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SUMMARY OF WORK IN PROGRESS AT THE FIRE RESEARCH STATION, BOREHAM WOOD, ON THE GROWTH AND SPREAD OF FIRE IN BUILDINGS

by

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SUMMARY

This is a brief summary of work in progress at the Fire Research Station, Boreham Wood, on the growth and spread of building fires.

All but one of the projects are studies of the physical processes of fire spread in a compartment. The remaining project is the beginning of a study of fire spread in buildings as revealed by the statistical data from United Kingdom fire brigade reports.

MINISTRY OF TECHNOLOGY AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION

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EARLY STAGES OF FIRE GROWTH IN COMPARTMENTS

1. Although much work has already been done on the growth of fire in a compartment, the variety of circumstances which can influence the behaviour of a fire is considerable and there is much too little systematic knowledge to produce, for example, a common international approach to the testing of flammable wall linings as there is available for testing the fire-resistance of structures.

At present four inter-related research studies are being made. The first is an international investigation, using small-scale compartments, of the effect of the amount and disposition of fuel, position and size of the ignition source, the size of the ventilation opening etc., the second a detailed study of the role of flames under ceilings and the third, some experimental work which will provide inputs into a theoretical model which has some statistical content. This is important since the variety of arrangements of furniture and of compartments themselves must be described statistically and in the last resort one often needs to express results as probabilities. In addition a highly simplified theoretical treatment of the effect of compartment insulation is being made.

1.1. <u>International co-operation</u>

An experimental programme studying the early stages of fire growth has been started in co-operation with several foreign laboratories. So far work in the United Kingdom has been carried out in a compartment 2 m x 1 m x 1 m, lined with asbestos millboard (Plate 1); the fuel consisted of either single cribs of wood covering most of the floor area, or of a number of smaller cribs spaced over the floor and lit in the centre or at one corner of the compartment.

Among the quantities measured at the Fire Research Station was the rate of spread of fire in the fuel. The distance of spread for one experiment is shown as a function of time in Fig. 1. Initially the fire spread slowly through the cribs at a rate which can be shown to correspond to that for cribs of wood in the open air, i.e. a rate characteristic of the crib rather than of the compartment. At 21 min a transition to a higher rate occurred in the spread towards the ventilation opening and at about 26 min the fire accelerated again, spreading rapidly over the top of the cribs to the end.

The investigation is being carried out in a balanced design to permit statistical analysis, the variables initially chosen being fire load density* (15 and 30 kg/m^2) and the type of crib (one continuous crib covering about two-thirds of the floor area or twenty-one separate cribs each 20 cm square and 5 cm apart). Significant differences have been found between the two levels of fire load density and the two types of crib. Spread was faster for the taller separated cribs. Further investigations showed that for the same fuel heights, the time to the point at which rapid spread commenced was not significantly different between separated and continuous cribs, though clearly this could not always be so for all conditions.

The second change in spread rate, unlike the first, was always reasonably well defined and was followed by a rapid spread of fire over the whole of the crib. Spread in these later stages was likely to be controlled by downward radiation from the heated ceiling and the flames travelling under the ceiling. Lining the compartment with hardboard had a marked effect on the transition point but not on the spread prior to it. Fig. 2.

Attempts are being made to relate the various measurements to each other; in particular the time when flames reach the ceiling prior to spreading sideways. This is usually closely associated with the transition to increased radiation onto the floor and walls.

Plates 2(a) and 2(b) show stages in the fire spread in one experiment and the absence of flames in the spaces between two separate cribs whilst the top is burning illustrates how important radiation from above can be.

1.2. Studies of flames beneath ceilings

A separate study is being made of the heat radiated onto unburnt materials. This may come both from the flames and the ceiling which has been itself heated by the flames. Such flames may either be horizontal extensions of vertical flames from fuel on the floor or they may be caused by the burning of a combustible lining material.

Experiments were carried out in a model representing the ceiling of a corridor 1.2 m wide and 7.3 m long with a fire at one end (simulated by a town gas burner); the flames and hot gases were channelled along the corridor by shallow side and rear screens.

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*Fire load density is weight of fuel per unit area.

Analysis of the results of the experiments with a non-combustible ceiling lining, has shown that a greater proportion of the heat of combustion is lost by radiation downwards from horizontal flames and the ceiling above them than from vertical ones; the difference may amount to a factor of four in some instances. Thus the importance of horizontal flames in increasing the rate of fire spread is twofold; first, they radiate more heat, and second, they are so placed that materials on the ground receive more heat from them than from the vertical flames. This means that the thermal properties of the ceiling can strongly influence the rate of growth of fire.

In the first experiments the effect of re-radiation from the lower parts of the walls and the floor was eliminated. However, in practical situations, as the walls and floor become heated, the heat loss per unit temperature rise decreases and the temperatures and intensities of radiation within the corridor increase. Figure 3 shows the intensities of radiation at the bottom of a layer of hot gases both with and without a floor. The no-floor condition is representative of the situation at the beginning of a fire when the floor is cold. The experiments with a floor represent the equilibrium temperature condition.

Thus the thermal properties of the floor as well as the ceiling are important.

Experiments in which the ceiling of the experimental corridor was lined with cellulose-based building boards have also been carried out with representative types of ceiling lining and attempts are being made, with some success, to correlate the experimental data with performance in a standard test.

1.3. Spread of fire between separated items of fuel

Experiments are being carried out to find at what spacing from a burning item of furniture, ignition of another item is possible in a compartment comparable in size to a room in a house. This information is clearly important in developing statistical models of the chance of a fire spreading.

Items of furniture, or groups closely spaced, which are tall in relation to ceiling height will give rise to flames which can reach the ceiling and fan out, markedly increasing the chance of other pieces of furniture becoming ignited.

Data of the kind presented in Fig. 3 could be used to define a length within which fire could spread from a primary fire to some other item. Such distances are associated with the size of the primary fire, its route of heat output and ceiling height.

Data on the type and arrangement of furnishings in offices together with the experimental information now being gained will allow the chance of 'flash-over' to be estimated.

1.4. <u>Effect of the insulation of the compartment on flash-over time</u>

If one were able to express quantitatively the relationship between the rate of heat output, time, and fuel temperature one could investigate theoretically the contribution of the rise in temperature of the fuel surface to the spread of fire in an idealised compartment. A preliminary study of this has been completed.

Preparatory to a computer exercise a simple linear relationship has been assumed.

$$\frac{dQ}{dt} = D\,(1 + \dot{\psi}/m)$$

where Q is the rate of heat production

t is time

ψ is the fuel surface temperature

and D and m are constants.

D is related to the rates of burning and spread in the absence of the accumulation of heat in the compartment. Better theoretical justification can be given for an equation:

$$\frac{dQ}{dt} = \frac{D}{(1 - \psi/\theta i)}$$

where θi is the ignition temperature and is c. $300^{\circ}C$, m has been chosen as $0.4\ \theta i$ to give the same flash-over times in a particular case. From the linear of these two equations and linearized heat balance equations allowing for radiation exchange between the various surfaces and conduction into the walls one can readily show that in the expression for any of the temperature rises there is one term of the form e^{t/t_f} and many others of the form e^{-t/t_n} (all t's being +ve). The characteristic time t_f depends on the thermal properties K thermal conductivity, c specific heat, and ρ density of all the walls etc. Some values are shown in Fig. 4.

The analysis is based on the supposition that there is a neutral plane in the compartment below which the gases are at ambient temperature but above which they are heated. The analysis is quite sensitive to this assumption as it is also to the heat transfer from the ceiling to floor level. No special allowance has been made so far for flame radiation; the flames heating the ceiling which in turn radiates downwards. The value of D which gives a best fit for the two extreme case of

(a) a compartment fully lined with fibre insulating board

(b) a compartment with only brick surfaces above the neutral planes was about twice that estimated a priori.

STATISTICAL STUDIES OF THE FIRE SPREAD IN BUILDINGS

2. An attempt is being made to extract information on fire spread from the statistical data reported by fire brigades. So far the studies have been of a preliminary nature but some interesting results have been obtained. The categories of fire spread listed in 'United Kingdom Fire Statistics', published by H.M. Stationery Office, include:

(i) Confined to item first ignited or from which heat first

(ii) Confined to room of origin

(iii) Confined to floor of origin

(iv) Confined to building of origin (multi-compartment, single-storey)

(v) Confined to building of origin (multi-compartment, multi-storey)

(vi) Confined to building of origin (single compartment)

and it is possible for certain years to sub-divide those in (ii) into fires in single and multi-storey buildings. The definition in (iii) as opposed to those of (iv) and (v) implies that the fires in (iii) are in multi-storey buildings.

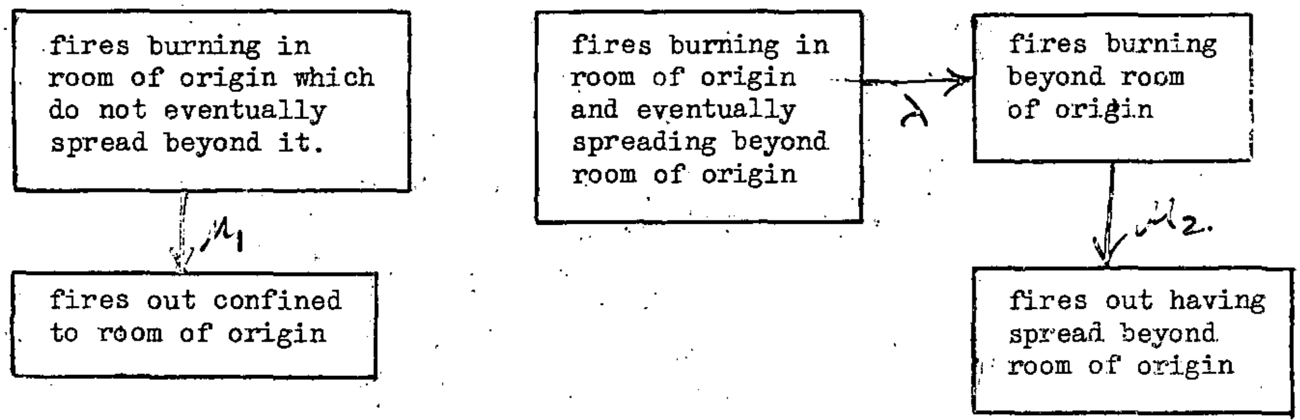
From such data excluding (i) and (vi) it is possible to obtain the frequency and probability with which fire spreads upwards, p_u, and sideways, p_s, from the room of origin during the course of the fire, given that the fire had become large enough to have spread beyond the item first ignited.

The statistics for 1963 are being analysed and the values of p_u and p_s have been obtained for fires of particular durations, the duration being the interval between attendance time and the time at which the brigade indicates that it has all the equipment it requires i.e. "stop". Figure 5 shows results for all buildings in use excluding dwellings. The fire durations were taken in steps of 0-4 min, 5-9 min, etc. and p_u and p_s were evaluated for each group. The almost linear relationship between the probability of spread and the fire duration is noteworthy. There are fewer fires of long than of short duration so that the scatter is higher for the longer durations, but the close connection between the duration and the probabilities p_u and p_s encourages the belief that there is a meaningful relationship.

For these fires as a whole the numerical value of the sum of the rates of increase of p_u and p_s with time, is 0.023 min^{-1}. For houses it is about 0.005 min^{-1}.

This difference probably reflects the greater effectiveness of a fire brigade in dealing with small domestic fires.

Mathematic models are being developed from which probability of controlling a fire and the probability of spread assuming it is not controlled can be evaluated. In their simplest form these can be represented by the examples.



μ_1, μ_2 and λ are transfer probabilities which one wishes to find.

There is some evidence that fires which eventually spread beyond the room of origin and those which do not are different populations and accordingly have had to be treated separately. Attempts are being made to see if any data in the fire reports e.g. the distribution of attendance times or the risk categories attributed by the brigades to various occupancies separate the fires into these categories.

References

(1) THOMAS, P. H. Theoretical Considerations of the Growth of Flashover of Compartment Fires. Ministry of Technology and Fire Offices' Committee Joint Fire Research Organization Fire Research Note 694/1968.

(2) THOMAS, P. H. Fire Spread in Buildings - A Statistical Approach. Ministry of Technology and Fire Offices' Committee Joint Fire Research Organization Fire Research Note 694/1968.

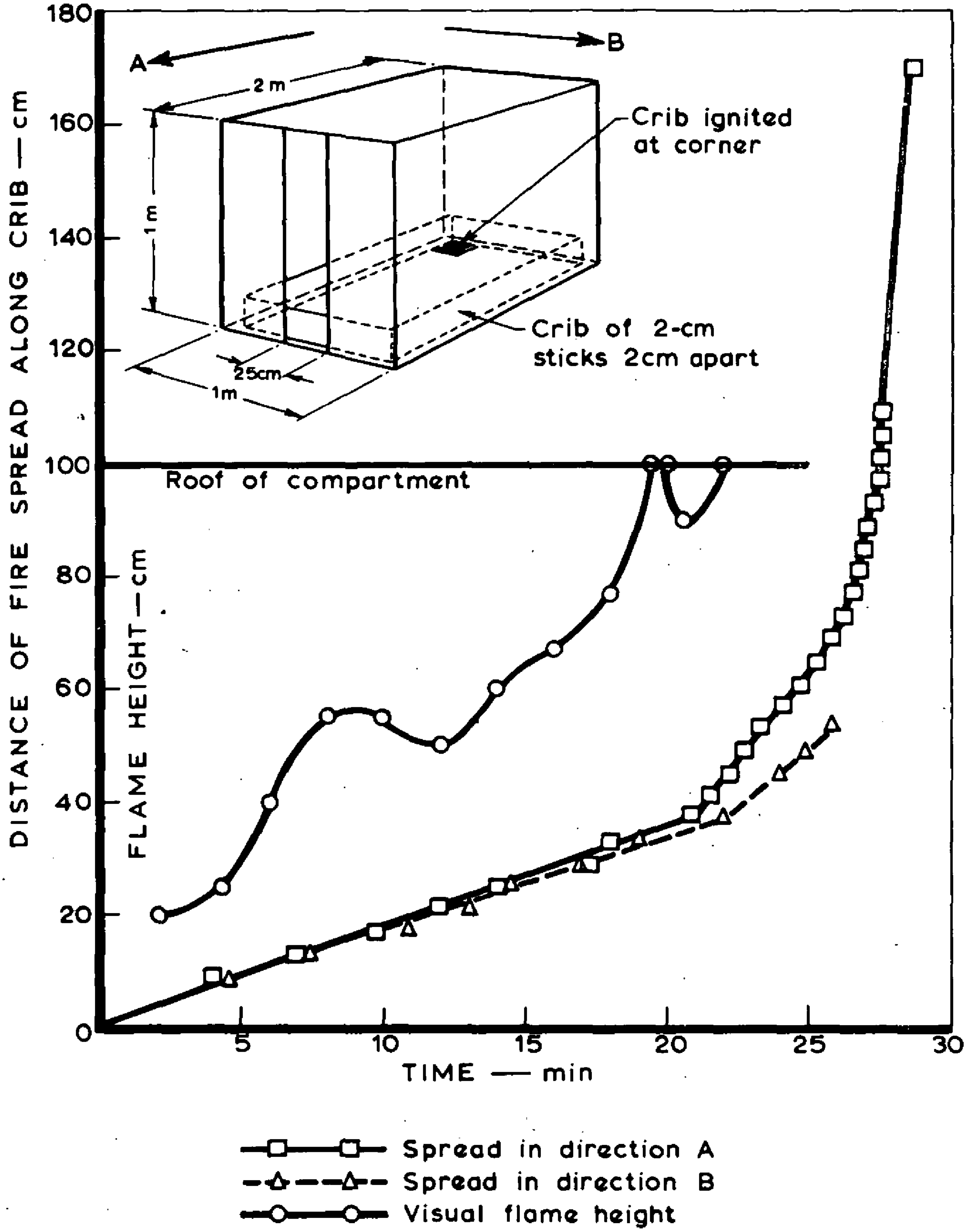


FIG. 1. SPREAD OF FIRE IN A COMPARTMENT

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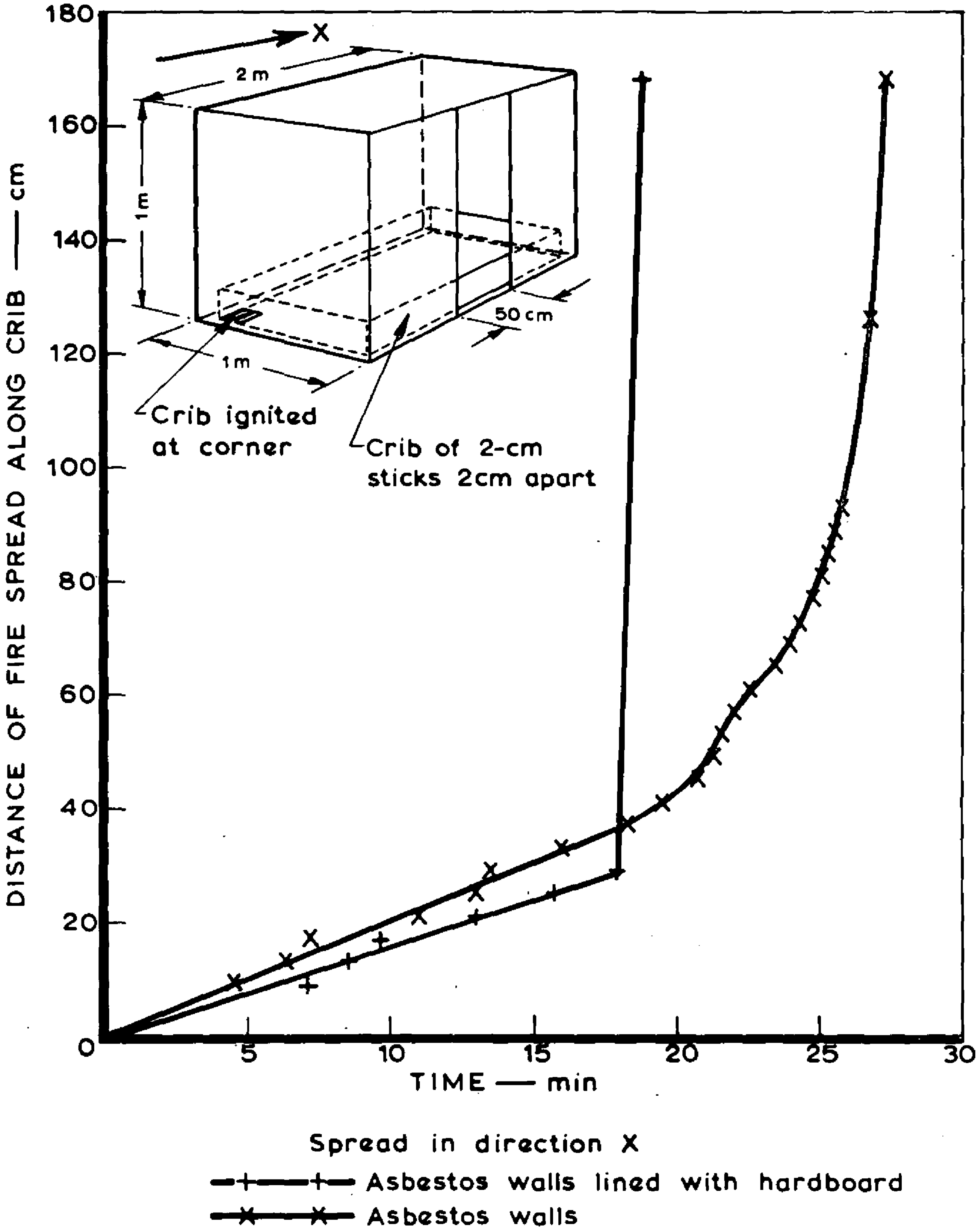

FIG 2. EFFECT OF LINING ON RATE OF SPREAD

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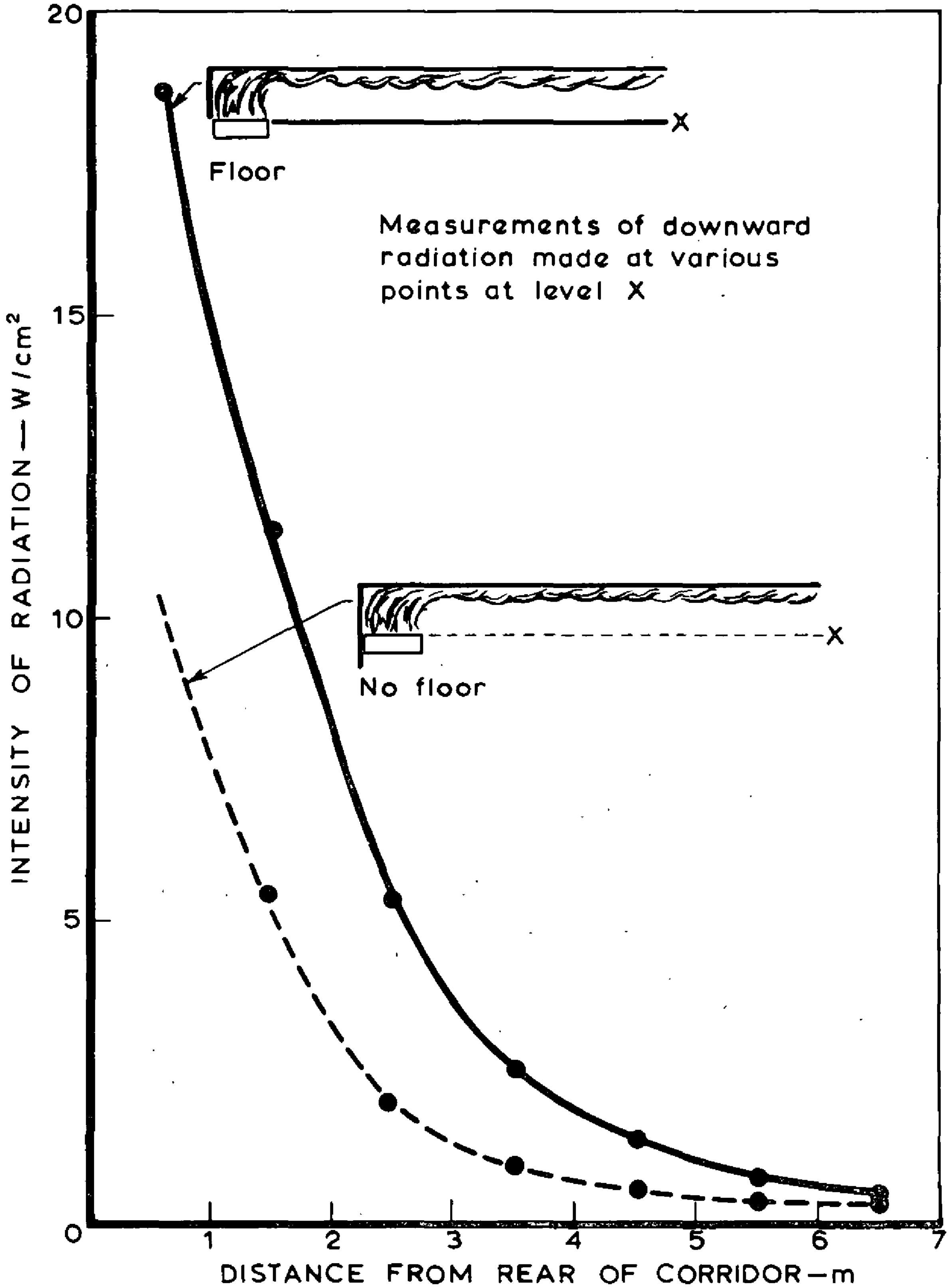


Gas flow 183 cm³/s per centimetre width of corridor

FIG. 3. RADIATION INTENSITY AT BOTTOM OF LAYER OF HOT GASES WITH AND WITHOUT FLOOR

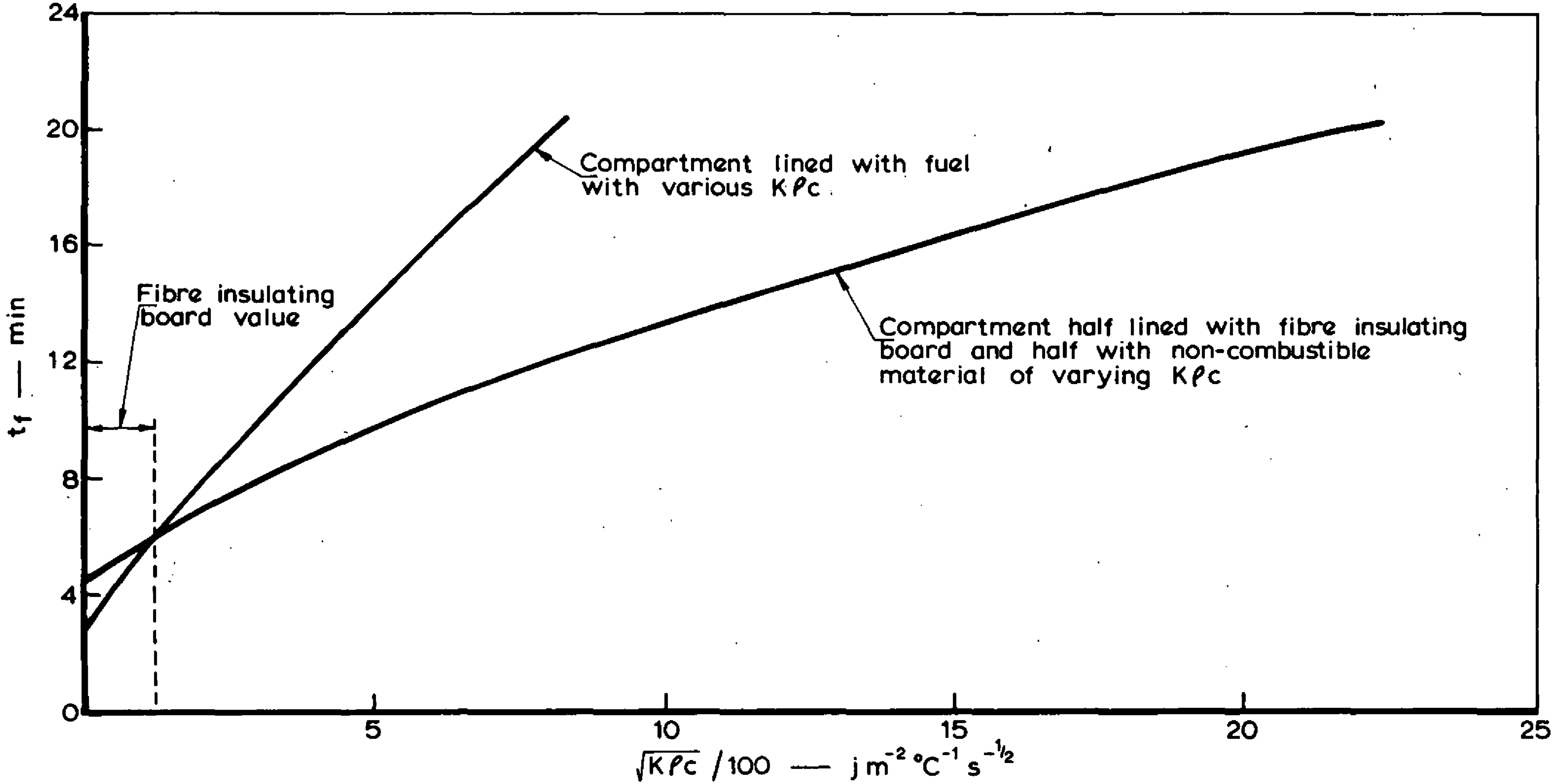


FIG.4. THE EFFECT OF Kρc ON FLASH-OVER

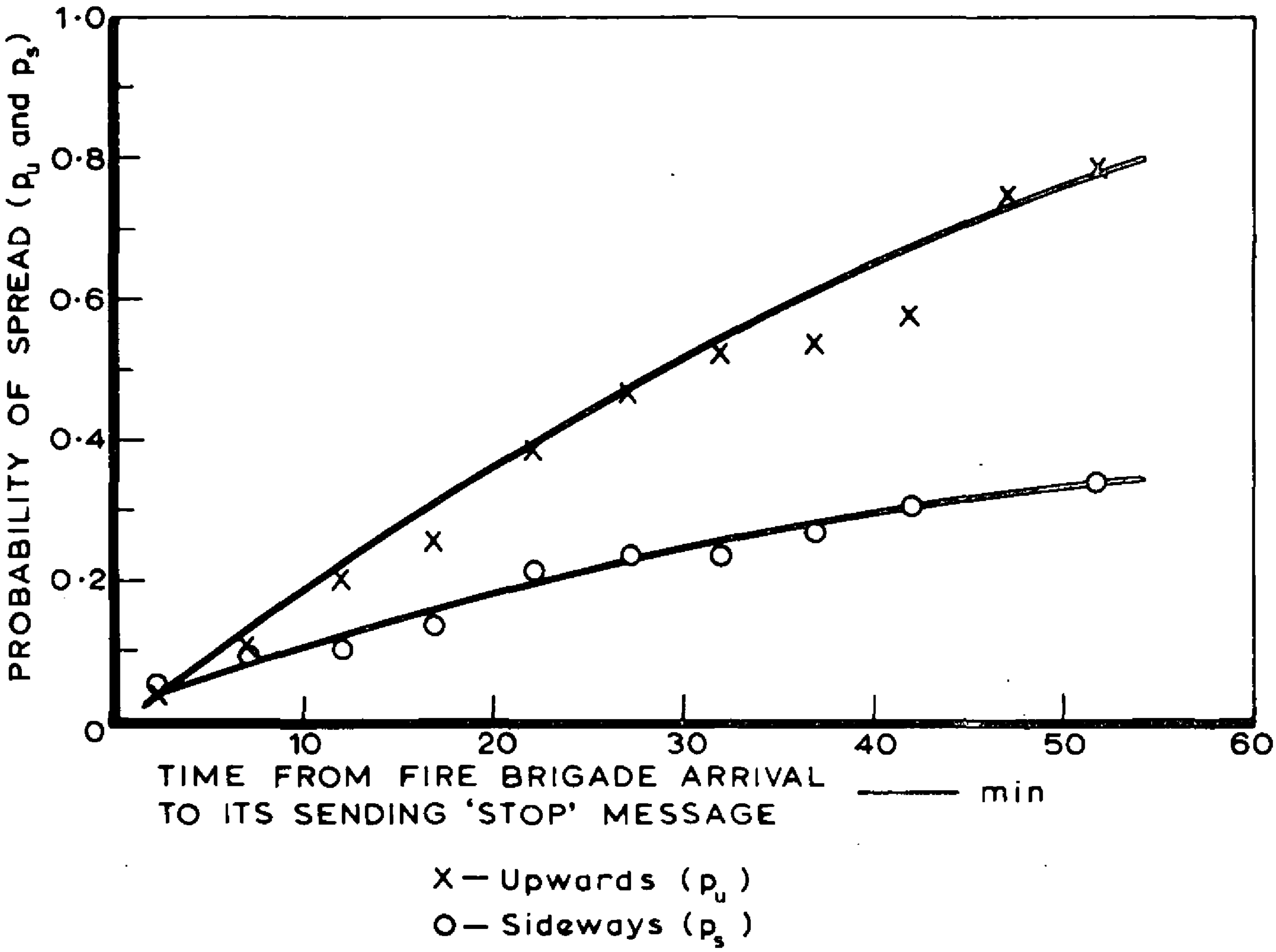
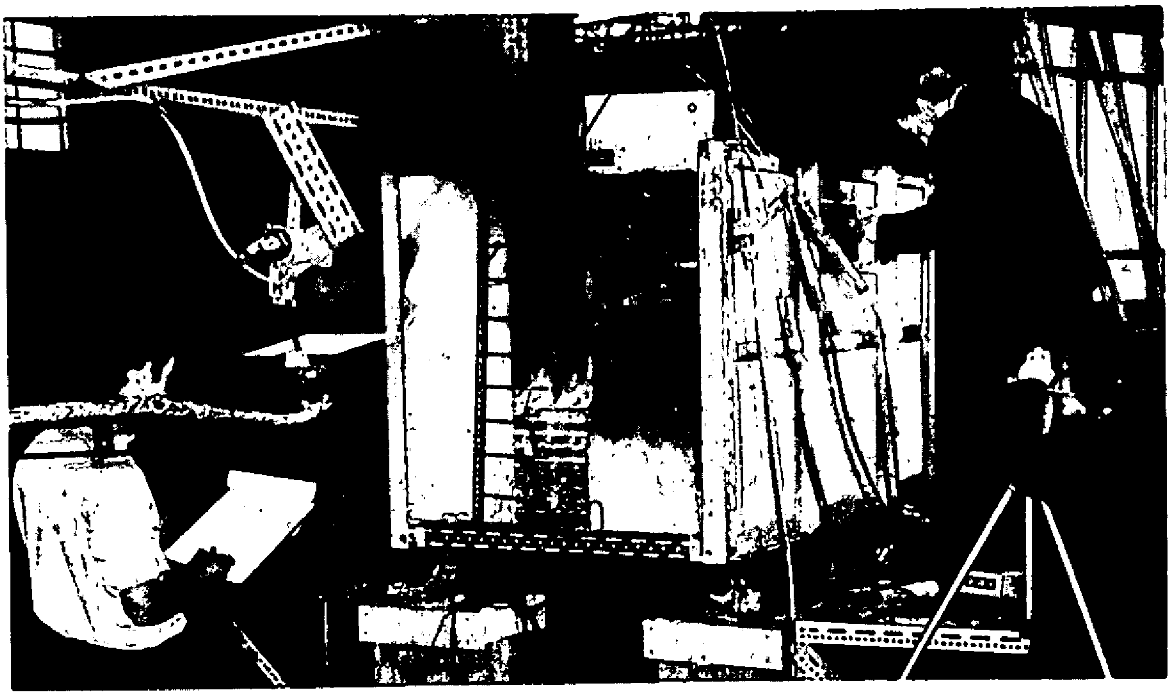
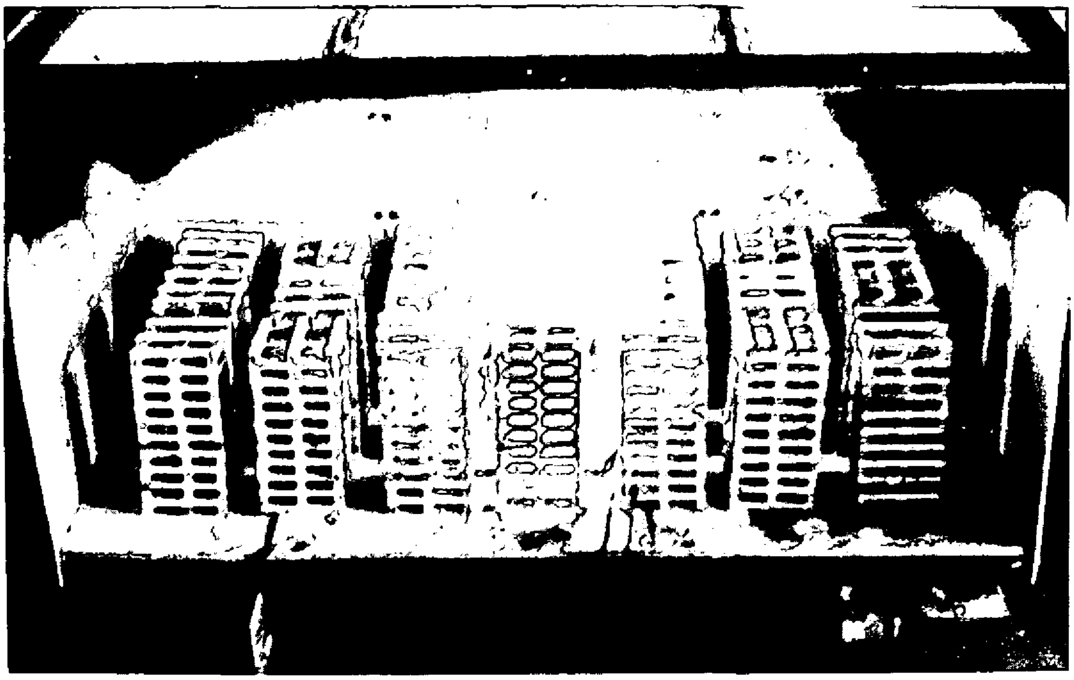


FIG. 5. PROBABILITY OF FIRE SPREAD BEYOND ROOM OF ORIGIN FOR NON-RESIDENTIAL BUILDINGS



GROWTH OF FIRE IN A MODEL COMPARTMENT

PLATE 01



(a) No horizontal flames beneath ceiling -
Fire spreads between cribs
(5 min)

(b) Horizontal flames beneath ceiling -
Fire spreads across top of cribs
($6\frac{1}{4}$ min)

STAGES OF FIRE SPREAD IN MODEL COMPARTMENT

PLATE 2