F.R. Note No. 252/1956
Research Programme
Objective F4/6 (P)

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION



# THE DOMESTIC FIRE HAZARD CREATED BY FLYING COALS AND SPARKS

by

J. H. McGuire, Margaret Law and Joan E. Miller

## Summary

The report gives the results of experiments to determine the probabilities of ignition of various types of material by a range of sizes of hot coal. The theoretical probabilities that such coals will pass freely through a spark guard typical of those on the market are also given and the two probabilities are combined to give an assessment of the value of the particular spark guard.

June, 1956.

Fire Research Station,
Boreham Wood,
Herts.

THE DOMESTIC FIRE HAZARD CREATED BY FLYING COALS AND SPARKS

by

J.H. McGuire, Margaret Law and
Joan E. Miller

1) Introduction

This investigation is concerned with the fire hazard created by flying coals and sparks from domestic open fires.

It was not feasible to reproduce in the laboratory, with a domestic open fire, the conditions to be investigated and a laboratory experimental approach to the problem has been devised. The results given in this report concern the probabilities of ignition of various types of material by various sizes of coal combined with an estimation of the probability of such coals passing freely through a spark guard typical of those on the market.

2) Choice of Experimental Procedure

In simulating the conditions in which a spark or flying coal might ignite a specified material in a domestic dwelling the following three factors must be considered:- a) the heating of the coal, b) the application of the coal to the material and c) the disposition of the material.

In preliminary experiments an electric oven at a temperature of approximately 900°C (representing a glowing fire) was used to heat the pieces of coal. It was found however that it was easier to ignite materials when the coals were heated in a bunsen flame (representing a roaring fire). With the bunsen flame there is a greater heat transfer to the coal; thus a piece of coal can be ignited quickly and can be dropped on to a specimen of material whilst it is still evolving enough volatiles to maintain flaming. It was therefore decided to heat coals with a bunsen burner throughout the experiments.

The pieces of coal were heated directly above the specimen of material and merely had to fall six inches.

The most hazardous disposition of the material is one in which the heat transfer from the piece of coal is a maximum whilst the air supply remains sufficient to maintain combustion. To meet these conditions the arrangement illustrated in Figure 1 and Plate 1 was used. Using one material and pieces of coal of the same weight preliminary tests were carried out to determine the angles between the material, the asbestos board and the horizontal which resulted in the highest frequency of ignition. These were found to be approximately the values illustrated in Figure 1 and these values were maintained throughout the subsequent tests.

The coal used in all the tests was Midland Singles, which is a bituminous, high-volatile, non-coking coal. It was broken up into small prisms with relative dimensions of the order of 2 x 1 x 1.

3) Materials Tested and Results

The following materials were tested:

a) Cotton Weight/unit area = $1\cdot2 \times 10^{-2}$ gm/cm²
b) Viscose Rayon Net " " " = $1\cdot8 \times 10^{-3}$ gm/cm²
c) Scrim " " " = $2\cdot2 \times 10^{-2}$ gm/cm²
d) Newspaper("The Times") " " = $5\cdot5 \times 10^{-3}$ gm/cm²
e) Belgian Cotton Carpet " " " = $0\cdot12$ gm/cm²
f) Surgical Cotton Wool

All specimens of material were dried before testing and about a 100 tests were made on each material with pieces of coal of various sizes.

Ignition of cotton wool was found to be easily possible with pieces of coal weighing only 0·005 gm. As this weight corresponds to a diameter of 0·075 inches for a spherical particle it was concluded that cotton wool would always present a hazard and that it would not be practicable to design a spark guard to overcome this.

With Belgian Cotton Carpet laid horizontally as in practice, no continuing fire was started when pieces of flaming coal with dimensions of the order of 0·5 inch were dropped on it. It was therefore concluded that this material did not present an appreciable hazard from this point of view and again no further tests were made.

The results for the remaining materials are presented in the form of histograms in Figures 2, 3, 4 and 5. In the case of scrim, ignition was found to be much easier if the scrim had been brushed before testing. Its appearance resembled the scrim commonly found underneath arm chairs. All specimens of scrim were therefore brushed before testing.

## 4. Interpretation of Results

The probability of ignition occurring when a live coal of a given size falls on a material has been assessed by probit analysis of the experimental results (Appendix 1) and the probit curves are shown in Figures 2 - 5. Coal fires eject hot coals over the size ranges illustrated but the probability of a given size of coal being ejected is not known. The results can however be used to assess the value of a spark guard. The probability of a piece of coal passing through a spark guard depends on the guard mesh and on the size and shape of the coal. An 8 mesh to the inch 22 S.W.G. guard is in common use and has been considered in this note. The effect of the size and shape of the piece of coal on the probability of passing through the guard is considered in Appendix 2. The maximum probability of a piece of coal irrespective of its shape passing freely through the guard is shown in Figure 6. By combining this probability curve with the probit curves it is possible to calculate the probability of a given size of coal both passing through the guard and igniting a material. This is illustrated in Figure. 7.

## Conclusions

The probability of a piece of burning coal igniting combustible material depends on the type of material and increases with the weight of the piece of coal. Of the materials tested (cotton wool, viscose rayon net, brushed scrim, newspaper, cotton and Belgian cotton carpet ) only Belgian cotton carpet would not give a continuing fire when a flaming piece of coal with dimensions of the order of 0·5 inch was dropped upon it.

The size of coal required to ignite cotton wool is so small that particles which have a high probability of causing ignition will easily pass through a spark guard typical of those on the market (having 8 mesh to the inch, 22 S.W.G.). For the remaining materials tested, however, the use of such a spark guard will substantially reduce the fire hazard. The probabilities of the optimum sizes of coal both passing through the guard and causing ignition are less than 0·004% for scrim, 0·0015% for rayon net, 0·0005% for newspaper and 0·0001% for cotton.

Appendix 1

Probit analysis

Analysis of the experimental results has been carried out on the assumption that the probability of ignition is Gaussian with respect to the cube root of the mass of the coal. Probit lines have been calculated on this assumption and their linearity has been tested by the $\chi^2$ test.

The equations of the probit lines for the four materials are given in Table 1 together with the 95% confidence limits

where y is the probit corresponding to a probability of ignition p

$$x = m^{\frac{1}{3}} \times 10$$

and m is the mass of coal in gm. which gives probability of ignition p

Table 1 Probit Analysis of the ignition of various materials

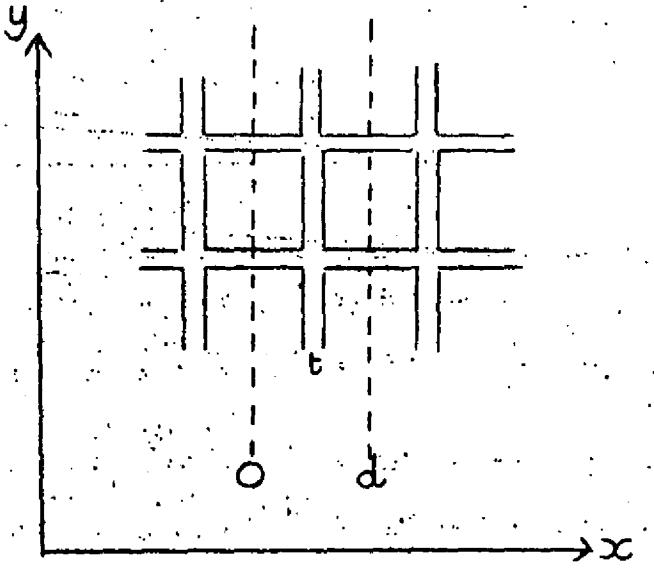
| Material | Probit line | 95% confidence limits to x. |
|---|---|---|
| Cotton | $y = 1{\cdot}441x - 2{\cdot}634$ | $1{\cdot}12x - 0{\cdot}65 \pm 1{\cdot}52\sqrt{0{\cdot}018 + 0{\cdot}057(x - 5{\cdot}45)^2}$ |
| Net | $y = 2{\cdot}509x - 3{\cdot}842$ | $1{\cdot}17x - 0{\cdot}62 \pm 0{\cdot}92\sqrt{0{\cdot}034 + 0{\cdot}241(x - 3{\cdot}62)^2}$ |
| Brushed Scrim | $y = 0{\cdot}986x + 0{\cdot}338$ | $1{\cdot}08x - 0{\cdot}37 \pm 2{\cdot}14\sqrt{0{\cdot}009 + 0{\cdot}018(x - 4{\cdot}9)^2}$ |
| Newspaper | $y = 2{\cdot}437x - 4{\cdot}634$ | $1{\cdot}15x - 0{\cdot}61 \pm 0{\cdot}93\sqrt{0{\cdot}026 + 0{\cdot}204(x - 4{\cdot}04)^2}$ |

## Appendix 2 The Probability of a Particle Passing Freely through a Mesh

The following analyses are confined to the probability of a particle passing freely through a mesh. It has been assumed that a particle which engages with the mesh, but yet passes through, will have lost so much energy that it will fall to the hearth near to the guard and will thus not constitute a severe fire hazard.

Since no information is available as to the distribution of the geometrical shapes of the particles it is only possible to assess the maximum probability by considering extremes of shapes. For spherical particles the probability must fall to zero at some critical size, but for slender particles it must always remain finite. The following analyses refer to spherical and cylindrical particles.

a) Spherical particle



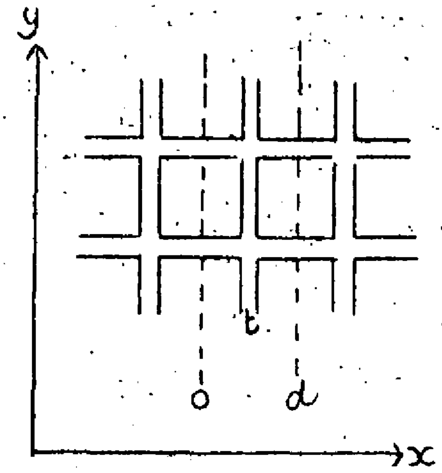

The total probability may be considered as the product of the probability of a sphere not engaging on a horizontal wire and the probability of a sphere not engaging on a vertical wire. The probability of a particle not striking a vertical wire will now be discussed. If the centre of a particle of diameter D lies within the x co-ordinate zero and d, the probability of its centre lying in any range $\delta x$ is $\delta x/d$. The particle will not strike the wire if the x co-ordinate of its centre lies within the range zero and $\frac{d}{2} - \frac{t}{2} - \frac{D}{2}$ or the range $\frac{d}{2} + \frac{t}{2} + \frac{D}{2}$ and d, i.e. a range d - t - D.

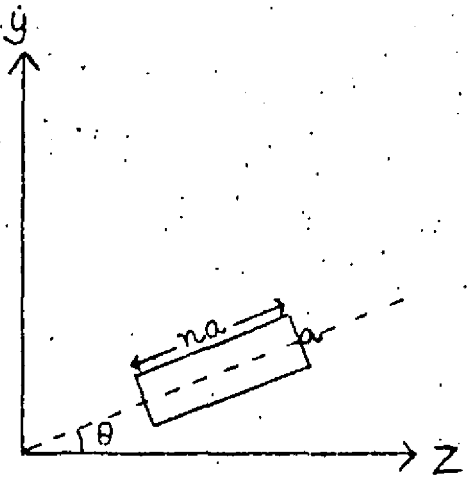
The probability of this occurring is $\frac{d - t - D}{d} = 1 - \frac{D + t}{d}$.

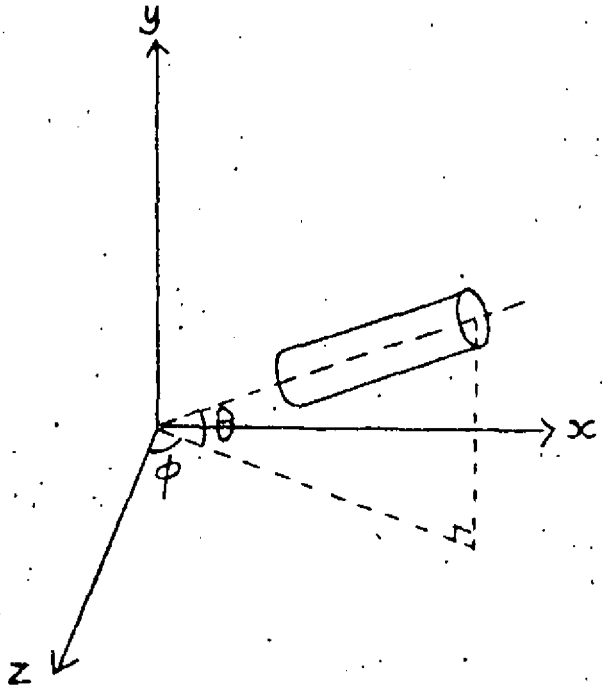
Of the particles which will not strike the vertical wires the fraction which will not strike the horizontal wires is also $1 - \frac{D + t}{d}$.

The probability a particle passing freely through the mesh is therefore $(1 - \frac{D + t}{d})^2$.

b) Cylindrical particle




The particle will be considered to have random orientation and direction of flight normal to the mesh. This latter assumption will lead to the hazard being somewhat over estimated and the results will therefore be conservative.

If the cylinder has diameter a length na and the axis makes an angle $\theta$ with the zx plane then the projection of the cylinder in the y dimension is

$$D_H = na\sin\theta + a\cos\theta$$

For a given $\theta$ the probability of passing freely between the horizontal wires is (from Section (a) )

$$P_H = 1 - \frac{D_H + t}{d} = 1 - \frac{a}{d}(n\sin\theta + \cos\theta) - \frac{t}{d}$$

The probability that $\theta$ will lie within the limits $\theta$ and $\theta + d\theta$ varies as $\cos\theta$
Combining these two possibilities gives $dP_H = \left\{1 - \frac{a}{d}(n\sin\theta + \cos\theta) - \frac{t}{d}\right\}\cos\theta \, d\theta$

where the limits of $\theta$ are $0$ and $\theta'$
and $a(n\sin\theta' + \cos\theta') = d - t$
If the axis of the cylinder makes an angle $\phi$ with the yz plane then the projection of the cylinder in the x dimension is given, for small values of $\theta$ by

$$D_V \simeq na\cos\theta\sin\phi + a\cos\phi$$

The probability of passing between the vertical wires for a given $\theta$ and $\phi$ is

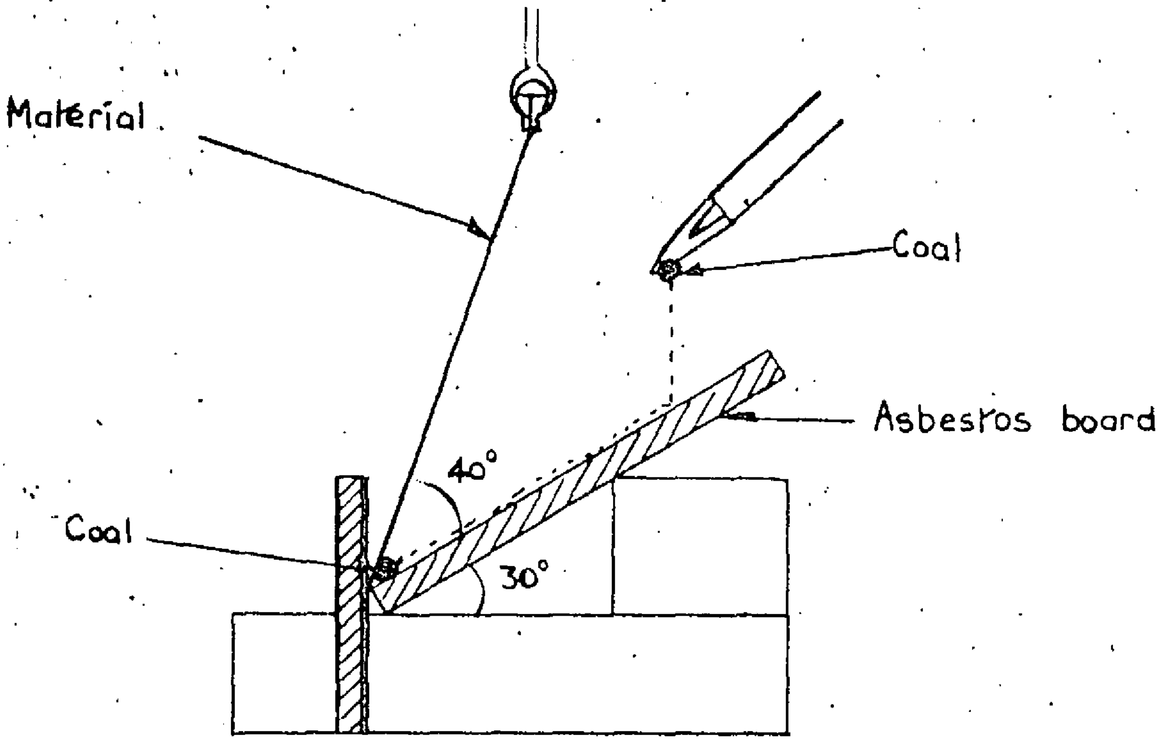



FIG. 1. PLAN OF APPARATUS

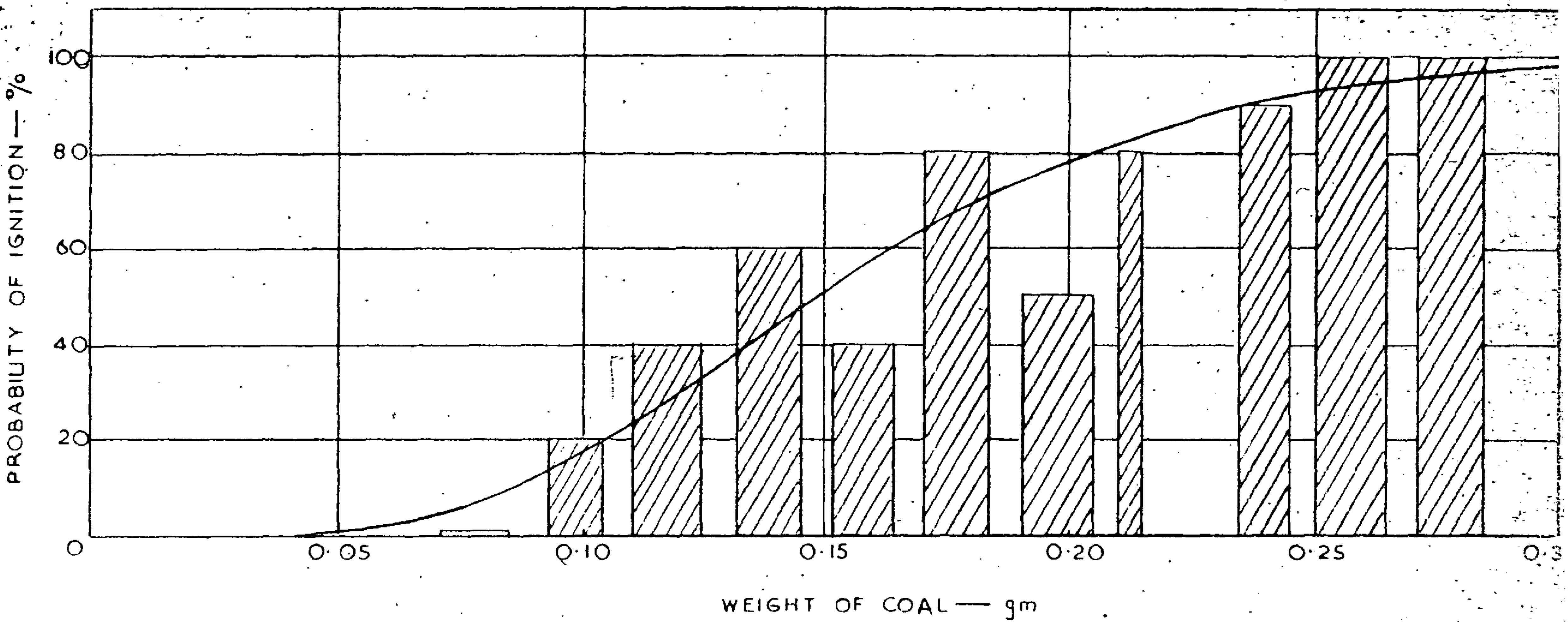



FIG. 2. PROBABILITY OF A PIECE OF COAL IGNITING COTTON

FR. 252 1/2299

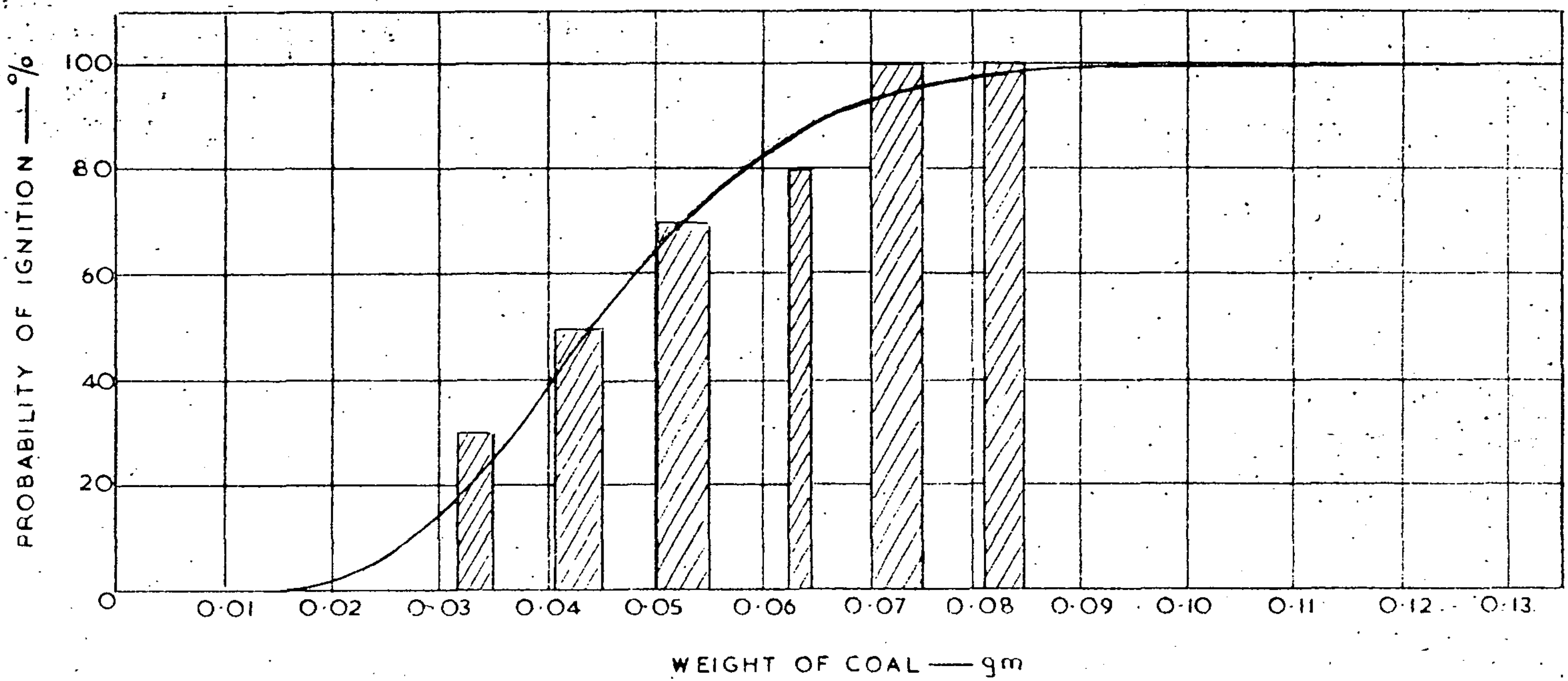



FIG. 3. PROBABILITY OF A PIECE OF COAL IGNITING VISCOSE RAYON NET

F.R. 252. 1/2300

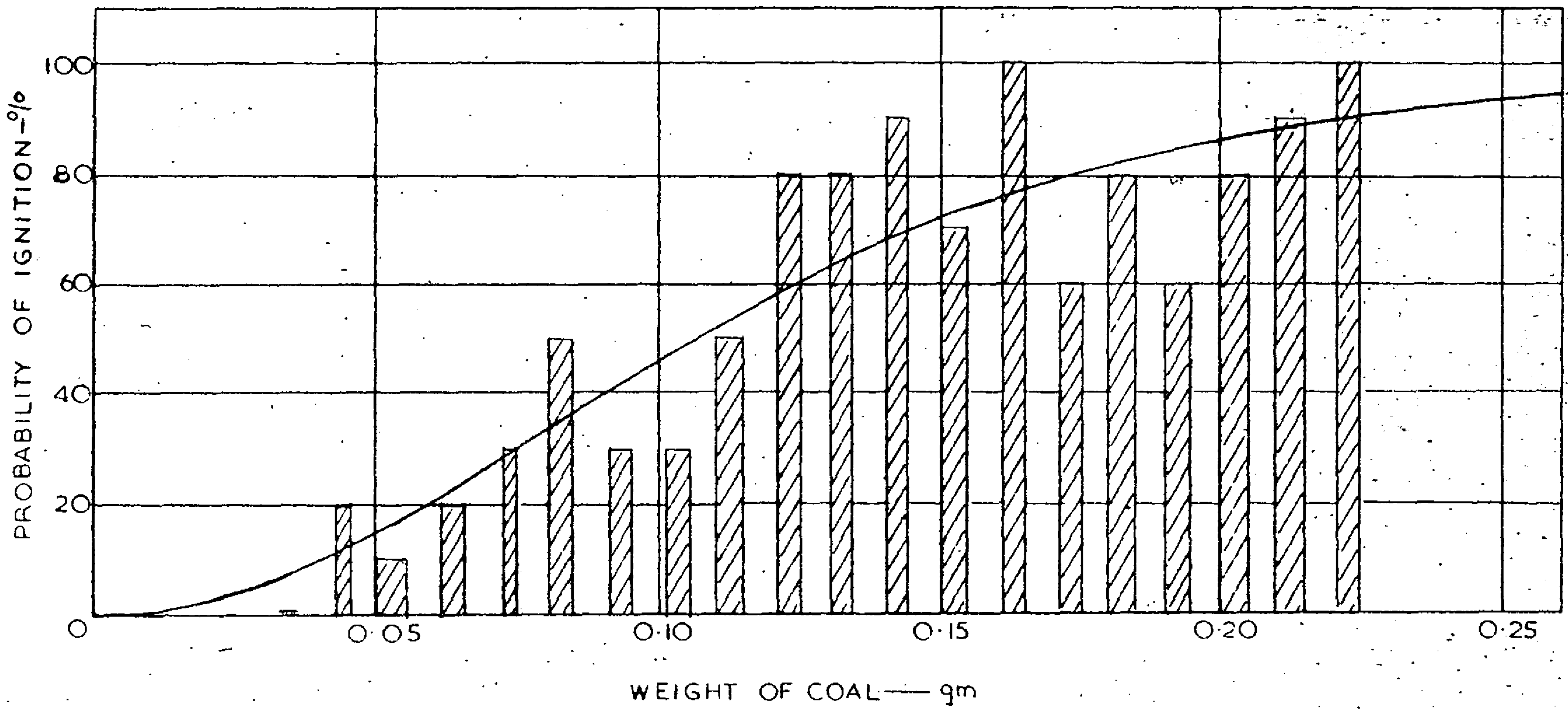



FIG.4. PROBABILITY OF A PIECE OF COAL IGNITING BRUSHED SCRIM

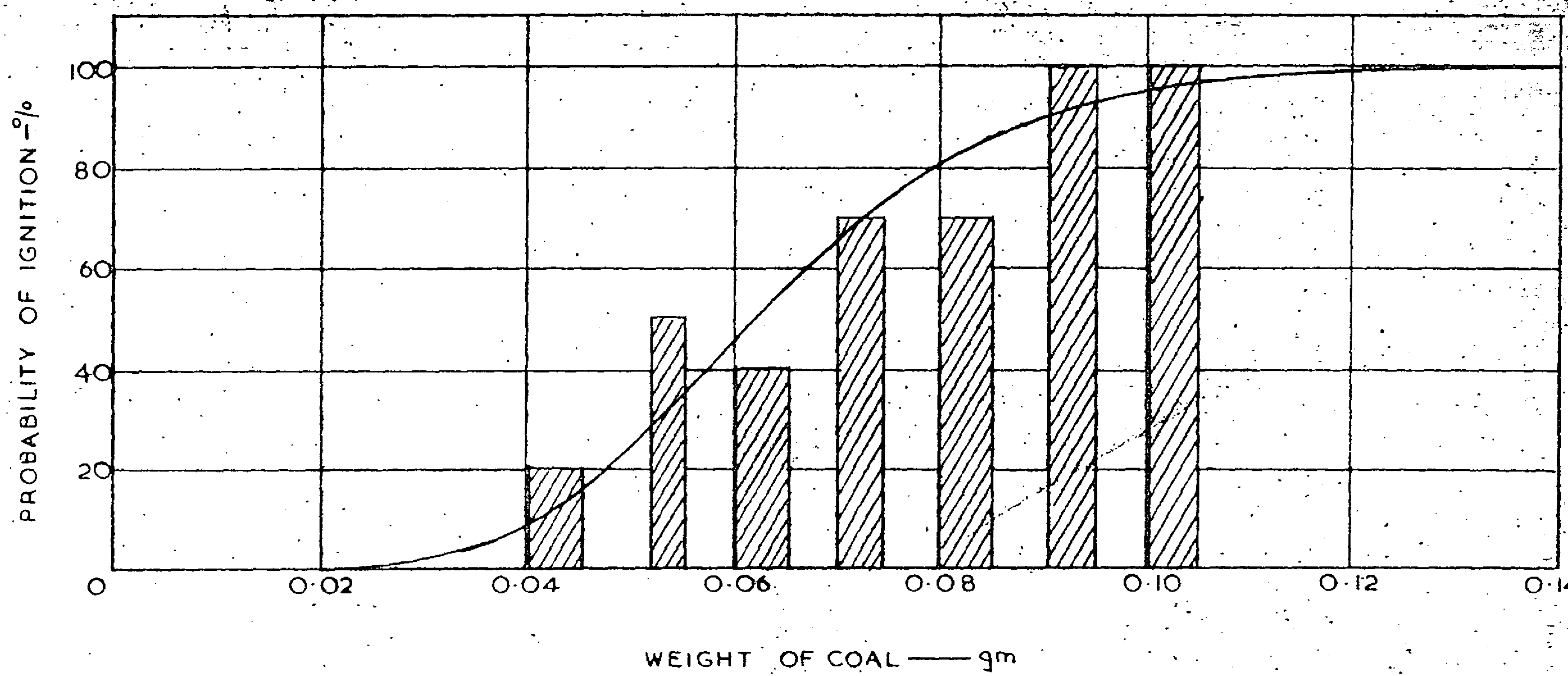



FIG. 5. PROBABILITY OF A PIECE OF COAL IGNITING NEWSPAPER

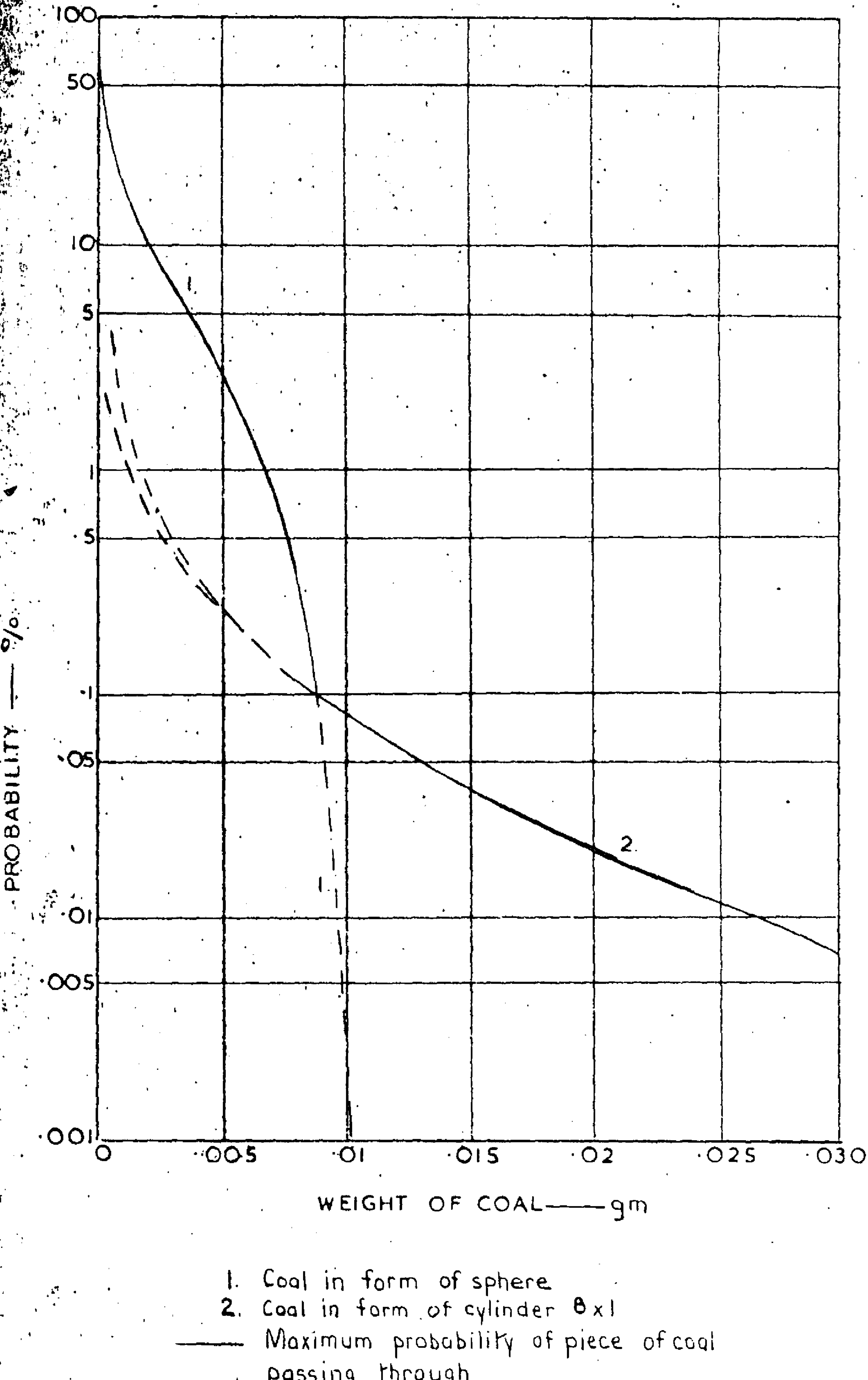



FIG. 6. PROBABILITY OF A PIECE OF COAL PASSING FREELY THROUGH THE SPARK GUARD

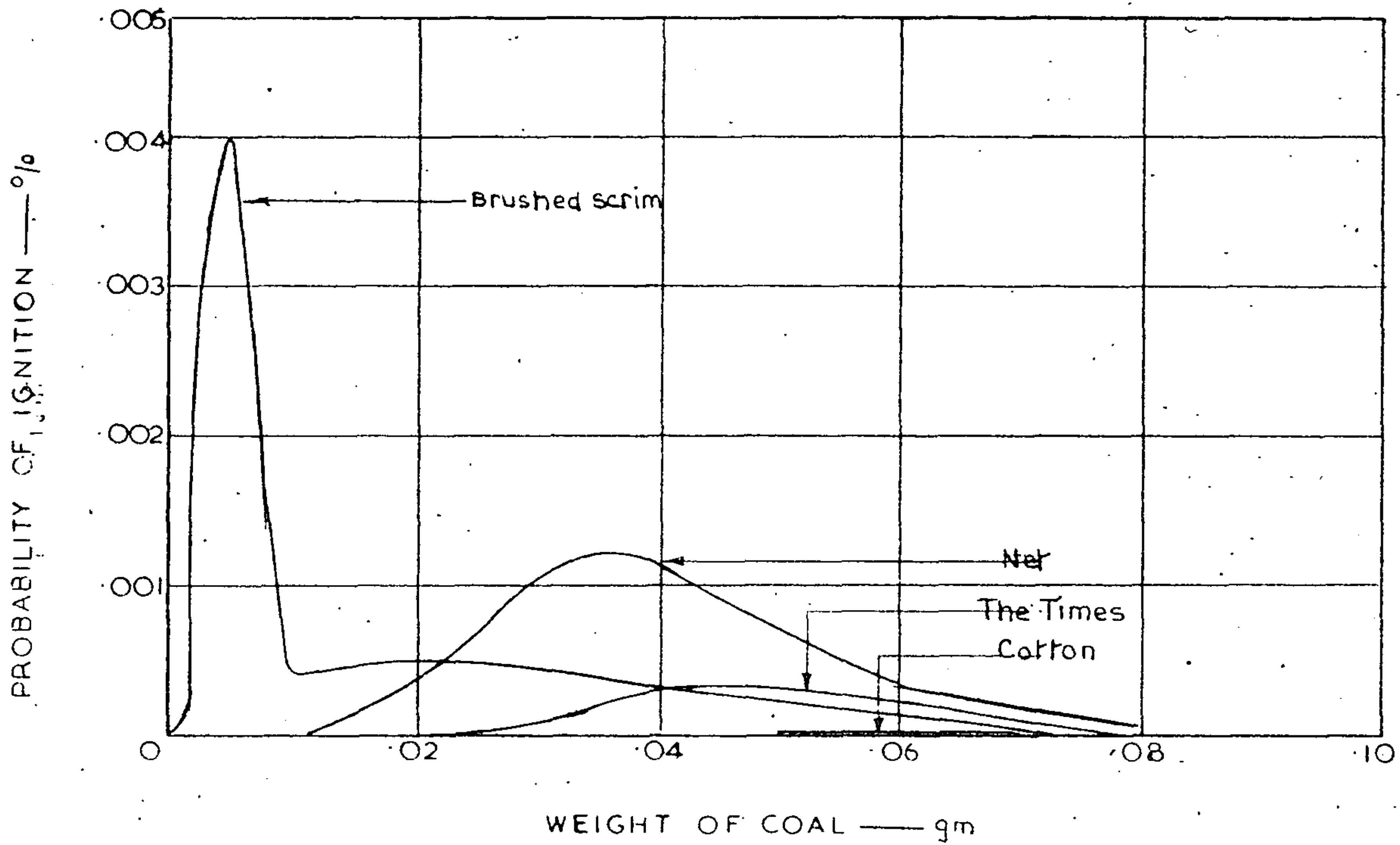



FIG. 7. PROBABILITY OF A PIECE OF COAL PASSING THROUGH THE GUARD AND CAUSING IGNITION OF MATERIAL

PLATE. I. VIEW OF APPARATUS

DS 10103/1