# Fire Research Note

# No.710

THE FIRE PROPAGATION TEST AS A MEASURE OF THE FIRE HAZARD OF A CEILING LINING

by

P. L. HINKLEY, H. G. H. WRAIGHT AND ANN WADLEY.

May, 1968.

FIRE
RESEARCH
STATION

Fire Research Station,
Borehamwood,
Herts.
Tel. 01-953-6177

F.R. Note No. 710
May, 1968.

# THE FIRE PROPAGATION TEST AS A MEASURE OF THE FIRE HAZARD OF A CEILING LINING

by

P.L. Hinkley, H.G.H. Wraight and Ann Wadley

SUMMARY

The rate of heat transfer to a specimen in The Fire Propagation Test has been measured. It rises as the test proceeds through a range corresponding roughly to that in the Spread of Flame Test (B.S. 476) and after about five minutes this rate of heat transfer becomes greater than that at the position of maximum spread for Class I material in the Spread of Flame Test. This presumably is one reason why The Fire Propagation Test distinguishes between low spread materials better than does the classification in the Spread of Flame Test.

The rates of heat transfer in both tests are much higher than that necessary for the pilot ignition of untreated cellulosic materials but they may not be sufficient for the pilot ignition of some treated ones. They are, also, less than the heat transfer rate recorded over an experimental fire in a model corridor. The calculated initial rate of spread of fire along a wooden floor in this model when lined with a ceiling of cellulosic building board is well correlated with the fire propagation index of the ceiling board. Further work is in progress to assess whether the test is sufficiently sensitive for a wider range of materials.



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

# THE FIRE PROPAGATION TEST AS A MEASURE OF THE FIRE HAZARD OF A CEILING LINING

by

P.L. Hinkley, H.G.H. Wraight and Ann Wadley

## INTRODUCTION

When the fire on the floor of a compartment has grown to the extent that flames are licking the ceiling, any further growth will result in flames extending horizontally beneath the ceiling. Most flammable ceiling linings will ignite at about this time, and this will further extend the horizontal flames. The radiation transmitted downwards from these flames, the heat transferred to the ceiling above them, and the effect on this of lining the ceiling with various types of cellulosic building boards has already been studied experimentally at the Joint Fire Research Organization[1], where it was found that the spread of fire in a compartment could be very markedly influenced by the heat radiated downwards onto unburnt materials. The results of those experiments help to provide a basis for appraising methods of testing the fire hazard of building boards. The present standard test in the United Kingdom is the "Spread of Flame" Test of B.S. 476 but it is proposed to adopt, initially as an alternative, the Fire Propagation Test[2,3] which is described briefly in the next section.

In this note we attempt to relate the performance of a material in the Fire Propagation Test to the spread of fire over a wooden floor beneath a ceiling lined with the material, and to compare the rates of heat transfer to a ceiling in a fire and to the material subjected to the two tests.

## THE FIRE PROPAGATION TEST

The Fire Propagation Test[3] is intended to assess the contribution which a combustible lining material makes to the growth of a fire in a compartment. The apparatus (Plate 1) is constructed of asbestos wood and consists essentially of a combustion chamber with internal dimensions of 191 x 191 x 90 mm ; one of the two large sides is covered with the material under test backed by one or two thicknesses of 1.27 cm thick asbestos board. The chamber is heated internally by two electric elements and a number of small gas flames with a heat output of 526 watts are directed at the specimen. The chamber is provided with a chimney and a ventilation hole in the bottom of the face opposite the specimen. In a test, the specimen is first exposed to the gas flames for $2\frac{3}{4}$ minutes and then additionally to electrical heating at a rate of 1800 watts which is reduced to 1500 watts after a further $2\frac{1}{4}$ minutes. The heat input is maintained constant at this lower rate until the end of the test, 20 minutes after the gas flames were ignited. During the test the flue gas temperatures are measured by two thermocouples, of 0.46 mm diameter wires inserted in the chimney cowl.

The apparatus is first calibrated by obtaining a record of the rise in temperature of the flue gases with an incombustible specimen of asbestos wood in place of the test specimen. This is representative of a good material for linings because not only is it incombustible but, having a high thermal conductivity and capacity, it absorbs heat in the early stages of a fire thus reducing the rate of spread. If the material to be tested is incombustible but has a low thermal conductivity and capacity the flue gas temperature will be slightly higher than that obtained with asbestos wood. The test does not, therefore, make a fundamental distinction between incombustible and combustible materials.

A mean time-temperature curve for three specimens of the material to be tested is determined, and an index of performance for the materials is calculated from the formula.

$$I = \sum (\theta_m - \theta_c)/10t$$

where I is the fire propagation index

$\theta_m$ is the temperature rise in deg.C of the mean curve for the material at time t from commencement of test

$\theta_c$ is the corresponding temperature rise in deg.C of the curve for the asbestos wood at the same time t

and t has the values $\frac{1}{2}$, 1, $1\frac{1}{2}$, 2, $2\frac{1}{2}$, 3, 4, 5, 6, 7, 8, 9, 10, 12, 14, 16, 18 and 20 minutes.

The lower the index the better the material.

This formula ensures that an increase in temperature (over that obtained during the calibrations) which occurs at the beginning of a test is very heavily weighted compared with one occurring later on. The weighting is justified in principle because the relative contribution of a combustible lining to the spread of fire in a compartment is greatest if the heat output from the lining occurs early in the spread when the heat output from the other combustible materials in the compartment is small.

The "gross" rate of heat transfer* to the centre of an asbestos wood specimen was measured by a method similar to that described by Christensen et al[4] and

* Defined as the algebraic sum of the rates of heat transfer(1) into the specimen by conduction (2) from the surface by radiation (3) from the surface by convection.

are shown in Fig. 1. Due to the gas jets alone it was about $0.5W/cm^2$, however, the flames impinged on a line below the centre of the specimen and the rate of heating locally may have been much higher[5], possibly $2.0W/cm^2$. When the electric heaters were turned on the rate of heat transfer rose to more than $2.5W/cm^2$; falling slightly when the power was reduced from 1800 watts to 1500 watts, but it subsequently rose steadily to about $5.0W/cm^2$ after 20 minutes. The rate of heat transfer at this time was still rising.

The gross heat transfer rates will be higher for good insulators (because the heat loss through the walls of the combustion chamber will be less) although they will still be of the same order and will vary with time in much the same way as with an asbestos wood specimen. After a combustible specimen has ignited there will probably be a large increase in the gross heat transfer rate.

## EXPERIMENTS WITH CEILING LININGS

Experiments were carried out in a model 7.3 metres long and 1.2 metres wide (Fig. 2) representing the ceiling of a corridor having a town gas burner at one end; the flames and hot gases from this fire being channelled beneath the ceiling by side and end curtains. Measurements were made of the heat transfer to the ceiling above the burner (where ignition of the ceiling lining occurred) and the distribution of radiation downwards to the floor along the centre of the corridor which will determine the fire spread along the corridor floor.

The ceiling was constructed from asbestos wood and in some experiments it was lined with a cellulosic building board. The different types of lining used together with their Fire Propagation indices and their classifications in the Spread of Flame test[6] are given in Table 1. These materials are described in general terms only and the test ratings showed in some instances that the materials were poor examples of their types.

TABLE 1

Materials investigated in the corridor experiments.

| Type of Building Board | Fire Propagation Index | Classification Spread of Flame Test |
|---|---|---|
| Hardboard with intumescent paint | 16.5 | 2 |
| Impregnated fibre insulating board | 18.7 | 1 |
| Panelboard with plastic paint | 23.7 | 2 |
| Impregnated medium hardboard | 29.7 | 4 |
| Stove-enamelled hardboard | 40.6 | 3 |
| Fibre insulating board with emulsion paint | 42.0 | 4 |
| Fibre insulating board with chlorinated rubber paint | 53.5 | 4 |
| Untreated fibre insulating board | 75.3 | 4 |

The rate of heat transfer to the ceiling immediately over the burner increased from 1W/cm$^2$ when the town gas flow was adjusted so that flames were just licking the ceiling to 17W/cm$^2$ when the town gas flow was about seven times as great. Any further increase in the flow of town gas resulted in a lower rate of heat transfer.

The experiments with lined ceilings were all carried out with the setting of town gas flow rate which originally produced a rate of heat transfer of 10W/cm$^2$ to the asbestos ceiling immediately over the fire. The effect of a combustible ceiling was to decrease this to about 7 $W/cm^2$, possibly because the gases emitted by the lining formed a protecting layer.

Towards the end of the corridor where the heat transfer due to flames from the burner was small compared with that due to flames from the burning ceiling lining, the rate of heat transfer to the ceiling was generally about $2W/cm^2$ although it was over $3W/cm^2$ with a stove-enamelled hardboard lining.

After the ceiling had ignited the radiation downwards to any point at floor level rose to a value much greater than that due to the primary fire alone. The variation of intensity with time 2.5 metres from the rear of the corridor is shown in Fig. 3; the time taken to reach the maximum intensity of radiation varied from about a half-minute for untreated fibre insulating board to about five minutes when the fibre insulating board was impregnated with a fire retardant salt. After this there were usually fluctuations about a mean value; these were usually associated with pieces of lining coming away from the ceiling. Generally the intensity of radiation decreased roughly exponentially with distance from the town gas fire, falling to $1W/cm^2$ at distances varying between 4 and 5 metres from the rear of the corridor according to the type of lining.

Stove-enamelled hardboard behaved in an anomalous manner; the radiation did not decrease with distance from the fire but was constant along the length of the corridor at a value of about $3W/cm^2$. Also the burning rate of this material was much higher than that of the others and large volumes of flame were produced. This anomalous behaviour may have been due to the way in which the flammable gaseous products of pyrolysis were emitted. With most materials they diffused at a low velocity out of the burning ceiling and mixed only slowly with the underlying air so that the local rate of combustion was small, but the flammable gases from the stove enamelled hardboard were emitted as jets at a relatively high velocity through small holes which appeared in the enamel coating; these jets mixed relatively rapidly with the underlying air and the local rate of combustion appeared to be much higher.

Some ad hoc experiments on the burning of different types of stove-enamelled hardboard in front of a 30 cm square radiant panel showed, however, that they did not all behave in the same way.

## COMPARISON BETWEEN HEAT TRANSFER RATES

In Fig. 4 the "gross" rates of heat transfer to the specimen during the Fire Propagation Test are compared with those in the Spread of Flame Test, the minimum rate required to ignite untreated cellulosic materials[7,8,9] and the rates measured in the corridor experiments.

About five minutes after the commencement of the fire propagation test the rate of heat transfer exceeds that in the Spread of Flame Test at the point of maximum spread allowed for Class 1 materials ($2.8 W/cm^2$). The Spread of Flame Test cannot distinguish between materials which do not spread flame beyond this point but in principle the Fire Propagation Test can. The maximum rate in the fire propagation test ($5 W/cm^2$) is much greater than the minimum necessary for "pilot" ignition of untreated cellulosic materials although it may not be sufficient for some types of impregnated fibre insulating board. It is sufficient, however, to cause these to decompose.

The maximum rate of heat transfer measured in the corridor experiments ($17 W/cm^2$) was much higher than the maximum rate in the Fire Propagation Test. However, materials which require a rate of heat transfer of this order before they ignite should not present a serious hazard in practical situations because the primary fire required to ignite the lining would be so large that the additional contribution of the burning lining should be relatively small. Even so, it may be argued that linings should be subjected in any test to rates of heat transfer of the same order as the maximum to which they may be subjected in practice and some increase in the rate of heat transfer towards the end of the fire propagation test may be desirable. Work is in progress to assess the sensitivity of the test to differences in good materials to see if an increased heating rate is necessary.

## FIRE PROPAGATION INDEX AND FIRE SPREAD

The differences in downward radiation from different types of ceiling lining can be interpreted in terms of their effect on the spread of fire along the floor beneath.

The spread of fire along the wooden floor (density $0.5 g/cm^3$) of a corridor due to the flames beneath the ceiling (Fig. 5) were calculated from the experimental results using an electrical analogue. It was assumed that, at each position along it, the floor ignited when its upper surface reached a temperature of 260 deg C above ambient and that there was no interaction between the flames from the burning floor and the flames beneath the ceiling. This would be true for a narrow strip of wood and in the early stages of spread on a wide floor.

The spread on a wooden floor beneath various types of ceiling including asbestos wood and a "perfectly insulating" one (having no thermal capacity or conductivity) is shown in Fig. 6. These curves all relate to the same size of primary fire. Comparison of Figs. 3 and 6 shows that the rate of spread of fire along the floor is apparently controlled initially by the rate of increase of the intensity of radiation downwards and for most lining materials (stove-enamelled hardboard is an exception) the final distance of spread depends on the maximum intensity of radiation.

The importance of thermal properties is illustrated by the curves for asbestos wood and a "perfectly insulating" ceiling. Fire would spread only slowly from the primary fire along a floor beneath an asbestos wood ceiling whereas it would spread faster beneath a perfectly insulating ceiling; however, when the flames from the burning floor do not contribute significantly to the primary fire the distance of spread is limited.

Generally the increase in area of the fire on the floor will increase the length of the horizontal flames beneath the ceiling and hence the downward radiation; this positive "feedback" effect would accelerate the rate of spread of fire until other factors (such as the limited amount of air which may be entrained) intervene. The initial rate of spread of fire would then assume an even greater importance.

The initial rate of spread over the floor was calculated from the time to spread 1.5 metres; this was found to correlate remarkably well with the fire propagation index of the material lining the ceiling for all the combustible materials investigated (<u>including</u> stove-enamelled hardboard)(Fig. 7). The success of this correlation is probably due to both parameters depending on the time to ignite and the subsequent rate of heat output from the material.

The correlation appeared to be slightly better than that between the rate of spread and the spread of flame classification (Fig. 8).

The final distance of spread along the wooden floor is fairly constant for different materials and does not correlate with either the fire propagation index or the B.S. 476 spread of flame classification. However, this distance has no meaning for a wide floor. In addition neither test indicates the anomalous behaviour of stove-enamelled hardboard, which is not reflected in its contribution to the initial spread of fire along the floor.

This may be due to the board being in the vertical position in the tests so that mixing between the flammable gases and the ambient air is generally much better than with boards in the horizontal position. The jets of flame emitted by the stove-enamelled hardboard would then be of less importance in the test than when used as a ceiling.

## CONCLUSIONS

(1) The Fire Propagation Test is, in principle, capable of distinguishing better between the performance of good linings than does the Spread of Flame Test.

(2) The rate of heat transfer to the specimen in the Fire Propagation Test increases to about $5 W/cm^2$ at the end of the test, if the specimen has not ignited. This is much higher than that required for the "pilot" ignition of untreated cellulosic materials[8] but may not be sufficient to ignite some treated ones and it is less than the maximum rate $17 W/cm^2$ which was measured directly over a town gas fire. Materials which only ignite at such high rates of heat transfer are however less hazardous than those which ignite at lower rates. The sensitivity of the test to such materials is currently being examined.

After ignition of the specimen rates of heat transfer will be much higher.

(3) The initial rate of spread of fire along a wooden floor beneath a burning ceiling lined with a cellulosic building board is correlated with the fire propagation index of the board. There is no correlation with the maximum distance of spread.

(4) The applicability of this correlation to other types of material such as plastics or to cellulosic materials used in other situations such as wall linings has still to be investigated.

## REFERENCES

(1) HINKLEY, P. L. and WRAIGHT, H. G. H. The contribution of flames under ceilings to fire spread in compartments. Part 2, Experiments with lined ceilings. Joint Fire Research Organization F.R. Note. In preparation.

(2) HIRD, D. and THOMAS, P. H. The growth of fires in rooms and a test for internal linings. Joint Fire Research Organization F.R. Note No. 207, 1955.

(3) Fire propagation test for materials. British Standard 476 : Part 6 : 1968.

(4) CHRISTENSEN, G., LOHSE, U., and MALMSTEDT, K. Full scale fire tests. Danish National Institute of Building Research SBI Report No. 59, 1967

(5) SIMMS, D. L. and HINKLEY, P. L. Protective clothing against flames and heat. Fire Research Special Report No. 3, London 1960. H.M.S.O. P.39

(6) Fire tests on building materials and structures. British Standard 476: Part 1 : 1953.

(7) LAWSON, D. I. and SIMMS, D. L. The ignition of wood by radiation. British Journal of Applied Physics 1952, 3, 394-6.

(8) SIMMS, D. L. On the pilot ignition of wood by radiation. Combustion and flame, 1963, 3 (3) 253-61.

(9) SIMMS, D. L. Surface spread of flame over wood. Joint Fire Research Organization, F.R. Note No. 553, 1964.

1/8355 F.R. 710

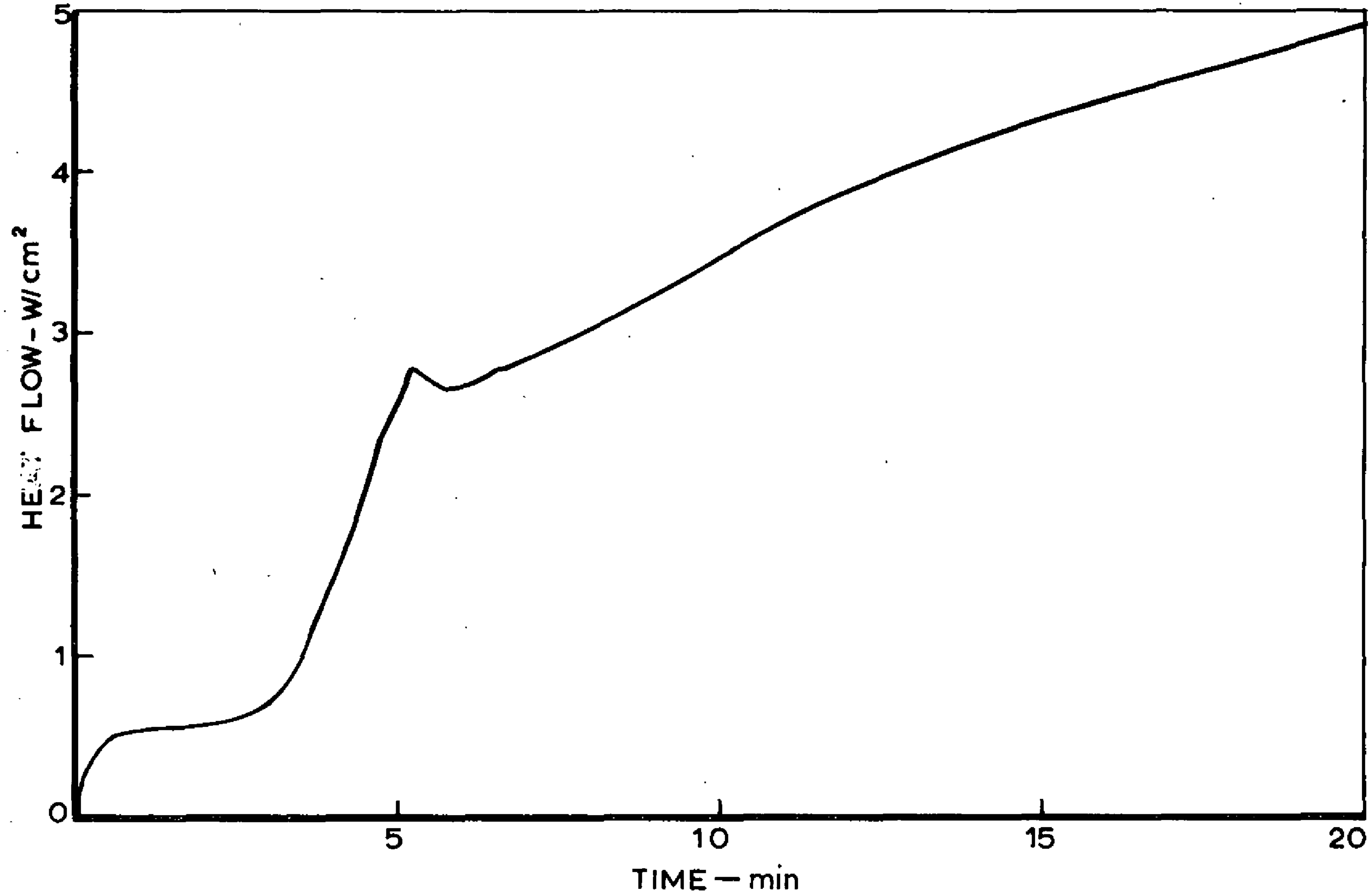



FIG.1. "GROSS" HEAT FLOW TO ASBESTOS WOOD IN FIRE PROPAGATION TEST

1/8356 F.R. 710

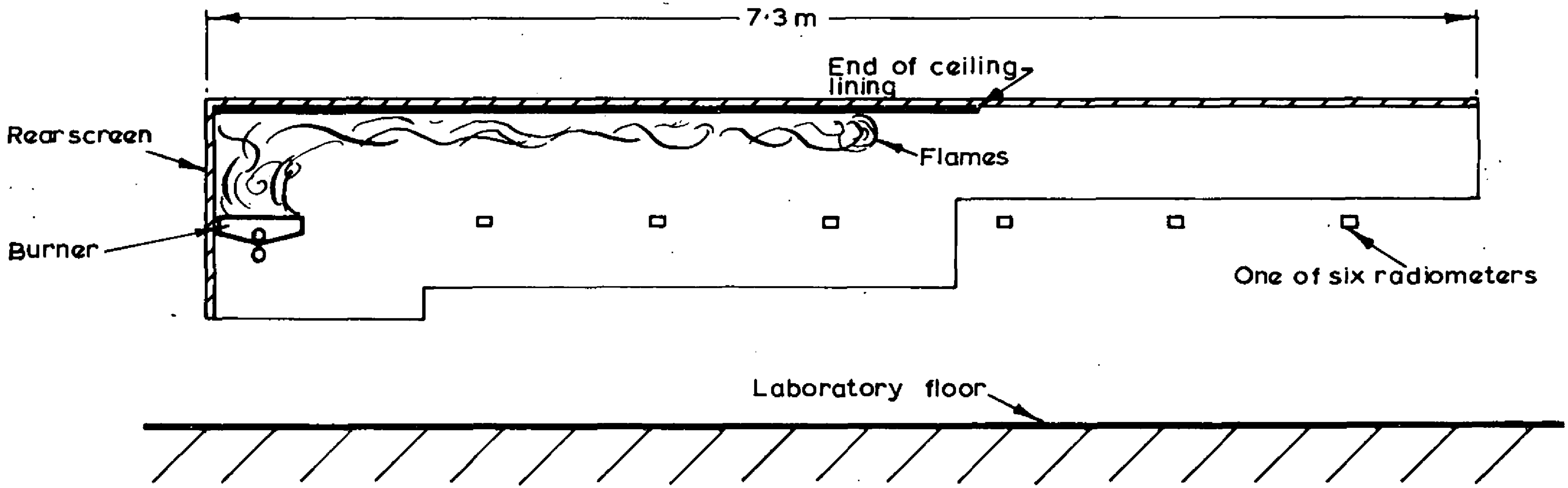



FIG.2. DIAGRAM OF MODEL CORRIDOR WITH LINED CEILING

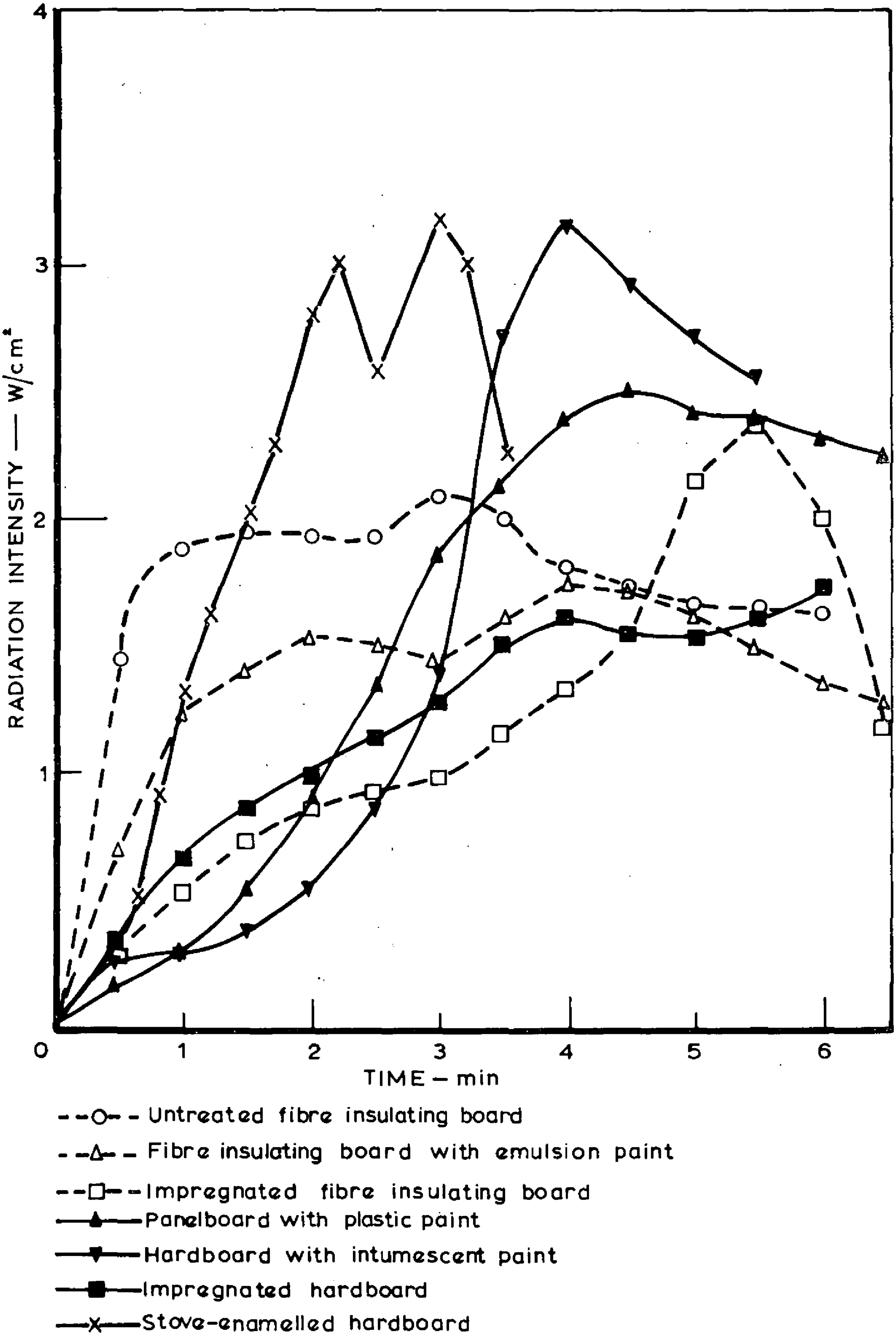
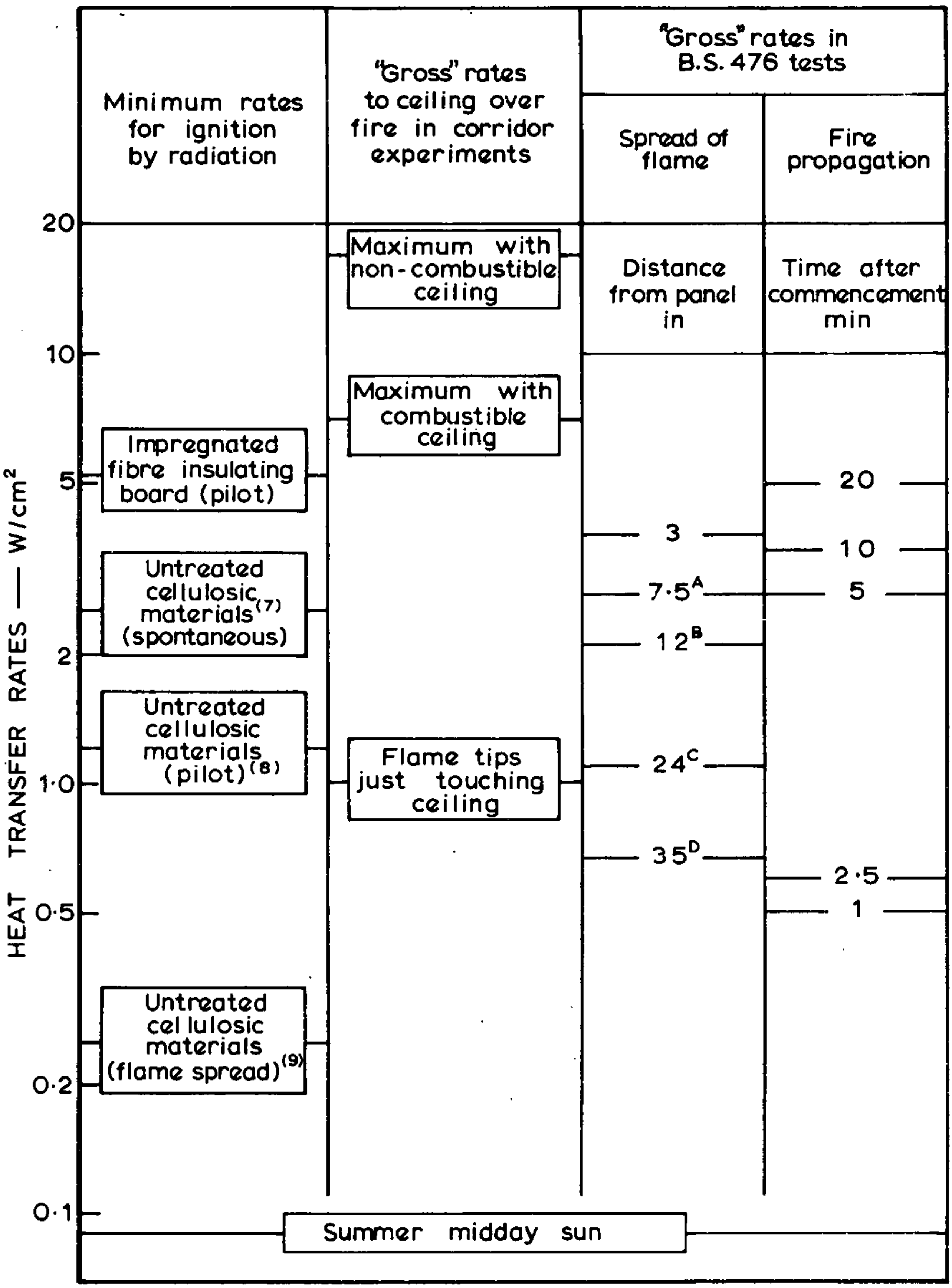



FIG.3. DOWNWARD RADIATION (AT 2·5 METRES)

1/8357 F.R.710




Notes

A Maximum allowable spread for Class 1

B Maximum allowable spread after 1½ minutes for Class 2 and 3

C Maximum allowable spread for Class 2

D Maximum allowable spread after 10 minutes for Class 3

1/8358 · F.R. 710

FIG. 4. COMPARISON OF HEAT TRANSFER RATES

1/8359 F.R. 710

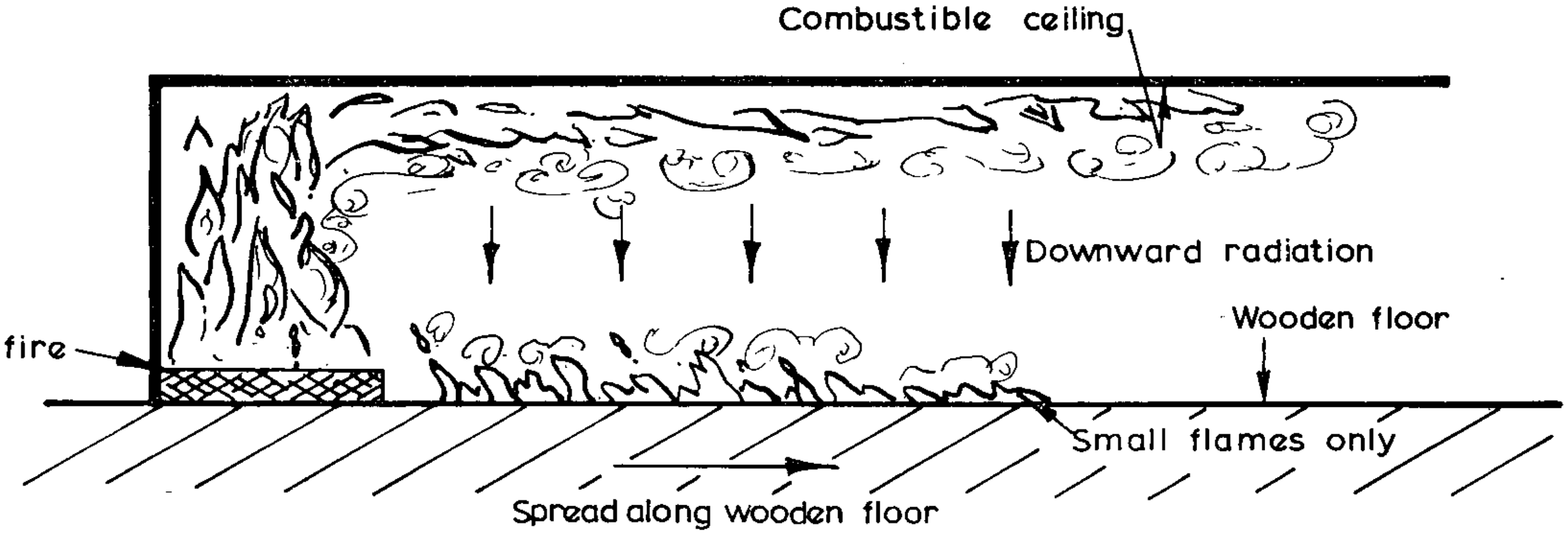



FIG.5. SPREAD ALONG A WOODEN FLOOR DUE TO DOWNWARD RADIATION FROM BURNING CEILING

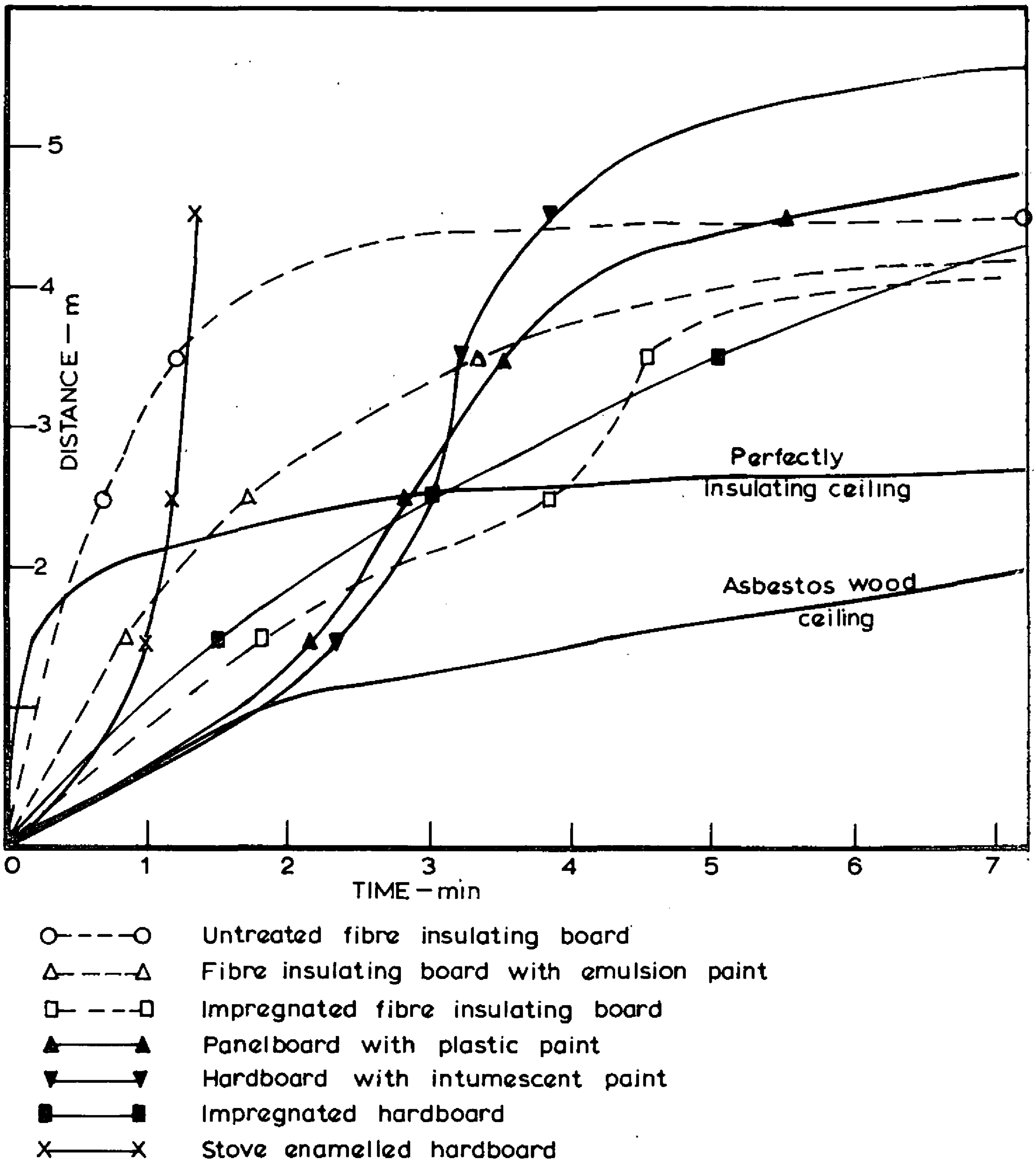



FIG. 6. CALCULATED SPREAD ON WOOD FLOOR UNDER LINED CEILINGS

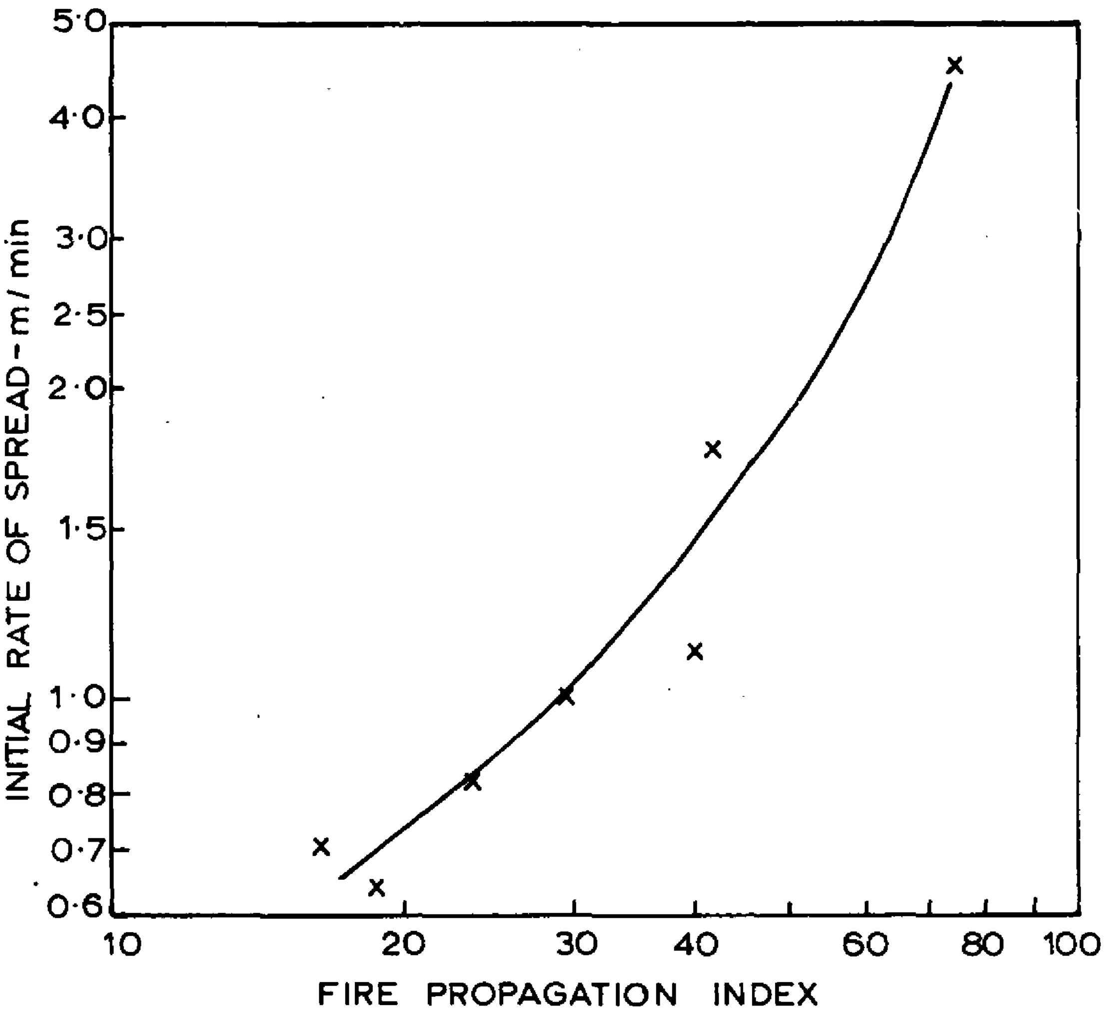



FIG.7. CORRELATION BETWEEN INITIAL RATE OF FIRE SPREAD AND FIRE PROPAGATION INDEX

1/8561 · F.R.710

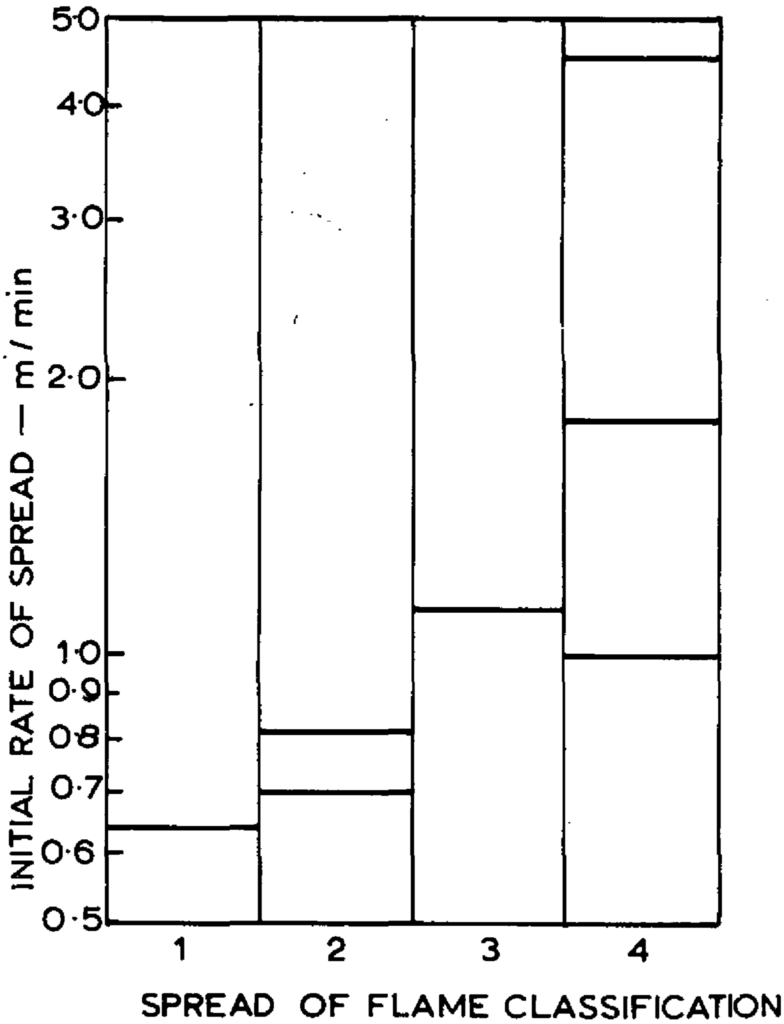



FIG. 8. CORRELATION BETWEEN INITIAL RATE OF FIRE SPREAD AND SPREAD OF FLAME CLASSIFICATION

1/8362 F.R. 710

PLATE 1. FIRE PROPAGATION TEST APPARATUS