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FIRE BEHAVIOUR OF BEDS AND BEDDING MATERIALS

by

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SUMMARY

Fire tests with measurements of temperatures, radiation levels and smoke production have been carried out using domestic beds fitted with full bedding materials in a full-scale compartment-corridor.

The tests have included mattresses made of polyurethane of various types, hair, spring interior and foamed rubber with mattress covers of cotton, flame retarded cotton or proofed nylon. Some tests with hair or glass fibre cloth protective interlinings are also recorded.

The study has shown that a rapid development of fire in bed and bedding materials can take place with certain combinations of mattresses and their covers. The type of cover is extremely important in the overall fire development particularly with polyurethane mattresses.

A substantial improvement in the fire behaviour of many of the principal types of beds tested can be achieved by a careful selection of bedding materials, such as the type of mattress cover, and in certain cases by the use of protective interlinings.

Department of the Environment and Fire Offices' Committee
Joint Fire Research Organization

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1. INTRODUCTION

This report describes a series of fire tests which have been carried out at the Fire Research Station in collaboration with the Supplies Division of the Property Services Agency of the Department of Environment, to study the burning characteristics of beds made up with various common bedding materials.

All fire tests were carried out using domestic type single beds situated, in turn, in the room of a full-scale compartment-corridor which has been used widely at the Fire Research Station for general studies of the behaviour of combustible materials and components in fires[1].

Many different types of bedding materials including mattresses, mattress covers, sheets, blankets, bedspreads and pillows are currently available for both domestic and contract use within the United Kingdom. A preliminary survey showed that a very large block of fire experiments would be required to resolve statistically the effects of individual materials on overall burning behaviour even if possible interactions were limited. Therefore, in order to keep the total number of tests to a minimum and acceptable level, some standardisation of experimental approach and control of variables was necessary.

The main aim of this work was to establish the general burning characteristics of beds following the development of flames. This is the flaming region which may occur directly, or following a long period of smouldering as from a cigarette, where the rapid development of fire in the bedding materials may lead quickly to a hazardous situation for occupants both within the room of origin and possibly elsewhere in the building.

The initial experiments outlined in this report were therefore designed to evaluate the size and location of a flaming ignition source which would be severe but representative of a realistic situation and ensure that the bedding materials were subjected to flames with some degree of reproducibility. In this work it was found that the main area of risk involved the unmade part of the bed exposed by folding back the bedclothes. With this in mind it was then possible to 'standardise' the testing procedure for much of the work by using a single ignition source and location, typical top coverings (sheets, blanket, bedspread and pillow) with variations of the other important bedding items, particularly the mattress and mattress cover.

A total of 18 full-scale fire tests are reported in the main series of tests and include mattresses of polyurethane (of various types), hair, spring interior and foamed rubber with various covers of cotton, flame retarded cotton and proofed nylon.

Work is also described where a layer of hair or glass fibre cloth has been used as an interlining between the mattress material and cover to give added protection in fires.

In the fire tests measurements of the temperatures and radiation levels have been recorded within the compartment and the optical density of the smoke issuing from the compartment-corridor facility. The optical density of the smoke combined with the rate of input of air for ventilation and the temperature of the smoke have been used to calculate the contamination potential of the smoke at intermediate times during each test and also the total smoke released during the 30 minute period of each test.

Toxic gases have not been monitored in the work described in this report. It must be recognised that toxic gases, and in certain situations atmospheric vitiation, are serious additional factors which must be taken into account in overall hazard analysis.

2. THE COMPARTMENT-CORRIDOR FACILITY

2.1 General structure

The test compartment is shown diagrammatically in Fig 1 and consists of a room 3 x 3 m in area and 2.4 m high with a communicating corridor 12.6 m long, 1.3 m wide and 2.4 m high. The vent between the room and corridor is 700 mm wide and extends the full height of the room and corridor.

The compartment and corridor[1] are constructed from panels of reinforced aerated concrete (600 mm wide) supported by an external steel frame. The panels of the compartment are 150 mm thick, and those of the corridor are 100 mm thick. All the concrete panels of the compartment are protected from the effects of heat by a 20 mm layer of refractory cement.

The sole means of ventilation of the compartment is the vent between the compartment and corridor. Thus the ventilation air enters the compartment along the lower part of the corridor and the smoke and hot gases from the fires are discharged into the upper part of the corridor.

The test compartment-corridor is situated inside a large open plan laboratory of dimensions 40 x 15 m and 12 m high to give protection from wind and weather. The laboratory can be ventilated by opening a section of the roof to remove combustion products.

2.2. Temperature measurements

The air temperatures in the compartment were measured using radiation-shielded thermocouples (chromel-alumel) spaced at 0.5 m intervals from the ceiling down to 0.4 m from the floor and attached to the smoke board S1 shown on the plan of the test facility in Fig.2. The temperatures of the fire gases at the ventilation slit and at the end of the corridor were monitored by thermocouples fitted 150 mm below the ceiling. The outputs from all the thermocouples were monitored continuously with pen recorders throughout each test.

2.3. Air input measurements

The velocity of the incoming air was monitored at the open end of the corridor at a point 300 mm above the floor midway between the walls, using a vane anemometer coupled to a pen recorder. This air input velocity together with a measured ventilation area gave the rate of air input into the facility which enabled the rate of output of smoke to be assessed in each test.

2.4. Smoke measurements

The smoke issuing from the open end of the corridor was monitored optically using a quartz-halogen light source and a selenium sulphide photocell arranged as shown in Fig.3. The quartz-halogen lamp was chosen for its ability to give a steady output over a long period of fire and the selenium sulphide photocell was used because its spectral response approximates to that of the human eye. The output from the photocell was recorded continuously throughout each test with a pen recorder to give a permanent record of light attenuation.

The general level and layering of smoke in the compartment was also monitored visually and by photography through the observation port shown in Fig.2. For this observation, two smoke boards S_1 and S_2, each painted with black and white segments at intervals of 0.3 m were located in the compartment as shown. Board S_2 was fixed to the wall at the rear of the compartment (4.4 m from the observation port) and board S_1 was fixed near the centre of the room and 2.4 m from the observation port.

2.5. Radiation measurements

The level of thermal radiation from the burning bed was monitored by means of a standard water cooled thermopile radiometer situated in the compartment, 2 m from the centre of the bed and 0.5 m above the level of the top surface of the bedspread (see Fig 2). The position of the radiometer in the compartment was chosen to give the level of radiation which might be encountered on the side of an adjacent bed in a closely packed dormitory.

2.6. Additional observations

The small observation port(shown on the plan in Fig.2)provided visual access to the bed and enabled a photographic record of each test to be obtained. A closed-circuit television with video recorder was used to assist observation and to relay a view of the burning bed to other observers. Floodlights in the compartment provided the necessary background lighting for these observations.

3. BEDS AND BEDDING MATERIALS

3.1. General materials

The beds used in this work were of domestic type each consisting of a metal spring base (single bed size) with steel legs to support the mattress about 350 mm above the floor. The headboards were made of chipboard (15 mm thick) covered with a decorative surface laminate with a total weight of 5.0 kg.

Bed frames were replaced periodically through the test series. A new headboard was fitted for each test.

Various types of mattresses and mattress covers were used in the tests and are defined in Table 1 and 2 respectively. The polyurethane foam and foamed rubber mattresses were tested with different covers and combination of covers. Both the hair and spring interior mattresses had integral covers. It should be noted that some mattresses (polyurethane) were made available in different sizes for the tests.

Feather pillows with heavy duty cotton covers and an additional cotton pillow slip were used in all tests. Total weight of each pillow was 1.5 kg.

Two cotton sheets (total weight 1.5 kg) were used in each test in the normal bottom and top positions. Each bed was fitted with a single cotton cellular blanket (1.4 kg)* and finally covered with a cotton bedspread (1.2 kg).

3.2. Layout for fire tests

The beds were each positioned inside the compartment as shown in Fig.2 to give a gap of 0.3 m between the bed and the rear wall of the compartment and to ensure that as much of the bed as possible was visible through the observation port.

For each test the beds were fully made up in a typical arrangement with mattress, mattress cover(s), bottom sheet, top sheet, blanket and bedspread. The feather pillow, with covers was positioned in the usual place between bottom and top sheets.

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* with the exception of Test 6 which used a 70% wool/30% nylon blanket

Table 1. General details of mattress materials

Report Code	Mattress	Dimensions (m) Length	width	depth	Weight (kg)
PU(S1)	A standard commercially available polyurethane foam, cut from slab stock	1.91	.92	.10	6.6
PU(S2)	As for PU(S1)	1.91	.76	.13	7.0
PU(N1)	A new type of polyurethane foam commercially available during the last few years, cut from slab stock	1.91	.92	.10	6.1
PU(N2)	As for PU(N1)	1.91	.92	.15	9.1
PU(C)	A cold cured polyurethane foam moulded to size	1.91	.92	.10	14.5
PU(FR)	A new experimental polyurethane foam, cut from slab stock and subsequently treated with fire retardant	1.91	.92	.15	15.0
PU(FP)	A standard polyurethane foam slab, painted with a thick surface layer of semi rigid fire retardant paint	1.91	.92	.10	7.2
Hair	A traditionally constructed animal hair mattress supplied in a cotton cover	1.91	.92	.15	14.5
SI	A modern mattress with an interior structure of metal springs covered with a layer of animal hair felt and cotton padding supplied in a fire retardant cotton cover	1.91	.92	.15	20.4
FRU	A foamed rubber moulded mattress slab	1.80	.76	.10	10.9

Table 2. General details of mattress covers

Report terminology	Cover
Cotton cover	Lightweight calico (185 g/m^2)
FR Cotton cover	Lightweight calico treated with an organophosphorus fire retardant
FR bag	Heavy duty cotton bag treated with a fire retardant (212 g/m^2)
Proofed nylon	Woven nylon fabric made waterproof with a polyurethane varnish, with a moulded plastic zip along one side (110 g/m^2)
Hair interlining	A 5 mm thick layer of random animal hair situated between the mattress and cover
Glass fibre interlining	A single layer of woven glass fibre fabric situated between the mattress and cover (127 g/m^2)

Both sheets and the blanket were tucked on both sides and at the base of the bed and the bedspread allowed to hang over the sides and base of the bed.

During the preparation for each test, the top sheet, blanket and bedspread were folded back and the bed clothes loosened to simulate very broadly the condition where a person had just left the bed.

All materials were conditioned for 6 hours in the compartment using a 2.5 kW fan heater to control the temperature to 22^{o}C.

All materials used were, as supplied, in brand-new condition with the exception of the mattress used in Test 14, see Table 4. This mattress was submitted to an accelerated ageing process based on British Standard 1887 : Part 1 in order to establish how the fire retardant treatment would be affected by a long period of normal use. This process involved 60,00 passes with a roller (102 kg) and subsequent autoclaving of the mattress.

4. IGNITION PROCEDURES

Crumpled sheets of newsprint were used as the ignition source for all the experiments outlined in this report and were ignited by a 0.5 kW electric heating element powered from a remote electrical source.

Some experiments are described using one crumpled double sheet of newsprint (approximately 25 g) but the majority of experiments involved 4 double sheets (approximately 100 g) crumpled into a ball of about 250 mm diameter with the electric element located within the ball.

For fire tests of the beds with 'bottom' ignition the balls of newsprint were placed beneath the bed as shown in Fig 4(a). With 'top' ignition the crumpled balls of newsprint were placed on top of the exposed part of the bed and just under the folded back clothes (Fig 4(b)).

5. RESULTS OF PRELIMINARY IGNITION STUDIES

Four preliminary fire tests were carried out to determine the effect of the size and location of the ignition source on the general fire development of the bed and bedding materials.

This block of fire tests is defined in Table 3 and involved the standard bedding materials with polyurethane mattress and single cotton mattress cover.

Table 3. Details of preliminary fire tests[ø]

Test No	Mattress	Mattress cover	Ignition source	
			size*	location
1 (a)	PU(S1)	Cotton	small	bottom
1 (b)	PU(S1)	Cotton	large	bottom
1 (c)	PU(S1)	Cotton	small	top
1 (d)	PU(S1)	Cotton	large	top

*small and large ignition sources refer to 1 and 4 double sheets of newsprint respectively

øcotton sheets, cotton blanket and cotton bedspread and a feather pillow were used in all tests

The temperatures produced at the ceiling level within the room (measured at smoke board S1) for the four tests 1(a) (b), (c) and (d) are given in Fig 5 and 6. A photographic record of test 1(d) is given Fig 7.

With the small ignition source beneath the bed (Test 1 (a)) there was an induction period of about 11 minutes where small flames under the bed and at the sides of the bed gradually heated the bed materials until a critical point was reached when a very rapid development of fire occurred. The maximum temperature of 420°C was attained at 13 minutes.

With a large ignition source beneath the bed (Test 1(b)) the fire spread more rapidly to the upper surfaces and the maximum temperature of 240°C was reached at 11 minutes.

With top ignition (Tests 1(c) and (d)) the temperature profiles (Fig 6) are broadly similar and the maximum temperatures of about 230°C were attained at about the 7 to 8 minutes mark in each case.

The top ignition tends to give a more rapid initial involvement of the bedding materials in fire. Further this involvement appears to be less critical than bottom ignition and more independent of size of ignition source. The top ignition source with 4 double sheets of newsprint was therefore used in all subsequent tests described in this report.

An important observation during these tests was that the initial fire spread and development involved the 'unmade' part of the bed ie that part of the bed which was exposed by pulling back the covers.

6. RESULTS OF MAIN SERIES OF TESTS

6.1. The test series

As explained in the previous section the main series of tests, defined in Table 4, were carried out with a large top ignition source. Cotton sheets, blanket and bedspread and feather pillow were used in all tests with the exception of test 6 when a wool/nylon blanket was substituted for the cotton blanket.

The test series was designed to include a range of common mattress materials with various covers, combination of covers and certain interlinings.

The fire tests of the preliminary series 1(a),(b),(c) amd (d) and the tests of the main series 2,3,4,5 and 6 all involved standard polyurethane foam. The mattress made available for test 6 was slightly larger than the others of the series. In the same way, the mattress in test 8 was of different dimensions to those used in tests 7 and 9.

Each fire test was monitored up to a maximum period of about 30 minutes.

6.2. Temperature records

Temperatures within the compartment were measured with radiation shielded thermocouples (attached to smoke board S1). It is not possible to include all of these measurements for each test in this report, but the temperatures obtained during test 1(d) are given in Fig.8. These profiles show the temperature distribution inside the room throughout the test. The general pattern of each profile is broadly similar and the highest temperatures are attained at ceiling level as might be expected. In all of the subsequent work of this report, compartment temperatures will be recorded as ceiling temperatures (ie from thermocouple 1).

The compartment temperatures (ceiling levels) were monitored continuously during each test. The maximum temperature and the time to maximum temperature have been extracted from those profiles and are recorded in the summary of results in Table 5. Temperature profiles of tests 4 and 5(standard polyurethane with proofed nylon cover and proofed nylon-glass fibre interlining) are shown in Fig.9

The temperatures recorded at the top of the compartment-corridor vent (doorway) were very similar to those recorded at ceiling level in the compartment and have not been reported.

Table 4. Mattress and mattress covers used in the main series of tests

Test No.	Mattress		Mattress cover
1(d)	Polyurethane	PU(S1)	Cotton
2	"	PU(S1)	FR cotton
3	"	PU(S1)	FR cotton inside FR bag
4	"	PU(S1)	Proofed nylon
5	"	PU(S2)	Proofed nylon over glass fibre
6*	"	PU(S1)	FR cotton
7	"	PU(N1)	Cotton
8	"	PU(N2)	FR cotton
9	"	PU(N1)	FR cotton over hair
10	"	PU(C)	Cotton
11	"	PU(C)	FR cotton
12	"	PU(FR)	Cotton
13	"	PU(FR)	FR cotton
14	"	∅ PU(FR)	Cotton
15	"	PU(FP)	FR cotton
16	Hair		Cotton (integral)⁎
17	Spring interior	SI	FR cotton (integral)⁎
18	Foamed rubber	FRU	FR cotton

∅After ageing (see text)

*In this test a 70% wool-30% nylon blanket was used.

⁎An 'integral' cover denotes that the cover formed part of the mattress system.

(Unless otherwise stated all tests involved cotton sheets, blanket and bedspread with a feather pillow)

6.3. Air input records

Records of the air input velocities to the corridor were obtained throughout each test using the anemometer but it is not possible to reproduce all of these measurements in this report. The rate of air input to the test facility is determined by the buoyancy of the combustion gases (related to temperature), and the air velocity profiles tended to approximate to the overall shape of the temperature profile with the maximum air input velocity occurring at approximately the same time as the compartment temperature. The maximum air input velocities for each test are given in the summary of results section in Table 5.

6.4. Smoke production

The optical density was measured as the smoke emerged from the end of the compartment. This was converted to optical density per metre path length (OD_m) which is defined as the logarithm to base 10 of the ratio of incident to attenuated light flux for a path length of 1 metre.

Assuming that the optical density is directly proportional to the number of smoke particles in a unit volume, then it is therefore possible to estimate[1] the amount of smoke P evolved during a period of burning (time t_1 to t_2) from the equation

$$P = \int_{t_1}^{t_2} S\,(OD_m)\ A\,dt$$

where S = exit speed of smoke in m/min

A = cross sectional area of the smoke plume in m^3

The exit speed of the smoke is calculated from the rate of air entry into the corridor and the temperature* of the fire gases at the end of the corridor. This calculation assumes that the mass flow rates of both entering air and emerging fire gases are the same.

The amounts of smoke, calculated in this way, released per minute (but calculated over 2 minute periods were obtained for both the preliminary ignition tests and the main series of tests. Examples of the smoke produced during tests 4,5 and 18 are shown in Fig 10 and 11.

The units of smoke (as $m^3\ OD_m 1$) are recorded as cubic metres of smoke related to an optical density (OD_m) of unity. It is important to note that this integrated smoke figure is a combination of smoke flow rate and optical density and has relevance in smoke contamination calculations and estimation of the total smoke released from the beds.

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*The temperatures of the fire gases at the end of the corridor were monitored continuously throughout each test but are not recorded in this report.

TABLE 5. SUMMARY OF RESULTS

Test No	Mattress	Cover	Temperature		Smoke				Maximum air input velocity (m/s)	Radiation	
			Max (°C)	Time to max (min - sec)	Maximum (ODm)	Time to max* (min - sec)	Total m^3(ODm1)	Maximum rate m^3(ODm1)min		Maximum (watts/cm^2)	Time to max (min - sec)
1(a)	PU(S1)	Cotton	420	13 00	0.17	7 00	105	12.7	0.78	NR	NR
1(b)	PU(S1)	Cotton	240	11 00	0.43	10 000	205	40.7	0.61	0.53	12 30
1(c)	PU(S1)	Cotton	225	8 00	0.38	26 00	288	33.0	0.75	NR	NR
1(d)	PU(S1)	Cotton	230	7 00	0.12	16 00	111	11.8	0.57	0.40	14 00
2	PU(S1)	FR Cotton	255	16 00	0.21	16 00	212	34.0	0.67	0.36	16 30
3	PU(S1)	FR Cotton + FR Bag	240	17 00	0.15	13 30	142	21.2	0.67	0.40	17 00
4	PU(S1)	Proofed nylon	550	7 00	0.26	8 00	177	76.0	0.88	5.30	7 00
5	PU(S2)	Proofed nylon + glass fibre	285	26 30	0.14	25 30	76	19.0	0.68	0.70	13 30
6	PU(S1)	FR Cotton※	195	13 00	0.24	12 30	144	28.4	0.60	0.83	8 00
7	PU(N1)	Cotton	315	7 00	0.24	8 00	91	27.0	0.66	0.83	13 00
8	PU(N2)	FR Cotton	245	15 00	0.37	14 00	221	58.7	0.58	0.55	15 00
9	PU(N1)	FR Cotton + hair	80	21 00	0.32	19 30	113	20.0	0.44	NR	NR
10	PU(C)	Cotton	330	10 00	0.29	8 30	248	39.8	0.69	1.23	30 00
11	PU(C)	FR Cotton	200	23 00	0.17	20 00	141	25.0	0.58	NR	NR
12	PU(FR)	Cotton	280	27 30	1.52	26 00	598	171.5	0.63	0.59	27 30
13	PU(FR)	FR Cotton	65	13 00	0.16	16 00	44	7.4	0.45	0.07	13 00
14	PU(FR)ø	Cotton	325	13 00	0.85	14 00	756	197	0.98	0.80	13 00
15	PU(FP)	FR Cotton	57	22 00	0.25	25 00	87	14.8	0.34	0.06	22 00
16	Hair	Cotton	65	12 00	0.11	18 00	41	5.5	0.30	0.03	12 00
17	SI	FR Cotton	130	32 00	0.37	25 00	89	20.4	0.39	0.13	32 00
18	FRU	FR Cotton	220	15 00	1.70	11 00	2198	282	0.85	0.57	15 00

*Time to maximum OD/m

øAfter ageing

※With wool-nylon blanket

The direct optical density (OD_m) recorded throughout each test is recorded in this report but the maximum observed values and time to maximum are given in the summary of results in Table 5.

6.5. Radiation measurements

The maximum radiation levels obtained using the radiometer and the time to maximum for each test are given in Table 5.

6.6. Additional observations

A photographic record of tests 4, 5 and 18 are shown in Fig 12, 13 and 14 respectively.

The photographs were not taken at fixed time intervals but were selected to show important features of the burning behaviour. The extent of destruction of the beds at the end of 30 minutes is given in the Appendix.

7. SUMMARY OF RESULTS

Relevant data have been collected from the overall fire measurements and summarised in Table 5, showing maximum temperatures, time to maximum temperatures, maximum optical density (OD_m) of the smoke and the maximum rate of output of smoke. Also shown are the total amount of smoke released from each bed over the 30 minutes of each test. The maximum air input velocity is recorded in each case and the maximum radiation level together with the time to maximum radiation.

8. DISCUSSION

Many factors are important in the overall assessment of the fire hazard of beds and bedding materials in real situations. For the work of this report, hazard analysis has involved studies of temperature development within the room of origin, radiation and smoke production. Toxic gases and oxygen vitiation are also important but have not been monitored directly in this present study.

8.1. Compartment temperatures

The compartment temperatures (coupled with visual observations) attained during the fire tests provide a useful means of assessing the rate of development of fire. In this respect the preliminary ignition studies with polyurethane foam and cotton covers show that a large top ignition source tends to give a more rapid involvement of the bed in the fire. An interesting point to note is that a small bottom source of ignition may preheat the bedding materials such that a more serious but delayed fire situation may arise.

Standard polyurethane foam (PU(SI)) with cotton cover (test 1(d)) has been used as the 'control' test for purposes of comparison. In relation to this, a FR Cotton cover (test 2) delayed the maximum involvement of the mattress by about 9 minutes. A double FR cover, consisting of a FR cotton cover inside a FR cotton bag did not appear to give much more added protection (test 3) than the single cover.

The proofed nylon cover gave a rapid involvement of the mattress in fire (test 4) and the maximum temperature of 550°C (the highest recorded in any test) was attained in 7 minutes. A glass fibre interlining between the proofed nylon cover and polyurethane foam (test 5) gave a substantial delay to the maximum involvement in fire which occurred, via a smouldering process at 26.5 minutes with a maximum temperature of 285°C.

The wool blanket used in test 6 in place of cotton with polyurethane PU(S1) and FR Cotton did not significantly alter the fire behaviour in comparison with test 2. This observation is consistent with the finding that the unmade part of the bed is the main risk area.

Modified forms of polyurethane foam behave differently in the fire tests. Tests 7 and 8 (PU(N1) and PU(N2)) showed that this type of foam was involved in fire in a similar manner to the control material (test 2) with added protection being provided by a FR cotton cover

A hair interlining between the polyurethane foam PU(N1) and the FR cotton cover in test 9 gave considerable added protection but the development of smouldering under these situations may need consideration.

The cold cured mattress PU(C) used in tests 10 and 11 showed improved properties over the standard control material of test 2 and the FR cover delayed the maximum involvement of the bed until 23 minutes.

The experimental polyurethane foam treated with flame retardant and tested with a cotton cover (test 12) did not become substantially involved in flames until 27.5minutes after ignition. A FR cover gave further protection and the maximum temperature (test 13) did not exceed 65°C. After an accelerated aging process and when tested with a standard cotton cover (test 14) the mattress was seriously involved in fire at 13 minutes.

A fire retardant painted polyurethane foam mattress covered with a FR cover (tes (test 15) was not readily involved in fire and the maximum temperature of the compartment did not exceed 57°C throughout the test. No accelerated ageing tests were carried out on this mattress.

The hair mattress (test 16) was not rapidly involved in fire even with a standard cotton cover and the maximum temperature did not exceed 65°C. The spring interior mattress with integral FR cover (test 17) gave a long induction period of smouldering but flames slowly increased in intensity to give a maximum temperature of about 130°C at 32minutes.

The foamed rubber mattress with FR cotton cover (test 18) became steadily involved in fire from ignition and produced a maximum temperature of 220°C at 15 minutes. The high smoke densities throughout this test made visual observations rather difficult.

8.2. Radiation

The level of thermal radiation from a burning bed is important because of possible fire spread to adjacent beds and furniture. The maximum radiation levels are given in the summary of results in Table 5 and were recorded at a point 2 metres from the centre of the bed to correspond broadly to the position of an adjacent bed in a dormitory.

Spontaneous ignition by thermal radiation is dependent upon a number of factors and particularly the nature of the material and the time of exposure. Other factors such as the angle of view and the relationship between radiation level and distance (since the radiation does not originate from a point source) may need consideration. For guidance purposes, a radiation level of 3.5 watts/cm^2 will ignite cotton bedding fabric in about 30 seconds, whereas 5.0 watts/cm^2 is required for wood fibre insulation board[2].

The maximum radiation levels in the tests (Table 5) are relatively low and less than 1.0 watt/cm^2 with the exception of two tests. In test 10 the cold cured mattress produced 1.23 watts/cm^2 at 30 minutes and the proofed nylon cover gave 5.3 watts/cm^2 at 7 minutes in test 4.

Within the broad limitations given above with respect to the interpretation of radiation intensity data it appears that spread by radiation to an adjacent bed (or item of furniture) may well take place with the proofed nylon cover. Radiation levels on items of furniture(such as bedside tables)placed near to the bed may be sufficiently high in other tests to promote ignition.

8.3. Smoke

Smoke is a well established hazard associated with the fire atmosphere and can obscure vision so that persons are trapped in dangerous environments.

Three factors are important in considering smoke release, firstly there is the optical density (OD_m), secondly the rate of production of smoke and thirdly the total volume of smoke produced. Because of the ventilation conditions of the compartment–corridor facility, the smoke may appear to be dense but if the temperatures are low then the total output of smoke may also be low because of the low throughput of gases in and out of the compartment.

The maximum optical densities of the smoke and an integrated figure for total smoke released over the 30 minutes of each test have been given in the summary of results in Table 5.

The total smoke (30 minutes) gives a useful figure for overall smoke comparisons of materials but does not indicate anything about smoke production as a function of time.

Rasbash[3] has shown that the optical density of smoke (OD_m) can be related to visibility as shown in approximate terms in Table 6.

Table 6. Relationship between OD_m and visibility by Rasbash, and volume of smoke necessary to contaminate a dormitory of 600 m^3

Visibility (m)	OD_m	Volume of smoke to contaminate 600 m^3 ($m^3 OD_m 1$)
10	0.075	45
5	0.18	108
2	0.63	378
1	1.5	900

From the rate of smoke generation curves (as in Fig 10 and 11) the time to a limiting visibility can be calculated for each fire test. This calculation makes a number of assumptions but can give valuable guide lines for assessing smoke hazard.

If it is assumed that a dormitory has a volume of 600 m^3 then a volume of 45 m^3 of smoke OD_m unity would be required to give a limiting visibility of 10 metres within the room. The volumes of $OD_m 1$ smoke required for different limiting visibilities are shown in Table 6.

The time taken during each test to attain a certain visibility can be assessed by a summation* of the data given in the smoke output curves (see Fig 10 and 11).

The times obtained in this way for each test to give visibilities of 10, 5 and 2 m are shown in Table 7. Test 18 was the only test where sufficient smoke was available to reduce the visibility to 1 m (at 13.1 minutes).

These calculated figures must be regarded as guide lines only. The calculations assume that only one bed is burnt and that the smoke is uniformly distributed throughout the room.

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*ie by summing the rate of release of smoke at each minute to find the time required to release a certain total volume smoke of optical density per metre of unity.

Table 7. Calculated times (min) for smoke production to produce 10, 5 and 2 metre visibility in a dormitory of 600 m^3 for each test

Test	Mattress	Mattress cover	Time (min) for contamination to		
			10 m	5 m	2 m
1a	PU(S1)	Cotton	16.3	NR	NR
1b	PU(S1)	Cotton	9.4	14.5	NR
1c	PU(S1)	Cotton	8.2	13.1	NR
1d	PU(S1)	Cotton	14.7	29.1	NR
2	PU(S1)	FR Cotton	14.0	19.0	NR
3	PU(S1)	FR Cotton inside FR bag	15.5	23.1	NR
4	PU(S1)	Proofed Nylon	5.1	7.1	NR
5	PU(S2)	Proofed Nylon over glass fibre	25.9	NR	NR
6*	PU(S1)	FR cotton	13.4	24.9	NR
7	PU(N1)	Cotton	7.6	NR	NR
8	PU(N2)	FR cotton	13.4	15.7	NR
9	PU(N1)	FR cotton over hair	20.4	29.5	NR
10	PU(C)	Cotton	9.0	15.8	NR
11	PU(C)	FR cotton	18.3	24.5	NR
12	PU(FR)	Cotton	19.2	21.7	25.8
13	PU(FR)	FR cotton	26.0	NR	NR
14ø	PU(FR)	Cotton	8.1	10.5	14.0
15	PU(FP)	FR cotton	22.6	NR	NR
16	Hair	Cotton (integral)	NR	NR	NR
17	Spring interior	FR cotton (integral)	22.4	NR	NR
18	FRU	FR cotton	4.5	5.5	8.9

NR not reached within 30 minutes of test.
* 70% wool/30% nylon blanket used
ø after ageing, see text

9. CONCLUSIONS

The following conclusions relate to the beds and bedding materials as defined and as tested in this report. Where other combinations of materials exist, for example in beds with polyurethane pillows other burning behaviour may be experienced.

A) General conclusions (ignition)

1. The main area of risk appears to be associated with the unmade part of the bed exposed by folding back the bedclothes. In this area, burning is very dependent on the type of mattress and particularly the mattress cover.
2. Top ignition sources, in comparison with underbed ignition, tend to produce a more rapid involvement of the bed and bedding materials in fire. Bottom ignition sources may preheat the bedding materials to give a serious but delayed fire.

B) Conclusions (main series of tests with top ignition)

1. A standard polyurethane foam mattress with cotton cover produced a maximum severity of burning (230°C) at 7 minutes. A FR cotton cover delayed the maximum severity to about 16 minutes. A double FR cover gave little added protection.
2. A standard polyurethane mattress with proofed nylon cover produced the highest temperature recorded in any of the tests(550°C at 7 minutes) fibre cloth interlining between the polyurethane foam and the proofed nylon cover gave substantial protection and delayed the development of a serious fire situation until 26.5 minutes after ignition.
3. The modified form of polyurethane foam gave little added protection when compared with standard material. However, a hair interlining with a FR cover did not produce a serious fire situation and the maximum temperature in the compartment did not exceed 80°C throughout the test.
4. A cold cured polyurethane foam showed improved fire properties over the standard grade. With the cotton cover the maximum involvement occurred at 10 minutes and with the FR cover at 23 minutes after ignition.
5. A new flame retarded polyurethane foam gave a substantial delay to fire involvement. The maximum temperature of 280°C was attained at 27.5 minutes with the cotton cover and a maximum of 65°C was attained with FR cotton at 13 minutes. After being submitted to an accelerated aging process, a marked deterioration in fire performance was observed.

6. A polyurethane foam coated with a flame retardant paint gave a substantial improvement in fire performance but no accelerated ageing or wear tests were carried out.

7. The maximum temperature achieved with the hair mattress did not exceed 65°C throughout the test. The spring interior mattress reached a maximum temperature of only 130°C after 32 minutes.

8. The foamed rubber mattress with FR cover gave a maximum involvement offire at 15 minutes (220°C). The smoke production hindered visual observation during this test.

9. The polyurethane mattress with proofed nylon cover gave a high radiation level of 5.3 watts/cm^2, which may be sufficient to ignite a nearby bed.

10. The foamed rubber mattress with FR cover gave a high level of smoke and sufficient to smoke-log a dormitory of 600 m^3 to a visibility of 2 m in a calculated time of 8.9 minutes, and to a visibility of 1 m in a calculated time of 13.1 minutes. No other combination of materials gave sufficient smoke to reduce a visibility to 1 m.

11. During the early stages of fire, polyurethane foam with a proofed nylon cover produced a high rate of smoke release to give visibilities of 10 and 5 m in the dormitory in calculated times of 5.1 and 7.1 minutes respectively.

10. ACKNOWLEDGEMENTS

The authors wish to thank Mr E Wheelock and Mr A Smith of the Supplies Division of the Property Services Agency of the Department of the Environment for many helpful discussions throughout this work and for making available the beds and bedding materials for tests..

11. REFERENCES

1. STARK, G.W.V. and FIELD, P. 'Smoke and Toxic Gases from Burning Building Materials - 1. A test rig for large scale fires', Fire Research Note No.1015, 1974.

2. Internal communication of unpublished data, Fire Research Station.

3. RASBASH, D.J. 'Smoke and Toxic Products Produced at Fires' Trans. J. Plastic Inst. Jan. 1967, p 55.

APPENDIX - Destruction at 30 min.

Extent of destruction at 30 min.

Test No.	
1(a)	top end burnt out, small flames at bottom end.
1(b)	" "
1(c)	whole bed burnt out
1(d)	"
2	top end burnt out, small flames at bottom end
3	" "
4	whole bed burnt out at 12 min.
5	whole bed burnt out
6	top end of bed burnt out, bottom end still burning
7	whole of bed burnt out at 15 min
8	top end burnt out, small flames at bottom end
9	bed covers charred, mattress smouldering, flaming from one point.
10	top end burnt out, bottom end burning fiercely
11	most of top end burnt out, bottom end burning fiercely
12	most of top end burnt out, bottom end still burning
13	most of mattress intact, covers charred, some smouldering at top end.
14	most of top end burnt out, bottom end still burning
15	mattress intact but smouldering, covers charred.
16	mattress intact, no smouldering, covers charred
17	mattress burning in centre
18	most of bed burnt out

In all cases where the whole bed was burnt out there were pieces of carbonised covers and the feather pillow remaining on the spring metal base.

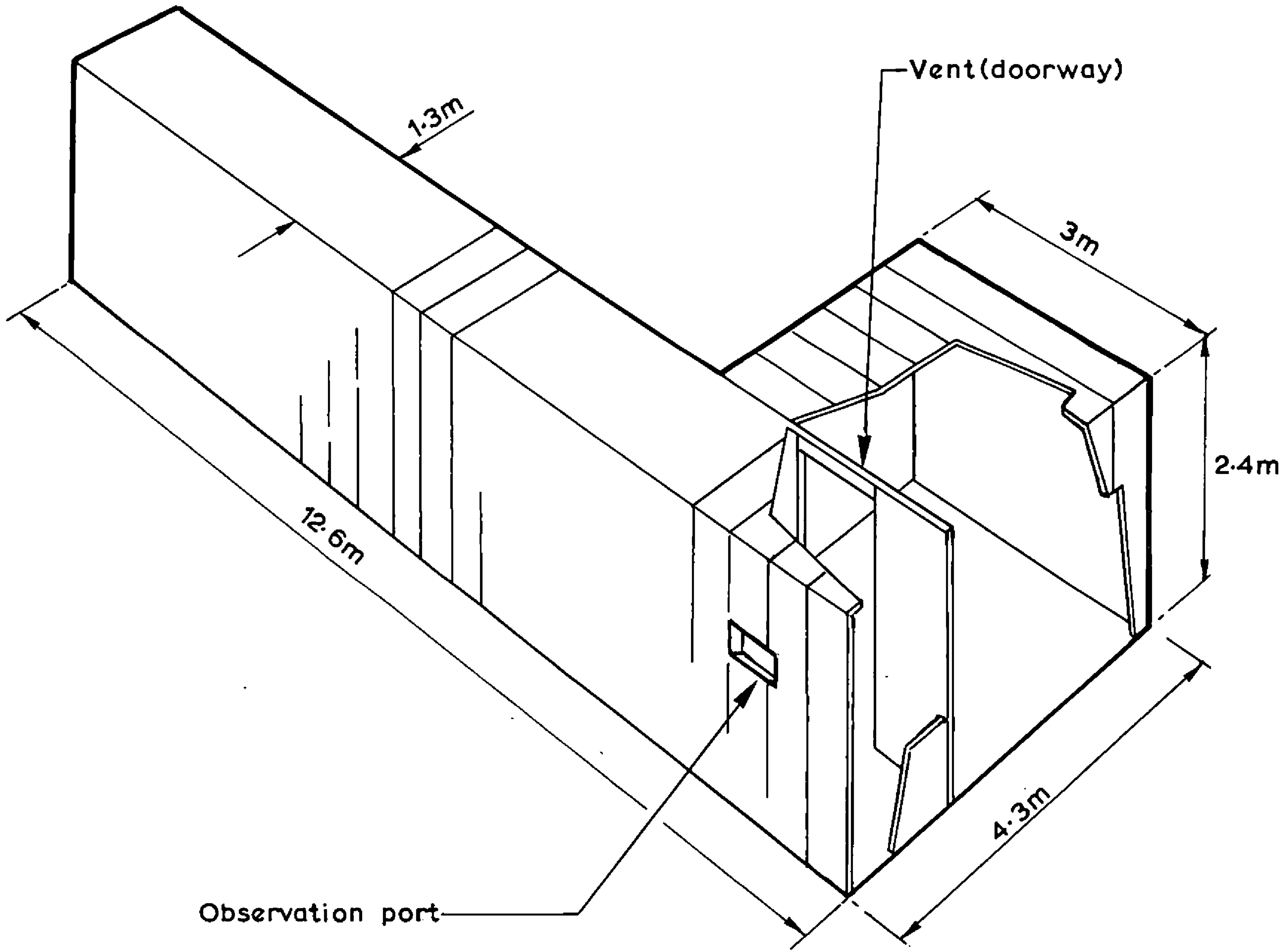


Figure 1 The Compartment corridor facility

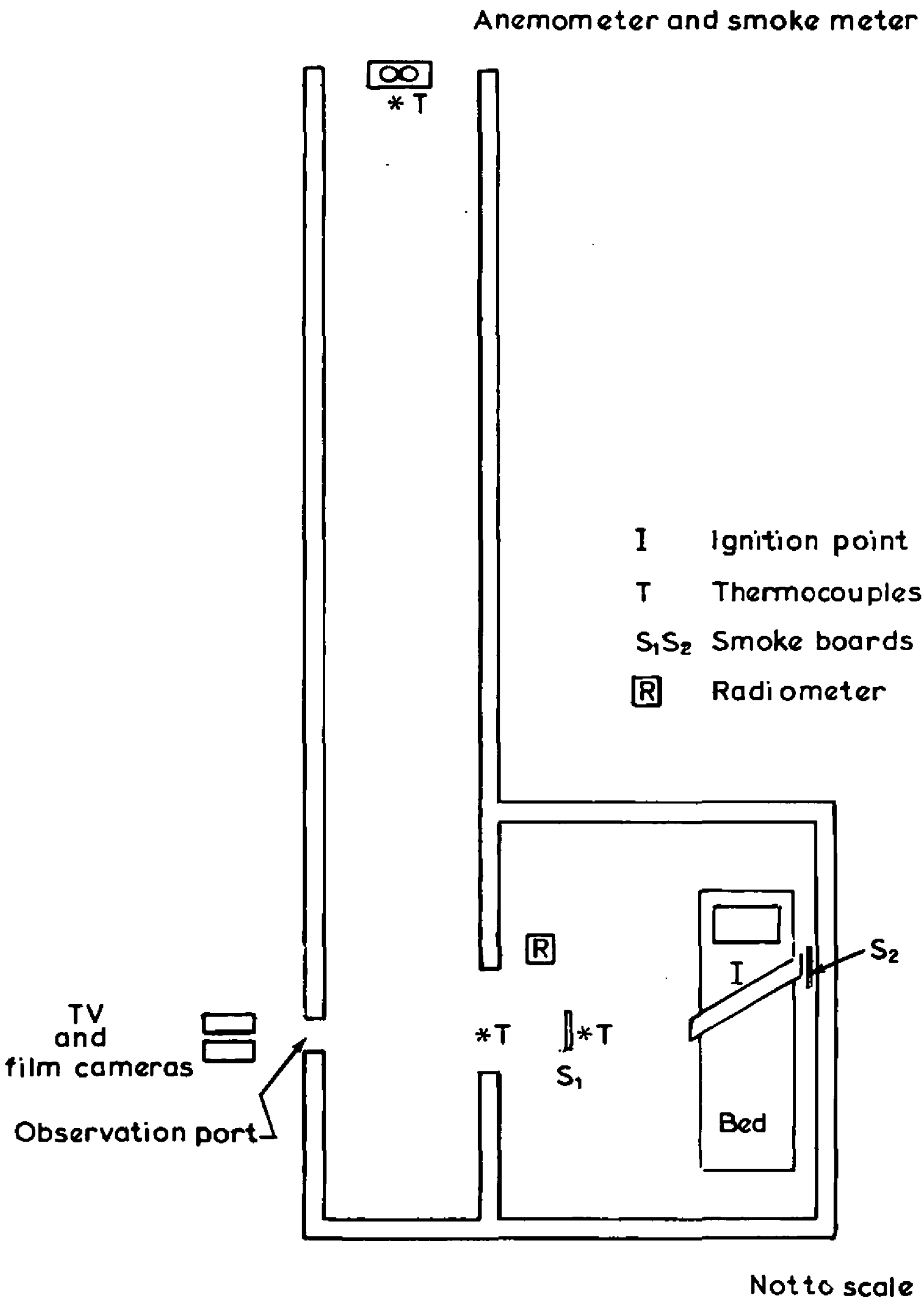


Figure 2 Plan of test compartment – corridor

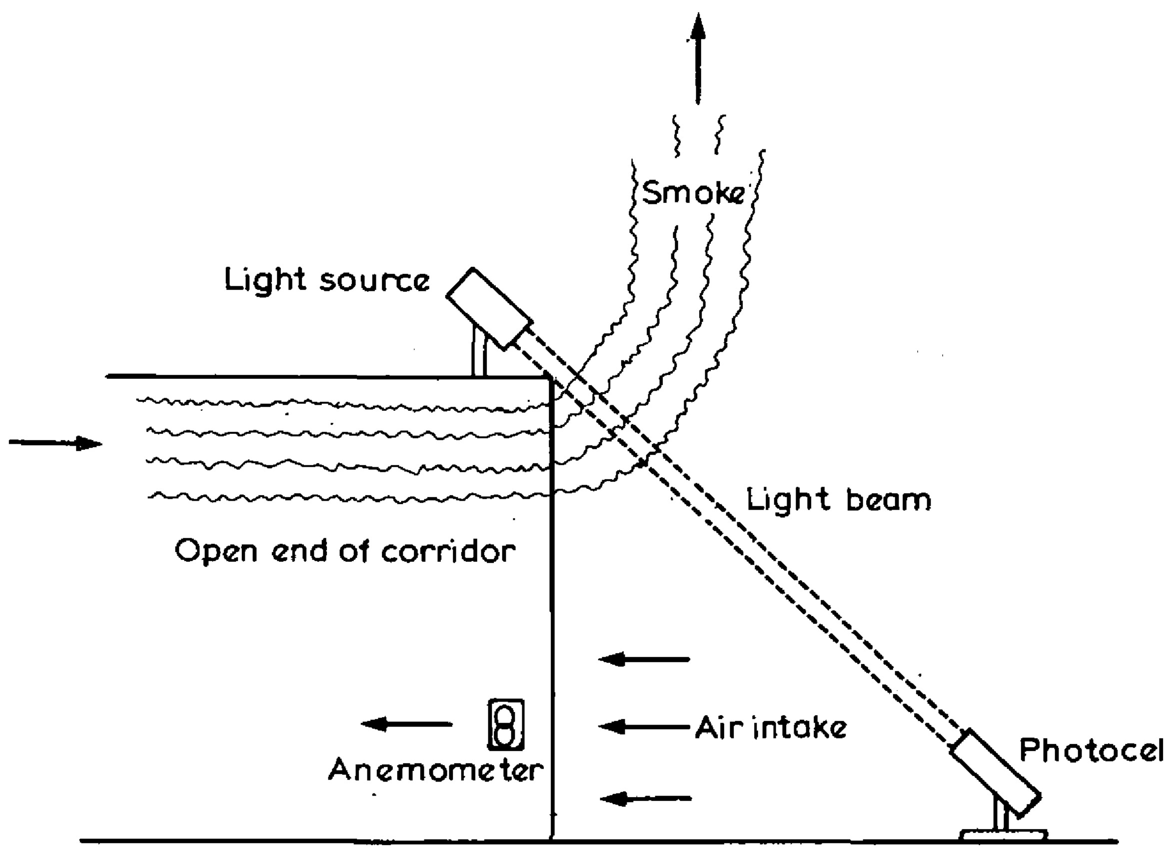


Figure 3 Method for measurement of optical density of smoke at open end of corridor

(a) Ignition source beneath bed

(b) Ignition source on top of bed

FIG 4. LOCATION OF IGNITION SOURCE

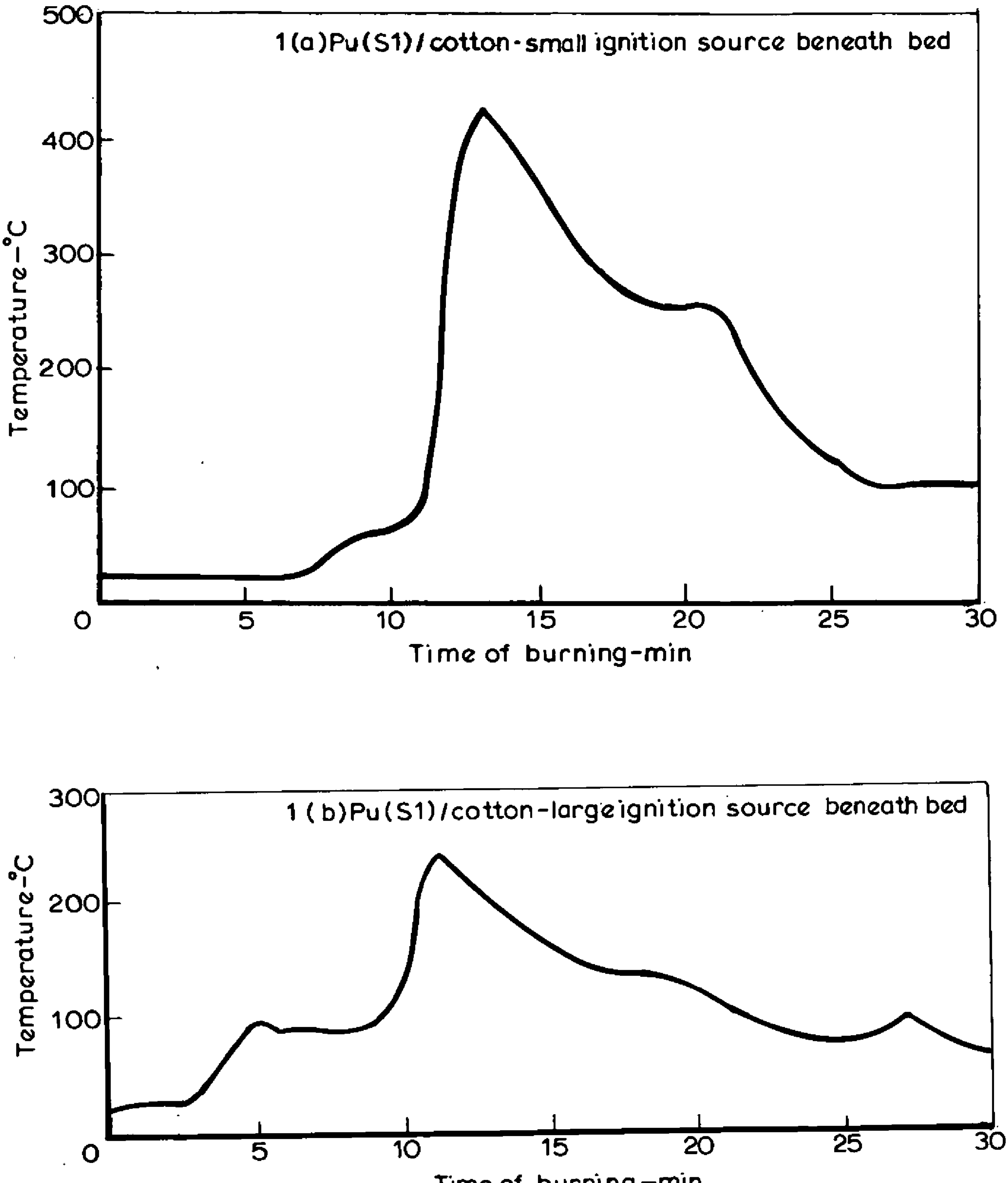


Figure 5 Compartment temperature, tests 1(a) and 1(b)

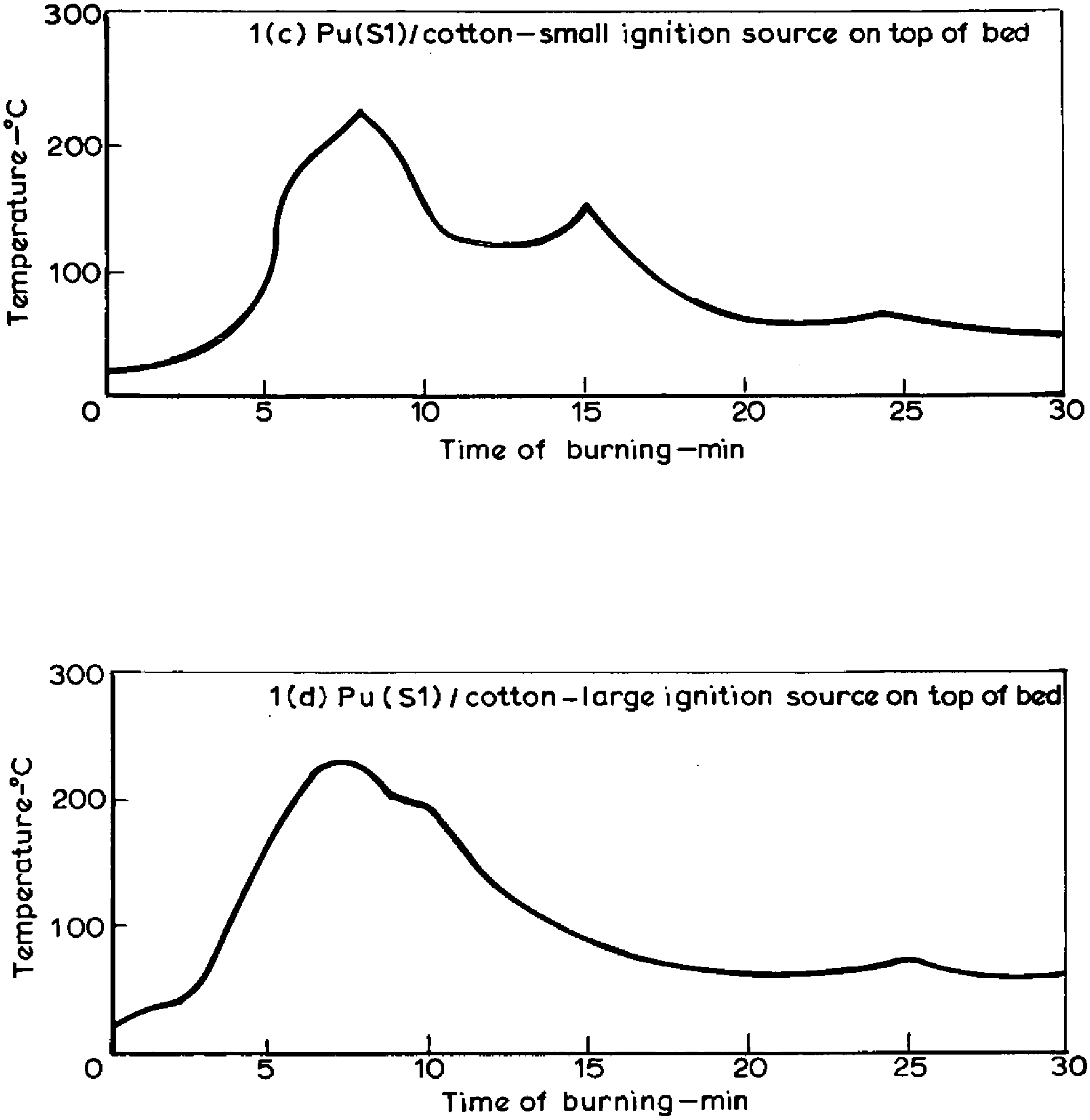
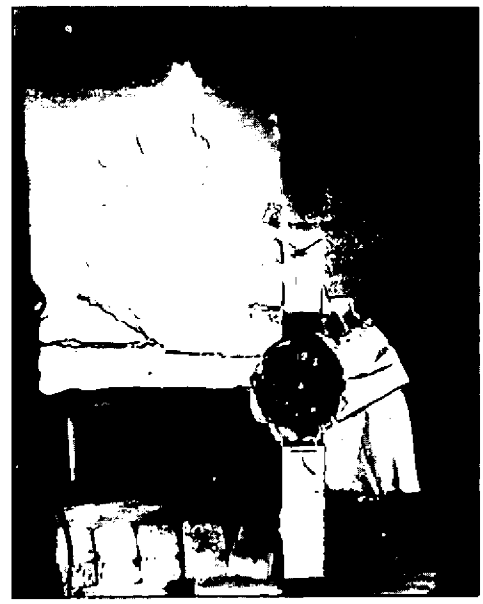


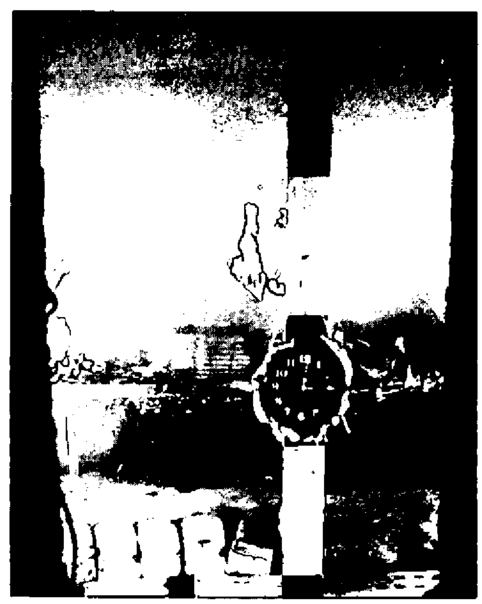
Figure 6 Compartment temperatures, tests 1(c) and (d)

(a) at 3 min 30 sec



(b) at 5 min 10 sec

(c) at 7 min 00 sec



(d) at 15 min 00 sec

PU(S1)/cotton

Ignition: 4 sheets of newsprint on top of bed

FIG 7 PHOTOGRAPHS OF TEST NUMBER 1 (d)

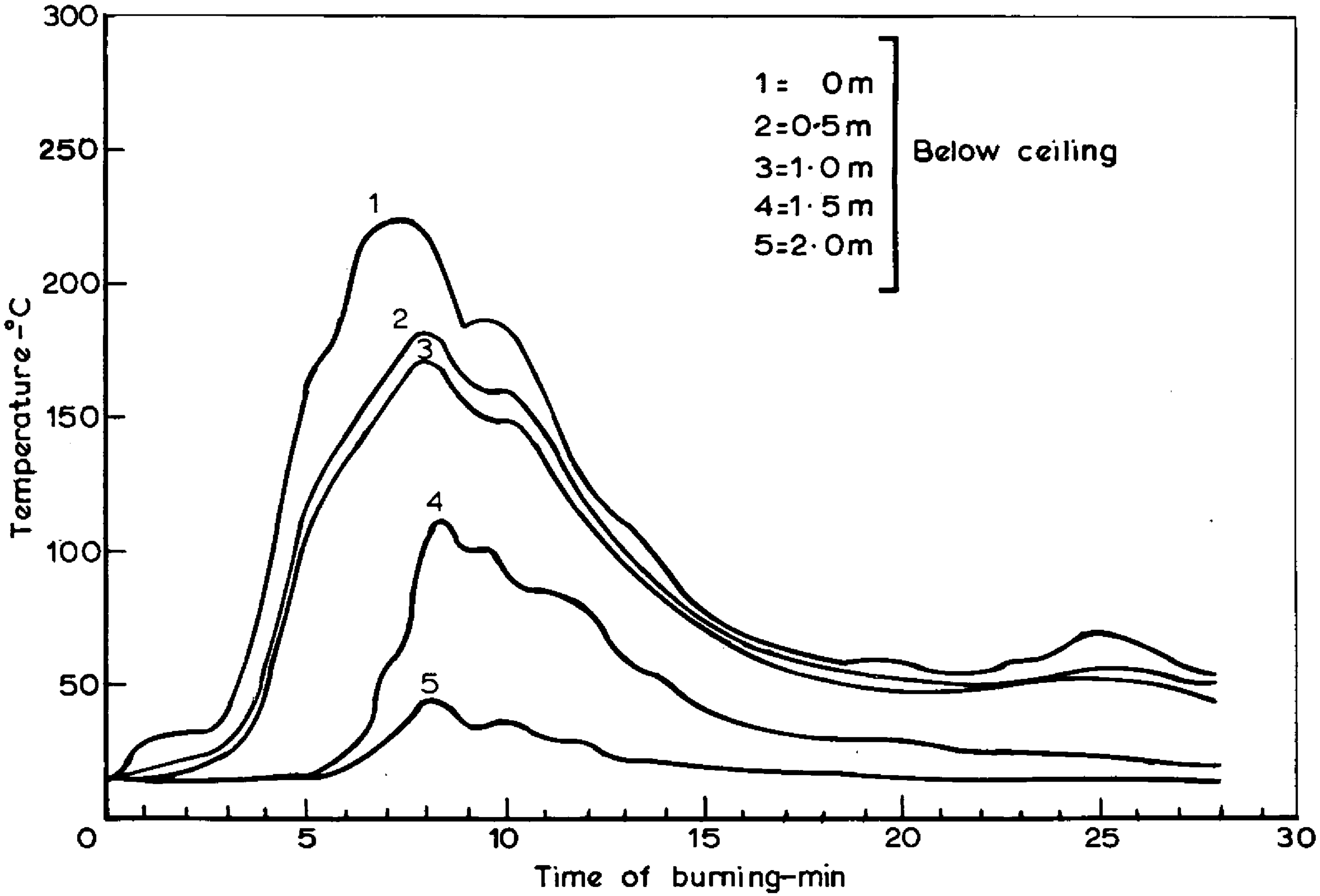


Figure 8 Temperature distribution in compartment, test 1(d)

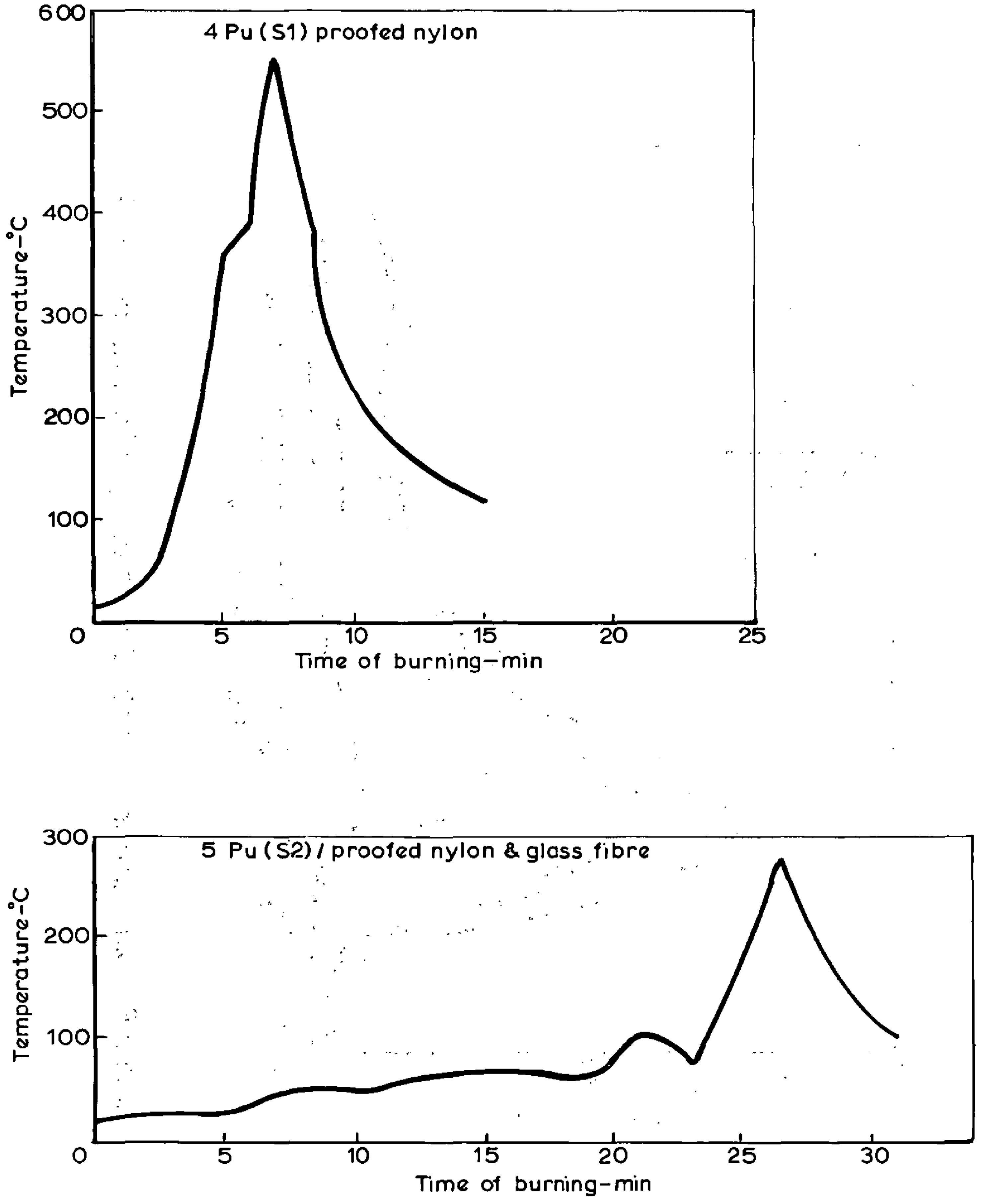


Figure 9 Compartment temperatures, tests 4 and 5

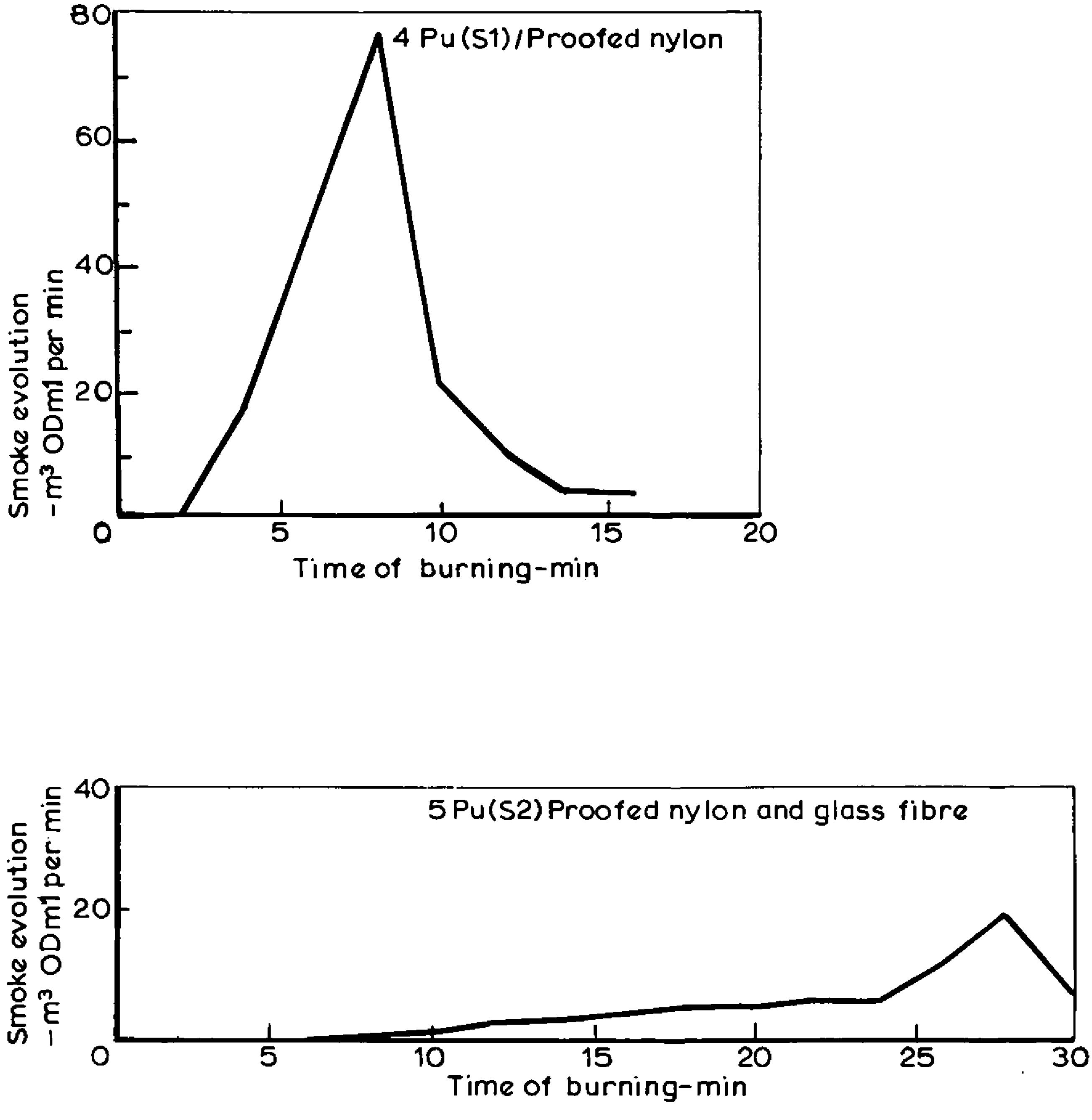


Figure 10 Smoke production, tests 4 and 5

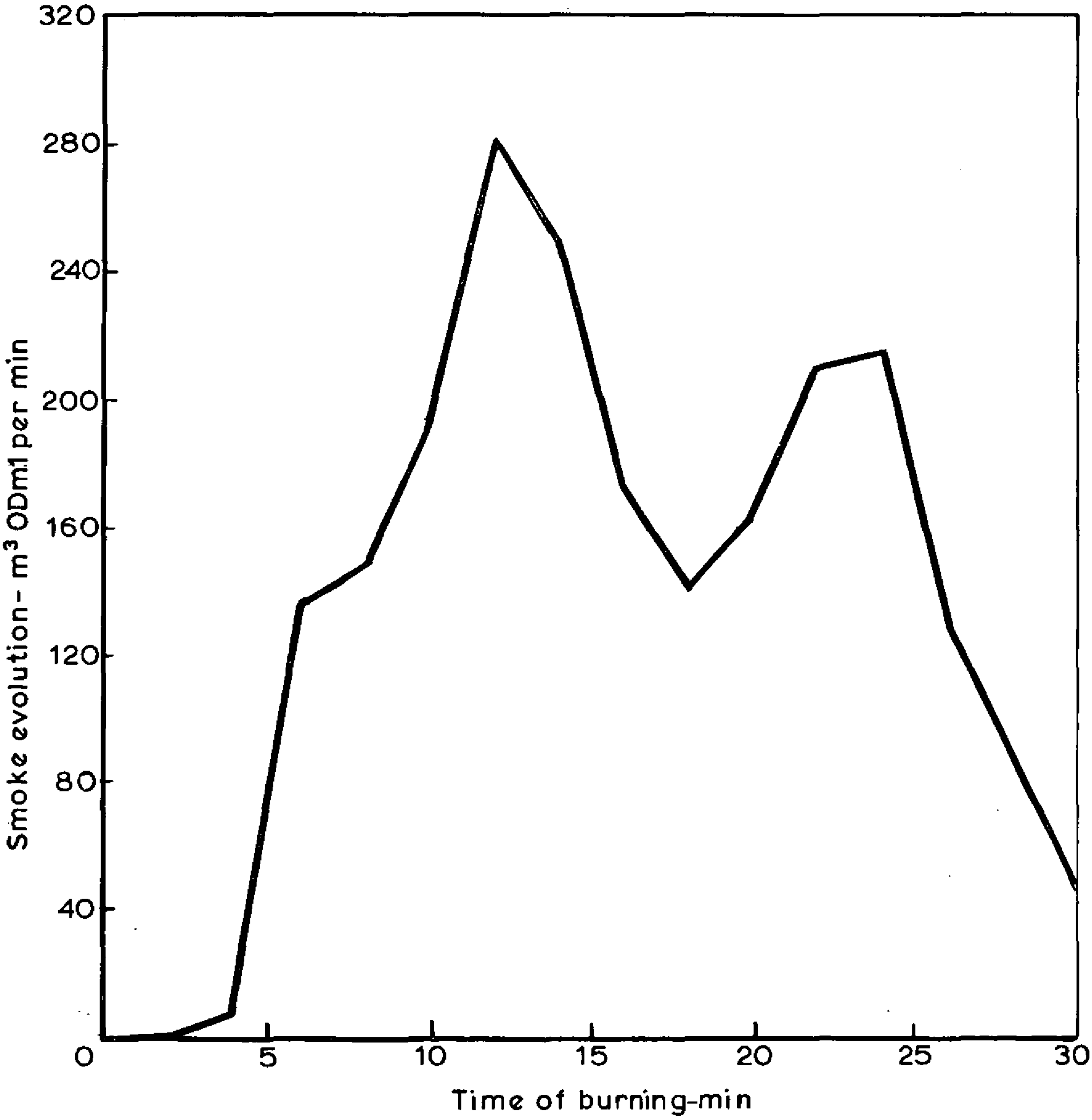
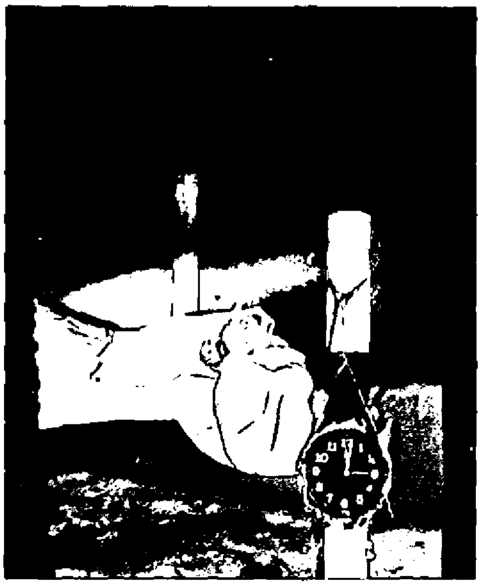


Figure 11 Smoke production Test 18



(a) at 1 min 10 sec

(b) at 2 min 30 sec

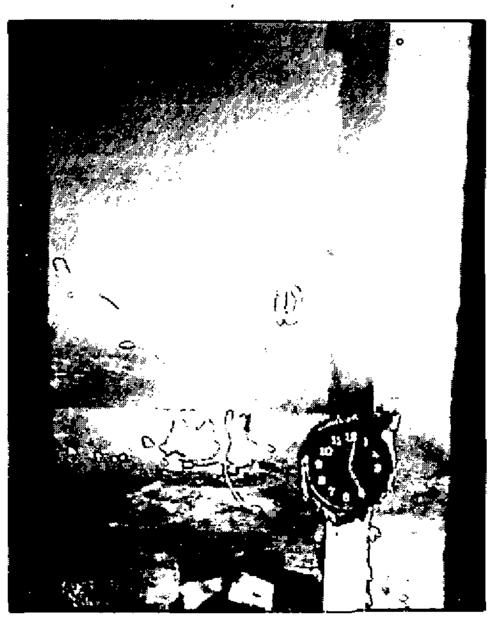
(c) at 5 min 10 sec

PU(S1)/proofed nylon

FIG. 12. PHOTOGRAPHS OF TEST NUMBER 4.

(a) at 11 min 00 sec

(b) at 19 min 00 sec



(c) at 25 min 00 sec

PU(S2)/proofed nylon + glass fibre

FIG. 13. PHOTOGRAPHS OF TEST NUMBER 5

(a) at 5 min 00 sec

(b) at 10 min 00 sec

(c) at 20 min 00 sec

FRU/FR Cotton

FIG 14. PHOTOGRAPHS OF TEST NUMBER 18

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