: EPS core in walls remaining at the end of test PIP 2

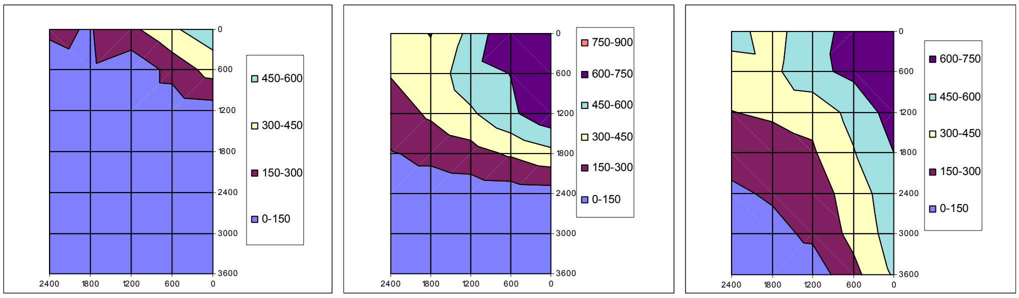

Figure 28: Temperature contours in ceiling of test 2 at 5, 10 minutes and end of test

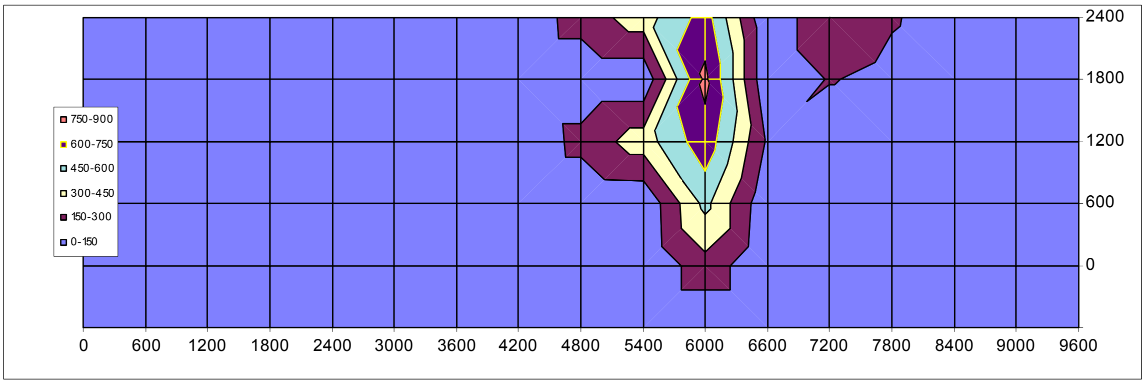

Figure 29: Temperature contours in walls of test PIP 3 at 5 minutes

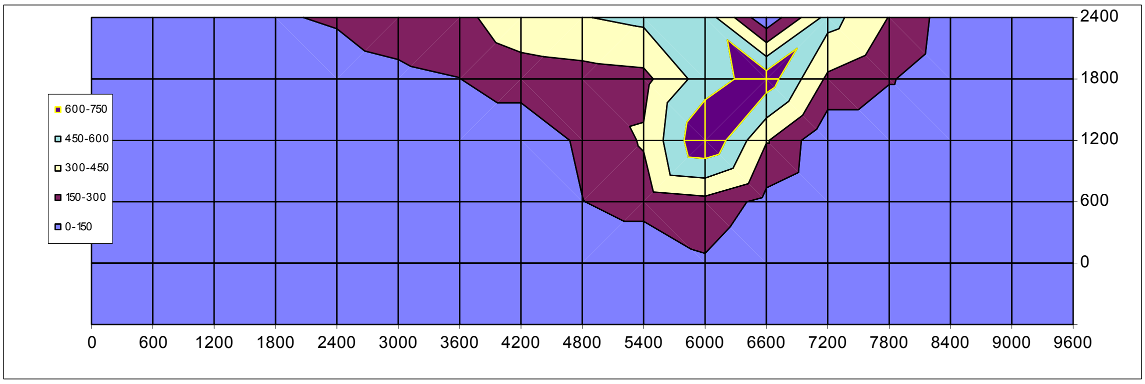

Figure 30: Temperature contours in walls of test PIP 3 at 10 minutes

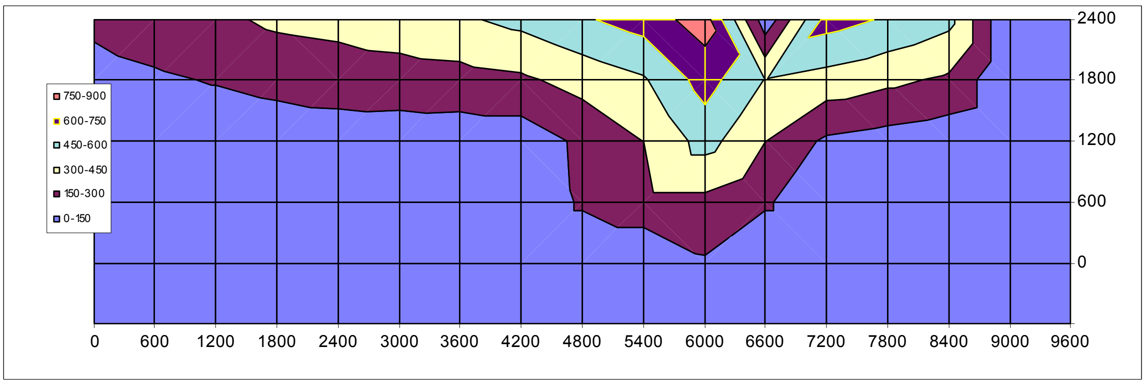

Figure 31: Temperature contours in walls of test PIP 3 at end of test 14:21

Figure 32: EPS core in walls remaining at the end of test PIP 3

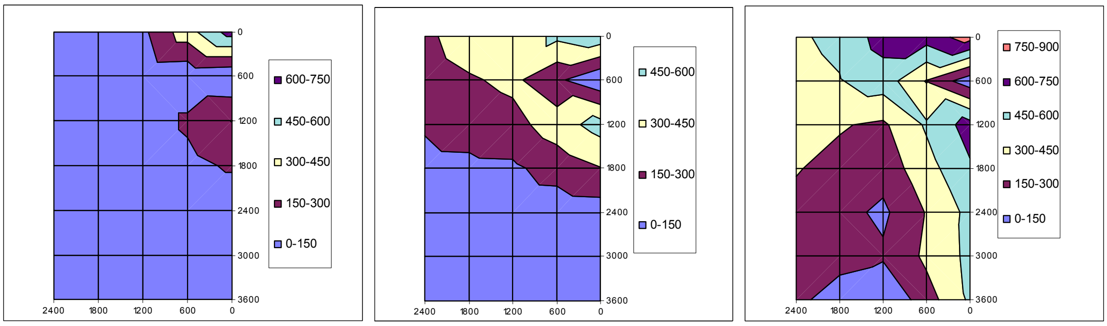

Figure 33: Temperature contours in ceiling of test PIP 3 at 5 minutes

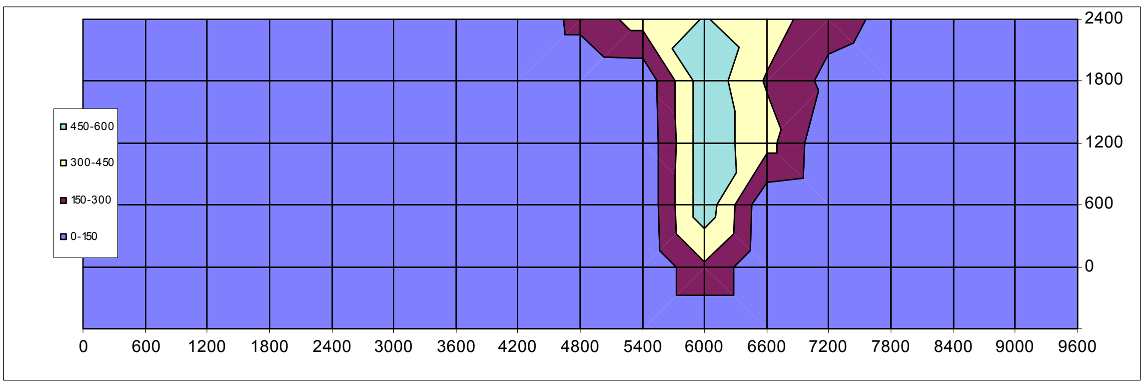

Figure 34: Temperature contours in walls of test PIP 4 at 5 minutes

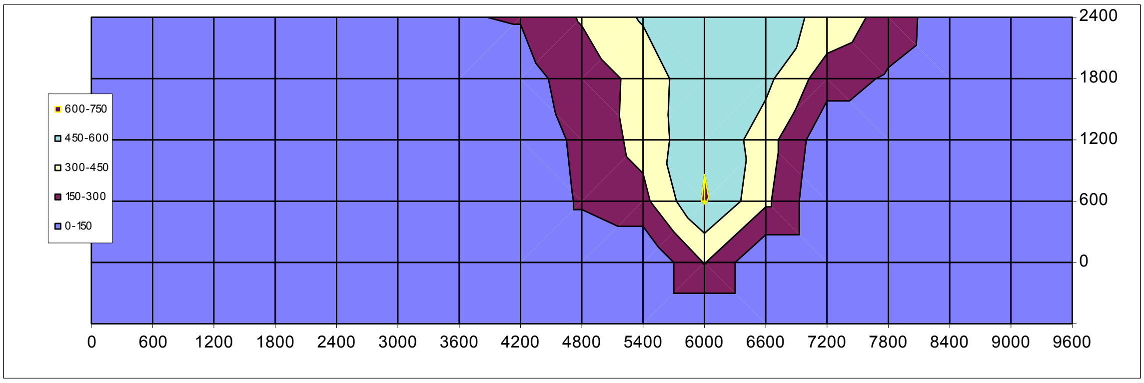

Figure 35: Temperature contours in walls of test PIP 4 at 10 minutes

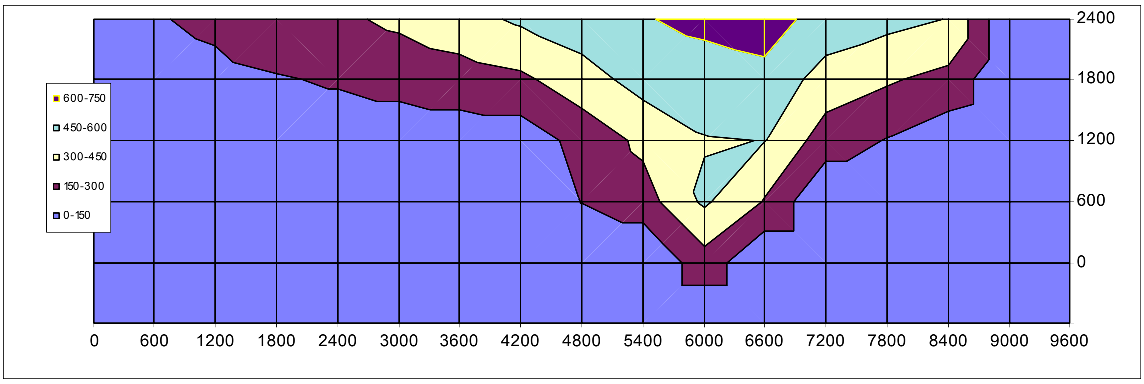

Figure 36: Temperature contours in walls of test PIP 4 at 15 minutes

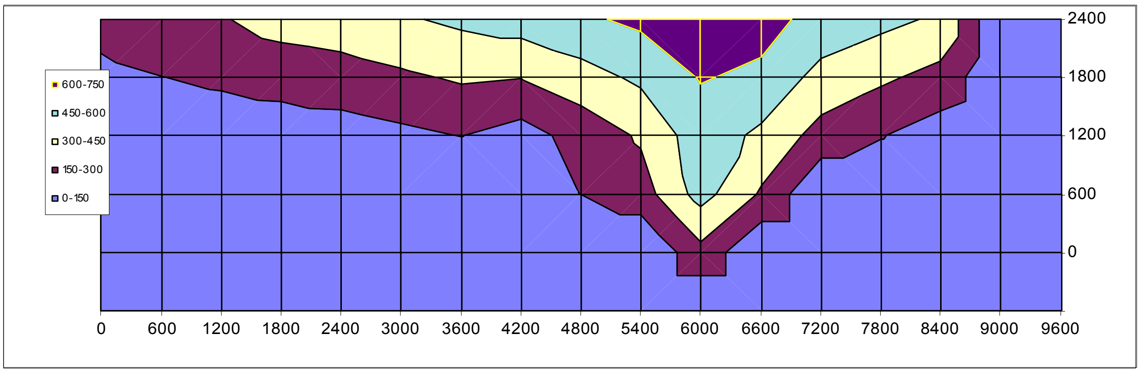

Figure 37: Temperature contours in walls of test PIP 4 at 20 minutes

Figure 38: EPS core in walls remaining at the end of test PIP 4

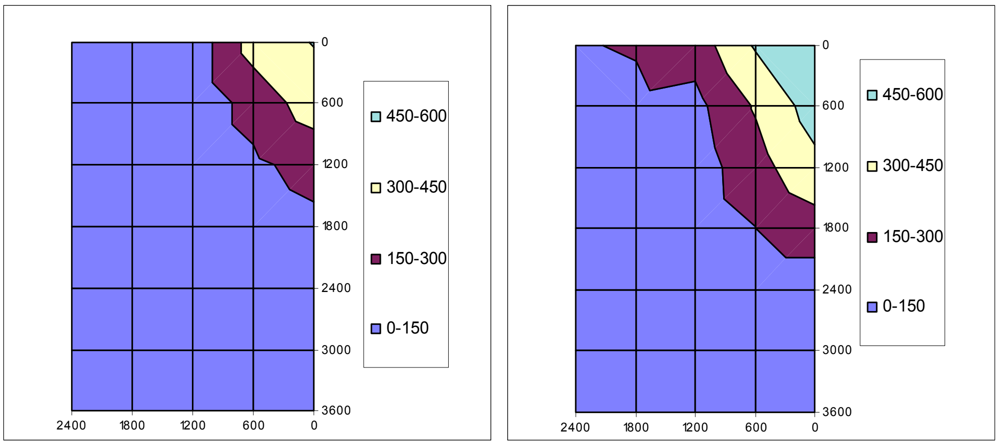

Figure 39: Temperature contours in ceiling of test PIP 4 at 5 and 10 minutes

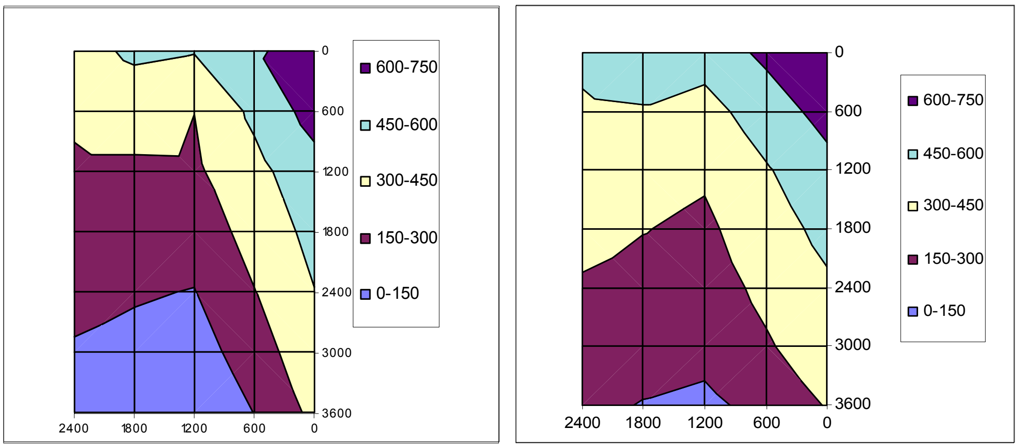

Figure 40: Temperature contours in ceiling of test PIP 4 at 15 and 20 minutes

8.3 Energy contained in panel cores producing heat required to flashover

To assess the potential of the PIPs under test to generate enough heat to reach flashover, a calculation based on the heat of combustion of the EPS core shows that for the 100 mm panels in the tests there is sufficient fuel in the core to maintain a HRR of 1 MW (excluding the burner contribution) for over 50 minutes.

8.3.1 Calculation of the FLED of the EPS core in PIPs

Heat of combustion of polystyrene = 46 MJ/kg

Density of polystyrene = 16 kg/m^3

Energy content of EPS = 46 MJ/kg x 16 kg/m^3 = 736 MJ/m^3

Internal surface area of panel = 2.4 x 3.6 x 3 + 2.4 x 2.4 = 44.64 m^2

Rate of surface recession over entire area to sustain 1 MW heat release rate (HRR)

1 MW =1 MJ/s

Volume of EPS to liberate 1MJ = 1/736 = 0.00136 m^3

Taken over the entire area of the internal surface of 44.64 m^2 the recession rate of EPS required to sustain a heat output of 1 MJ is: 0.00136 m^3/44.64 m^2 = 0.03 mm or 0.03 mm/sec (1.83 mm/min) for 1 MW. This is in excess of the burner output of 100 or 300 kW.

8.3.2 The role of the flame barriers in an ISO 9705 test

So the fuel in the EPS core (~95 mm thickness) is sufficient to sustain flashover conditions for a period of over 50 minutes assuming that it burns at a minimal rate. In practice not all the surface of the fuel becomes available at the same time, but substantial areas do if the steel skins become detached. It is concluded that the quantity of fuel available is an order of magnitude in excess of that required to cause a flashover that would lead to a failure in accordance with ISO 9705 conditions. This equates to a large amount of potential stored energy. The effect of the flame barriers remaining intact significantly limits the rate at which fuel becomes available and by doing so decreases the likelihood of flashover.

However, not all of the fuel potential in the core becomes available to the fire. In the wall panel cavities a substantial proportion of the core that is in the hot upper layer melts and flows downwards often out of the hot zone and in the process melts more EPS that it comes in contact with as it flows downwards to the cooler lower layer. Some of it reaches the floor where it forms molten pools and being in a cooler zone and protected by the steel skins makes no contribution to the fire. The extent to which this is permitted to occur is dependent on the effectiveness of the flame barriers and in particular the joints. The flame barriers, while they remain intact, will reduce the radiant heat load and eliminate exposure to hot gases, reduce available oxygen and contain the fire retardant gases liberated by the core when heated. The air gap formed as the core melts away from the steel skin also acts as insulation further impeding the flow of heat to the core. Opening of the joints when under fire attack will significantly reduce the effectiveness of the flame barriers. This allows hot gases to enter the cavity further melting the EPS, more oxygen is also available for combustion and the fire retardant gases are able to escape. The net result is that the increased heating and temperatures accelerate the process exposing more core material. So the most important factor in the fire performance is with keeping the flame barrier joints intact.

8.4 Compartment conditions

The following graphs in Figure 41, Figure 42, Figure 43 and Figure 44 show the derived temperature data in the four trials. Temperatures were recorded in the corner opposite the burner at a distance of 300 mm from each wall at heights of 260, 670, 970, 1270, 1420, 1570, 1720, 1910 and 2100 mm as recommended in ISO 9705 (1993). The layer height was derived on the basis that the temperature increases with height and the interpolated elevation where the temperature rise from the lowest level to 10% of the difference between that and the maximum temperature is deemed to be the layer height. The temperature of each layer is then the weighted mean temperature above or below the layer height.

The upper layer temperatures so derived (averaged) are lower than the individual temperatures recorded near the ceiling which are in turn expected to be lower than those closer to the burner. The differences range from 300°C down to 100°C, but depending on whether it is in a high temperature range such as 500 to 800°C or a low range such as 200 to 300°C in either condition the peak temperature at that time is about 50% greater than the derived temperature for the hot layer. A similar relationship holds for the lower layer.

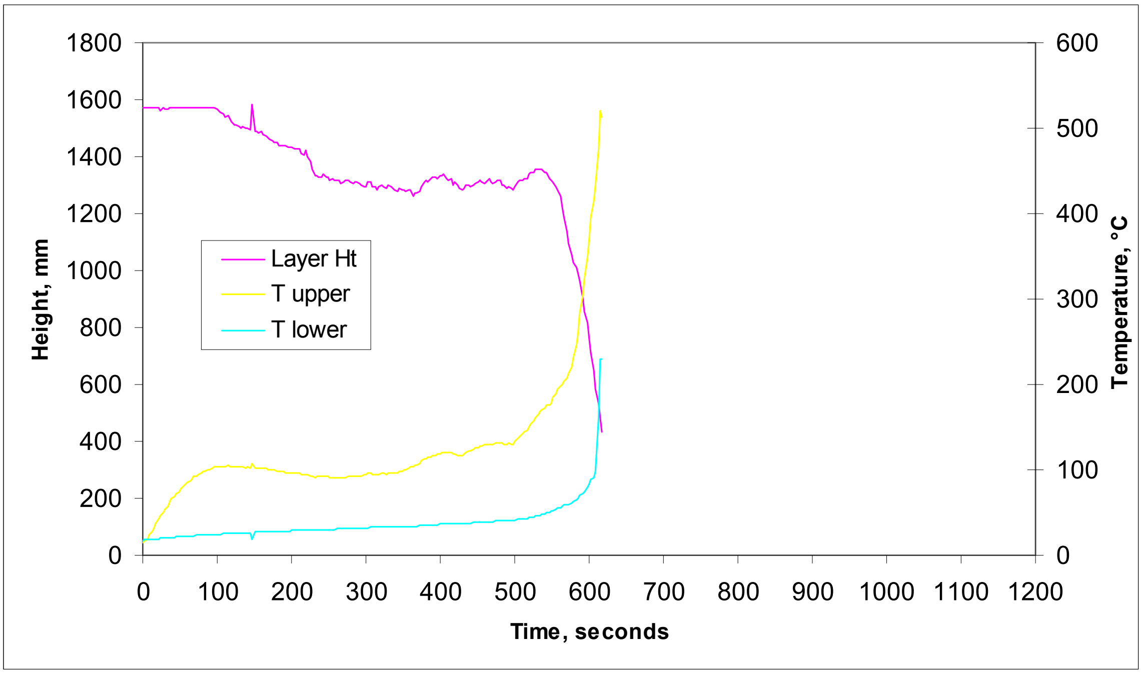

Figure 41: Fire conditions in room space in PIP 1

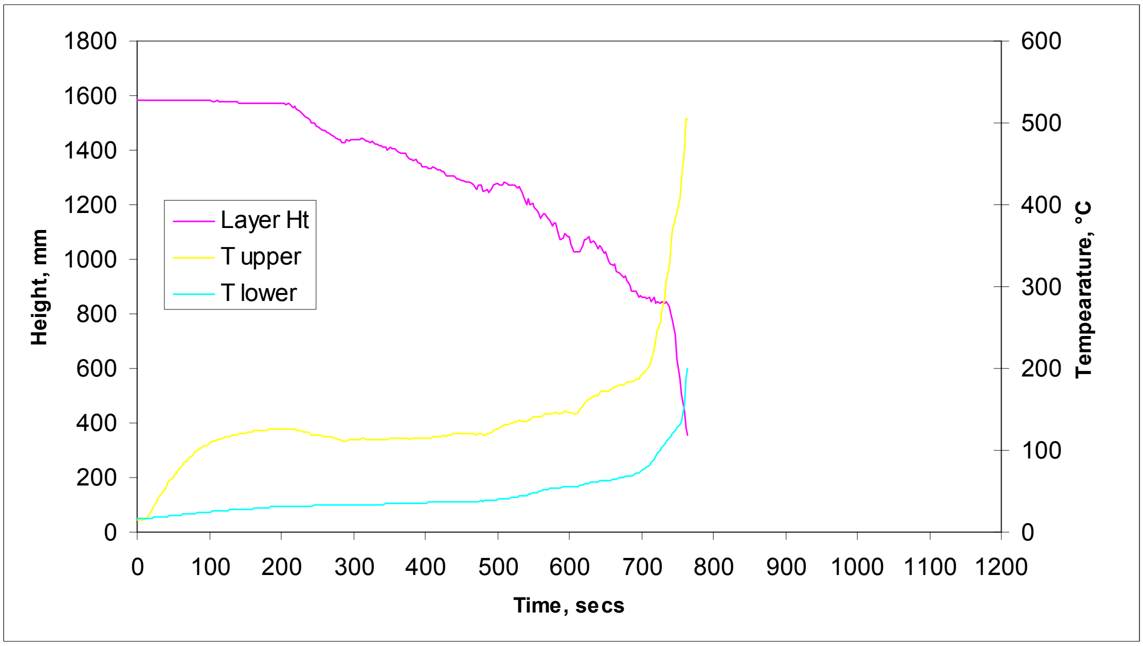

Figure 42: Fire conditions in room space in PIP 2

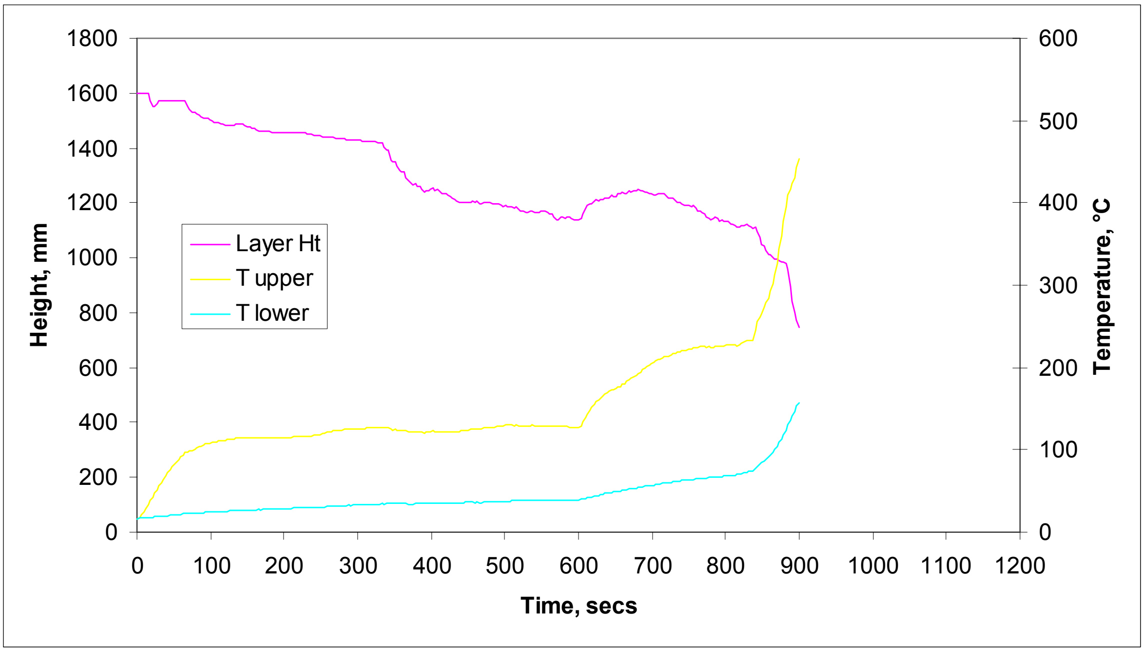

Figure 43: Fire conditions in room space in PIP 3

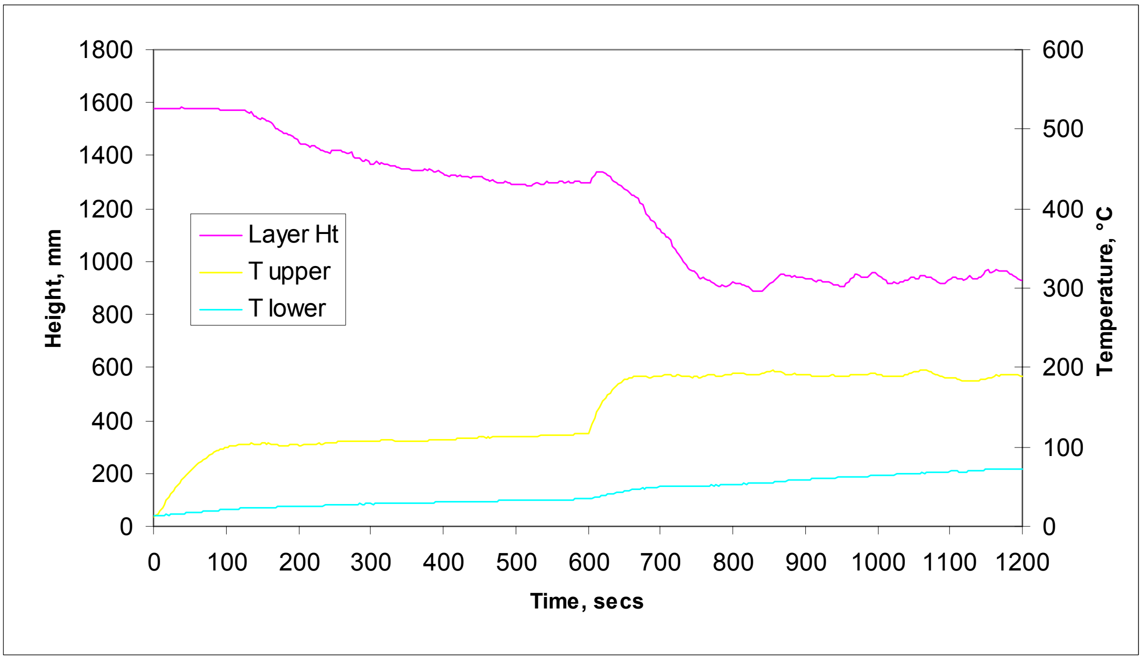

Figure 44: Fire conditions in room space in PIP 4

The upward trend of the upper layer temperature is directly related to the HRRs plotted in Figure 45. The downward trend of the upper layer temperature in PIP 1 and PIP 2 in the 100 to 300 second range is reflected in the reduced HRR when the smoke (EPS vapour some of it partially burnt) descended in the compartment effectively snuffing out the burner flame by providing a fuel rich mixture thus limiting the available oxygen. This phenomenon is confirmed by the observations in Table 6 for the loss of visibility for PIP 1 and PIP 2.

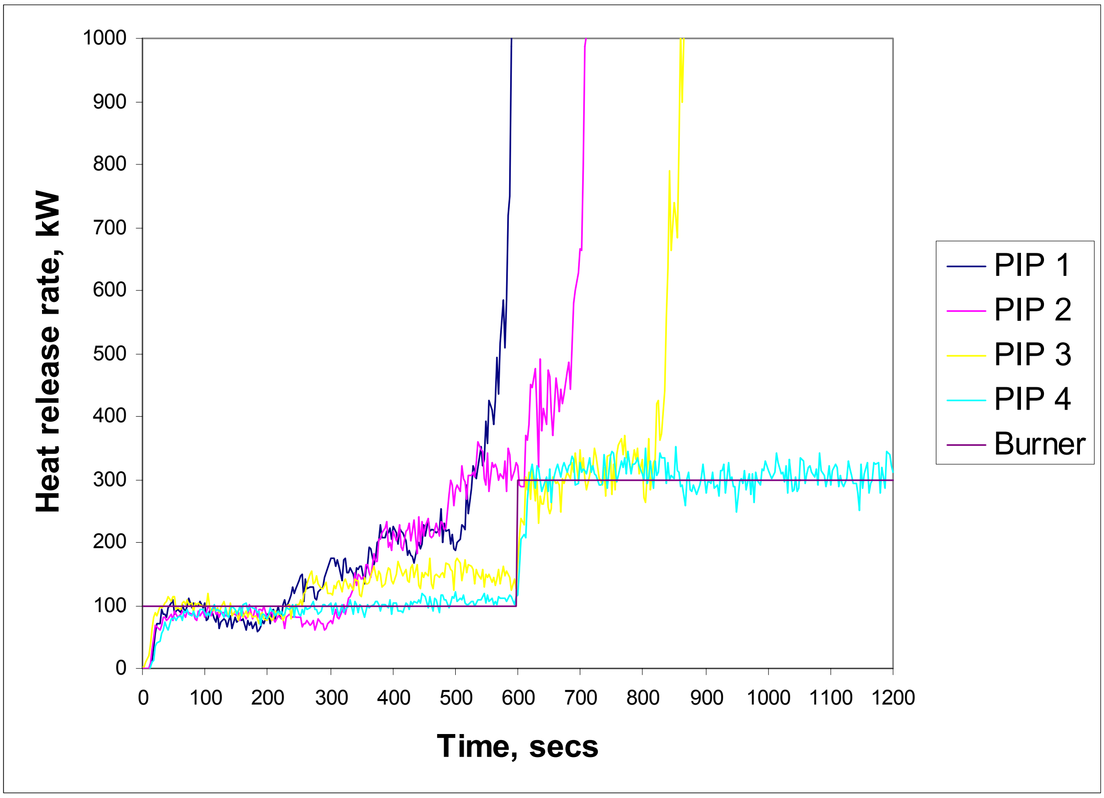

Figure 45: Heat release rate from compartment

9. APPENDIX 2 – CURRENT FLAME BARRIER TEST METHOD

From C/AS1 (DBH, 2005)

C10.1 Flame barriers

C10.1.1 An assembly incorporating the *flame barrier,* and any proposed jointing methods in that barrier, shall be subjected to the *standard test* for *fire* resistance (Paragraph C7.1.1) for a period of at least 10 minutes. The size of the test specimen shall be in accordance with the *standard test* for *fire* resistance. At the completion of the test, the exposed face of the *flame barrier* shall be inspected.

C10.1.2 The *flame barrier* shall pass the test if no cracks, openings or other fissures have developed which would permit vision through the *flame barrier* or joint. This inspection may, at the discretion of the test laboratory, be made during the process of the *standard test* for *fire* resistance if an *adequate* assessment can be made of the heated face of the specimen after 10 minutes duration.

COMMENT:
This test differs from the *standard test* for *fire* resistance. In the *standard test*, criteria for *integrity* and temperature rise across the test specimen, and are applied to the complete *building element* assembly. For a *flame barrier,* the criteria are applied only to the barrier material protecting the other components of the assembly.

C10.1.3 A *flame barrier* achieving a thermal barrier index of no less than 10, when tested to Uniform Building Code Standard 26-2, need not comply with Paragraphs C10.1.1 and C10.1.2.