F I R E C O D E R E F O R M

Technical Report
FCRC – TR 96-12

Large Scale Experiments for Validation of Bldg Fire Performance Parameters

FCRC Project 2 – Stage A
Fire Performance of Materials

Fire Code Reform Research Program
June1996

Background

The Fire Code Reform Research Program is funded by voluntary contributions from regulatory authorities, research organisations and industry participants.

Project 2 of the Program required investigation of the fire performance of materials used extensively in building construction and currently controlled by regulations. The objectives were to confirm the need for regulatory control and identify the necessary levels of fire performance required from the materials, taking into account the different occupancy and fire conditions that could apply and the likely existence of other required fire safety system components.

This Report was prepared during the course of the work and deals specifically with the large scale experiments that were undertaken to validate Building Fire Performance Parameters. The Report was prepared by CSIRO-Division of Building, Construction & Engineering, Graham Rd, HIGHETT, (P 0 Box 56), Victoria 3190..

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Comments

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FIRE CODE RESEARCH PROGRAM

PROJECT 2

FIRE PERFORMANCE OF MATERIALS

Commissioned by Fire Code Reform Centre Ltd

Research Paper 5

LARGE SCALE EXPERIMENTS TO PROVIDE DATA FOR VALIDATION OF BUILDING FIRE PERFORMANCE PARAMETERS

by

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PREFACE

This Report has been prepared by CSIRO Division of Building, Construction and Engineering as part of the Fire Code Reform Research Program funded by the Fire Code Reform Centre Ltd. Specifically it forms part of Project 2: Fire Performance of Materials.

CONTENTS

1. INTRODUCTION

In Task 8 of Project 2 (Stage A) of the Fire Code Reform Program, CSIRO is required to:

> undertake experimental validation to demonstrate that the set performance parameters indeed deliver the objectives for a range of fire scenarios appropriate for
>
> (a) wall linings; and
> (b) ceiling linings.

This report details the work undertaken to satisfy these requirements and the results obtained. As the validation experiments have been undertaken in advance of the completion of Tasks 4-7, comparison of the results with performance parameters will be the subject of a future report.

2. EXPERIMENTAL SCENARIOS

The full-scale experiments were conducted in the CSIRO facilities at Highett (Figure 1). Two different building layouts were used — room, and room plus corridor. The experiments were selected on the following principles:

- walls and ceilings are not always treated the same in the BCA {e.g. Specification Cl.10 Subclauses 4(b) and 4 (c)};
- room fire experiments should, so far as possible, be conducted in accordance -with the standard IS0 room fire test;
- results of the full-scale experiments must be able to be related to actual combustible contents;
- both materials that burn readily and materials that may not burn so readily should be included.
- duplicate experiments should be included to give a guide to repeatability.

In addition, in order to facilitate comparison with experiments in Project 4, one lining material and one ignition source were selected to be the same as a lining and ignition source used in Project 4. The schedule of experiments is given in Tables 1 and 2.

2.1 Experiment Setups

The room fire tests were conducted in a room conforming to IS0 9705[1]. The room size is 3.6 x 2.4 x 2.4 m high (Figure 2). The doorway is located in the centre of one of the shorter walls and opens under a hood. The 3 x 3 m hood is connected to an exhaust system, designed to collect all combustion products issuing from the room. The exhaust system which has a maximum air flow in excess of 3.5 m^3/s at ambient conditions, is instrumented to measure temperature, differential pressure, concentration of oxygen, carbon monoxide and carbon dioxide, and loss in light transmission across a diagonal in the exhaust duct. These measurements allow calculation of the total amount of heat, smoke and gases produced, as well as the rate of heat release at all stages of the fire.

The room plus corridor fire tests were conducted in the facility described in McArthur and Jolliffe[2]. It comprises a room built to the overall dimensions of the ISO room (3.6 x 2.4 x 2.4 m high), but with the doorway leading to the corridor in one of the longer walls (Figure 3). The corridor dimensions are IO x 1 x 2.1 m high, the minimum cross-sectional dimensions allowed by the BCA. It terminates beneath the same 3 x 3 m hood as the fire test room, and hence, combustion products are collected by the exhaust system described above.

2.2 Ignition Sources

The ignition sources used in the room fire test were an IS0 gas burner and an armchair (Table 1), whilst in the room plus corridor fire test, a three seater sofa was used (Table 2). The ISO gas burner is a sandbox burner described in Clause A.2.1 of IS0 9705[1]. It was operated in accordance with Clause A.1.2 of ISO 9705. Its rated heat output is shown in Figure 4.

The armchairs were constructed to order, and are identical to those used in Project 4. The armchair components are listed in Table 3, and the measured rate of heat release of an armchair under free burning conditions in the Furniture Calorimeter is shown in Figure 5.

When an armchair was used in the room fire experiments, it was located in one of the room corners further from the doorway, the same corner as that specified in IS0 9705 for the gas burner. The armchair was subjected to a 150 g wood crib ignition source, as described in Ramsay and Dowling[3]. The crib was placed on the seat cushion, abutting the centre of the seat back, and ignited on three sides with a gas flame.

The ignition source for all the room/corridor fire experiments was a three-seater steel framed sofa mock-up as described in NT Fire 032[4], with the exception that arm rests were not used. The sofa was padded with six cushions of polyurethane foam conforming with AS 22815, which are described in detail in Table 4. The measured rate of heat release of the three-seater sofa mock-up in the room/corridor facility is shown in Figure 6. In all room/corridor experiments the sofa was located against the wall furthest from the corridor, with one end abutting the shorter wall near the corridor (Figure 3). The sofa was ignited by applying a lighted match to the centre point of the rear top edge of the central seat cushion, igniting both the central seat and back cushions simultaneously. The service door (Figure 3) was then closed and sealed.

2.3 Lining Materials

The wall and ceiling lining materials referred to in Tables 1 and 2 are fully described in Table 5. Results obtained with these materials in the Cone Calorimeter[6], 'Early Fire Hazard Test'[7], Ignitability Test[8] and Smoke Chamber[9] are given in given in Tables 6 to 9.

For the room fire experiments, wall linings are fixed over a 16 mm gypsum plaster (glass reinforced) substrate on the three walls that do not contain the door, in accordance with ISO 9705. The ceiling and floor are lined with the same gypsum plaster, whilst the wall containing the door is lined with 16 mm calcium silicate board. When assessing ceiling lining materials in the room fire experiments, the ceiling lining is fixed over gypsum plaster, and the three unlined 'test' walls are gypsum plaster. The floor and fourth wall are lined with gypsum plaster and calcium silicate board respectively, as for the wall lining experiments.

In the room/corridor fire experiments the linings being examined were mounted over ceramic fibreboard on the two walls and/or ceiling as required. The unlined walls or ceiling were ceramic fibreboard. The floor was lined with cellulose reinforced cement sheet.

3. RESULTS

The heat release curves for the 8 room fire experiments and 6 room/corridor fire experiments are given in Figures 7 to 20, whilst additional data for the room fire experiments is given in Table 10 and for the room corridor fire experiments in Table 11.

Experiments R1, R2 and C1, in which the ignition sources were burnt with plasterboard as the only material on the walls and ceiling can be considered as tests involving the ignition sources only. Even though the paper facing of the plasterboard was burnt over a considerable area of the room and room/corridor ceiling and walls the combustion due to the paper is known to be too small to be measurable.

3.1 Armchair Free Burn

An armchair was burnt on a furniture calorimeter with free ventilation from all sides and with combustion products being extracted from above the area of the experiment (free burn situation). This was done to provide data on the combustion of this source when it burnt without re-radiation from surrounding walls or *overlying* hot combustion products, and without limitations on oxygen access.

Figure 5 shows the heat release rate from this experiment. The slow initial build-up (for the first 100 seconds) is related to the time taken for flames to fully involve the timber crib used to ignite the chair. Once the chair itself became involved the rate of heat release increased steadily to a first peak of around 400 kW, after 160 seconds. At this time the top of the seat cushion and the front of the back cushion were burning strongly. The fire proceeded at a steady state until such time as flames reached through to the bottom of the seat cushion, when molten material began to bum in a pool underneath the chair. The heat from this pool fire playing on the underside of the chair increased the severity of the burning of the seat cushion resulting in more material falling to the floor, increasing the size of the pool fire. The overall resultant acceleration in rate of heat release is shown in Figure 5 in terms or a rapid rise to a second peak at around 900 kW. The rate of heat release then fell as the fuel was consumed. The small peak in the plot of decreasing rate of heat release is due to the burning of the fuel at the front of the seat cushion which had up to this time not been exposed to radiated heat from either the burning of the seat or from the pool fire.

3.2 Experiment R1, ISO Gas Burner, Plasterboard Walls and Ceiling

Figure 6 shows the rate of heat release for this experiment. The paper facing on the plasterboard on the ceiling began to burn after about 100 seconds and this involvement slowly spread until the facing on all of the ceiling and on the walls up to the level of the top of the room doorway was burnt. The measured rate of heat release was, however, that of the burner itself, for the reason given above.

3.3 Experiment R2, Armchair, Plasterboard Walls and Ceiling

The burning of the armchair in the room followed the same pattern as for the free bum (see Section 3.1 above) but the bum proceeded slightly more quickly and was considerably more severe. As in Experiment R1 (see Section 3.2 above) the paper facing of the plasterboard ceiling and part of the walls was burnt. Figure 21 shows the armchair burning about 200 seconds after ignition of the timber crib which was used to ignite it. The peak rate of heat release, as shown in Figure 7, was around 2000 kW. Table 10 shows that flashover conditions were reached, by several measures, at 240 seconds. Flames out the door ceased, however, some 20 seconds after they began, and the intensity of the fire decreased rapidly as the fuel in the armchair was used up.

3.4 Experiment R3, ISO Gas Burner, Fire Retarded Plywood Walls

ignition of the walls where the burner flames impinged on the began within 30 seconds of the start of the experiment. Ignition spread steadily around the top of the walls as the temperature of the layer of hot gases above the top of the room doorway increased. After around 240 seconds flame began issuing from the door and spreading rapidly down the walls. Figure 9, the graph of rate of heat release versus time for this experiment, shows a very rapid increase in fire severity over the next 60 seconds, prior to the bum being extinguished after about 520 seconds. The apparent peak rate of heat release, 4600 kw may have been exceeded had the bum been allowed to continue but since flames were violently issuing out of the door down to around 400 mm above ground level at this time it is likely that the fire was close to a ventilation-controlled peak.

3.5 Experiment R4, ISO Gas Burner, Fire Retarded Plywood Ceiling

Strong involvement of the ceiling did not begin until after about 400 seconds. Figure 22 shows the ISO burner, and flames spreading over the ceiling at about this time. This involvement increased until after 490 seconds flames began to issue from the doorway of the room. At the peak of the burn flames through the doorway were down to only 1.5 metres above ground. By the time the burner output was increased (at 600 seconds) most of the ceiling material had been consumed or fallen to the floor.

3.6 Experiment R5, ISO Gas Burner, Plywood Walls

Once ignition of the wall panels adjacent to the burner occurred, 20 or so seconds into the experiment, flames spread steadily over the tops of the other wall panels, with a considerable build-up of smoke under the ceiling. Flames began to issue from the door after 140 seconds and, as indicated in Figure 11, the fire rapidly grew in intensity. Flames in the doorway dropped to within 0.5 metres of the ground and the heat release rate at extinguishment (205 seconds) was 4500 kW. The burn proved difficult to extinguish, reigniting strongly twice after application of the room sprinkler. A fire hose was used to aid extinguishment.

3.7 Experiment R6, ISO Gas Burner, Plywood Ceiling

This burn reached flashover conditions after around 330 to 400 seconds (see Table 10) and reached a peak rate of heat release of 2300 kW (see Figure 12). This is a genuine peak rate since this burn was allowed to continue until the ceiling had burnt away (after 450 seconds) and the fire had died down.

3.8 Experiment R7, Walls

Once the armchair became involved the adjacent wall panels also caught on fire and flames spread rapidly around the top of the walls. Flashover conditions were reached within 160 seconds (see Table 10) and Figure 23 shows paper targets burning on the floor shortly after this time. Figure 13 shows a rapid increase in the rate of heat release up to 4000 kW at the time of extinguishment, after 195 seconds. Figure 24 shows flames pouring out of the doorway down to around 0.6 metres, shortly before extinguishment.

3.9 Experiment R8, ISO Gas Burner, Plywood Walls

Once ignition of the wall panels adjacent to the burner occurred, 20 or so seconds into the experiment, flames spread steadily over the tops of the other wall panels, with a considerable build-up of smoke under the ceiling. Flames began to issue from the door after 160 seconds and, as indicated in Figure 74, the fire rapidly grew in intensity. Flames in the doorway dropped to within 0.4 metres of the ground and the heat release rate at extinguishment (235 seconds) was 4400 kW

3.10 Experiment Cl, 3 Seat Sofa, Plasterboard Walls and Ceiling

The fire on the sofa spread to involve all seat cushions. After about 80 seconds a pool fire began to spread under the sofa and the fire intensified rapidly, generating flashover conditions in the room after around 100 seconds. The fire peaked some 20 seconds later and died down quickly as the remaining fuel was used up. Figure 16 shows that the peak rate of heat release was a little over 2000 kW. No flames came out of the end of the corridor.

3.11 Experiment C2, 3 Seat Sofa, Fire Retarded Plywood Walls

As Figure 16 indicates, the progress of this fire was almost identical, in terms of heat release rate, to that of the 3 seat sofa on its own. As the sofa fire died down small flames could be seen on the top corners of the wall panels at the start of the corridor. They died out on one side, but continued to advance slowly along the top of the panels on the other side of the corridor. The flames were extinguished after 30 minutes, by which time they had moved less than 5 metres along the top of the corridor wall. Figure 2.5 shows the sofa burning under a heavy cloud of smoke, just prior to flashover. Figure 26 shows small flames on one wall of the corridor, about 20 minutes into the experiment.

3.12 Experiment C3, 3 Seat Sofa, Fire Retarded Plywood Ceiling

As Figure 17 shows, the sofa fire was similar in rate of heat release and time of burning to those in the previous experiments. As the sofa fire died down flames could be seen on the ceiling panels at the start of the corridor. They slowly grew in size and began to spread along the corridor. As panels further along the corridor were pre-heated by the smoke and hot gases passing along them the rate of fire growth increased until, after 415 seconds, flames began issuing from the end of the corridor. The fire rapidly increased in intensity, with flames rushing down the whole length of the corridor and pouring several metres out into the smoke collection hood at the end. The corridor fire reached a peak rate of heat release of 1500 kW at around 500 seconds (see Figure 17) after which time it was extinguished.

3.13 Experiment C4, 3 Seat Sofa, Plywood Walls

Figure 18, the graph of rate of heat release versus time for this experiment, shows that the sofa bum was followed quickly by strong involvement of the wall panels Flames began to issue out of the end of the corridor after 205 seconds, with the fire rapidly increasing in intensity to reach a rate of heat release of nearly 3500 kW at the time of extinguishment (270 seconds). Figure 27 shows the fire shortly before it was extinguished. Flames at the start of the corridor have reached about 1.2 metres down the wall panels. Flames at the end of the corridor are 0.8 to 0.9 metres deep.

3.14 3 Seat Sofa, Plywood Ceiling

The ceiling panel at the start of the corridor could be seen burning across the end as the sofa fire died down and the smoke cleared. This fire slowly began to extend along the first panel, then spread along the corridor at an increasing rate, with flames reaching the end of the corridor after 240 seconds. Figure 19 shows that the fire reached a rate of heat release of 2000 kW by around 300 seconds, when it was extinguished. Figure 28 shows the flames near this peak.

3.15 Experiment C6, 3 Seat Sofa, Plywood Walls

Figure 20, the graph of rate of heat release versus time for this experiment, shows that the sofa bum was followed very quickly by strong involvement of the wall panels. Flames began to issue out of the end of the corridor after 135 seconds, with the fire rapidly increasing in intensity to reach a rate of heat release of nearly 3500 kW at the time of extinguishment (200 seconds).

4. DISCUSSION

4.1 Choice of Experimental Scenarios

The large-scale fire test facilities at Highett are to some degree flexible. The fire test room can have any dimensions up to 5.0 x 3.6 x 2.7 m high, and ideally a range of room sizes should be used. However, the limited experimental program allowed for in Project 2 meant that it was necessary to keep the number of experiment variables to a minimum. Work in the EUREFIC program had shown that when testing linings, smaller rooms provided a more severe exposure, defined by the occurrence of flashover, even though there is less material to be involved[10]. Therefore it was decided to use the ISO/ASTM standard room. This provided the added advantage that it would allow more meaningful comparison of data with data obtained in other experimental programs that had used the same size room. This was judged to be of importance to the overall thrust of fire code reform.

4.2 Choice of Ignition Sources

There are two gas burner regions that are commonly used – the ISO preferred regime (Figure 4), which uses 100 kW for 10 minutes, followed by 300 kW for 10 minutes, and the ASTM proposed regime* [1] which uses 40 kW for 5 minutes, followed by 160 kW for 10 minutes. In previous work[12] at CSIRO it had been found that materials that performed well when subjected to the ASTM gas burner did not necessarily perform as well when subjected to the more severe IS0 gas burner. After consideration of both sources, it was decided that the IS0 gas burner gave a heat output that was more like that of modem furniture[13]. In addition, as the IS0 burner had been used in all EUREFIC work[14], there was the added advantage of being able to compare results with those obtained in the EUREFIC program.

4.3 Choice of Lining Materials

The lining materials (Table 5) were chosen after a market survey on availability. Materials were selected, on the basis of past experience with wall linings, so there would be one material that would not cause flashover in the IS0 room (gypsum plaster), one material that would cause flashover in the ISO room (plywood) and one of uncertain performance (fire-retarded plywood).

4.4 Results

The following discussion is principally a series of comparisons between the results from pairs of experiments that are alike in all but one feature, such as ignition source, lining type (wall or ceiling) and lining material (plywood with and without fire retardant treatment). The differences caused by variations of such features are examined in terms of rate of heat release and of the time taken to reach various points in the burns. Comparisons are also made between results from the two sets of duplicate experiments, one pair of room fires and one pair of room/corridor fires, which were carried out to give a measure of the repeatability of the experiments.

4.4.1 Armchair free burn cf armchair bum in fire lest room (armchair free burn, Experiment R2)
The effect of the enclosure size is graphically shown in the difference between these two bums (Figures 5 and 8). The peak rate of heat release increased from 900 kW in the free burn to 2000 kW in the room situation. The total time of burning was, however, only slightly longer for the free burn.

The armchair used in these experiments was of particularly heavy construction and the 900 kW peak in the free burn was at the high end of the range of peak heat release rates which have been observed for single lounge armchairs in previous work. Typical chairs at the low end of the range show peaks from 250 to 300 kW. The armchair bum in the room was the first occasion on which the authors had observed flashover conditions being generated by the burning of a single seat armchair in a room otherwise basically devoid of fuel.

4.4.2 Armchair cf ISO gas burner in plasterbonrd-clad room (Experiments RI, R2)
Whilst the IS0 gas burner program is designed to simulate the burning of a typical lounge chair, the armchair used in the experiments has a higher rate of heat release than most. Data in Table 10 and a comparison of Figures 7 and 8 highlights the difference in the rates of heat release of these two ignition sources. The effect of this difference is not particularly noticeable in comparable experiments with non-fire-retarded plywood wall linings (R5, R7 and R8) because the plywood ignites readily. Had the armchair been used as the ignition

source in an experiment matching Experiment R4, with a fire retarded plywood ceiling, it is likely that the difference in results would have greater than that found for plywood.

4.4.3 ISO gas burner cf armchair – plywood wall linings, room fire test (Experiments

Apart from a slight time delay in the early development of the armchair-ignited fire, due to the time taken for the timber crib ignition source to ignite the armchair, these experiments gave very similar results in terms of rate of heat release and rate of increase of rate of heat release (see Table 10 and Figures 11 and 13). For this material the ignition source size was not critical.

4.4.4 Fire retarded plywood wall linings cf fire retarded plywood ceiling linings - roomjire test, ISO gas burner. (Experiments R3, R4)

The wall linings caught alight more quickly than the ceiling linings. Data in Table IO and a comparison of Figures 9 and 10 show that the wall lining fire grew to flashover conditions more quickly and had to be extinguished. By comparison the fire involving the ceiling lining just managed to reach flashover conditions, then burnt to completion in a relatively benign manner. Whilst there is considerably less material available for combustion in the ceiling lining than in the wall linings, the configuration must be seen as the dominating influence in the early stages of fire development. The configuration represents a low level ignition source in a room comer.

4.4.5 Plywood wall linings cf plywood ceiling linings – room fire test, ISO gas burner (Experiments

The differences between the results of these experiments were similar in nature to those discussed above for the fire retarded plywood. Data in Table 10 and a comparison of Figures 11 and 12 show that the wall lining fire was faster to flashover than the ceiling lining fire by about the same amount of time (250 seconds). The difference between maximum intensity of the two burns was, however , less than was the case with the fire retarded materials. Whilst the wall linings generated a similar 4500 kW blaze prior to extinguishment, the ceiling lining fire reached a peak of 2300 kW, more in line with the comparative amounts of plywood presented in the two configurations.

4.4.6 Plasterboard wall linings cf plywood wall linings – armchair in ISO room . (Experiments R2 and R7).

In the early stages of the experiments, the behaviour of the armchair dominated and the rates of fire growth were similar (Figures 8 and 13). However, with the ignition of the plywood, the behaviour of the wall linings dominated, leading to earlier flashover for the plywood linings than for the plasterboard linings (Table 10).

4.4.7 Duplicate experiments – ISO gas burner, plywood walls, room fire test

As Figures 11 and 14 and data in Table 10 indicates, these burns were good replicates with less than 10% variation from the mean for all measured parameters.

4.4.8 Fire rcfarded plywood wall linings cf fire retarded ceiling linings – room/corridor fire test (Experiments

As shown in the data in Table 11 and by Figures 16 and 47 there was a great difference in results between the wall linings and the ceiling linings. The bum involving the wall linings only reached a very slow steady-state rate of burning along the top of one wall whereas the ceiling bum developed to full invoivement of the ceiling lining with a rate of heat release at extinguishment of 15 kW. This result differs-from that-in the room fire test where the walls caught fire more rapidly than the ceiling, and went on to a more severe burn-out. This difference is a result of the different scenarios represented. Whilst the walls may play a role in early fire growth, the ceilings are seen to be more important in fire spread, and hence represent a greater hazard.

4.4.9 Plywood wall linings cf plywood ceiling linings – room/corridor fire test. (Experiments C4, C5)

These two fires were similar in both their rate and extent of development, both resulting in intense burns which had to be extinguished. The rates of heat release at extinguishment, 3500 and 2000 kW for walls and ceiling respectively, are in line with the amount of material consumed. Data for these experiments is given in Table 11 and Figures 18 and 19. The difference between fire spread on walls and on the ceiling is less than in equivalent room burns, probably due in part to the narrow (1 m) corridor.

4.4.10 Duplicate experimen fs – *plywood walls, room/corridor* test *(Experiments C4, C6)*

Comparison of the graphs of rate of heat release for these experiments (Figures 18 and 20) shows that whilst they were similar in magnitude, there was a time difference of up to 70 seconds in the development of the fire on the walls. Study of the videotape of these burns gives no clue as to why this difference occurred. Data in Table 11 shows that whilst ignition times varied from the mean by less than 10%, other parameters varied from the mean by as much as 24%. Whilst such variations are larger than desired, they are not unusual in large-scale fire experiments, and reinforce the need to conduct replicate experiments.

5. SUMMARY

The results indicate that the choice of materials was appropriate, with the plasterboard, plywood and fire-retarded plywood providing a broad range of behaviour in the large-scale tests.

The plasterboard did not go to flashover in the ISO room fire test with the ISO burner, or in the room/corridor fire test. However, when the fire load in the ISO room was increased, by replacing the gas burner with the large armchair, the role of the contents was decisive, and flashover occurred rapidly. This result demonstrates that the role of the contents can be decisive and can overwhelm the role of the linings.

Tine plywood linings went to flashover in all experiments. The time to flashover varied firstly depending on whether the plywood was installed as wall or as ceiling linings, and secondly on whether the lining was in the room of fire origin or in an adjacent corridor. The overall spread of results, however, was not great for this material.

The fire retarded linings went to flashover in the ISO room fire test, whether installed as wall linings or as ceiling linings. But in the room/corridor test, where the linings were installed in the corridor adjacent to the room of fire origin this was not the case. The fire retarded plywood went to flashover when installed as ceiling linings, but did not go to flashover when installed as wall linings. This result indicates that ceiling linings probably play a greater role in fire spread, especially away from the area of fire origin, than do wall linings.

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7. REFERENCES

1. ISO (1993). Fire Tests — Full-scale Room Test for Surface Products. ISO 9705, International Organisation for Standardisation, Geneva.
2. McArthur, N.A. and Jolliffe, C.B. (In press). Development of a Demountable Fire Test Corridor for Assessment of Floor Coverings. Submitted to 5th International Symposium on Fire Safety Science.
3. Ramsay, G.C. and Dowling, V.P. (1983). A Protocol of Fire Behaviour of Furniture Using Flaming Ignition Sources, Part 2: Actual Furniture Items. CSIRO Division of Building Research, Melbourne.
4 Nordtest (1987). Upholstered Furniture: Burning Behaviour — Full-scale Test, NT *Fire* 032. Nordtest, Helsinki.

5. Standards Australia (1993). Flexible Cellular Polyurethane for Seat Cushioning and Bedding. AS 2281, Standards Australia, Sydney.

6. ASTM (1994). Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter. ASTM E 1354-94, American Society for Testing and Materials, Philadelphia, Pennsylvania.

7. Standards Australia (1989). Australian Standard 1530 – Methods for Fire Test on Building Materials, Components and Structures: Part 3 – Simultaneous Determination of Ignitability, Flame Propagation, Heat Release and Smoke Release. SAA, Sydney, Australia.

8. Standards Australia (1989). Australian Standard 1530 – Methods for Fire Test on Building Materials, Components and Structures: Part 5 – Test for Piloted Ignitability. SAA, Sydney, Australia.

9. ASTM (1993). Standard Test Method for Specific Optical Density of Smoke Generated by Solid Materials. ASTM E 662-93, American Society for Testing and Materials, Philadelphia, Pennsylvania.

10. Kokkala, M., Göransson, U. and Söderbom, J. (1990). EUREFIC — Large Scale Fire Experiments in a Room With Combustible Linings. Some Results from Project 3 of the EUREFIC Fire Research Programme, SP Report 1990:41. Swedish National Testing and Research Institute, Borås, Sweden.

11. ASTM (1983). Proposed Method for Room Fire Test of Wall and Ceiling Materials and Assemblies, In 1983 Annual Book of ASTM Standards, Vol. 04.07. American Society for Testing and Materials, Philadelphia, Pennsylvania, pp.958–978.

12. Ramsay, G.C., Dowling, V.P., McKechnie, B. and Leonard, J. (1995). Methods for Assessing the Fire Performance of Phenolic Resins and Composites, In Fire Science and Technology: Proceedings of the Second Asia-Oceania Symposium, Khabarovsk, Russia, 13-17 September, 1995. Asia-Oceania Association for Fire Science and Technology, pp.355–366.

13. Wickström, U., Sundstrbm, B. and Holmstedt, G. 1983. The Development of a Full-scale Room Fire Test. *Fire Safety J.*, **5**, 191-197.

14. Sdderbom, J. 1991. EUREFIC – Large Scale Tests According to IS0 DIS 9705. Project 4 of the EUREFIC Fire Research Programme, SP Report 1991:27, Swedish National Testing and Research Institute, Borås.

Table 1. Schedule of room fire experiments

Experiment	Material	Configuration	Ignition source
R1	Plasterboard	Walls & ceiling	ISO gas burner
R2	Plasterboard	Walls & ceiling	Armchair[a]
R3	Plywood, FR	Walls	ISO gas burner
R4	Plywood, FR	Ceiling	ISO gas burner
R5	Plywood	Walls	ISO gas burner
R6	Plywood	Ceiling	ISO gas burner
R7	Plywood	Walls	Armchair
R8[b]	Plywood	Walls	ISO gas burner

a Same chair as used in FCRC Project 4
b Duplicate of experiment R5

Table 2. Schedule of room/corridor fire experiments

Experiment	Material	Configuration	Ignition source
C1	Plasterboard	Walls & ceiling	Three-seater sofa
C2	Plywood, FR	Walls	Three-seater sofa
C3	Plywood, FR	Ceiling	Three-seater sofa
C4	Plywood	Walls	Three-seater sofa
C5	Plywood	Ceiling	Three-seater sofa
C6[a]	Plywood	Walls	Three-seater sofa

a Duplicate of experiment C4

Table 3. Details of armchair

Component	Description	Mass (kg)
Frame	Kiln-dried *Pinus radiata*	10.00
Seat base	Particleboard	3.40
Arm supports	Pine structural plywood	1.70
Cushion padding (1)	Polyurethane foam (Joyce H30-100)	2.10
Cushion padding (2)	Dacron polyester fibre	2.35
Cushion cover	100 % polyester	1.50
Webbing	Elastomer	0.10
Fasteners	Zinc-plated steel bolts and staples	0.25

Table 4. Details of three-seater sofa cushions

Number	6
Material	Dunlop general purpose polyurethane foam, A23-130
Grade (AS 2281)	N23–130
Dimensions	560 x 560 x 100 mm
Density	23 kg/m^3
Mass	750 g

Table 5. Details of lining materials

Material	General description	Thickness (mm)	Density (kg/m^3)
Plasterboard	Paper-faced, glass fibre reinforced gypsum plaster	16	810
Plywood	Three ply Lauan	4	580
Plywood, FR	Three ply Hoop Pine, "Firex" impregnated	4	550

Table 6. Cone Calorimeter[a]

Material	Irradiance (kW/m^2)	Ignition time (s)	End of test (s)	Total heat evolved[b] (MJ/kg)	Peak RHR (kW/m^2)	Time of peak RHR[b] (s)	60 s average RHR[c] (kW/m^2)	average RHR[d] (kW/m^2)	Average EHC[b] (MJ/kg)	Average SEA[b] (m^2/kg)	CO yield[b] (kg/kg)
Plasterboard	25	no ignition	—	—	—	—	—	—	—	—	—
	35	245 ± 5	105 ± 3	24 ± 2	102 ± 1	118 ± 3	41± 2	26 ± 2	2.5 ± 0.6	45 ± 5	0.023 ± 0.0001
	50	190 ± 0	44 ± 0	30 ± 1	107 ± 2	58 ± 3	49 ± 1	78 ± 3	3.4 ± 0.3	23 ± 2	0.030 ± 0
Plywood	25	112 ± 29	248 ± 28	200 ± 18	273 ± 33	150 ± 65	168 ± 3	92 ± 2	8.6 ± 1.0	57 ± 4	0.013 ± 0.002
	35	49 ± 3	180 ± 5	188 ± 7	291 ± 37	90 ± 39	152 ± 28	119 ± 3	10.7 ± 0.5	70 ± 15	0.016 ± 0.004
	50	30 ± 7	158 ± 34	215 ± 46	426 ± 20	85 ± 43	174 ± 21	155 ± 10	13.0 ± 1.4	67 ± 10	0.017 ± 0.010
Plywood, FR	25	116 ± 9	248 ± 19	180 ± 12	274 ± 48	183 ± 3	146 ± 14	83 ± 12	7.9 ± 0.5	61 ± 5	0.014 ± 0.003
	35	54 ± 8	187 ± 8	174 ± 9	294 ± 100	128 ± 3	117 ± 11	106 ± 4	9.7 ± 0.5	59 ± 6	0.010 ± 0.002
	50	18 ± 1	145 ± 9	174 ± 9	317 ± 26	95 ± 5	113 ± 5	137 ± 10	11.3 ± 0.3	59 ± 5	0.007 ± 0.003

EHC = effective heat of combustion, RHR = rate of heat release, SEA = specific extinction area (a measure of smoke, CO = carbon monoxide

[a] All results are mean ± standard deviation for three replicates
[b] From start of test
[c] From ignition
[d] From to end of test

Table 7. Results from A{ 1530 Part 3 (Ea y est')[a]

Material	Plasterboard	Plywood	
Ignitability index (range O-20)	0	16	16
Ignition time (minutes)	NA	4.42	4.28
Standard error	NA	0.2	0.04
Spread of flame index (range O-10)	0	9	8
Flame propagation time (Seconds)	NA	22.3	32.6
Standard error	NA	4.7	1.1
Heat evolved index (range O-10)	0	10	8
Heat release	NA	252.3	220.3
Standard error	NA	10.5	2.8
Smoke developed index (range O-10)	1	3	3
Smoke release $\log_{10}(m^{-1})$	0.011	0.037	0.045
Standard error	0.025	0.004	0.008

[a] AU results mean of 6 specimens
NA Not applicable because specimen did not ignite

Table 8. Results from Part 5 ('Ignitability Test')[a]

Material	Irradiance (kW/m^2)	Ignition time (seconds)	Standard deviation
Plasterboard	40	92	2.1
	50	44	9.3
Plywood	40	47	2.2
	50	32	1.8
Plywood FR	40	36	2.5
	50	21	1.5

[a] All results mean of 5 specimens

Table 9. Results from ASTM E662 ('NBS Smoke Chamber')

Specimen	Exposure	Mass loss (%)	Maximum optical density (Dm)	Dm corrected	Time to Dm (minutes)
Plasterboard	Radiant	9	43	43	13
	Flaming	13	7	7	9
Plywood	Radiant	63	301	299	11
	Flaming	73	32	31	13
Plywood FR	Radiant	68	364	351	9
	Flaming	73	18	16	7

[a] Ail results mean of 3 specimens

Table 10. Results of room fire experiments

Experiment	Event times (s)					
	Ignition of lining	Hot layer descends to 1.9 m	Upper layer temperature is 600°C	Rate of heat release is 1 MW	Flames out door	End of expt.[a]
R1	N[b]	N	N	N	N	1200
R2	N	100	240	240	240	690/E
R3	22	160	155	260	240	315/E
R4	290	430	425	535	490	1200
R5/R8[c]	20 ± 0	120 ± 10	115 ± 10	163 ± 13	150 ± 10	218 ± 13/E
R6	240	320	330	400	380	1200
R7	130	100	145	160	160	195/E

[a] The letter E denotes those experiments that were extinguished
[b] N denotes that event did not occur
[c] Duplicates

Table 11. Results of room/corridor fire experiments

Experiment	Event times (s)					
	Ignition of lining	Hot layer descends to 1.9 m	Upper layer temperature is 600°C	Rate of heat release is 1 MW[a]	Flames out end of corridor	End of expt.[b]
C1	N[c]	N	N	N	N	1200
c 2	130	N	N	N	N	1200
C3	140	400	415	475	415	555/E
C4/C6[d]	130 ± 10	160 ± 20	165 ± 40[e]	185 ± 35[e]	170 ± 35	233 ± 38/E
C5	135	220			240	330/E
C	120	140			135	195/E

[a] Ignoring peak from sofa
[b] The letter E denotes those experiments that were extinguished
[c] N denotes that event did not occur
d Duplicates
e One value estimates by extrapolation. Second peak in Experiment C6 occurs soon after peak from sofa (see Figure 20).

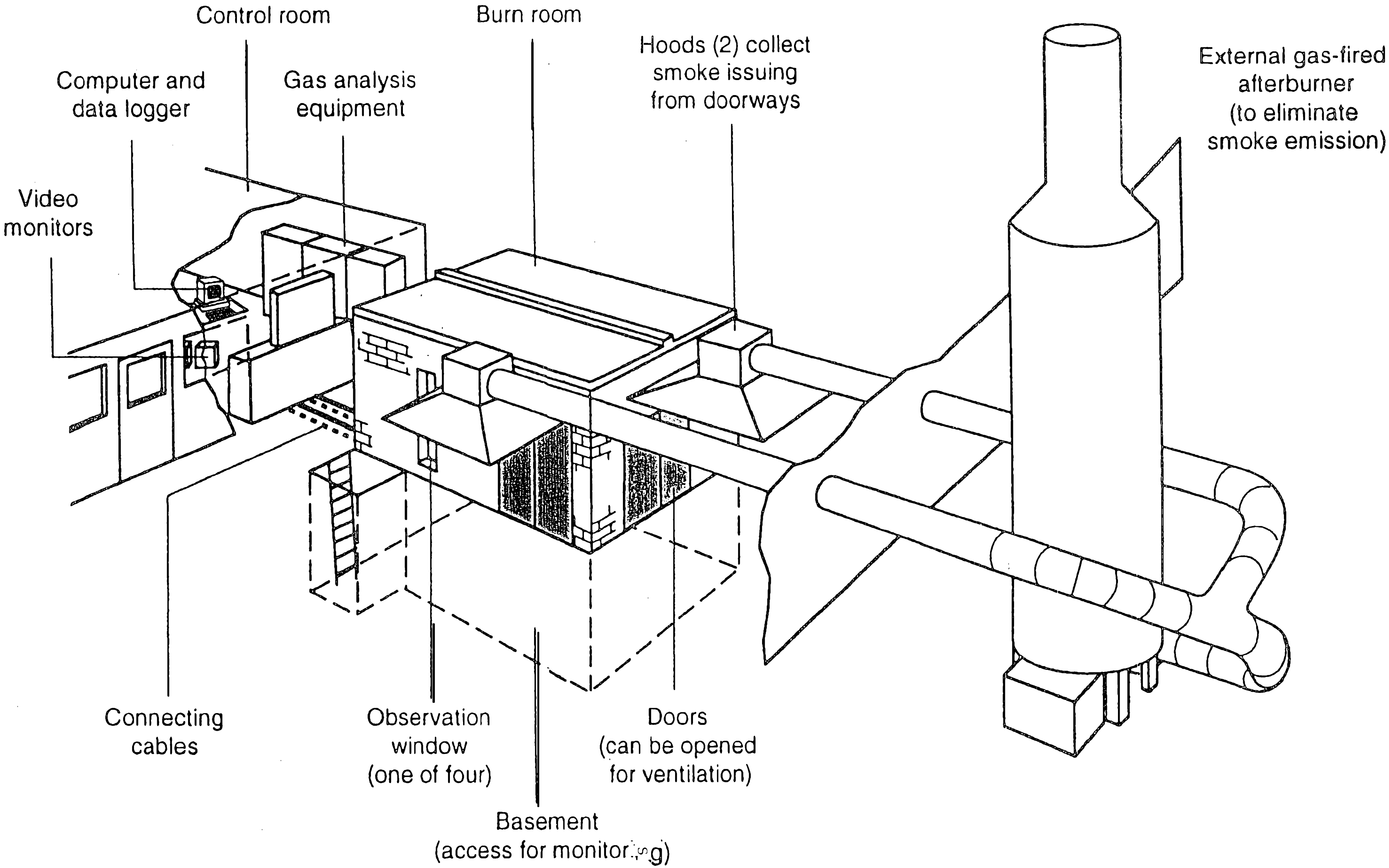


Figure 1. Facility for conducting large-scale fire tests

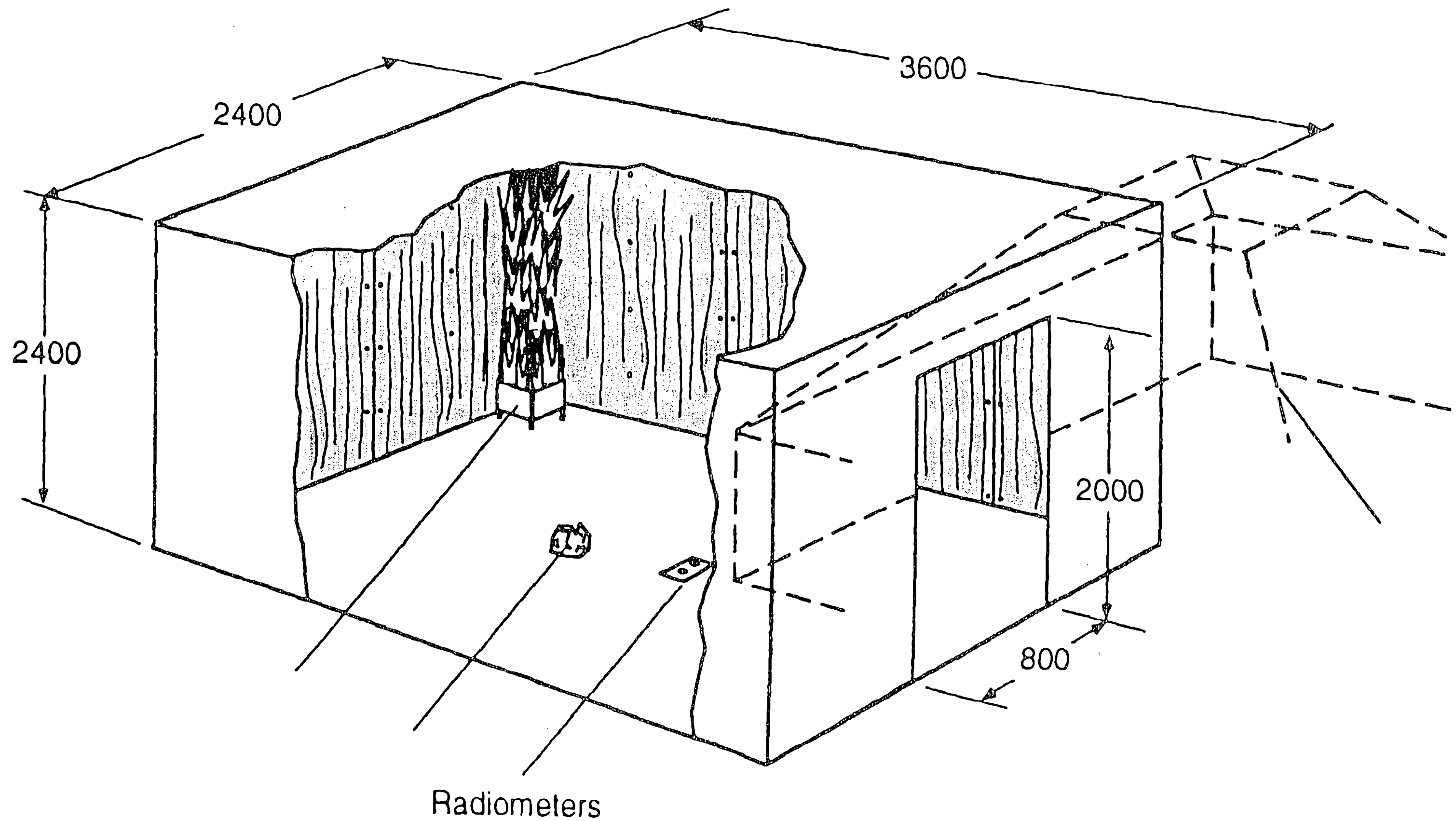


Figure 2. ISO

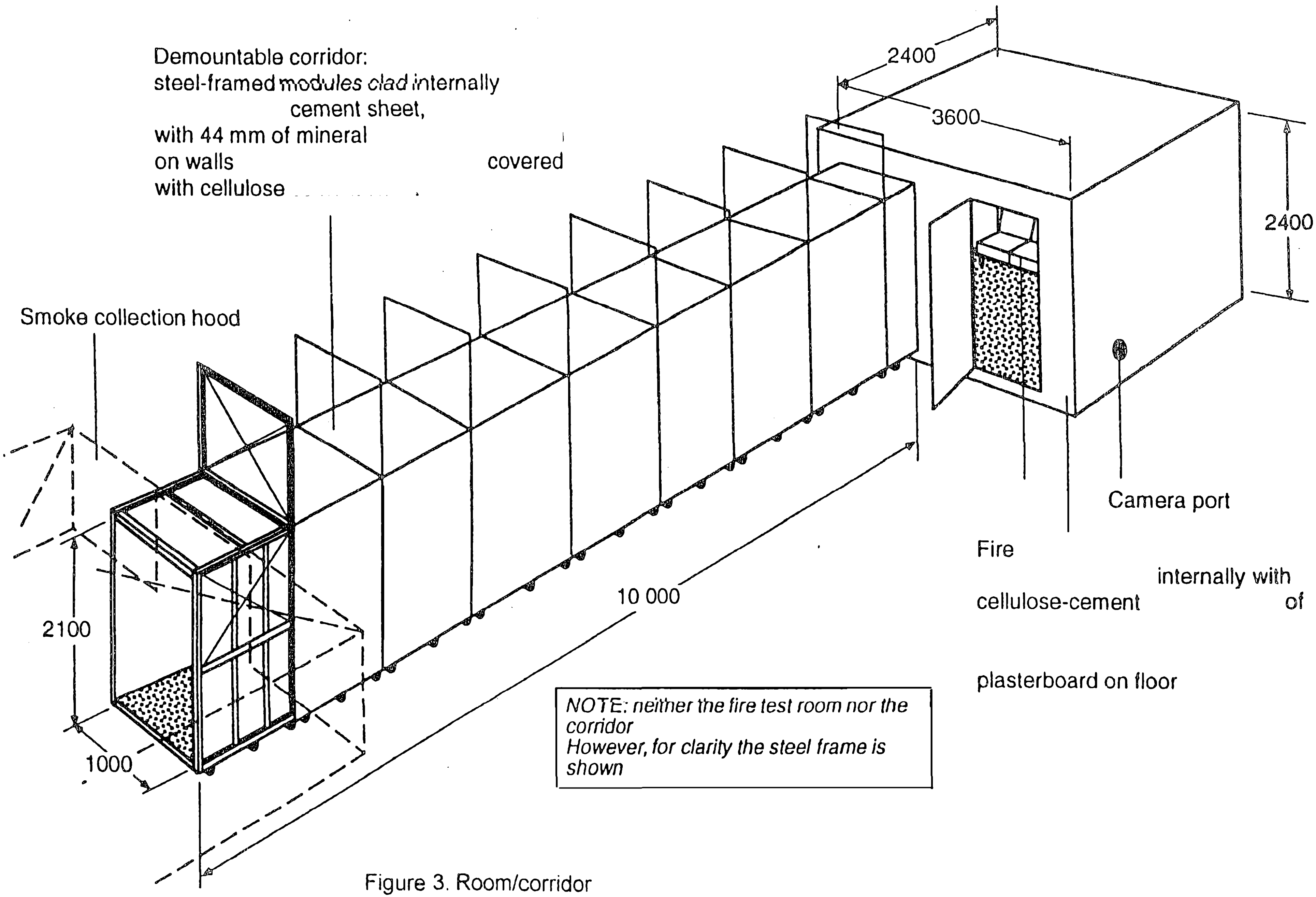


Figure 3. Room/corridor

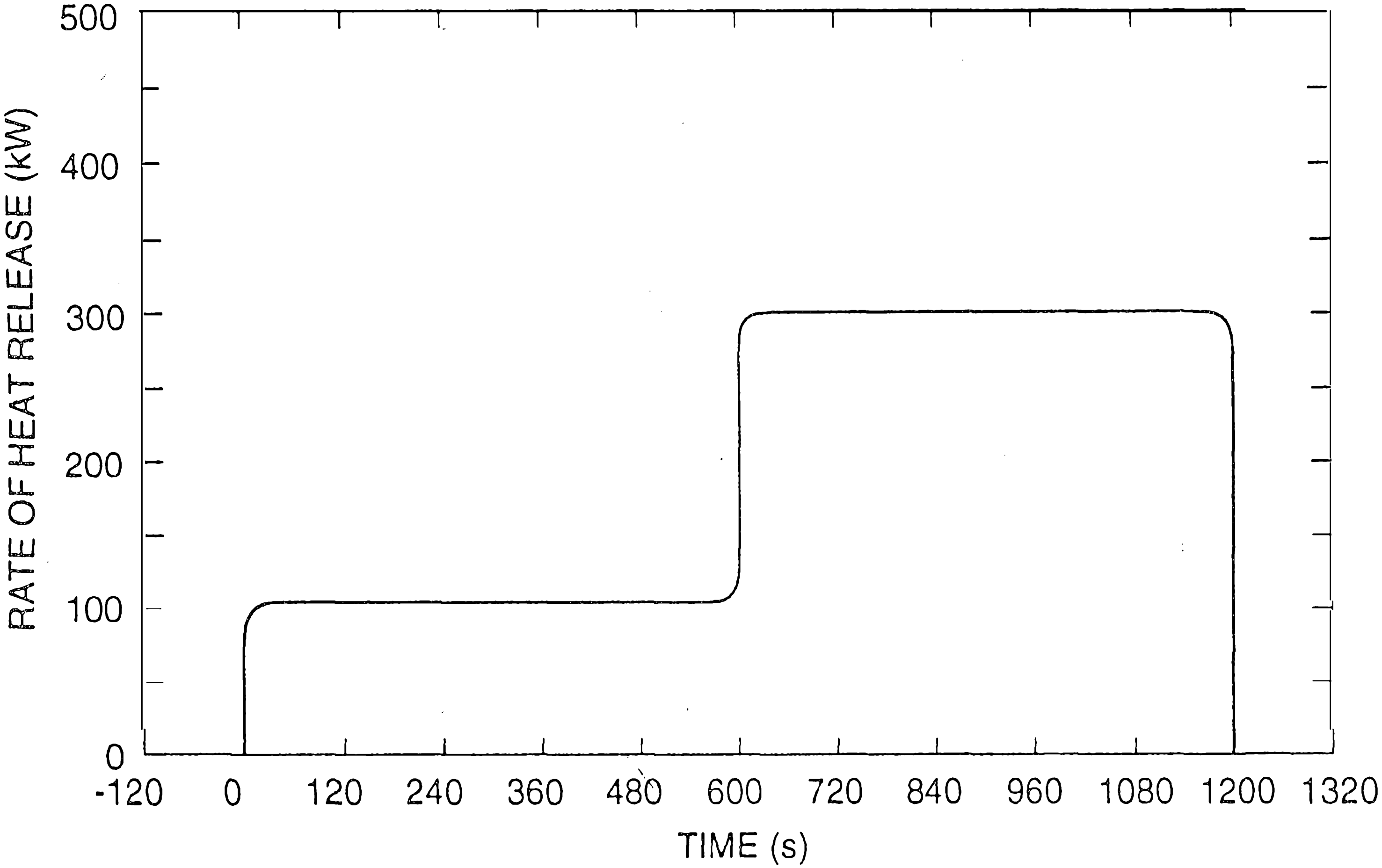


Figure 4. Heat output from ISO gas burner

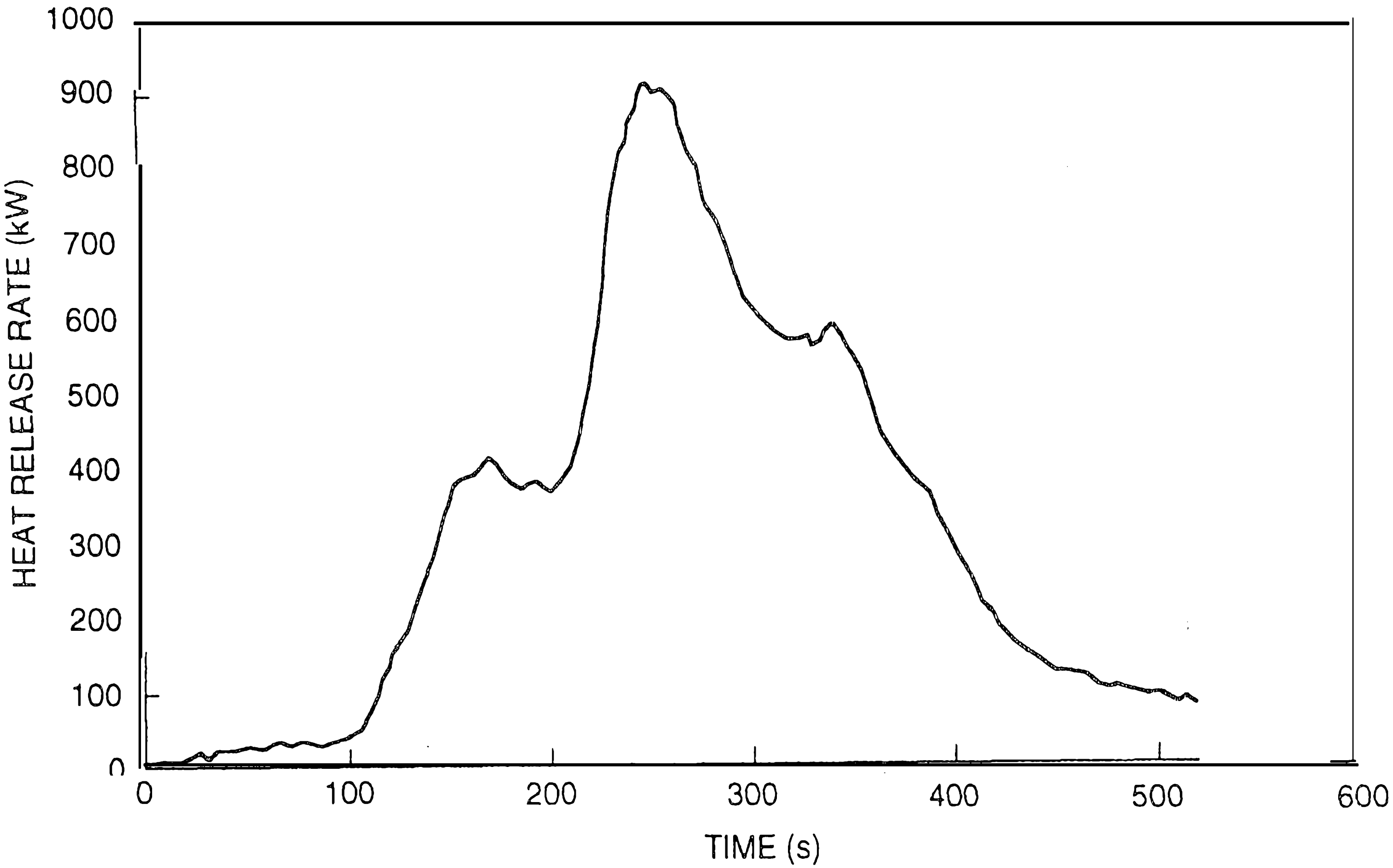


Figure 5. Heat output from armchair (free burning)

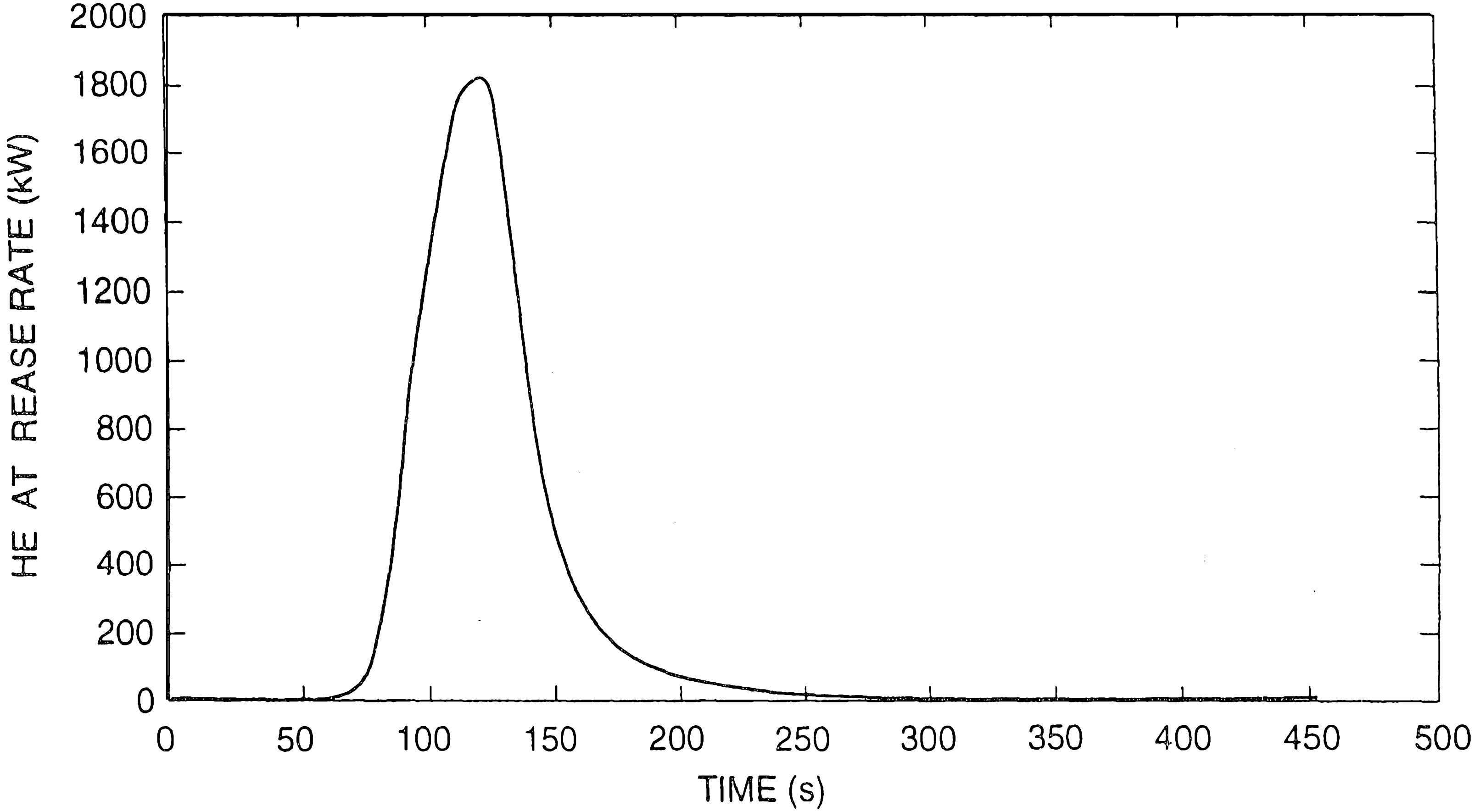


Figure 6. Heat output from three-seat sofa

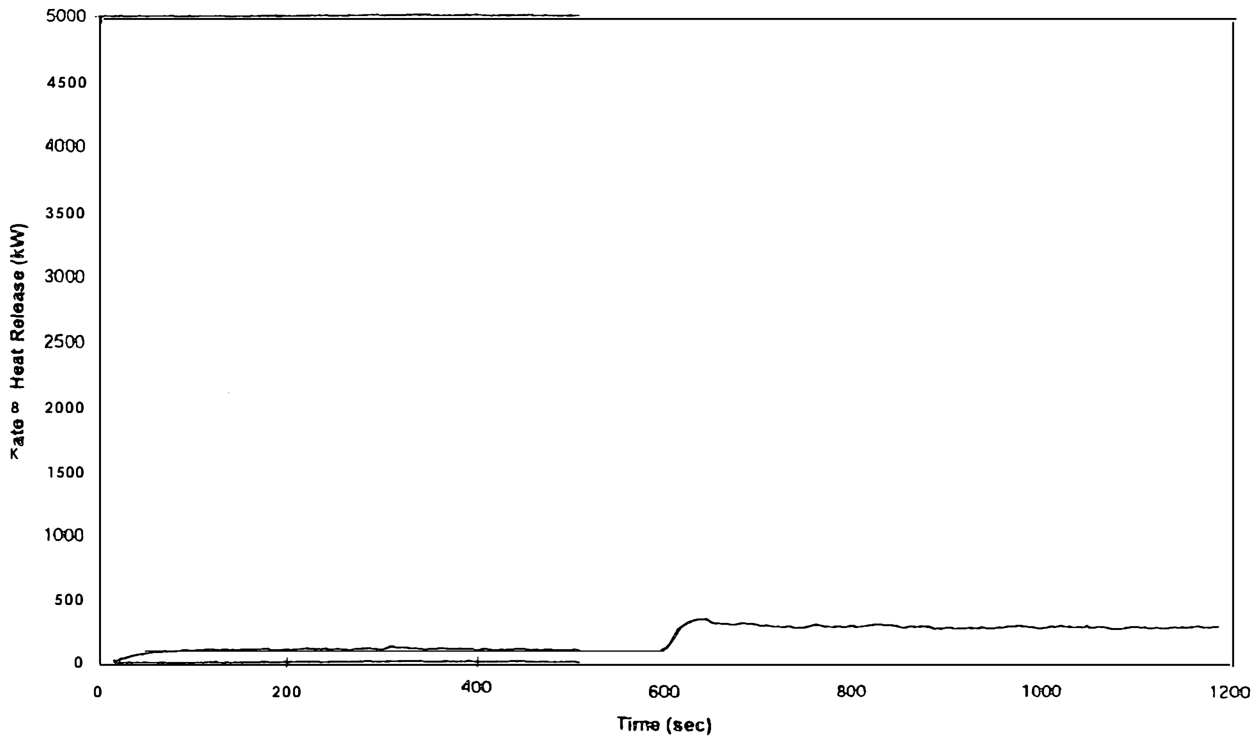


Figure 7. Gross rate of heat release for experiment R1.
burner, plaster ceiling).

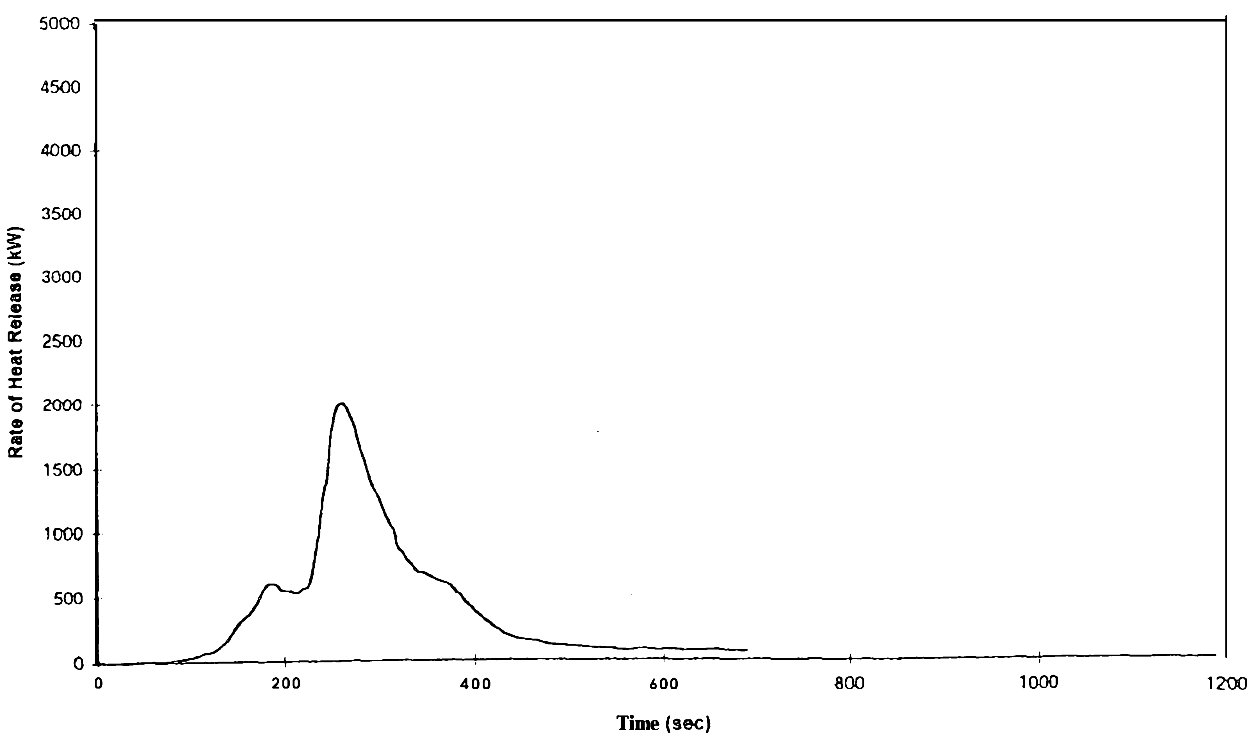


Figure 8. Gross rate release for experiment R2.
(Armchair, plaster walls and ceiling).

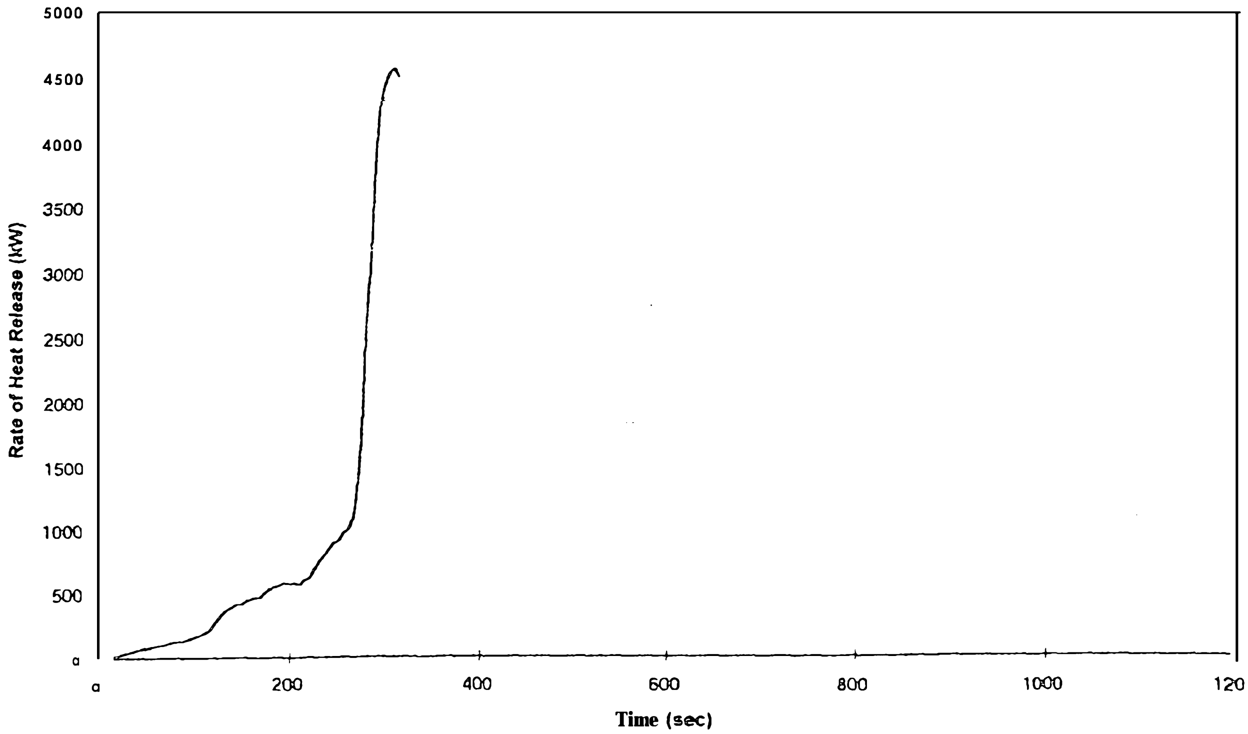


Figure 9. Gross rate of heat release for experiment R3.
(ISO gas burner, FR plywood wails).

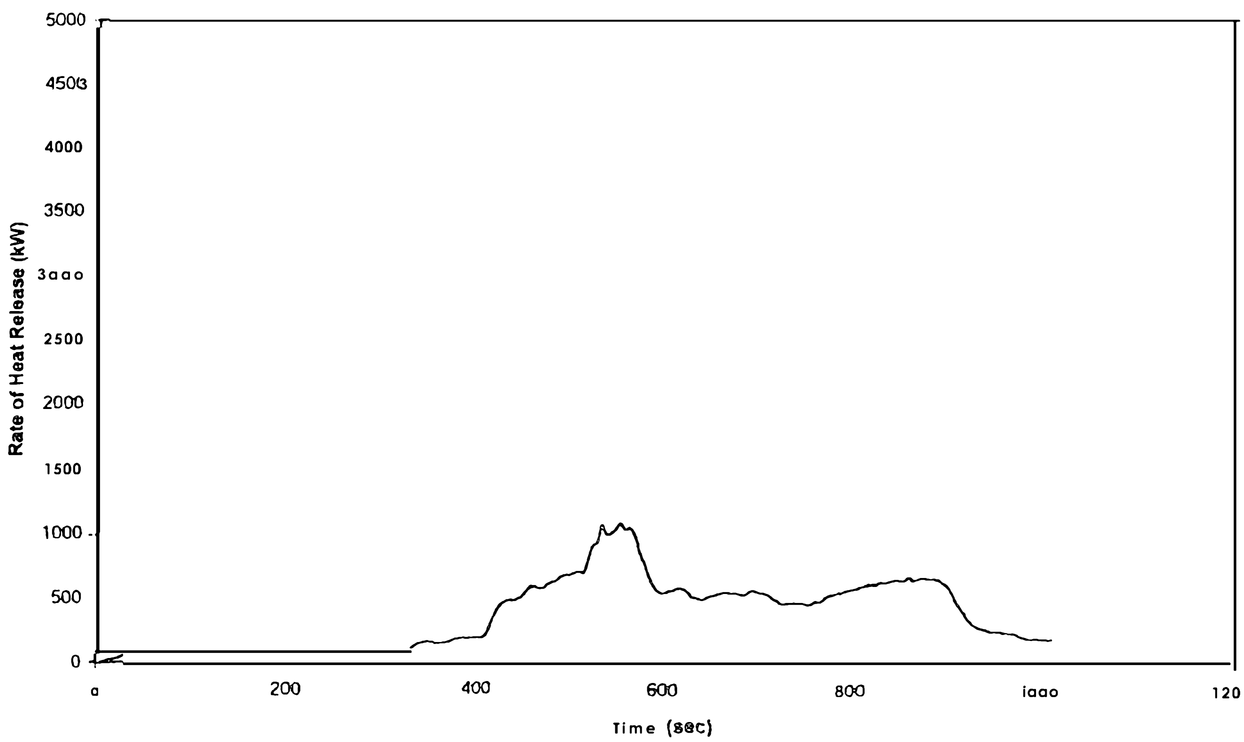


Figure 10. Gross rate of heat release for experiment R4.
(ISO gas burner, FR plywood ceiling).

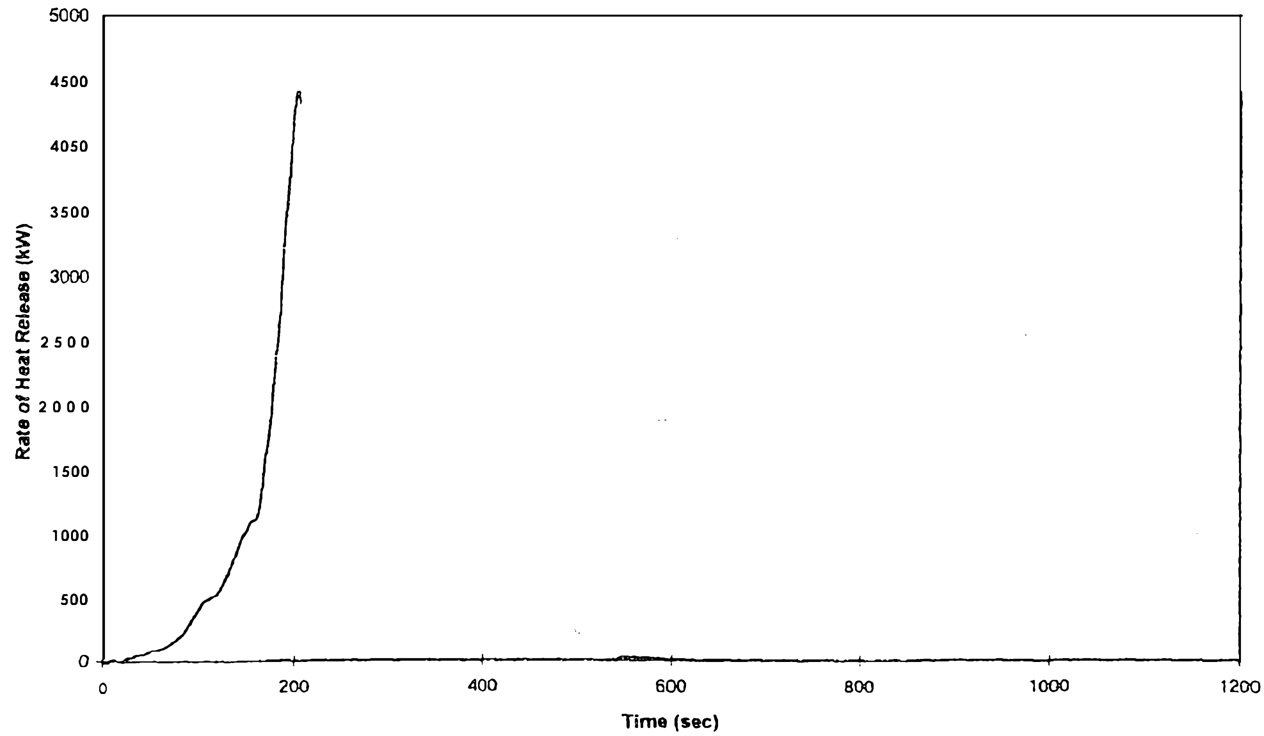


Figure 11. Gross rate of heat release for experiment R5.
(ISO gas burner, plywood walls).

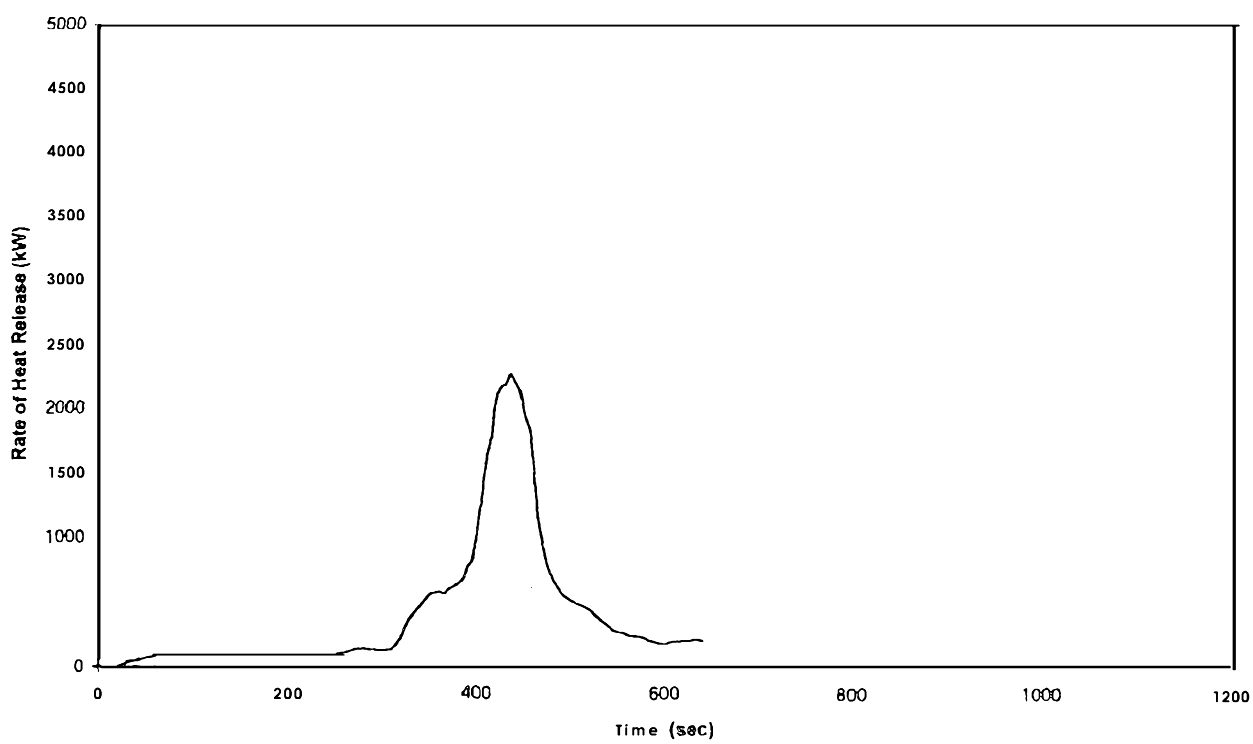


Figure 12. Gross rate of beat release For experiment R6.
(ISO gas burner, plywood ceiling).

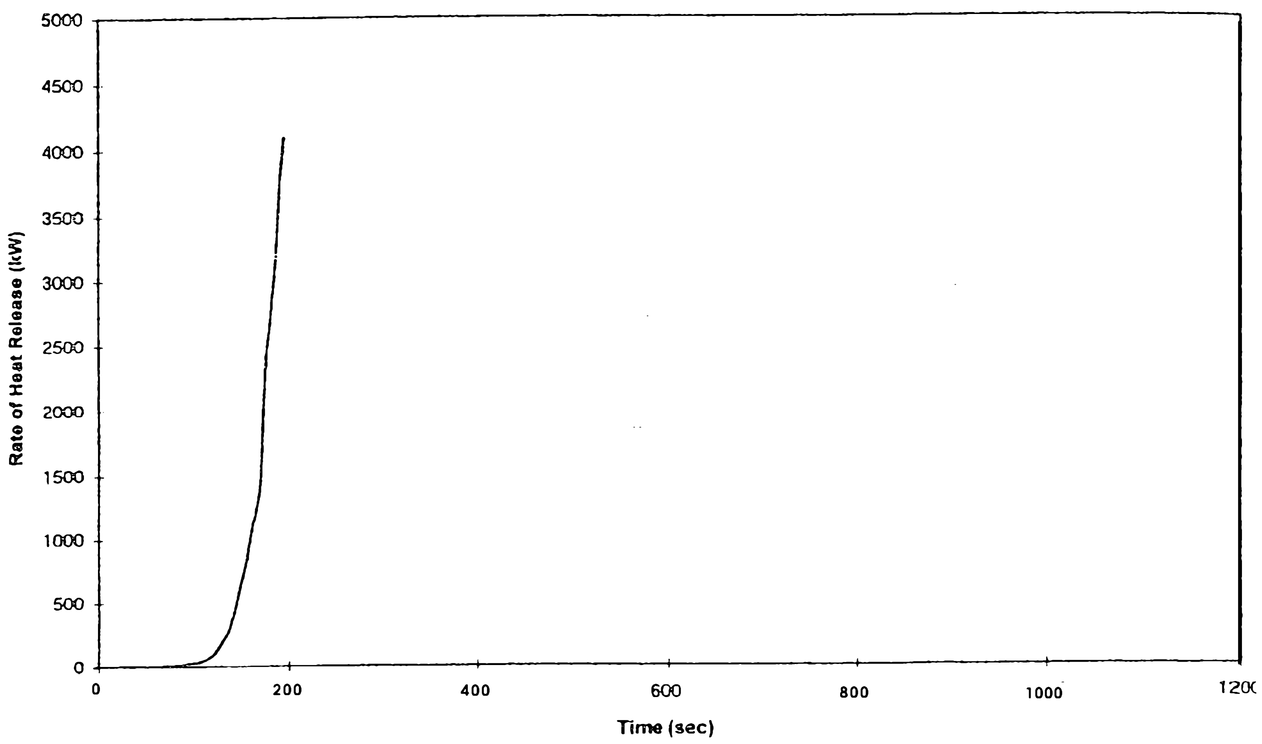


Figure 13. Gross rate of heat release For experiment R7. (Arm&sir, plywood walls).

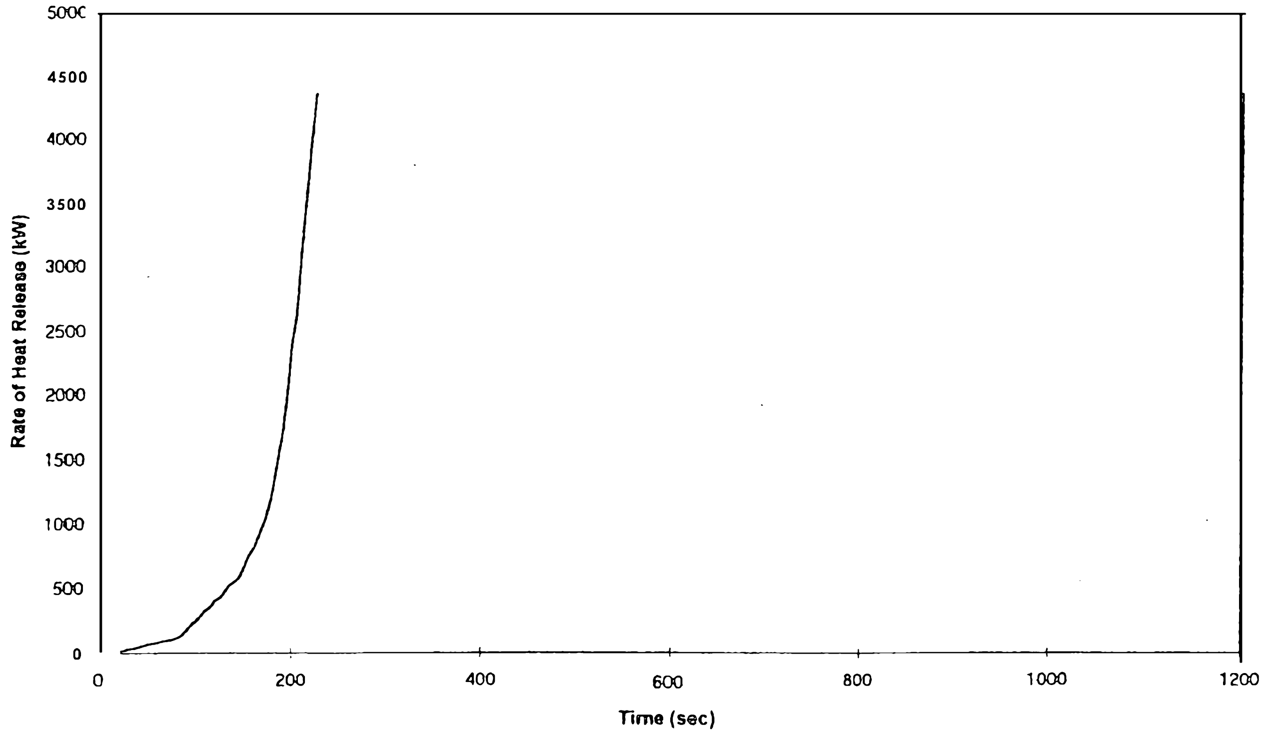


Figure 14. Gross rate of heat release for experiment R8. (ISO gas burner, plywood walls).

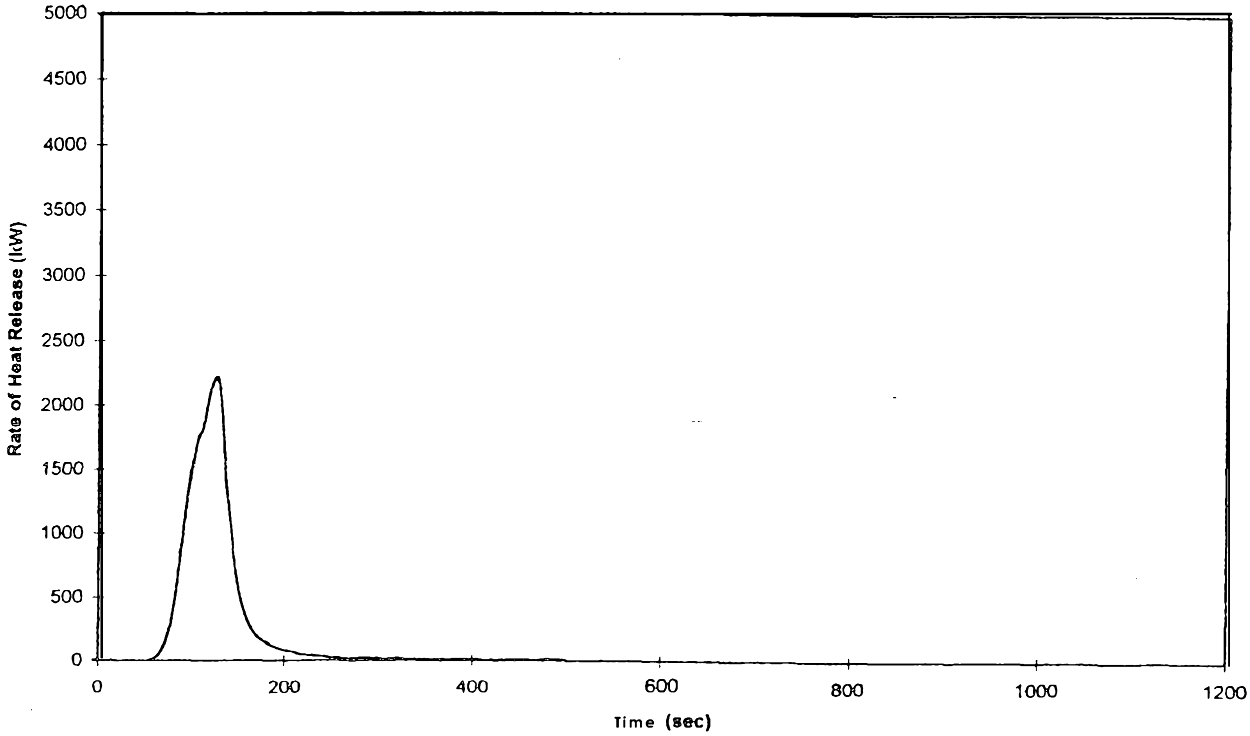


Figure IS. Gross rate of heat release for experiment *C1*.
(Plaster walls and ceiling).

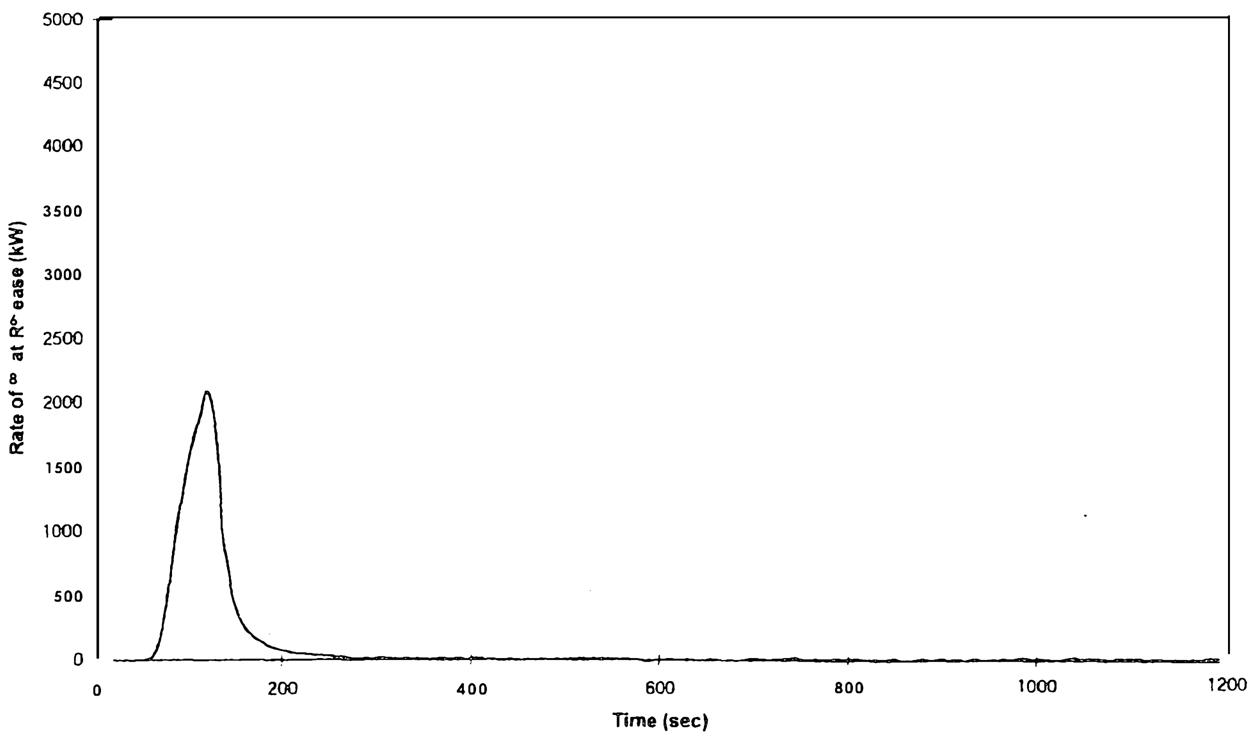


Figure 16. Cross rate of heat release For experiment C2.
(FW

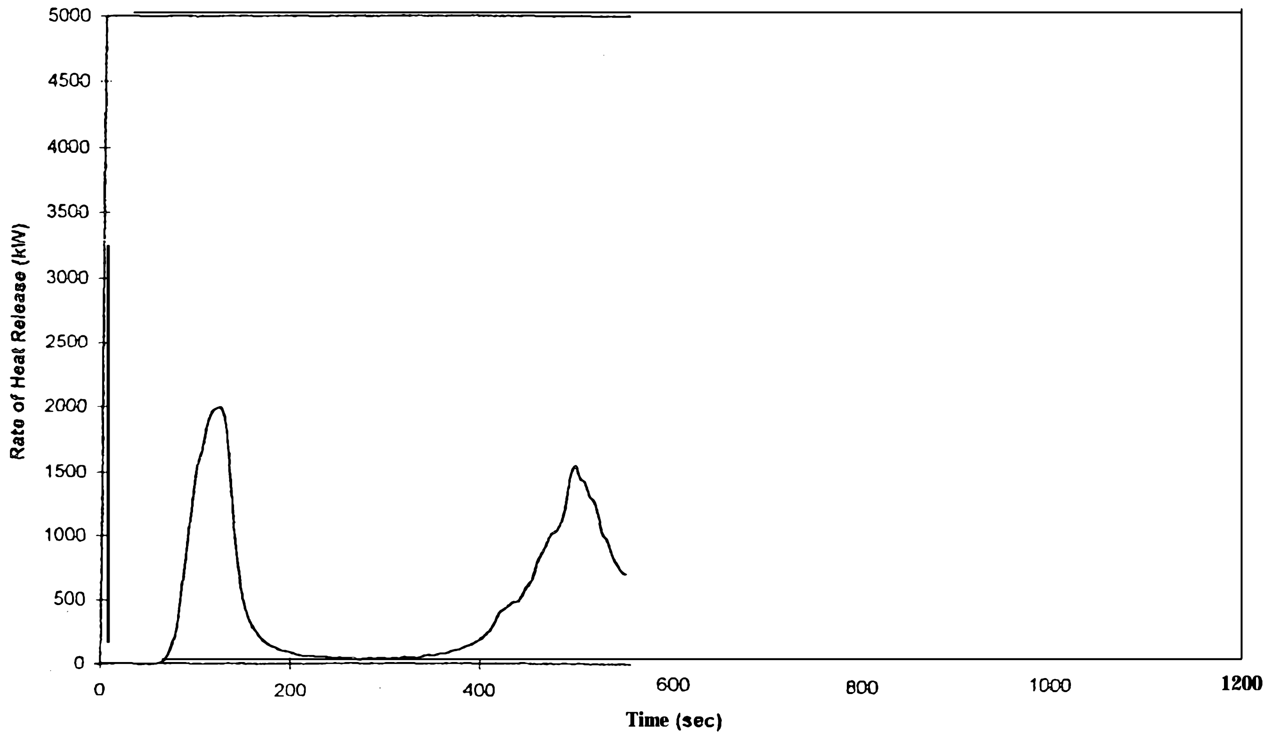


Figure 17. Gross rate of heat release For experiment C3. (FR plywood ceiling).

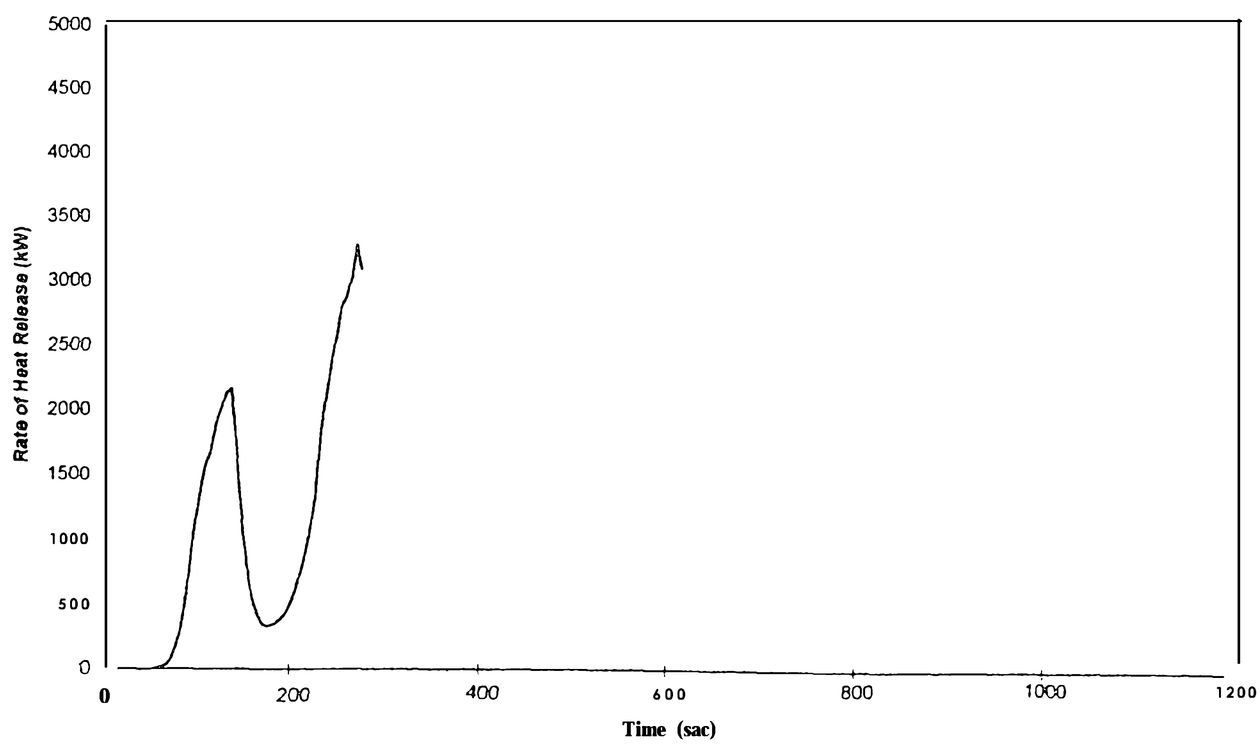


Figure 18. Gross rate of heat release For experiment C4. (Plywood walls).

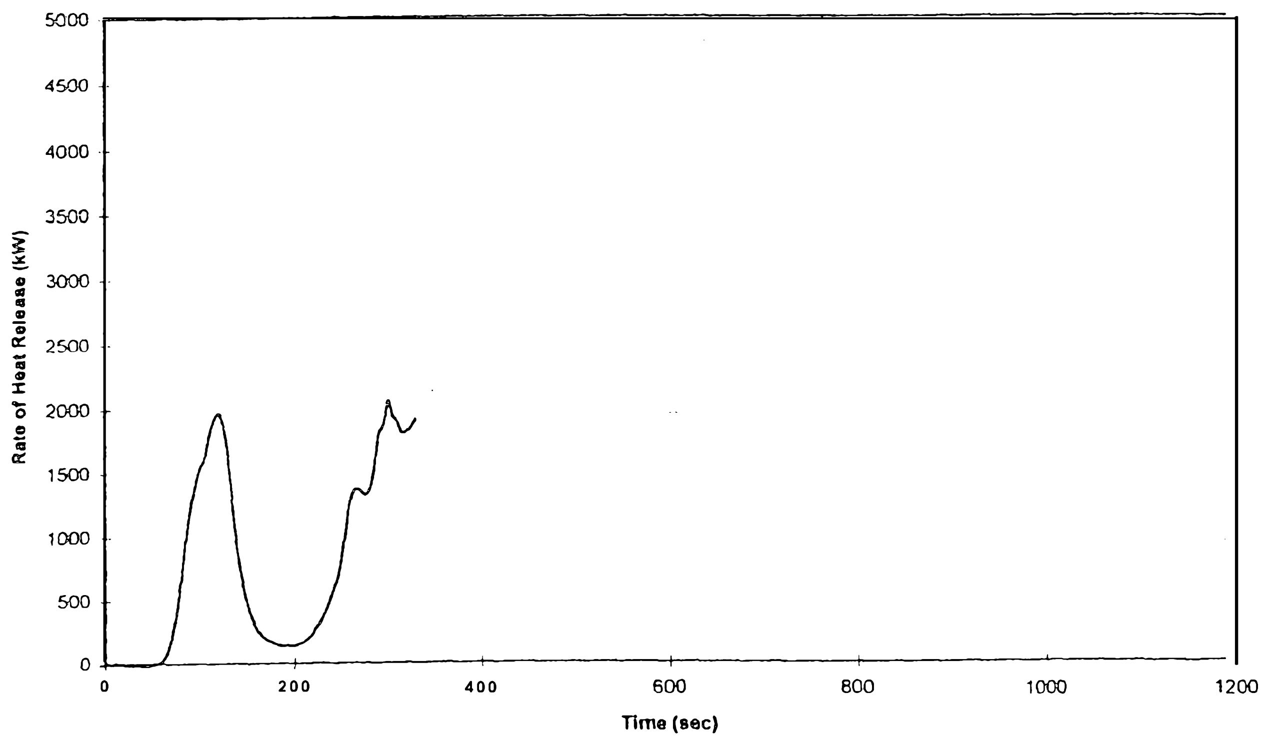


Figure 19. Gross rate of heat release For experiment C5.
(Plywood ceiling).

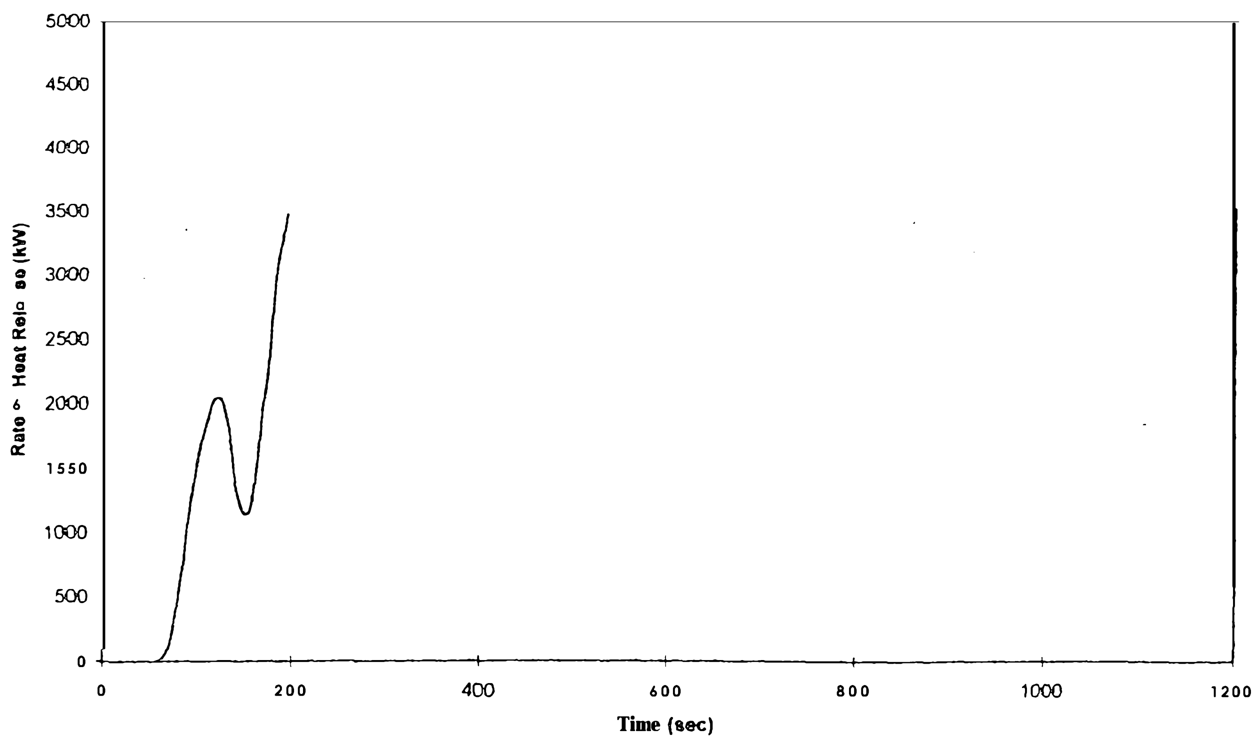


Figure 20. Gross rate of heat release For experiment C6.
(Plywood walls).

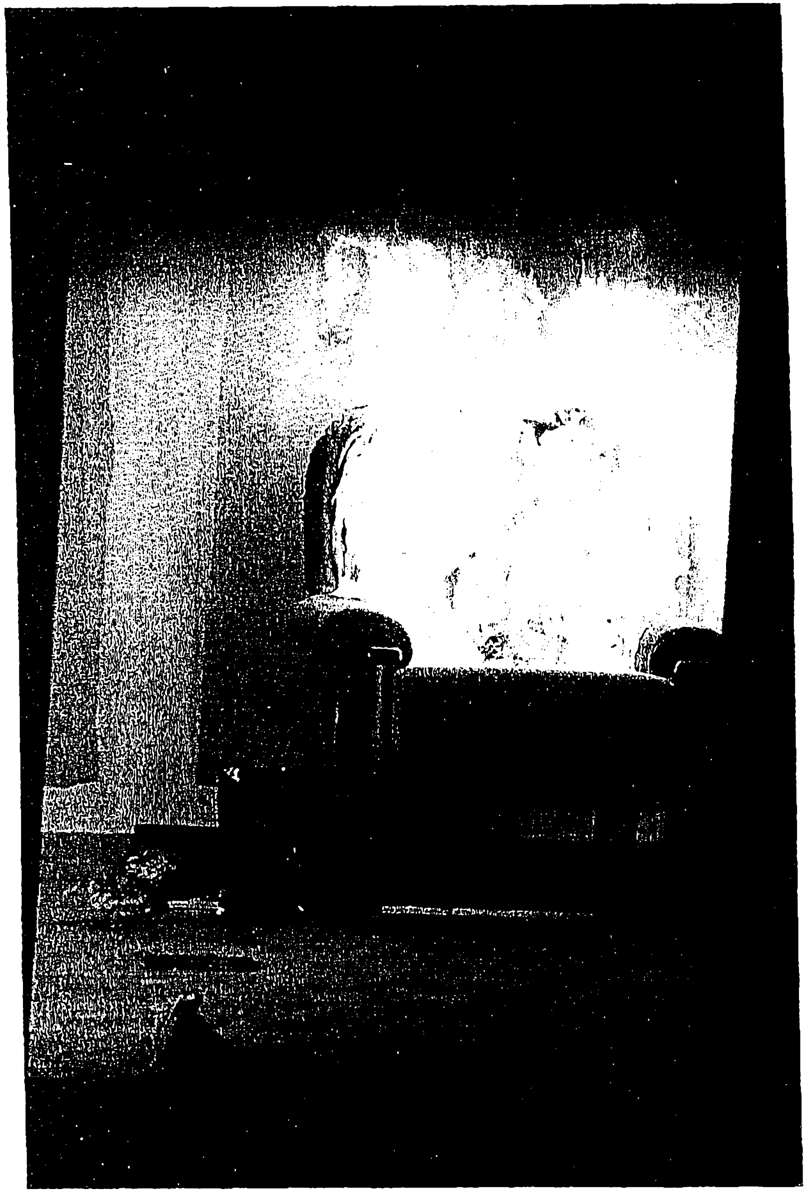
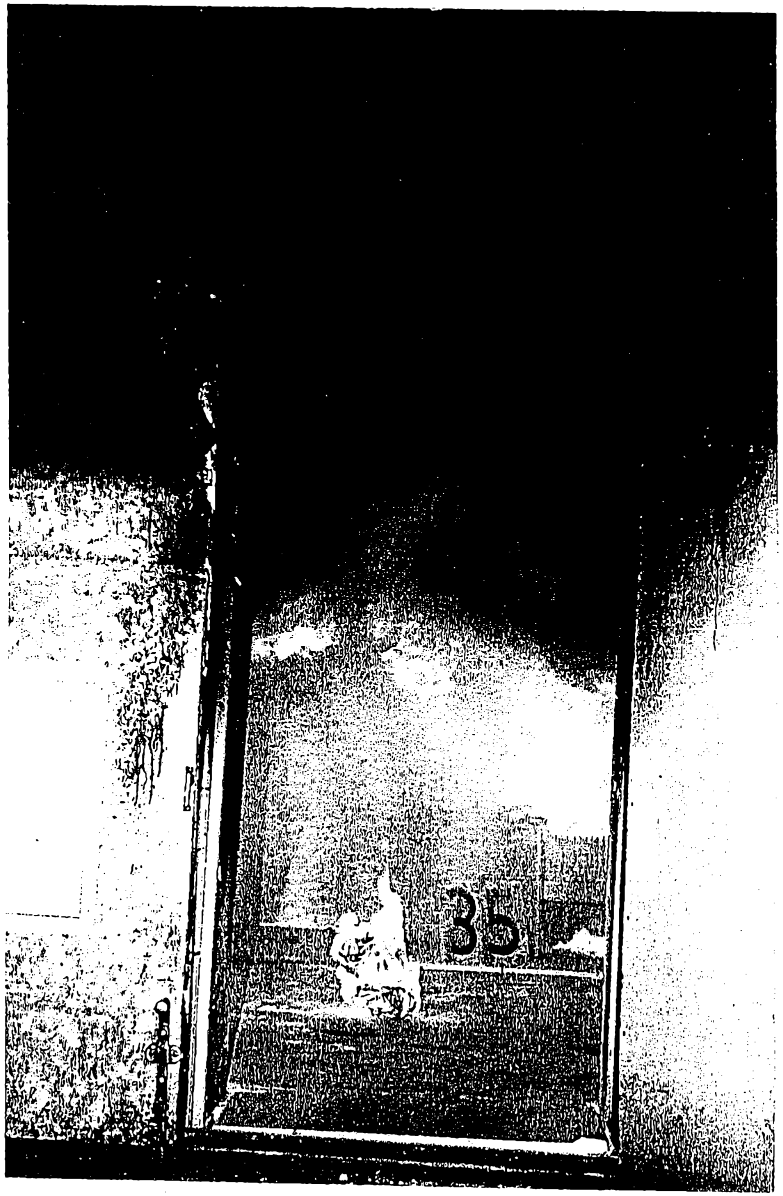


Figure 21. Armchair ignition source, some 200 seconds into an experiment.

Figure 22. ISO gas burner at 100 kW output, with fire retarded plywood ceiling



23. Experiment R7 in progress; with
newspaper targets burning on the floor

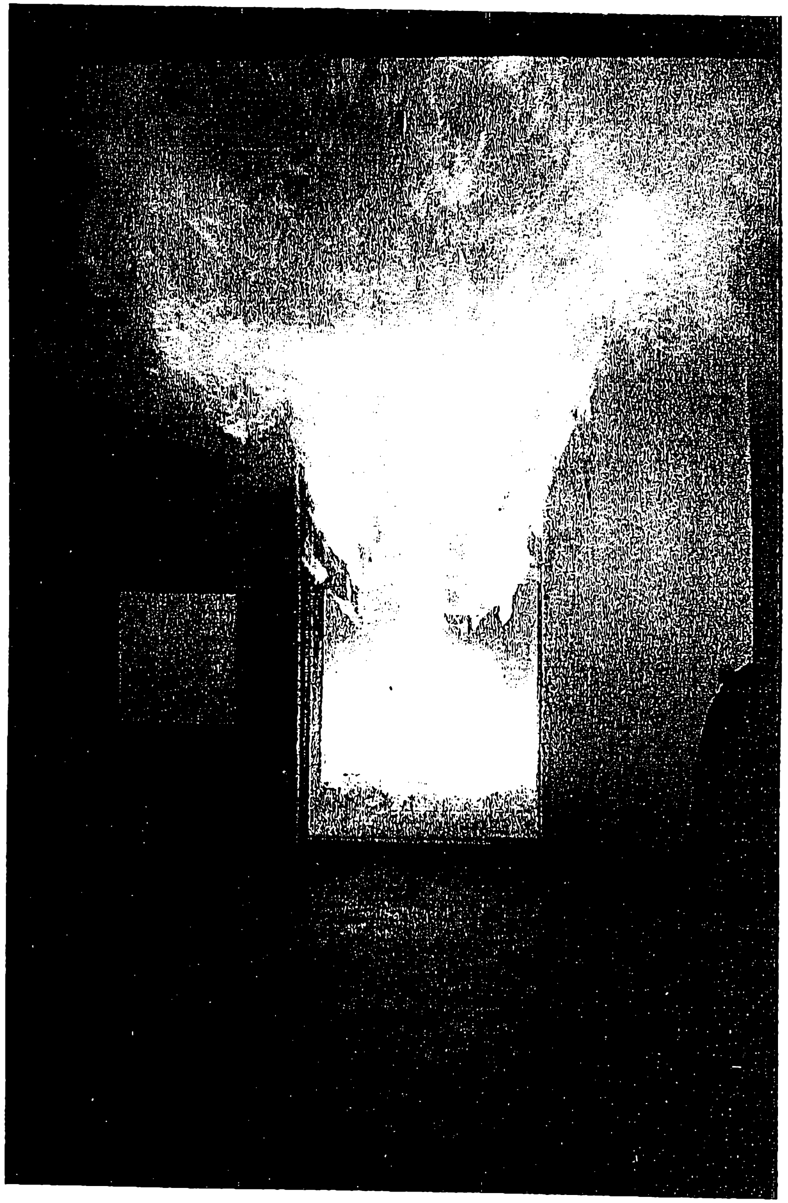


Figure 24. R7, 190 seconds after ignition.

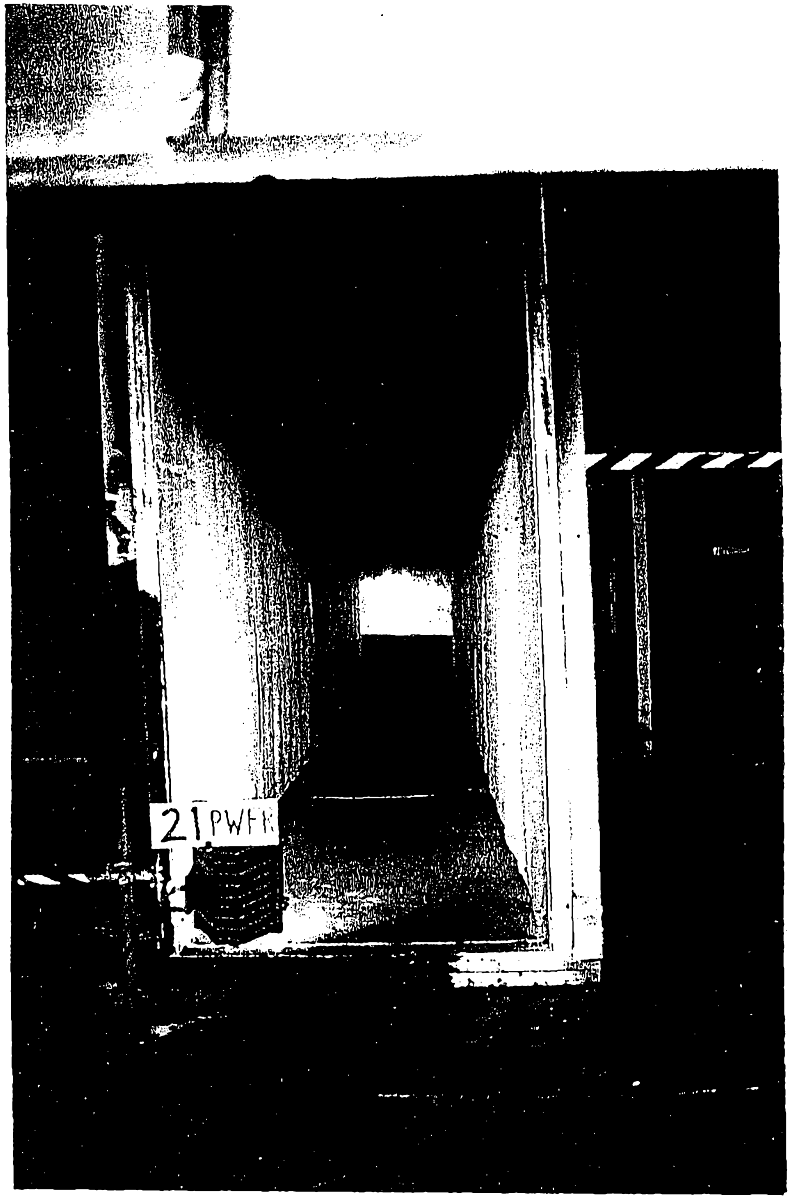


Figure 25. Sofa burn approaching flashover in the room attached to the fire test corridor.

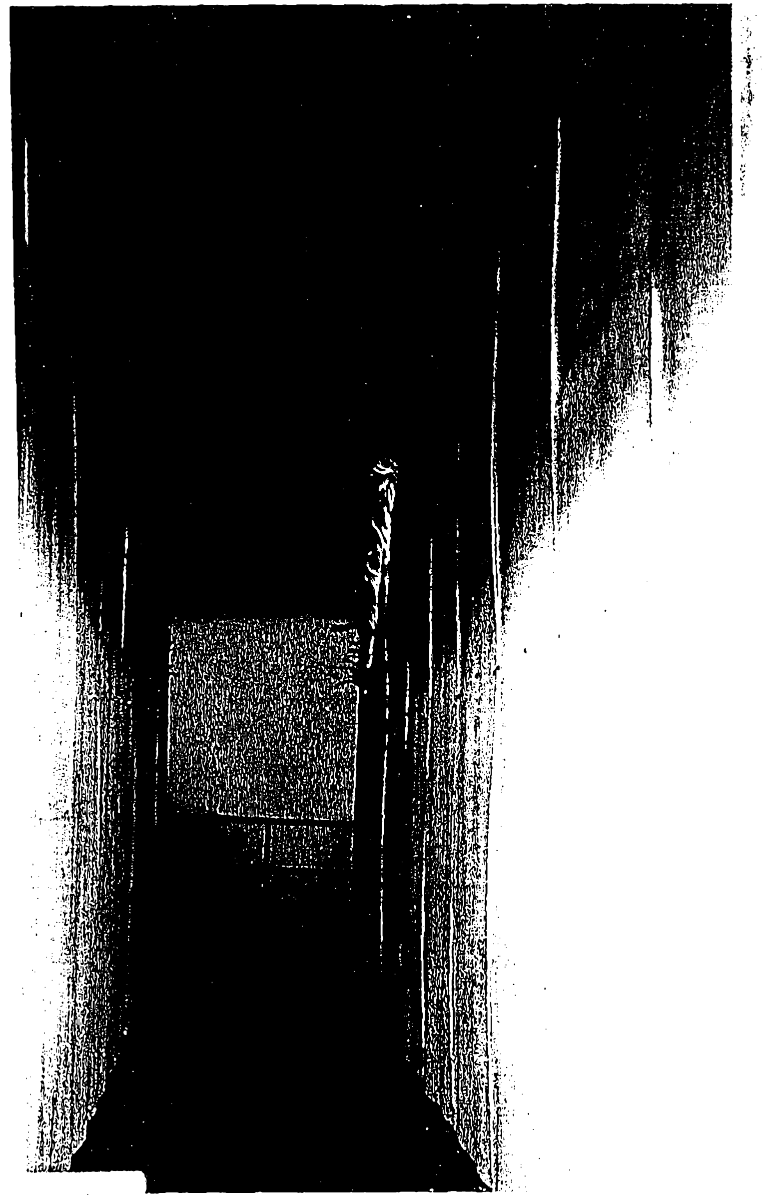


Figure 26. Fire retarded plywood wall burning slowly, 20 minutes into Experiment C2.


Figure 27. Plywood wall panels burning strongly (3500 kW) during Experiment C4.

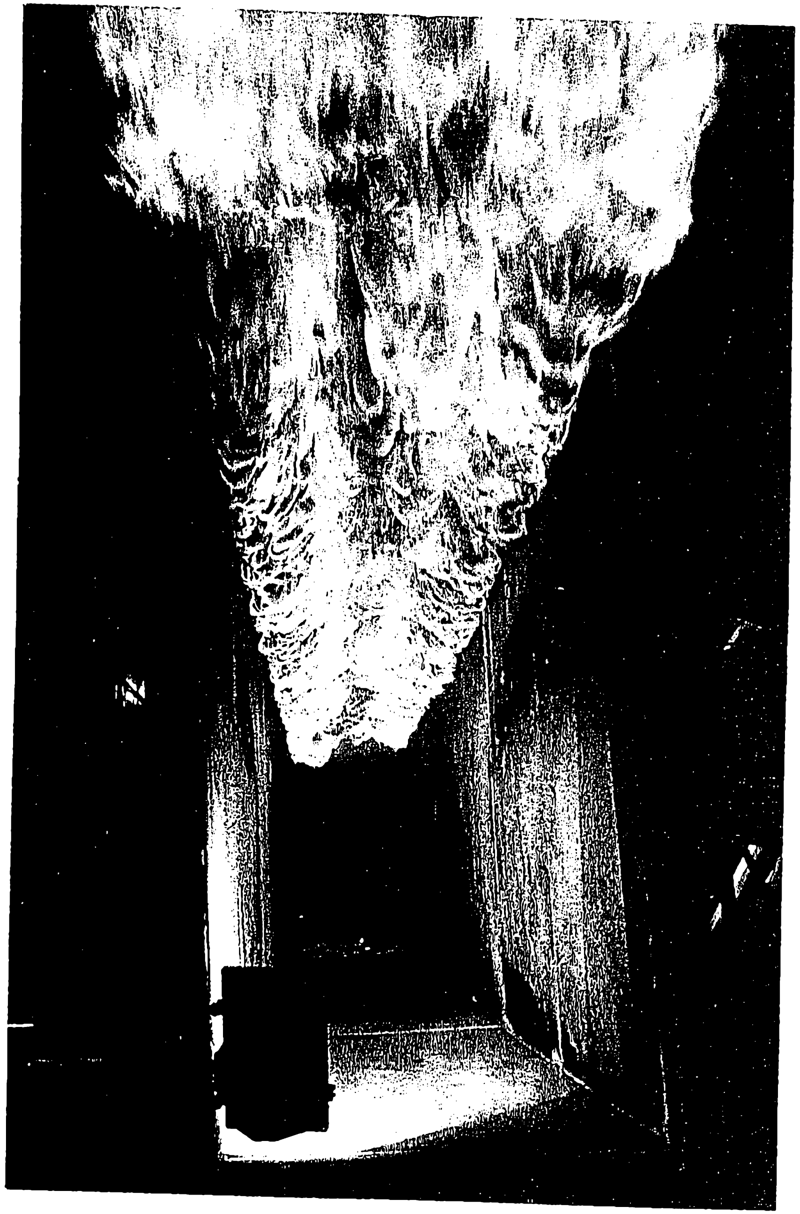


Figure 28. Plywood ceiling panels burning strongly (2000 kW) during experiment C5.