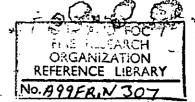# THE EFFECT OF SIZE OF IRRADIATED AREA ON THE SPONTANEOUS IGNITION OF MATERIALS

PART 1: THE EFFECT ON IGNITION TIME

by

D. L. Simms, Margaret Law, P. L. Hinkley and R. W. Pickard

of the Department of Scientific and Industrial Research and Fire Offices'
Committee Joint Fire Research Organization

Summary

The effect of the irradiated area of a material on its ignition
time has been investigated. The ignition time of an infinite area has
been predicted for various materials. Factors to correct the ignition
times for small areas have been calculated.

April 1957.

Fire Research Station,
Boreham Wood,
Herts.

THE EFFECT OF SIZE OF IRRADIATED AREA ON THE SPONTANEOUS IGNITION OF MATERIALS

PART 1: THE EFFECT ON IGNITION TIME

by

D. L. Simms, Margaret Law, P. L. Hinkley and R. W. Pickard

1. Introduction

Materials exposed to radiation from, say, a burning building or an atomic explosion, will be irradiated over a much larger area than specimens tested in the laboratory so that in order to predict the behaviour of these materials on a large-scale consideration must be given to the influence of the actual size of the irradiated area on the experimental results.

Practical considerations limit the size of radiation field available in the laboratory and generally the higher the characteristic temperature of the radiation the smaller the field. Whereas with a 1 ft square gas-fired radiant panel [1] at a temperature of 1,100°K areas of irradiation over 60 cm² can be readily obtained the carbon arc source [2] at about 4,000°K can only provide radiation over an area of order 3 cm². Experiments have been carried out on the ignition of various materials irradiated over different areas. The size of the area affects both the time to ignite and the minimum intensity at which ignition occurs. This report deals with the problem of ignition time. The materials are listed in Table 1. In all cases they were dried at 95°C and allowed to cool over phosphorus pentoxide.

Table 1

Materials used, colour, thickness, weight/unit area, or density

Material	Colour	Weight/unit area g/cm^2	Density g/cm^3	Thickness cm
Fibre insulation board (Type 1)	(Natural) (Blackened)	–	0.26	1.25
Fibre insulation board (Type 2)	Natural	–	0.27	1.25
Filter paper	Black	0.0098	–	0.023
Cotton fabric	White	0.023	–	0.040
Oak	(Natural) (Blackened)	–	0.61	1.25

2. Experimental method and results

Experiments were carried out using three sources of radiation.

2.1. Radiant panel [1]

This is a gas-fired radiant panel 1 ft square operating at a temperature of about 800°C. The experimental method has been described in detail elsewhere [3]. The area irradiated with this source is over 60 cm². A similar panel, 3 ft square, has also been used.

2.2. Tungsten filament lamp and ellipsoidal mirror [4]

Radiation from a tungsten filament lamp placed at the first focus of an ellipsoidal mirror is converged by the mirror to the second focus. The intensity of radiation is uniform to within 90 per cent over an area of 1 cm².

2.3. Carbon arc and ellipsoidal mirror

The apparatus is described in detail elsewhere [2]. The radiation from a high intensity carbon arc lamp is focussed on the specimen by an ellipsoidal mirror in a similar manner to that from the tungsten filament lamp described above. The intensity of radiation is uniform to within 90 per cent over an area of 3 cm².

2.4. Experiments carried out

The experiments were designed to investigate the effect of area irradiated on the time for spontaneous ignition of both thin and thick materials. With the panel source the area of fibre insulation board irradiated was varied either by using specimens of different sizes or by masking off part of the radiation field with asbestos wood shields with holes of different sizes. In the experiments on filter papers which have been carried out more recently an aluminium mask was used.

To investigate the effect of specimen size for a fixed area of irradiation some experiments were carried out with the tungsten filament lamp and carbon arc on specimens with an area larger than the area of irradiation. Some experiments were made with rectangular specimens in front of the radiant panel. No difference was observed between results for 1 in. x 3 in. specimens with the longer side horizontal or vertical (Fig. 13A) and results for rectangular specimens of shape factor 3 : 1 are included in this report in terms of area only.

The range of experiments is shown in Table 2.

Table 2

Areas irradiated and areas of specimens for all experimental conditions

Material	Colour	Source	Area of specimen cm^2	Area of specimen (cm^2) receiving over 90% of peak intensity
Fibre insulation board Type 1	Natural	1 ft sq panel	1.6, 6.5, 14.5 25 58 77	Total
			6.5, 14.5, 26 behind shield	0.65 to 6.5
	Candleblack	1 ft sq panel	1.6, 3.6, 6.5 14.5, 26, 19	Total
			1.6, 6.5 behind shield	0.65 to 6.5
		Tungsten filament lamp	1.6, 6.5, 14.5, 26	1
Fibre insulation board Type 2	Natural	1 ft sq panel	1.6, 6.5, 26, 58 19, 9.7	Total
		3 ft sq panel	26, 58, 77 230, 930	Total
Oak	Natural	Carbon arc	1.6, 6.5, 26	3
	Candleblack	Tungsten filament lamp	1.6, 6.5, 14.5, 26	1
Filter paper	Black	1 ft sq panel	39	1.5, 3.0, 4.5, 9.0, 18 27, 36
		Carbon arc	0.8, 1.0, 4	3
Cotton	White	1 ft sq panel	16, 26, 32 52, 77	Total

2.5. Results

The mean results of the experiments on area are given in Figs. 1A-13A (Appendix). These results have been corrected for absorptivity[5].

2.5.1. Effect of specimen size for given areas of irradiation

For the lamp and carbon arc sources where the irradiated area is less than the area of the specimen the results are independent of the size of the specimen (Figs. 8A-10A). For the shielded specimens the results are also independent of the actual size of the specimen (Figs. 11A and 12A).

2.5.2. Effect of irradiated area

The time taken to ignite at any given intensity increases with decreasing size of irradiated area. The quantitative results can be used to obtain correction factors to apply to experimental results.

3. Minimum representative area and correction factor for ignition time

3.1. Ignition time for infinite irradiated area

From the smooth curves drawn through the results in Figs. 1A-6A the variation of time to ignite with irradiated area "A" has been found for different intensities and by plotting $\frac{1}{\sqrt{A}}$ (the choice of $\frac{1}{\sqrt{A}}$ as the function is one of convenience), against the time to ignite, the ignition time for infinite area "A" has been found by extrapolating the curves to intercept the time axis when $\frac{1}{\sqrt{A}}$ equals zero. It has been assumed that for large values of A time to ignite is independent of area, and the curves have therefore been drawn to intercept the time axis at right angles.

The curves for black filter paper are shown in Fig. 1. Similar curves have been obtained for natural and candleblack fibre insulation board type 1, natural fibre insulation board type 2, and white cotton. The variation of the time to ignite for an infinite area with intensity of radiation is shown in Figs. 14A, 15A, for these materials.

3.2. Minimum representative area

From the curves of $\frac{1}{\sqrt{A}}$ against ignition time it is possible to find the minimum areas above which there is an error of less than 10 per cent or 20 per cent in the measured ignition time as compared with that for an infinite area. These minimum representative areas are plotted as a function of intensity in Figs. 2 and 3.

The minimum representative area is a rapidly varying function of intensity for intensities below about 3 cal cm^{-2} sec^{-1}. The results show a very large scatter and though there seems to be some evidence of systematic differences between materials these differences can probably be ignored within the accuracy of these experiments and correlations. It is assumed that above 2.5 cal cm^{-2} sec^{-1} there are similarly no differences, and the results for black filter paper are therefore applied to other materials for higher intensities. Above 3 cal cm^{-2} sec^{-1} the minimum representative area is practically constant at about 10 cm^2 for a 10 per cent error and 3 cm^2 for a 20 per cent error in ignition time.

3.3. Correction factor for ignition time

From the graphs of $\frac{1}{\sqrt{A}}$ against ignition time the factor to correct the time to ignite for a given area to that for an infinite area can be found.

Most of the work using the radiant panel source has been carried out with specimens measuring 5 cm x 5 cm. The correction necessary to reduce these results to those for an infinite area is shown in Fig. 4 as a function of the intensity of radiation. The correction factor can probably be neglected for intensities greater than about 2 cal cm^{-2} sec^{-1}.

The correction factor for the ignition times obtained using the carbon arc source is shown in Fig. 5 for black filter paper. For intensities above about 3 cal cm^{-2} sec^{-1} it is constant at 0.8 and it is assumed that the correction factor is the same for the other materials. In calculating this factor it has been arbitrarily assumed that the area of irradiation of the carbon arc source is the area in which the intensity is over 90 per cent of the maximum value in the centre of the field.

4. Effective area of irradiation of carbon arc source

As the distribution of intensity from the carbon arc source is not uniform it is necessary to define an effective area of irradiation for this source if the results are to be correlated with those for other sources. The intensity is uniform to within 90 per cent of the peak value over an area of 3 cm^2 and the variation in ignition time with peak intensity for specimens of black filter paper (i.e. where the absorptivity is the same for all kinds of radiation) not less than 3 cm^2 in area is in close agreement with that for specimens 3 cm^2 in area receiving uniform radiation from the panel. For this type of source it is probably valid, therefore, to define the effective area of irradiation as the area receiving over 90 per cent of the peak value.

5. Discussion

It is interesting to consider the origin of this effect of the size of the irradiated area. It can be estimated that for the range of ignition times and sizes of irradiated area in these experiments that lateral conduction in the solid is negligible [5]. Convective losses per unit area at the exposed face are not independent of linear size, but the variation in heat loss and therefore presumably its effect on ignition time may be calculated to be small. The effect of area lies presumably in its effect on the stream of volatiles. This would be understandable because the mixing of the flammable gases evolved from the surface with oxygen will depend on the size of the volatile stream. These questions are discussed elsewhere [6].

6. Conclusions

For a specimen of material receiving a given intensity of radiation the time to ignite increases as the area of irradiation decreases, the ignition time depending on the area irradiated and not on the size of the specimen. The increase in time to ignite is greater at low intensities of radiation and for decreasing areas of irradiation the minimum intensity at which ignition will occur increases.

The experimental results for materials irradiated over a small area may be corrected to predict the ignition time for an infinite area of material. The minimum representative area for a 20 per cent error has been found to be approximately constant and about 3 cm^2 for intensities of radiation greater than 3 cal cm^{-2} sec^{-1}. The correction factor to the ignition times of natural and blackened fibre insulation board (types 1), black filter paper, natural fibre insulation board (type 2) and white cotton has been found and for the carbon arc source the factor is constant, equal to about 0.8 for intensities of radiation greater than 3 cal cm^{-2} sec^{-1}

References

1. Simms, D. L. and Miller, Joan. Radiant characteristics of a gas-fired panel. Department of Scientific and Industrial Research and Fire Offices' Committee Joint Fire Research Organization. F.R. 217/1955.

2. Hinkley, P. L. A source of high intensity radiation employing an arc lamp and an ellipsoidal mirror. Department of Scientific and Industrial Research and Fire Offices' Committee Joint Fire Research Organization. F.R. 270/1956. Restricted.

3. Lawson, D. I. and Simms, D. L. The ignition of wood by radiation. Brit. J. App. Phys. 1952, 5, 288-292.

4. A source of radiation employing a tungsten filament lamp and ellipsoidal mirror. In preparation.

5. Simms, D. L., Law, Margaret and Hinkley, P. L. The effect of absorptivity on the ignition of materials by radiation. Department of Scientific and Industrial Research and Fire Offices' Committee Joint Fire Research Organization. F.R. 308/1957.

6. Thomas, P. H. and Simms, D. L. Some practical limitations to the use of small irradiated areas on solids. Department of Scientific and Industrial Research and Fire Offices' Committee Joint Fire Research Organization. F.R. 163/1955.

7. Simms, D. L. The mechanism of ignition. Department of Scientific and Industrial Research and Fire Offices' Committee Joint Fire Research Organization. In preparation.
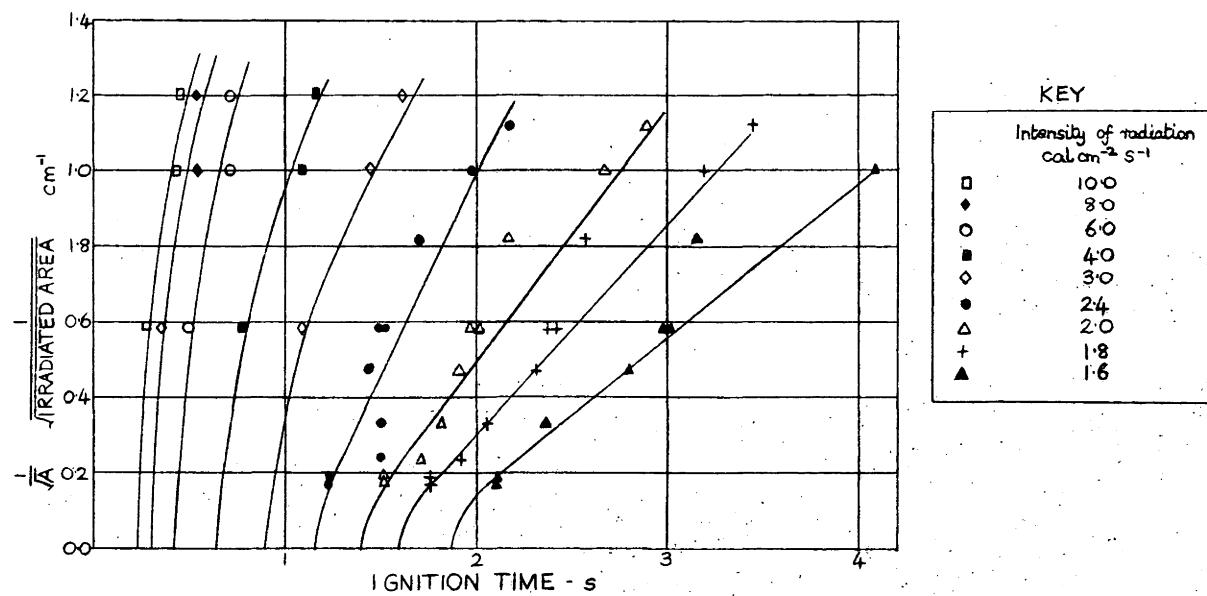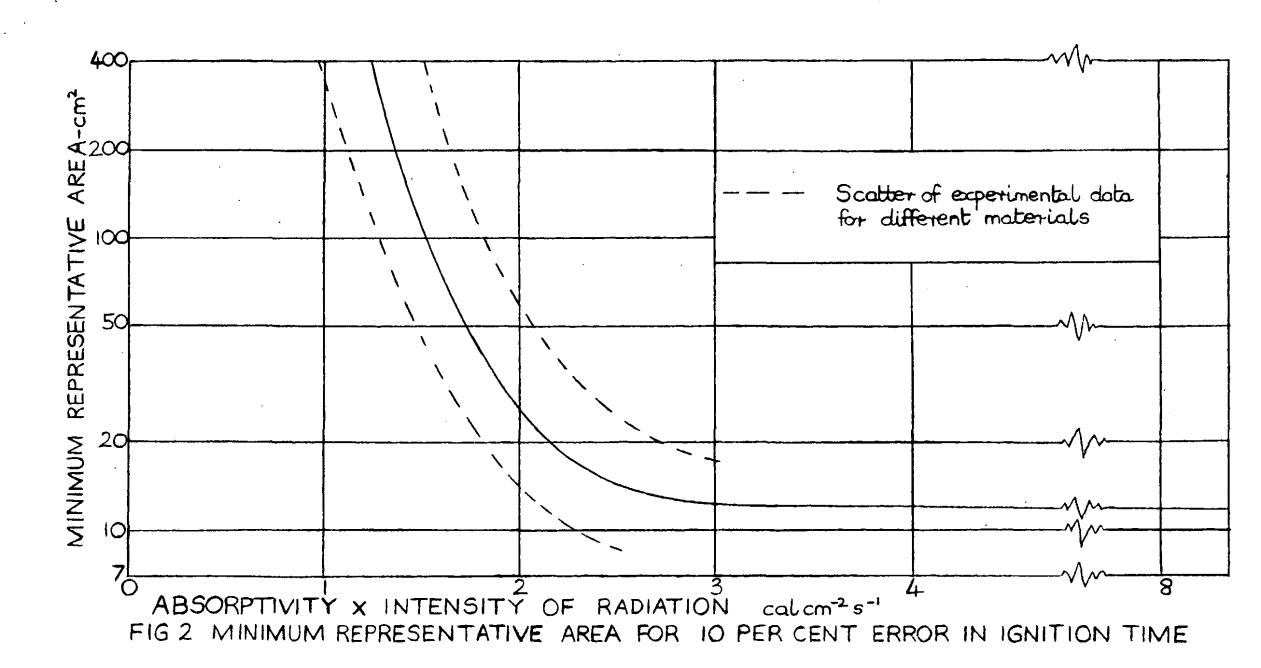
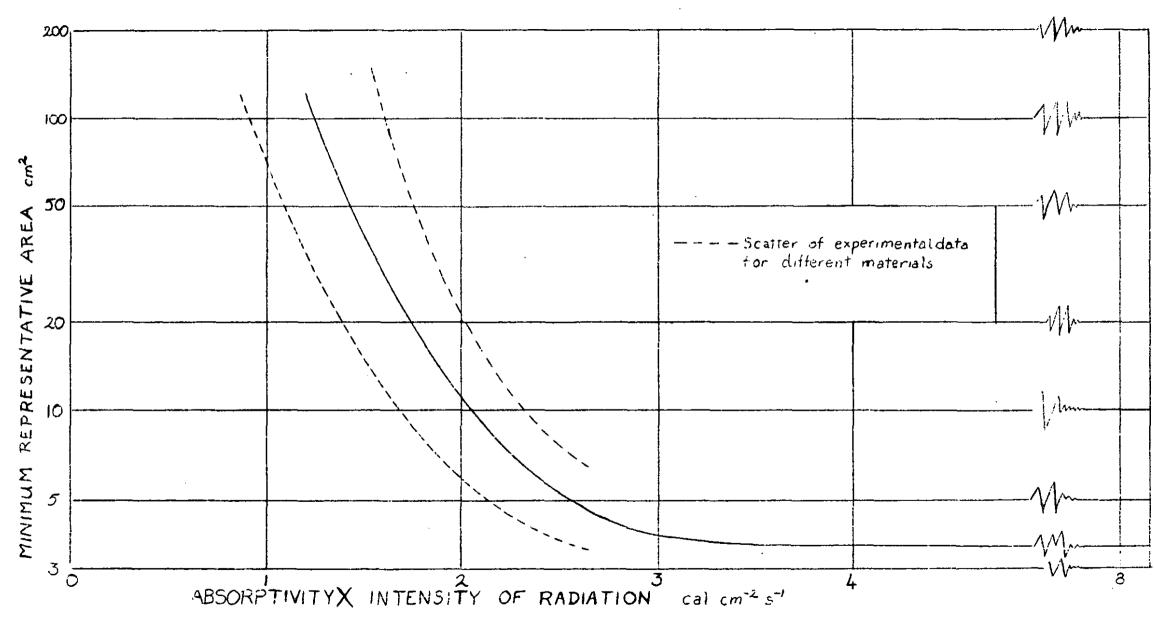FIG I VARIATION OF IGNITION TIME WITH IRRADIATED AREA OF BLACK FILTER PAPER FOR DIFFERENT INTENSITIES OF RADIATION

KEY

Intensity of radiation cal cm^{-2} s^{-1}

Symbol	Intensity
□	10·0
◆	8·0
○	6·0
■	4·0
◇	3·0
●	2·4
△	2·0
+	1·8
▲	1·6

Y-axis: $\dfrac{1}{\sqrt{\text{IRRADIATED AREA}}}$ $\dfrac{1}{\sqrt{A}}$ cm^{-1}

X-axis: IGNITION TIME - s

FIG 2 MINIMUM REPRESENTATIVE AREA FOR 10 PER CENT ERROR IN IGNITION TIME

FIG 3 MINIMUM REPRESENTATIVE AREA FOR A 20 per cent ERROR IN IGNITION TIME
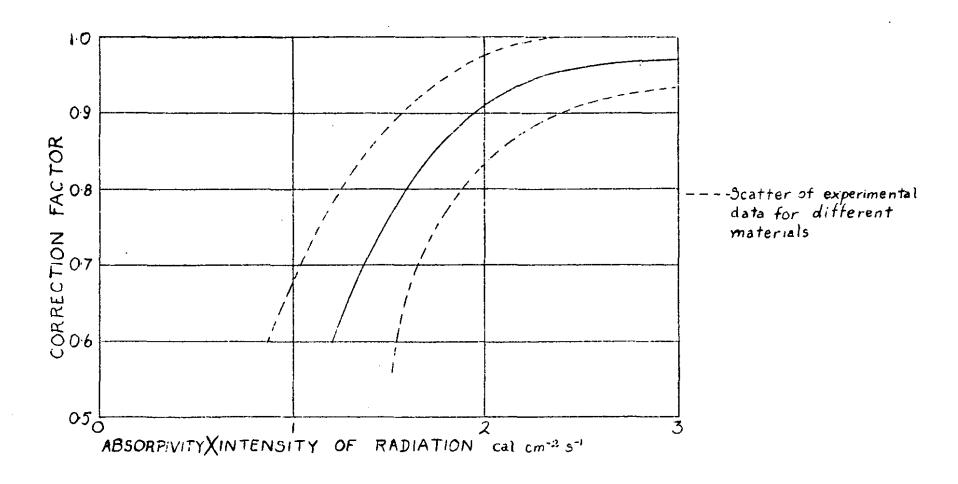
FIG 4 FACTOR TO CONVERT IGNITION TIMES FOR A 25 cm² AREA IRRADIATED BY THE RADIANT PANEL TO THOSE FOR AN INFINITE AREA
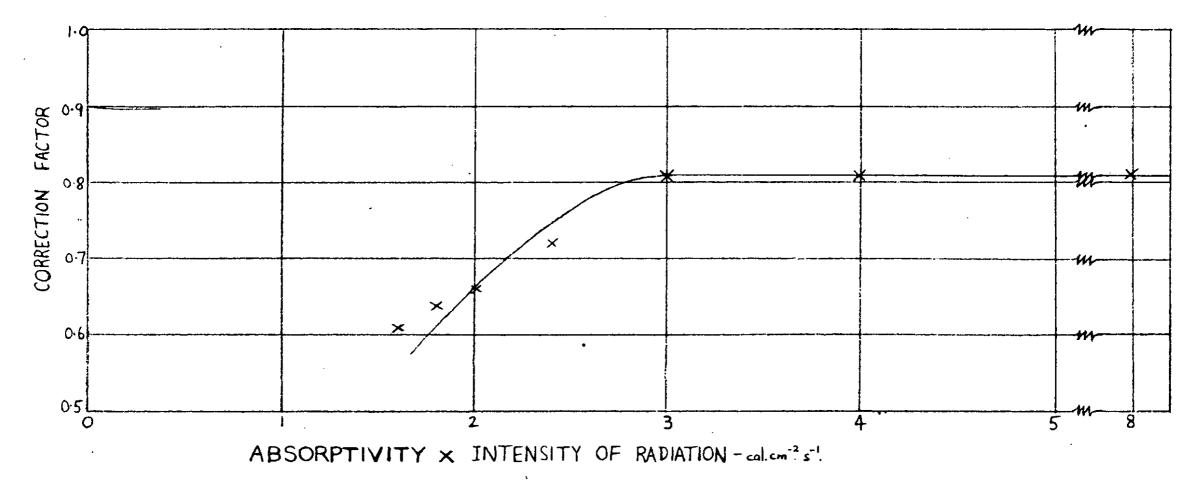
FIG. 5. FACTOR TO CONVERT IGNITION TIMES FOR A SPECIMEN IRRADIATED BY THE CARBON ARC
SOURCE (3 cm²) TO THOSE FOR AN INFINITE AREA.