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

THE PERFORMANCE OF SPARK GUARDS

by

J. H. McGuire & Margaret Law

Summary

The probabilities that various sizes of live coal will ignite various domestic materials have been determined. In addition the maximum probability that a coal will pass through a mesh has been calculated. Combining the two results has given a measure of the efficiency of spark guards in reducing fire risk.

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1. Introduction

The fire brigades in the United Kingdom are notified of about 6,000 incidents each year in which domestic open fires, either guarded or not, are responsible for igniting nearby materials other than structural timber underneath the hearth. Although all means of ignition (e.g. clothing falling on to the fire whilst being aired, ignition by radiation etc) are included in arriving at the above figure it is probable that the use of almost any form of spark or fire-guard * would substantially reduce the figure since it would ensure that combustible materials were kept clear of hot coals. The scope of this note is confined to the fire risk created by flying coals and sparks and the reduction in this risk which can be brought about by the use of a spark guard. The ignitability of materials by flying coals and sparks has been determined experimentally and the effect of using a spark guard has been assessed by combining the above results with predictions of the probability that a live coal will pass through a specified spark guard mesh.

The effect of the use of a spark guard on room heating is also discussed and brief reference is made to the use of non-flammable nylon net as a spark guard.

2. The Ignition of Domestic Materials by Live Coals

In the experimental work standard conditions were obtained by heating the coals in a bunsen flame. They were thus ignited quickly and could be projected on to the samples of material whilst still distilling volatiles at a sufficient rate to maintain flaming. To represent the most hazardous conditions likely to be encountered in practice, the coals were dropped direct on to the material, a distance of about three inches.

The experimental disposition of the material was as shown in Fig.1 and Plate 1 and gave conditions of air supply to the coal and heat transfer between the coal and the fabric which favoured ignition.

The coal used in all the tests was Midland Singles, which is a bituminous, high volatile, non-coking coal.

Table 1 lists the materials tested for ignition by burning coals.

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* A fire-guard is a rigidly fixed device intended firstly to prevent children and infirm people from falling on to the fire and secondly to reduce the risk of ignition of clothing which, whilst being worn, might otherwise be brought into contact with hot coals. A spark guard is a device intended to retain flying coals and sparks and is usually not as robust as a fire-guard.

TABLE I

MATERIALS TESTED

Material	Weight/unit area
Cotton	1.2×10^{-2} gm/cm^2
Viscose Rayon Net	1.8×10^{-3} gm/cm^2
Hessian Scrim	2.2×10^{-2} gm/cm^2
Newspaper ("The Times")	5.5×10^{-3} gm/cm^2
Belgian Cotton Carpet	0.12 gm/cm^2
Surgical Cotton Wool	———

All the specimens of material were dried before testing and the scrim was brushed since it was found to be more easily ignited in this condition. Its appearance, when brushed, resembled that of the scrim commonly found underneath arm chairs.

Cotton wool, irrespective of its disposition, was readily ignited by pieces of coal weighing only 0.005 gm. As this weight corresponds to a diameter of only 0.075 inch 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, 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 no further tests were made on it.

The results for brushed scrim are shown in Fig.2 in the form of a histogram in which each block represents ten experiments. It has been assumed that a finite probability of igniting materials exists even for coals smaller than those tested and a probability curve for all ranges of weight of coal has been calculated by probit analysis (see Appendix I). This is also shown in Fig.2. The adoption of probit analysis automatically involves the assumption that a finite (though very small) probability of igniting a material exists even for an infinitely small piece of coal whereas theoretically there is almost certainly a threshold energy level below which a fire cannot be initiated. The consequent exaggeration of the hazard where very small coals are concerned will influence the estimation of the performance of spark guards. This effect will be discussed later.

A probit analysis was made of the histograms derived from testing the remaining materials and the resulting probability curves (including that for brushed scrim) are shown in Fig.3.

3. The Performance of Spark Guards

(a) The Reduction in Fire Risk

Expressions have been derived (see Appendix II) from which the maximum probability that a piece of coal will pass through any specified square mesh may be calculated. Combining such data with the results given earlier in this note gives the maximum probability that a live piece of coal will both pass through a spark guard and ignite a sample of material on which it falls.

The meshes considered were 8 mesh and 6 mesh 22 S.W.G., 4 mesh 20 S.W.G. and two permanent finish non-flammable nylon* meshes illustrated in Plate 2.

The size distribution of the coals and sparks emitted by open fires is not known, but the probability of a coal of any size both passing through a given mesh and igniting a material will not exceed a maximum value. The maximum values for the various meshes, taken from Figs. 4-8, are listed in Table 2 and can be taken as a measure of the efficiency of a spark guard in reducing fire risk. If no guard is used the probabilities of ignition for weights of coal greater than about 0.2 gm tend to unity with the experimental conditions adopted.

TABLE 2

MAXIMUM PROBABILITIES OF IGNITION OF THE MATERIALS LISTED IN TABLE 1

Guard		Maximum probability of ignition (parts per million)
8 mesh 22 S.W.G.		40 ppm.
6 mesh 22 S.W.G.		340 "
4 mesh 20 S.W.G.		24,000 "
Non-flammable	Nylon A	3.3 "
	Nylon B	34 "

The extrapolation, by probit analysis, of the curves for probability of ignition (Fig.3) may exaggerate the hazard where sizes of coal of less than 0.03 gm are considered. As regards Table 2 this will have the effect of minimising the value of the finer mesh guards.

To confirm that the non-flammable nylon nets would in fact not melt in practice, they were hung vertically and, whilst subjected to an intensity of radiation of 0.5 cal. cm^2 sec. (representing the maximum intensity they would receive from an open fire), flaming coals with linear dimensions up to half an inch were projected on to them. The nets were structurally undamaged. If a hot coal rested against either of the nets however the nylon in contact with the coal melted.

(b) The Effect on Room Heating

A domestic open fire heats a room largely by radiation and the use of a guard will reduce radiative heating by, to a close approximation, the amount which is intercepted by the elements of the mesh. The consequent heating of the guard contributes little to the heating of a room because the guard is cooled by the substantial airflow from the room which passes directly up the flue. As a measure of the reduction in radiation the obscuration has been calculated in the case of the metal meshes and measured experimentally in the case of the nylon nets. The results are given in Table 3.

* The non-flammable nylon net used is bonded with a low melting temperature agent so that, if subjected to a flame, it melts before spreading flame.

TABLE 3

OBSCURATION

Guard	Obscuration
8 mesh 22 S.W.G.	40 %
6 mesh 22 S.W.G.	30 %
4 mesh 20 S.W.G.	27 %
Non-flammable (Nylon A	13 %
Non-flammable (Nylon B	18 %

(c) Strength of meshes

Spark guards with metal meshes have been widely used for many years and have been found to be satisfactory from the strength point of view. The three meshes considered are typical of those on the market and are adequately strong. Nylon net guards, however, have never been available and although they are strong enough to deflect hot coals they might be damaged by misuse. It was found that Nylon A could be punctured by forcing a pencil against it but that Nylon B was considerably more robust and should be able to stand considerable rough usage.

4. Conclusions

The results in Tables 2 and 3 show that the 6 and 8 mesh guards are far more effective than the 4 mesh guard in reducing fire risk whilst the amounts by which they reduce room heating are increased by much smaller factors.

The nylon meshes are superior to the wire meshes both in their efficiency in reducing fire risk and in the extent by which they reduce room heating. They are however not quite so robust and of course if hot coals come to rest against them they will melt. This might happen if the nylon net extends down to hearth level and large coals fall on the hearth.

Nylon net will have a valuable application in the manufacture of combined fire and spark guards. To date these have not been popular since, if constructed of fine wire mesh, they substantially reduce room heating. By using a nylon instead of a fine wire mesh this effect will be much less marked.

It should be noted that, of the domestic materials tested, cotton wool was found to present so exceptional a hazard that it would not be practicable to design a spark guard giving a substantial reduction in the risk.

Acknowledgment

The work described in this note forms part of the programme of the Joint Fire Research Organization of the Department of Scientific and Industrial Research and Fire Offices' Committee and the note is published by permission of the Director of Fire Research.

Acknowledgment is due to the Assistant Director, Mr. D. I. Lawson for drawing attention to the potentialities of non-flammable nylon net as a spark guard and to Miss J. E. Miller for much of the work described.

APPENDIX I

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 χ^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	$y = 1{\cdot}441x - 2{\cdot}634$	$1{\cdot}12x - 0{\cdot}65 \pm 1{\cdot}52\sqrt{0{\cdot}018 + 0{\cdot}057(x - 5{\cdot}45)^2}$
Viscose Rayon Net	$y = 2{\cdot}509x - 3{\cdot}842$	$1{\cdot}17x - 0{\cdot}62 \pm 0{\cdot}92\sqrt{0{\cdot}034 + 0{\cdot}241(x - 3{\cdot}62)^2}$
Hessian Scrim	$y = 0{\cdot}986x + 0{\cdot}338$	$1{\cdot}08x - 0{\cdot}37 \pm 2.14\sqrt{0{\cdot}009 + 0.018(x - 4.9)^2}$
Newspaper	$y = 2{\cdot}437x - 4{\cdot}634$	$1{\cdot}15x - 0{\cdot}61 \pm 0{\cdot}93\sqrt{0{\cdot}026 + 0{\cdot}204(x - 4{\cdot}04)^2}$

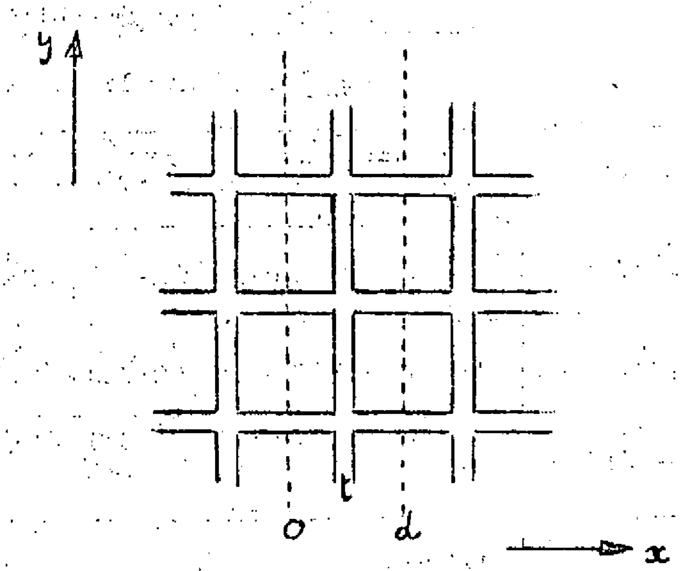
APPENDIX II

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



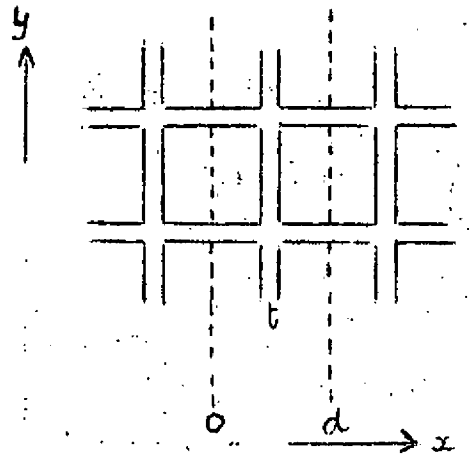
The total probability may be considered as the product of the probability of a sphere not engaging on a horizontal wire and the probability of a sphere not engaging on a vertical wire. The probability of a particle not striking a vertical wire will now be discussed. If the centre of a particle of diameter D lies within the x co-ordinate zero and d, the probability of its centre lying in any range δx 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.

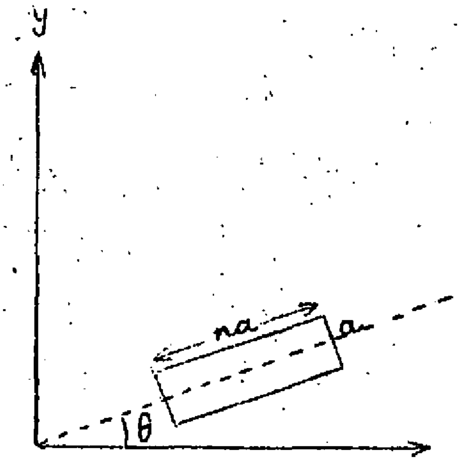
The probability of this occurring is $\frac{d - t - D}{d} = 1 - \left(\frac{D + t}{d}\right)$

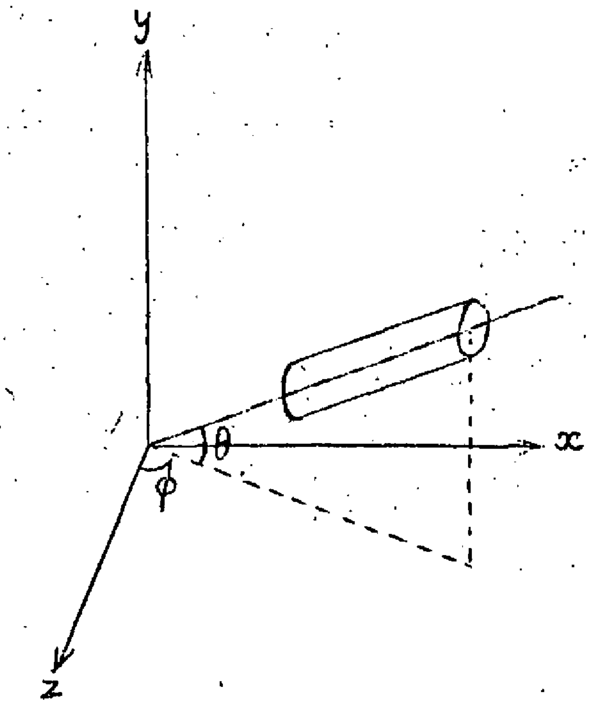
Of the particles which will not strike the vertical wires the fraction which will not strike the horizontal wires is also $1 - \left(\frac{D + t}{d}\right)$

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

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 θ 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 θ 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 Θ will lie within the limits θ and $\theta + d\theta$ varies as $\cos\theta$

Combining these two probabilities gives $dP_H = \left[1 - \frac{a}{d}\left(n\sin\theta + \cos\theta\right) - \frac{t}{d}\right]\cos\theta\, d\theta$

where the limits of θ are 0 and θ'

and $a(n\sin\theta' + \cos\theta') = d - t$

If the projection of the cylinder in the xz plane makes an angle ϕ with the z axis then the projection of the cylinder in the x dimension is given, <u>for small values of θ</u>

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

The probability of passing between the vertical wires for a given θ and ϕ is

$$P_v = 1 - \frac{D_v + t}{d} = 1 - \frac{a}{d}(n\cos\theta\sin\phi + \cos\phi) - \frac{t}{d}$$

The probability that ϕ will lie between ϕ and $\phi + d\phi$ is linear. Combining these two probabilities gives

$$dP_v = \frac{2}{\pi}\left\{1 - \frac{a}{d}(n\cos\theta\sin\phi + \cos\phi) - \frac{t}{d}\right\} d\phi$$

where the limits of ϕ are 0 and ϕ'

and $a(n\cos\theta\sin\phi' + \cos\phi') = d - t$

The total probability of passing freely through the mesh is given by

$$P = \int_0^{\theta'}\int_0^{\phi'} dP_H\, dP_v$$

For particles of such dimensions that θ' & ϕ' are small, this expression reduces to

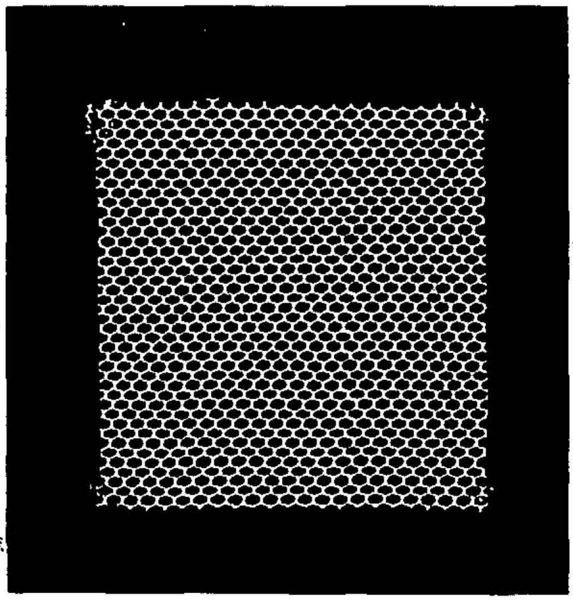
$$P = \frac{(d - t - a)^4}{2\pi n^2 a^2 d^2}$$

c) Combination of Results

It is unlikely that a very slender needle-like piece of coal would be ejected from a fire; but as a limiting case a cylindrical particle having a length 8 times its diameter has been considered.

The two expressions derived in (a) and (b) have been evaluated and plotted in Figure 9 for the various meshes taking the density of coal as 1·27 gm/cm^3 and $n = 8$ in the case of the cylinders. The extreme probabilities for all shapes of particle are given by the solid curves in Figure 9. The probability curves for $n = 2$, 4 or 6 lie below these curves.

PLATE. I. VIEW OF APPARATUS

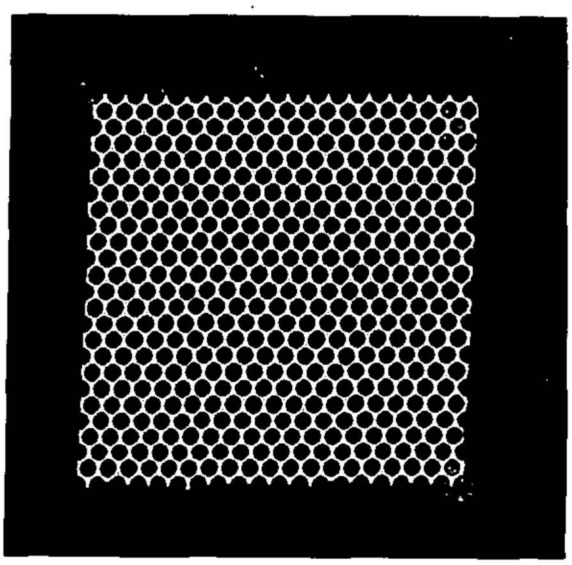


NON FLAMMABLE

NYLON NET 'A'

45 DENIER

INCHES



NON FLAMMABLE

NYLON NET 'B'

150 DENIER

PLATE 2. NYLON NETS TESTED

DS 55082/1 213 60 4/57CL

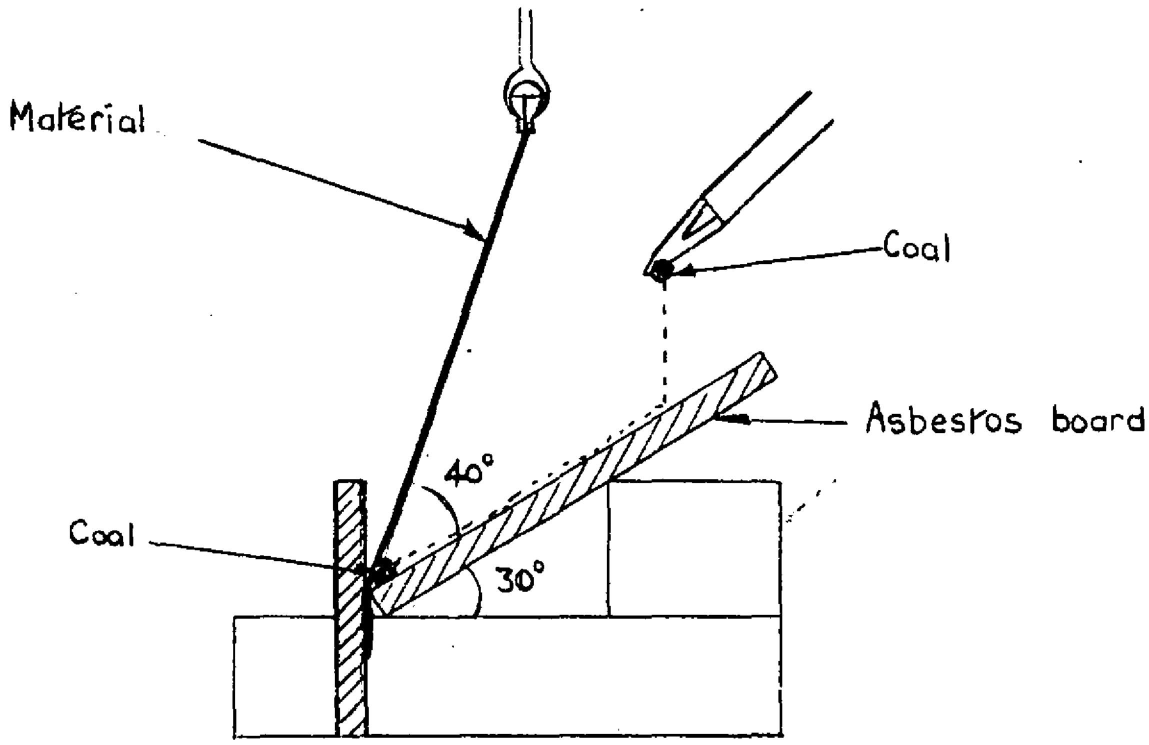


FIG. 1. PLAN OF APPARATUS

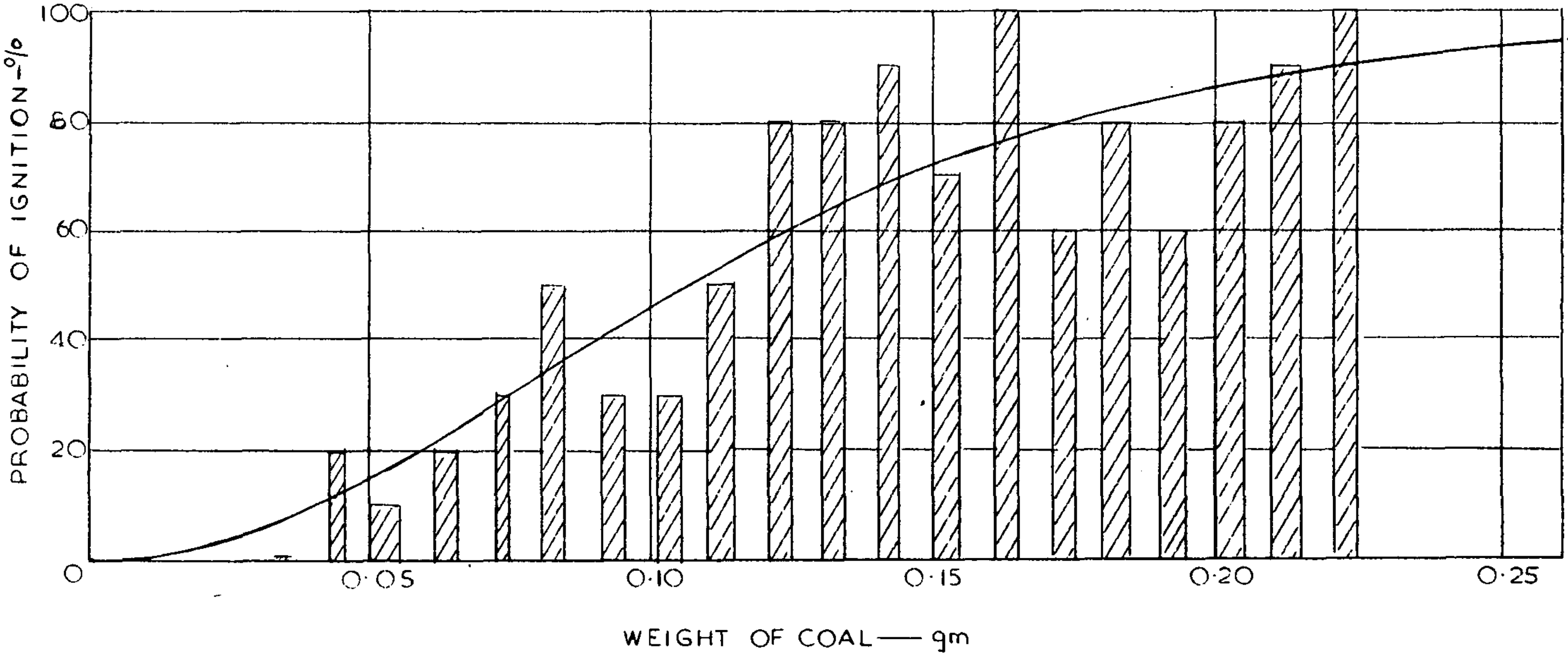


FIG. 2. PROBABILITY OF A PIECE OF COAL IGNITING
BRUSHED SCRIM

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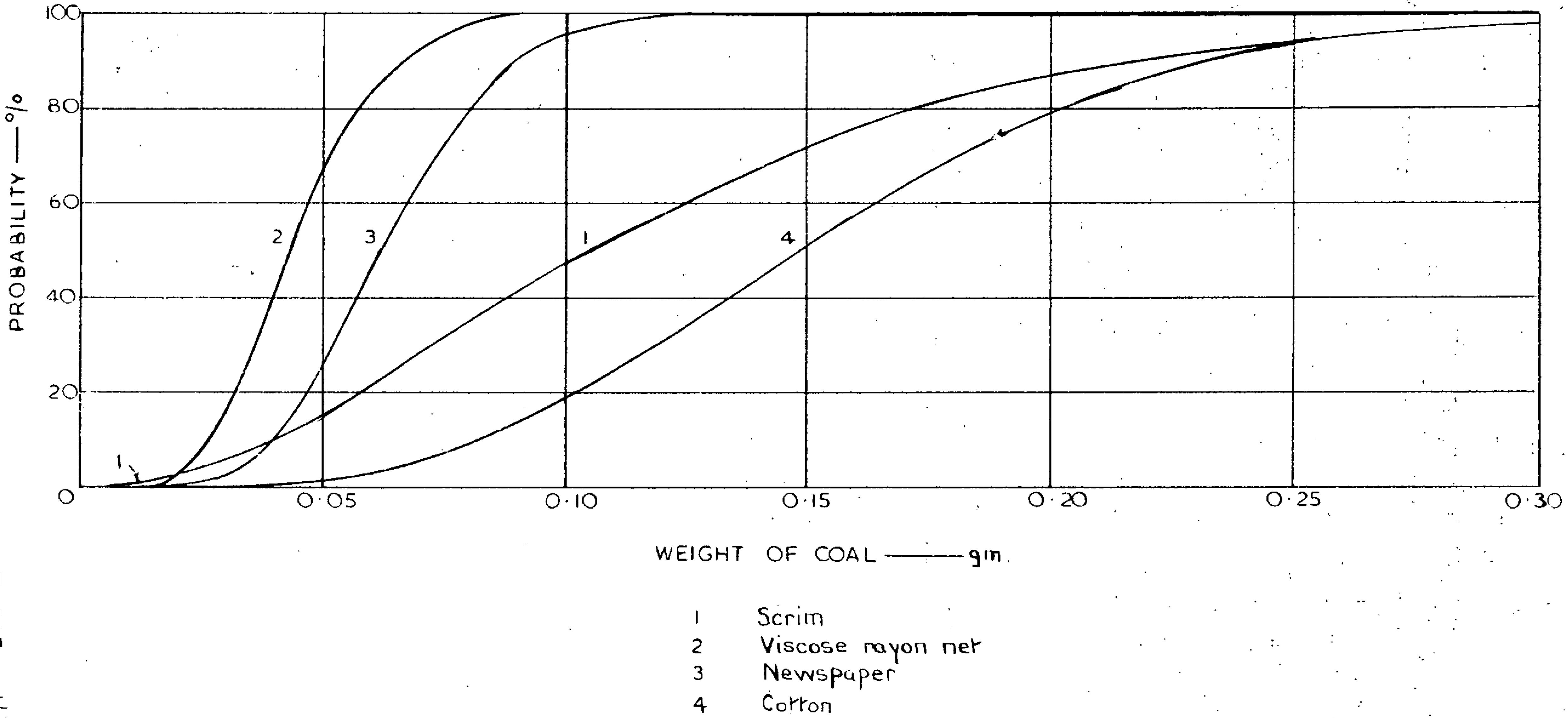


FIG. 3. PROBABILITY OF A PIECE OF BURNING COAL IGNITING VARIOUS MATERIALS

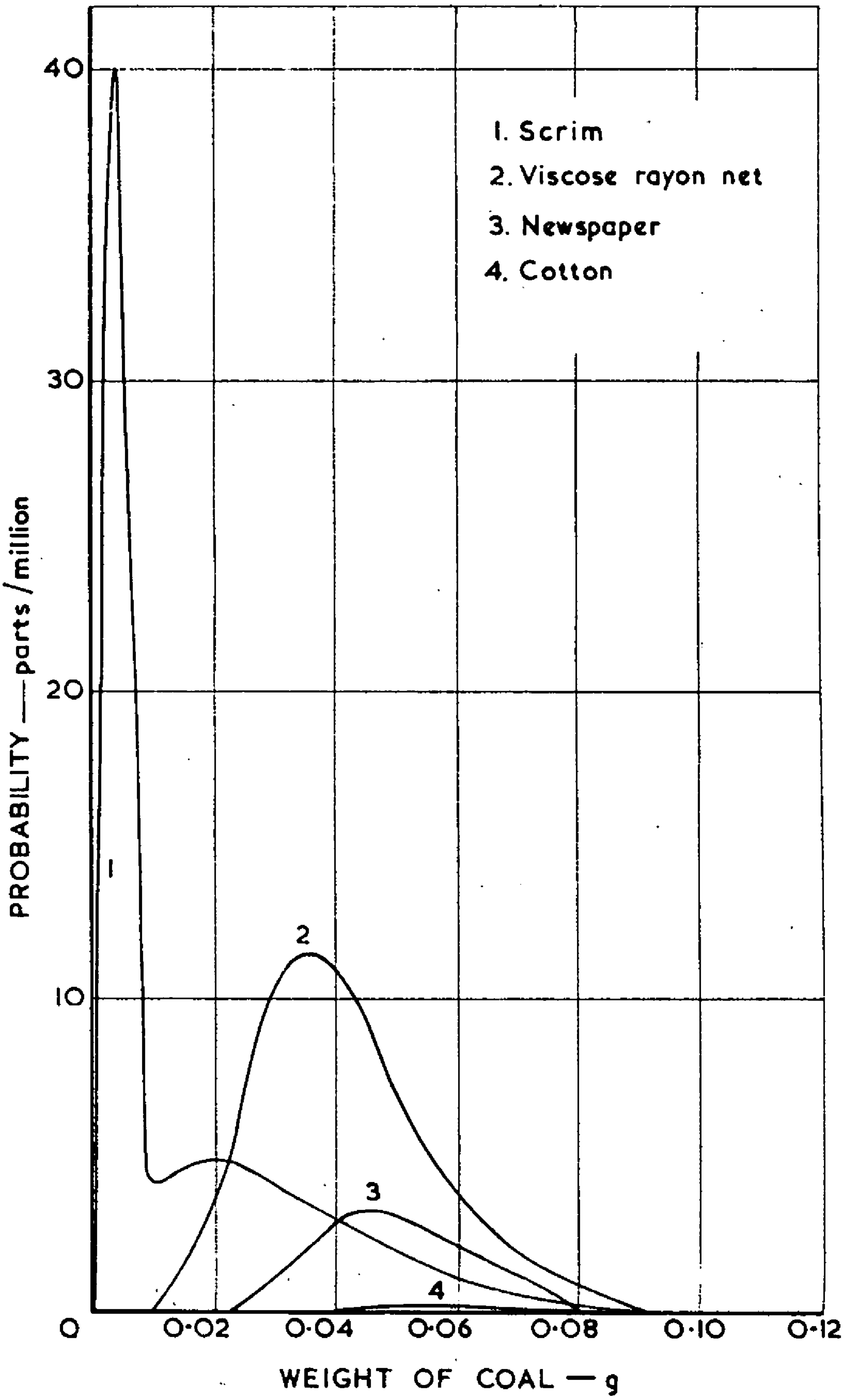
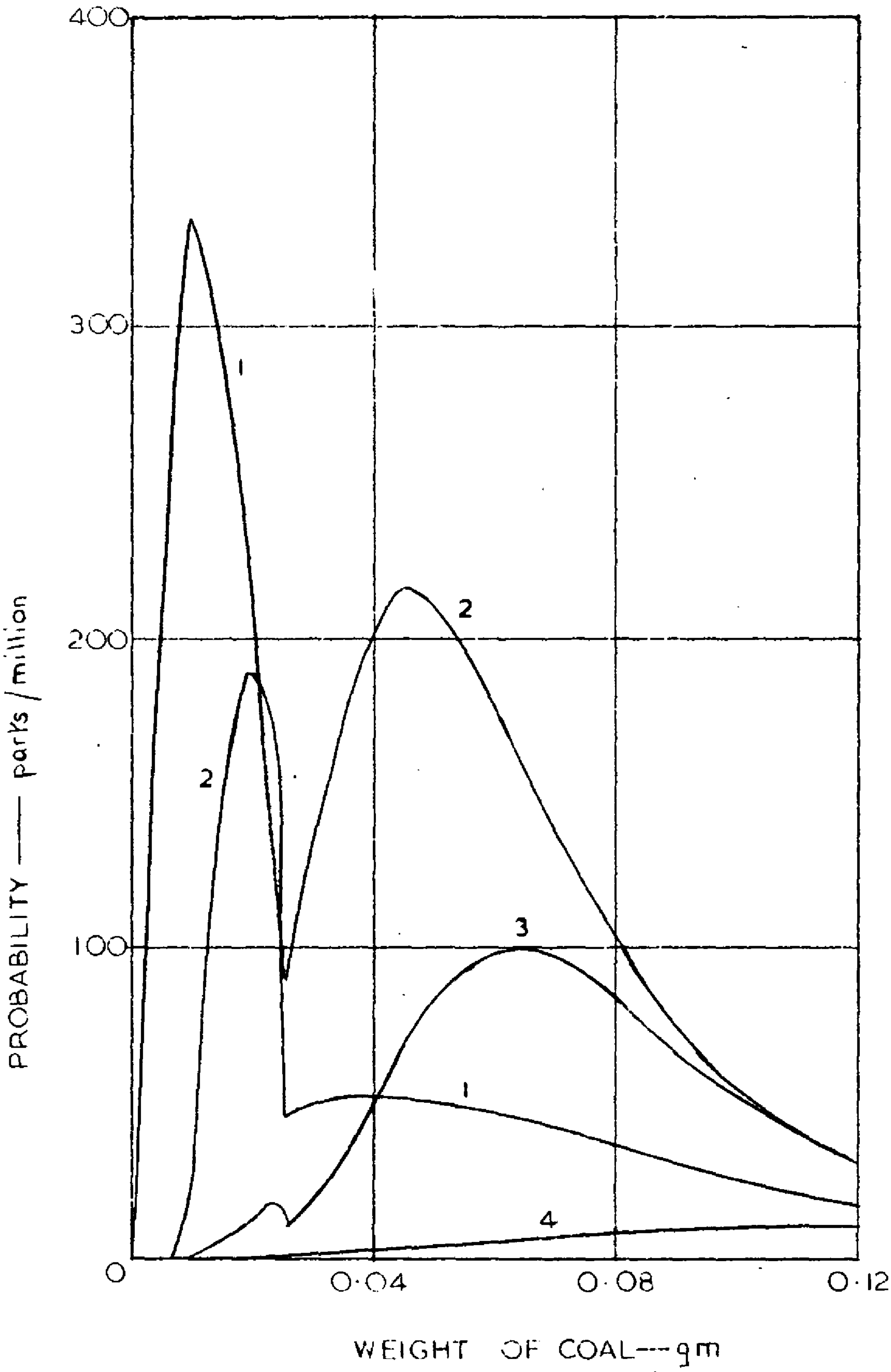


FIG. 4. PROBABILITY OF A PIECE OF COAL BOTH PASSING THROUGH 8 MESH 22 S.W.G. AND IGNITING VARIOUS MATERIALS



1 Scrim
2 Viscose rayon net
3 Newspaper
4 Cotton

FIG. 5. PROBABILITY OF A PIECE OF COAL BOTH PASSING THROUGH 6 MESH 22 S.W.G. AND IGNITING VARIOUS MATERIALS

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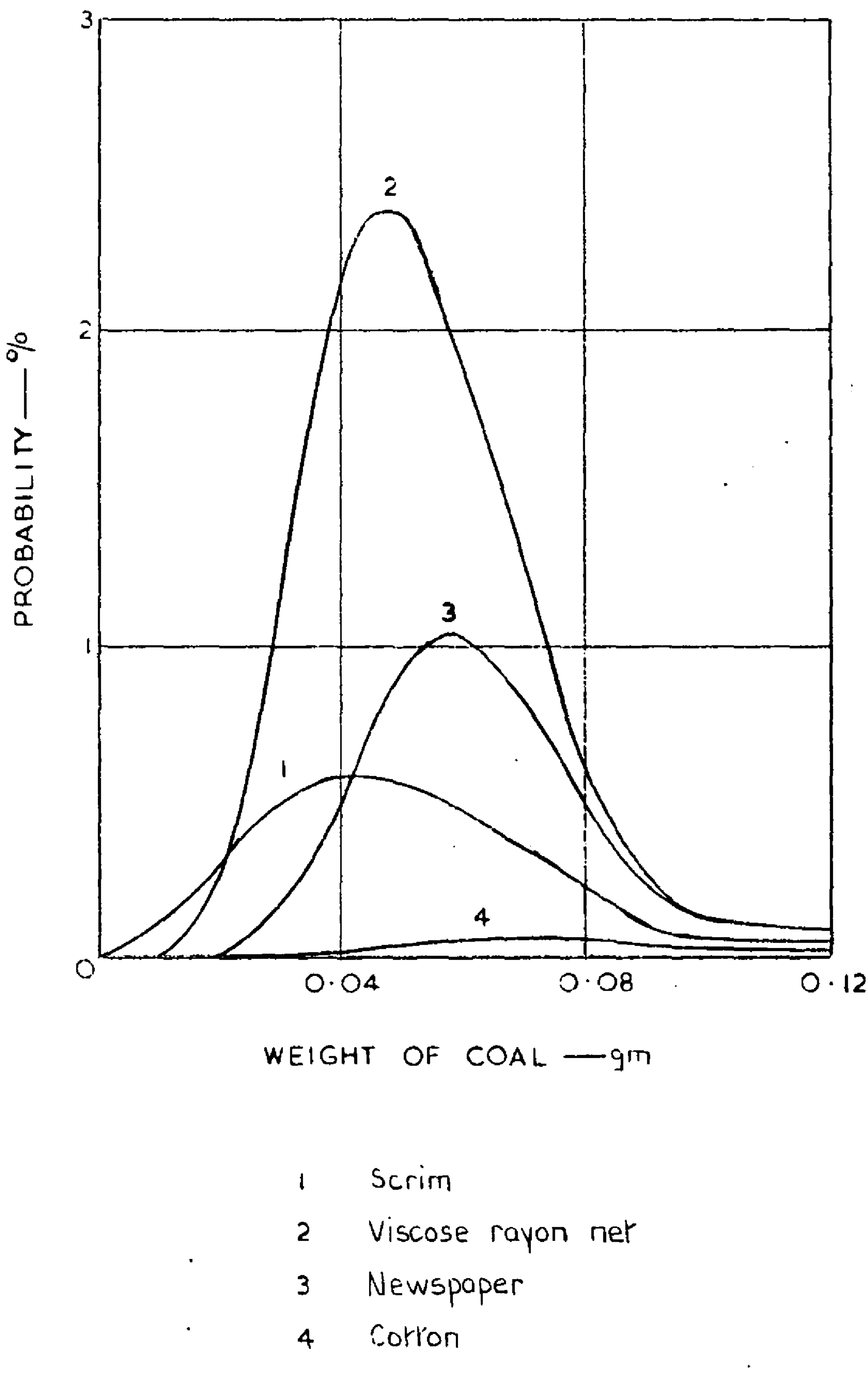

FIG. 6. PROBABILITY OF A PIECE OF COAL BOTH PASSING THROUGH 4 MESH, 20 S.W.G. AND IGNITING VARIOUS MATERIALS

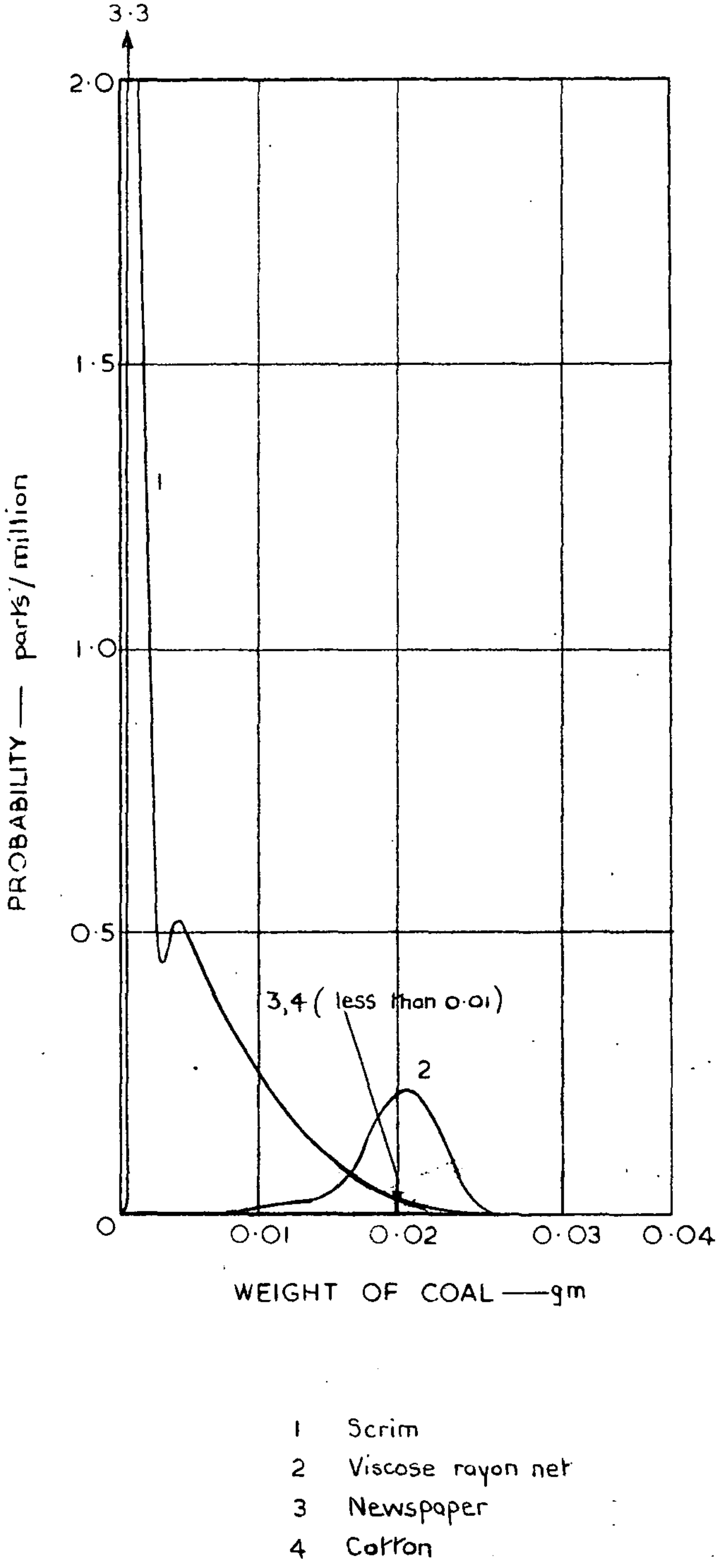

FIG. 7. PROBABILITY OF A PIECE OF COAL BOTH PASSING THROUGH NYLON MESH A AND IGNITING VARIOUS MATERIALS

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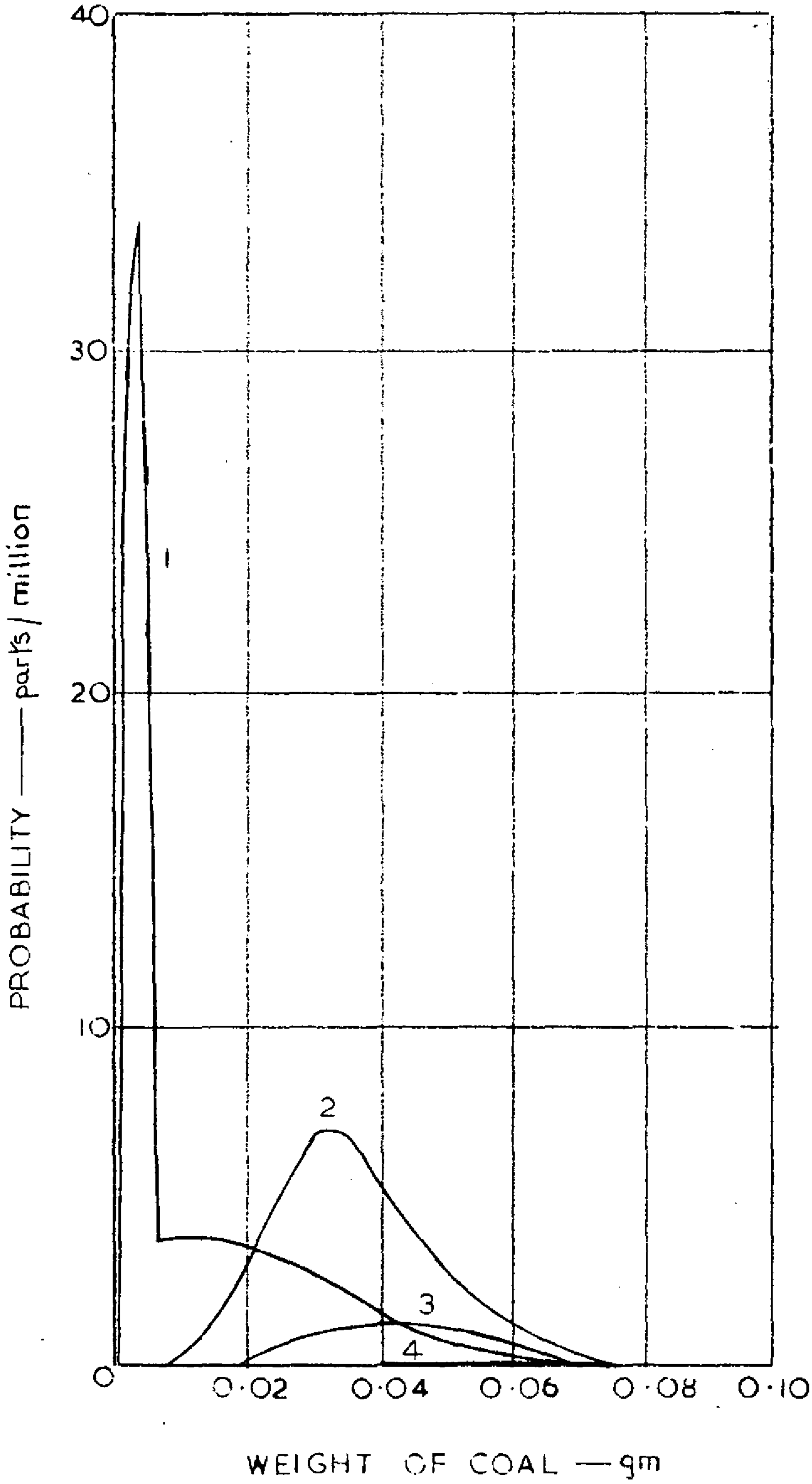
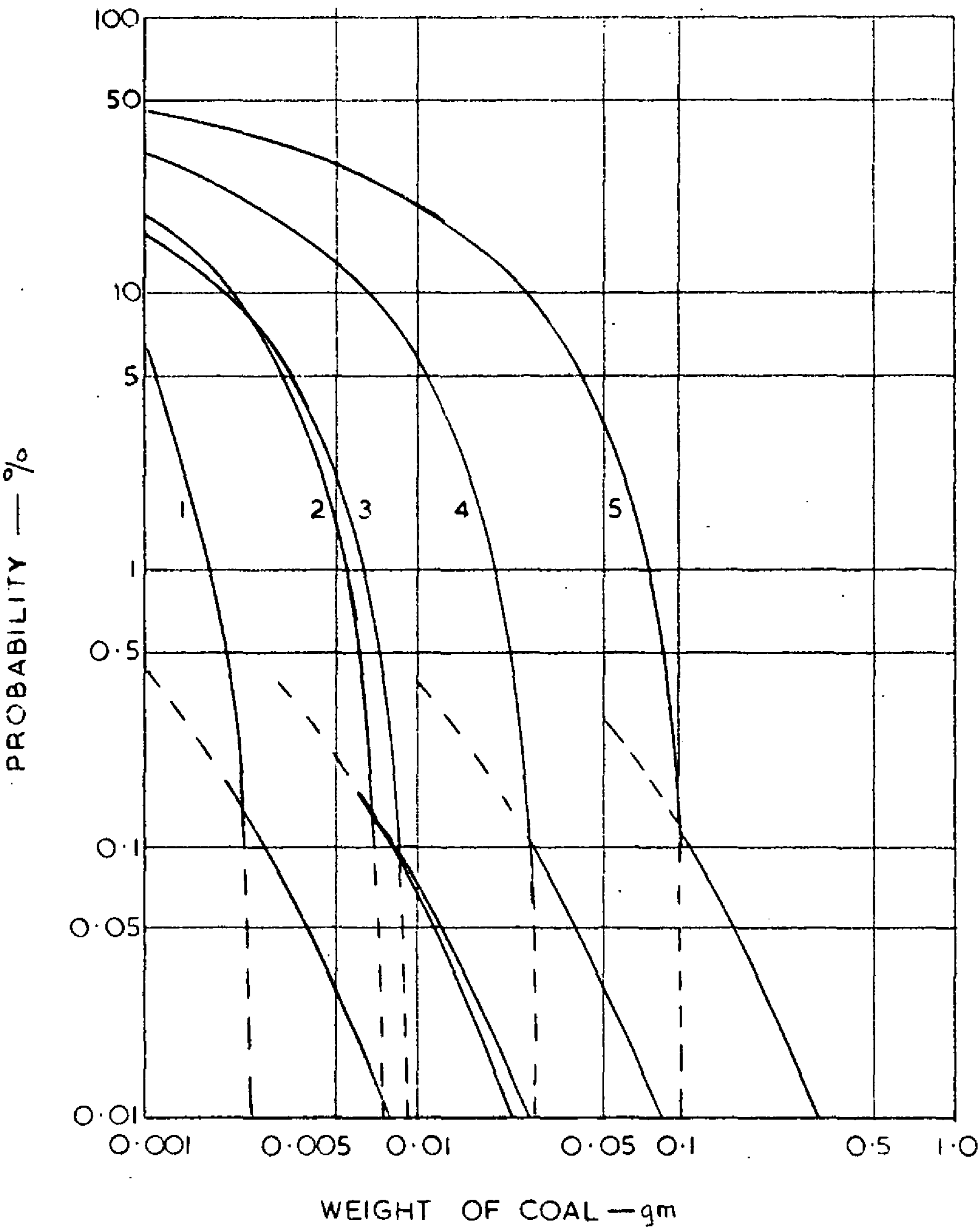


1 Scrim
2 Viscose rayon net
3 Newspaper
4 Cotton

FIG. 8. PROBABILITY OF A PIECE OF COAL BOTH PASSING THROUGH NYLON MESH B AND IGNITING VARIOUS MATERIALS



1 Non flammable nylon net A

2 Non flammable nylon net B

3 8 mesh 22 S.W.G.

4 6 mesh 22 S.W.G.

5 4 mesh 20 S.W.G

FIG. 9. MAXIMUM PROBABILITY OF A PIECE OF COAL PASSING FREELY THROUGH A MESH