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

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MATERIALS SUITABLE FOR CLOTHING AIRCRAFT FIRE CRASH RESCUE WORKERS - PART II

by

P. L. Hinkley, D. L. Simms, and D. W. Millar

Summary

The results of further tests on the protection against fire afforded by various materials are described and the tests themselves critically discussed.

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1. Introduction

Part I of this report (1) describes tests for the evaluation of protective clothing and estimates the value of some clothing assemblies including a number of suitings. The tests were designed to assess the protection given to rescue workers by the assemblies against flame and against radiation, horsemeat being used to simulate human flesh. The time taken for the surface of the meat in contact with the clothing to rise by 25°C was used as a measure of the protection afforded by the assembly. The thermal protection afforded by the materials was measured with the assembly in slight compression. In practice, poor contact between skin and clothing would increase the thermal insulation because of better air circulation and the high thermal resistance of the air gap, but there are bound to be areas where the contact between the skin and the clothing is good, e.g., shoulder, knees, elbows and the protection times obtained from the experiments in Part I and in this paper represent the more hazardous conditions. The previous tests (1) indicated that a good type of suiting consisted of an outer flameproofed layer, an interlining designed to provide an air gap, and a suitable lining.

This note describes further work on suitings and also some minor modifications to the tests and to the test procedure. For this work, the Ministry of Supply, (R.D.A.E.I.) supplied various materials to be tested in different combinations and also some composite materials consisting of inner and outer layers bonded together with rubber. The materials of the best set of assemblies were to be made up into garments for field trials where their effectiveness in practical fire fighting and their comfort when worn for long periods at the ready would be evaluated. A list of materials, together with their Fire Research Organization reference numbers, their thicknesses and their weights per unit area is given in Table 1.

Table 1

Materials tested

Purpose	Description	Appearance or colour	J.F.R.O. reference No.	Thickness mm	Weight per unit area g/cm^2
Outer material	Lasting cloth, wool (flameproofed)	blue	R.143	1·1	0·029
	Lasting cloth, wool (not flameproofed)	white	R.144	1·1	0·03
	Fearnought, wool (not flameproofed or waterproofed)	white	R.154	2·9	0·08
	Asbestos cloth	white	R.145	0·8	0·038

Table 1 (cont'd)

Purpose	Description	Appearance or colour	J.F.R.O. reference No.	Thickness mm	Weight per unit area g/cm^2
Inter-lining	Wool pile (cotton backed)	green	R.146	4·0	0·045
	Open mesh fabric (cotton)	white	R.148	5·1	0·049
	Quilted fibreglass between two layers of cotton poplin (heavy)	diamond stitching	R.163	2·6	0·045
	Quilted fibreglass between two layers of cotton poplin (light)	zig-zag stitching	R.162	1·6	0·034
Combined outer material and inter-lining	Double texture rubber bonded fabrics Wool (K_1)	fawn facing dark brown lining	R.152	3·0	0·11
	Wool (K_2)	fawn facing brown lining	R.151	3·4	0·15
	Wool (K_3)	light fawn facing green lining	R.149	4·6	0·10
	Wool lining cotton facing (K_4)	brown facing	R.150	3·2	0·093
Lining material	Cotton poplin	off-white	R.147	0·1	0·12
Under-clothing	String vest (knitted cotton)	white string	R.63	5·4	0·092

2. Experimental procedure and results

2.1. Flame test

This test is described in detail in Part I of this report (1). Horsemeat was placed in contact with the inner face of the clothing assembly, the outer face of which was exposed to flames from a petrol fire. The rear and edges of the assembly were shielded from the flames by an asbestos wood board. The time taken for the surface of the horsemeat to rise in temperature by 25°C was noted, the petrol flames were then extinguished and any further rise in temperature was noted. The 26 s.w.g. thermocouple used in the first series of experiments for temperature measurements was replaced by a copper disk $\frac{1}{2}$ in. in diameter and 0·008 in. thick having a

36 s.w.g. copper-constantan thermocouple soldered to the centre of one face. The disk tended to adhere to the surface of the horsemeat ensuring better thermal contact. Four samples of each assembly were tested. In order to eliminate the effects of progressive changes such as ageing of the horsemeat and the slow increase in temperature of the apparatus, the pieces of material were allocated randomly to the various assemblies, and the tests were carried out in random order.

Some tests were carried out to compare the effect of reversing the wool pile and some to determine the effect of using underclothing (a string vest) on the protection times afforded by three assemblies having a long, an intermediate and a short protection time. The results are given in Table 2, and the appearance of the assemblies after the flame tests are shown in the plates.

Table 2

Results of flame tests (average of four tests)

Outer material	Interlining	Lining	Time for 25°C temperature rise - sec.	Further temperature rise - °C	Additional time for further temperature rise - sec.
Blue lasting cloth (flame-proofed)	Wool pile (pile outwards)	Cotton poplin	58	2	9
	Open mesh fabric (two layers)	"	63	2	12
White lasting cloth (not flameproofed)	Wool pile (pile outwards)	Cotton poplin	49	2	8
	Open mesh fabric (two layers)	"	64	4	21
	Heavy quilted fibreglass	None	50	4	9
	Light quilted fibreglass	None	37	8	8
Asbestos cloth	Wool pile (pile outwards)	Cotton poplin	37	5	11
	Open mesh fabric (two layers)	"	54	4	15
Fearnought (not flame-proofed)	Wool pile (pile outwards)	Cotton poplin	105	1	30
	Open mesh fabric (two layers)	"	116	4	40
	Heavy quilted fibreglass	None	73	0	-

Table 2 (cont'd)

Outer material	Interlining	Lining	Time for 25°C temperature rise - sec.	Further temperature rise - °C	Additional time for further temperature rise - sec.
Fearnought (not flame-proofed)	Light quilted fibreglass	None	59	0·5	2
	None	Cotton poplin	34	2	8
Rubber bonded-double texture materials	K_1 (wool)	"	44	6	20
	K_2 (wool)	"	65	7	27
	K_3 (wool)	"	57	5	15
	K_4 (wool lining cotton facing)	"	33	17	16
White lasting cloth	Wool pile (pile inwards)	Cotton poplin	51	2	14
	Wool pile (pile outwards)	"	48	1	12
	"	Cotton poplin/ string vest/ cotton poplin	78	2	11
Fearnought	Wool pile (pile inwards)	cotton poplin	72	0	-
	Wool pile (pile outwards)	"	70	0	-
	"	Cotton poplin/ string vest/ cotton poplin	142	1	22
Double texture rubber bonded wool and cotton fabric K_4		Cotton poplin	25	1	6
		Cotton poplin/ string vest/ cotton poplin	41	16	20

2.2. The Radiation Test

This test is described in detail in Part I of this report (1). It is similar to the flame test except that the $2\frac{1}{2}$ in. square area of the face of the assembly is exposed, not to flames, but to radiation having an intensity of 2 W/cm^2. The 26 s.w.g. thermocouple used in the first series of tests (1) was replaced by the copper disk thermocouple with its cold junction in a constant temperature enclosure. Each test was repeated four times. Samples of material were allocated randomly between the various assemblies and the tests were carried out in a random order.

Where the outer materials had similar reflectivities the radiation tests did not place the assemblies in a significantly different order than that in which the flame tests placed them. Accordingly only the outer materials and a selection of the others were tested.

The results are given in Table 3. Each result is the mean of four tests.

Table 3

Results of the radiation tests

Outer material	Interlining	Lining	Time for 25°C temperature rise sec.	Further temperature rise °C	Additional time for further temperature rise sec.
Blue lasting cloth (flame-proofed)	Wool pile (pile outwards)	Cotton poplin	53	3	7
	Open mesh fabric (two layers)	"	93	6	19
White lasting cloth (not flameproofed)	Wool pile (pile outwards)	"	76	5	15
	Open mesh fabric (two layers)	"	83	3	24
Asbestos cloth	Wool pile (pile outwards)	"	62	3	17
	Open mesh fabric (two layers)	"	81	9	32
Fearnought (not flame-proofed)	Wool pile (pile outwards)	"	110	3	25
	Open mesh fabric (two layers)	"	152	3	46
	None	"	53	2	9
Double texture rubber bonded materials	K_1 wool	"	44	7	22
	K_2 wool	"	45	8	26
	K_3 wool	"	67	3	17
	K_4 wool lining cotton facing	"	36	6	14

3. Analysis of results

3.1. Flame test

The various assemblies generally ranked in the same order as their components except that the performance of Fearnought and probably of lasting cloth is worsened when used with quilted fibreglass. The standard deviation for Fearnought was about 40 sec.; for the other materials it was 8•5 sec.

An analysis of the variation between outer materials shows that there is no difference between the two types of lasting cloth, that lasting cloth is significantly better than asbestos to the extent of 14 ± 7•5 sec. and that Fearnought is by far the best of all. It is however by far the most variable. The estimated difference between Fearnought and lasting cloth is 51 ± 21 sec.

Open mesh fabric is somewhat better than wool pile to the extent of 12 ± 6 sec. (on average 20%). The rubber bonded fabrics differ significantly among themselves and also from Fearnought used without an interlining. The differences between the mean times of the four materials are sufficiently large to suggest that the order of decreasing merit is (K_2, K_3, K_1, K_4).

3.2. Radiation test

An analysis of the results of the radiation tests given in Table 3 does not place the materials in the sandwich assemblies in a significantly different order to that given by the flame test. The variability of the radiation test for materials other than Fearnought is higher than that of the flame test; the estimated standard deviation being 13•7 sec. The estimated standard deviation for Fearnought is 33•2 sec.

Analysis of the results for the rubber bonded materials shows that the mean time for K_3 is significantly higher than those for the other materials but that otherwise the test is not sufficiently sensitive to show the existence of an order of merit for the rubber bonded materials.

4. Discussion of materials

In general, the behaviour of the individual materials did not differ in the various assemblies. It is therefore possible to consider each material separately.

4.1. Outer materials

4.1.1. Fearnought

This gave better results than any other outer material. Not only were the protection times longer but, except when an interlining of open mesh fabric was used, the subsequent temperature rise after removal of the source of heat was lower.

When heated, Fearnought swells and forms a mass of frothy carbonaceous material having a very low density and which, in these tests, protected the underlying fabric. This largely accounted for the long, variable protection times. As the layer was very fragile, it would rapidly disintegrate with the wearer's movement and in practice therefore the superiority of Fearnought would not be so apparent as in the tests.

The Fearnought tested was not waterproofed and suffered from the disadvantage that it could absorb large quantities of water.

4.1.2. Lasting cloth

Flameproofing appears to have no effect on the protection afforded by lasting cloth against either flames or radiation.

Lasting cloth is flammable and under the influence of flames or radiation it tended to disintegrate exposing the interlining. Some of the assemblies including lasting cloth continued to burn for a few seconds after the extinction of the petrol fire. The swelling observed on lasting cloth was not so marked as with Fearnought.

4.1.3. Asbestos

This has the advantage of not being easily disintegrated by flames or radiation, although the fabric becomes weak after prolonged heating and is not durable even when new. The protection times are shorter than for either Fearnought or lasting cloth and the temperature rise after removal of the source of heat tends to be higher.

4.2. Inner linings

4.2.1. Open mesh fabric (double layer)

The protection times against both flames and radiation were higher than for the other interlining materials. This material is flammable and inspection after a test usually showed it to be badly scorched. Plates 1, 6 and 7.

4.2.2. Wool pile

Tests showed that the protection times with the pile inwards and outwards were not significantly different for this material. The backing, being cotton, is easily ignited but the wool pile when heated forms a mass of carbonaceous material which tends to protect the underlying material (Plates 2, 4 and 6). For this reason it is probably to be preferred to open mesh fabric in spite of the shorter measured protection times.

4.2.3. Quilted fibreglass

These were the least satisfactory of the interlining materials tested. Statistical analysis showed that their use apparently reduced the effectiveness of Fearnought and probably of lasting cloth as well. When used with lasting cloth, the temperature rise after removal of the source of heat tended to be high, particularly with the light weight material. Both these effects may be attributed to the easily ignited cotton poplin covering (Plates 5 and 9). The lines of stitching were also a source of weakness; in one experiment the flame was propagated through a line of stitching to ignite the inner layer of cotton poplin.

4.3. Double texture rubber bonded fabrics

The rubber bonded fabric having the longest protection against flames was K_2, while that having the longest protection against radiation was K_3. This may be a result of the differences in reflectivity. K_2 was the heaviest material while K_3 was the thickest.

The best fabrics (K_2 and K_3) gave protection times comparable with those given by lasting cloth with an interlining. However, the weight per unit area is rather greater for the double texture fabrics than for the other assemblies and the temperature rise after removal of the sources of heat is also greater. The cotton facing of K_4 ignited in the flame test and continued to burn after removal of the source of heat and is therefore unsuitable for use in a protective garment.

Vertical strips of all the rubber bonded materials could be ignited by a small petrol flame and would continue to burn. In these tests the rubber layer was exposed at the edges, a condition which would be avoided in the made up garments. However in the flame tests the rubber lining did not ignite although a strong smell of scorched rubber was generally noticed. Once ignited, rubber is difficult to extinguish and for this reason a rubber interlayer cannot be regarded as satisfactory and should be replaced by a less flammable material. Since the interlayer is impervious to water this type of material might prove more satisfactory than the conventional assemblies if the wearer were to be sprayed with water or foam.

4.4. Effect of underclothing

The protection time for three representative assemblies was increased by a factor of from $1\frac{1}{2}$ to 2 by using a string vest. Orthodox woolen underwear is very little use (2).

4.5. Effect of weight/unit area and thickness of materials

The protection time afforded by individual assemblies against flame and radiation does not appear to depend on their weights per unit area. The total weight of a garment does to some extent affect its comfort in wear, but other factors such as stiffness must also be considered.

The protection time afforded against flames by various assemblies is shown plotted against their thickness (Fig. 1). There is some evidence to show that protection time does depend upon thickness (which might be expected as thermal resistance is roughly proportional to thickness), but the results are too widely scattered for definite conclusions.

4.6. Further temperature rise after removal of heating source.

The temperature rise after the removal of the source of heating may be due to the ignition of the materials of the assembly or to the heat stored in it. It is undesirable to have easily flammable materials in the assembly since the outer layer may be destroyed locally and expose them.

To minimize the temperature rise due to heat stored in the assembly and to hasten cooling of the skin, protection should be achieved by having an assembly with a high thermal resistance rather than a high thermal capacity as the latter would have a relatively greater store of heat.

5. Discussion on tests

5.1. The effect of the selected temperature rise on the value of the protection time obtained

It was emphasised in part I of this report (1) that the selection of a temperature rise of 25°C was arbitrary and that this was probably greater than that needed to cause severe pain (3). It was considered that the selection of this level of temperature rise would be unlikely to affect the general order in which the assemblies were placed by the tests.

In order to verify this assumption the times taken for the rear surfaces of the various assemblies in the first group of flame tests to rise by 15°C were plotted against the corresponding times for a temperature rise of 25°C.

The resulting graph is shown in Fig. (2). Although the scatter of the points about a straight line is fairly large, they are well distributed about the line. The slope of the line is 25/15, so that the ranking of the materials would not be materially changed if a rise of 15°C were selected instead of the rise of 25°C at present chosen.

5.2. Relation between radiation and flame tests

The protection times afforded against flames are plotted against the protection times afforded against radiation in Fig. 3. The points are distributed, with a large scatter, about a straight line; the protection times given by the flame test are of the order 0·8 of those obtained from the radiation tests. The mean heat transfer from the flame cannot therefore have been greatly in excess of $2\ W/cm^2$ and so except for those materials having a high reflectivity (4) the flame test is only slightly more severe than the present radiation test.

6. Practical considerations

The original terms of reference of this investigation stated that the suits would be worn on duty. The rescue workers were not expected to enter a fire zone as it would then be impossible to bring out the crew. They would only attempt rescue after the fire had been brought under control.

The intensity of 2 W/cm^2 has been considered (1) to be of the right order of magnitude for these conditions where the lower parts of the body might be subjected to flames, e.g. from pockets of petrol in the foam or burning grass. In an emergency such as a petrol tank explosion or flash back there may be a large increase in radiation and the rescue workers might be immersed in flames.

The expected relationship between protection time and rate of heat transfer at high rates of heating to a first approximation is a reciprocal one. Thus clothing providing protection against a radiant intensity of 2 W/cm^2 for 3 minutes might be expected to provide protection against 10 W/cm^2 for about 30 seconds. Although these figures are only tentative it is probable that there would be sufficient time for the rescue workers to retreat without injury provided that their clothing did not continue to burn after ignition.

Only comprehensive field trials can establish the quantitative relation between the test results and practice.

In these tests the protection time is defined as the time for the skin temperature to rise 25°C. This probably ranks materials in their proper order but the temperature rise is greater than that needed to produce severe pain. On the other hand the tests were carried out with the materials on slight compression and in contact with the skin. In practice, poor contact between skin and clothing would increase the thermal insulation and air circulating within the suit would tend to reduce the effect of local heating.

If the rescue worker retreats from the source of heat as soon as he feels pain his skin temperature will not necessarily fall immediately, it may continue to rise at a rate dependant upon the thermal properties of the clothing. The extent of burn damage to skin is dependent both on the temperature and the time of exposure and maintaining the surface of the skin at a temperature which initially only produces pain or discomfort may, in only a short time, produce a burn. Thus, the greater the tendency for the inside of the clothing to maintain or increase its temperature, the lower the safety margin given by the first onset of pain. Since materials maintain their temperatures after exposure, the clothing should be designed so that it can be rapidly removed.

7. Conclusions

7.1. Materials

7.1.1. Outer materials

The best tested was Fearnought. Lasting cloth besides being flammable, disintegrates quickly on heating. The double texture fabrics K2 and K3 might be satisfactory if a less flammable bonding material were substituted for the rubber but the cotton faced material K4 is not suitable as the facing is easily ignited.

7.1.2. Interlining material

The best of the materials tested was the wool pile; this could be improved by using a woollen backing for it. The string vest material might smoulder under flame conditions and most of its insulation value disappears if the outer garment is destroyed. The fibreglass lining is unsatisfactory; it is not a sufficiently good insulator in the form supplied and the cotton poplin covering is flammable.

7.1.3. Underwear

The importance of underwear in the form of a string vest has been clearly shown. Orthodox woollen underwear give very little protection (2).

7.1.4. Further temperature rise

If materials which maintain their temperature after exposure are used, the garments should be so constructed that they can be quickly removed.

7.2. Test procedure

7.2.1. Flame test and radiation test

The flame test, except for fabrics having a high reflectivity is only a little more severe than the radiation test and the results are similar. It is, however, essential that it be used for highly reflecting materials.

7.2.2. Relation of tests to practical conditions

The tests may be used to compare the various assemblies of materials, but firm conclusions could only be drawn from field trials.

8. Acknowledgment

This work was carried out for the Ministry of Supply under contract.

References

(1) PICKARD, R. W. and SIMMS, D. L. Materials suitable for clothing air craft fire crash rescue workers Part I. Department of Scientific and Industrial Research and Fire Offices ' Committee Joint Fire Research Organization F.R. Note No. 153/1955.

(2) SIMMS, D. L. and HINKLEY, P.L. The protection against fire afforded by certain underwear materials. Department of Scientific and Industrial Research and Fire Offices' Committee Joint Fire Research Organization F.R. Note No. 218/1955 (as F.R.O.S.I. No. 503 Part II 1955.

(3) BUETTNER, K. Effects of extreme heat on man. Journal American Medical Association, 1950, Page 735.

(4) SIMMS, D. L. and HINKLEY, P. L. Materials suitable for clothing air craft fire crash rescue workers Part III. Department of Scientific and Industrial Research and Fire Offices' Committee Joint Fire Research Organization F.R. Note No. 221/1955.

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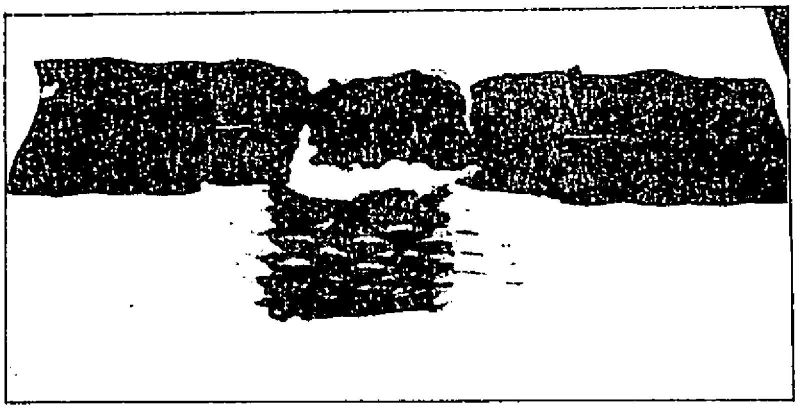

PLATE.I. FIREPROOFED LASTING CLOTH AND OPEN MESH FABRIC

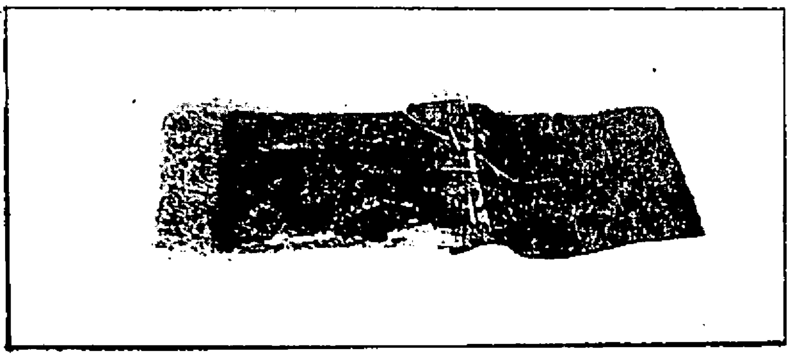

PLATE.2. FIREPROOFED LASTING CLOTH AND WOOL PILE

PLATE.3. LASTING CLOTH (NOT FIREPROOFED) AND OPEN MESH FABRIC

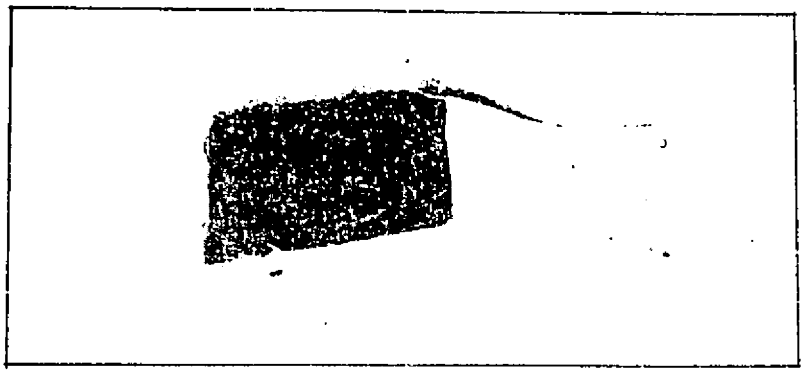

PLATE.4. LASTING CLOTH (NOT FIREPROOFED) AND WOOL PILE

ASSEMBLIES AFTER FLAME TESTS

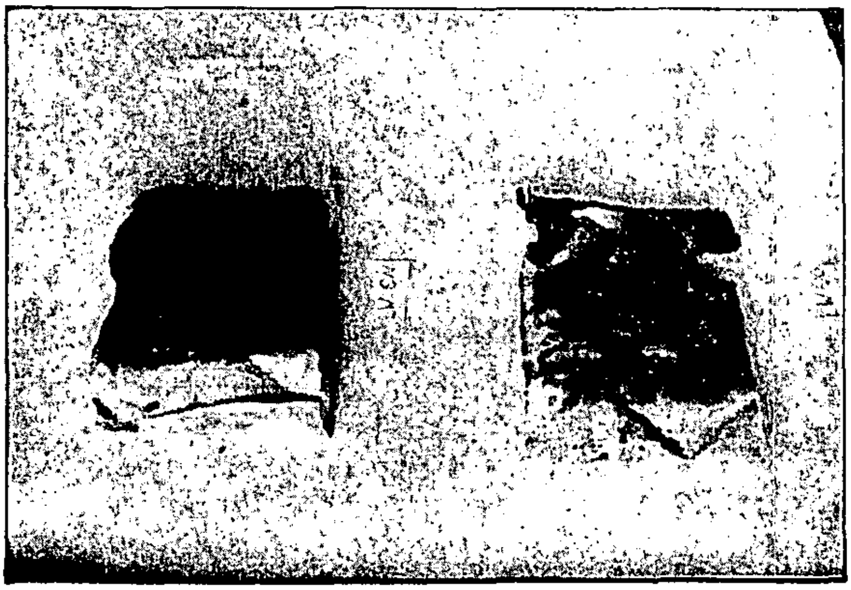

PLATE. 5. LASTING CLOTH AND LIGHT QUILTED FIBREGLASS

LASTING CLOTH AND HEAVY QUILTED FIBREGLASS

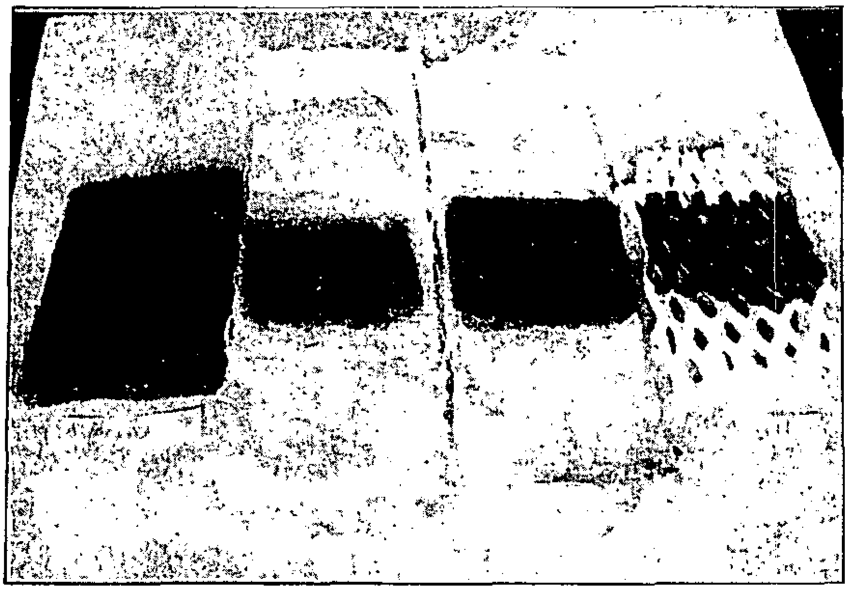

PLATE. 6. ASBESTOS AND WOOL PILE (REAR SURFACE SHOWING SCORCHING)

ASBESTOS AND OPEN MESH FABRIC

ASSEMBLIES AFTER FLAME TESTS

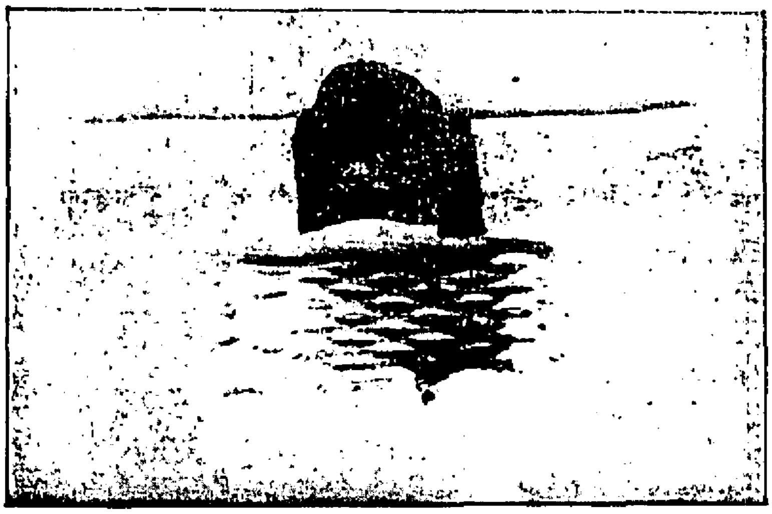

PLATE.7. FEARNOUGHT AND OPEN MESH FABRIC
(NOTE SWELLING OF FEARNOUGHT)

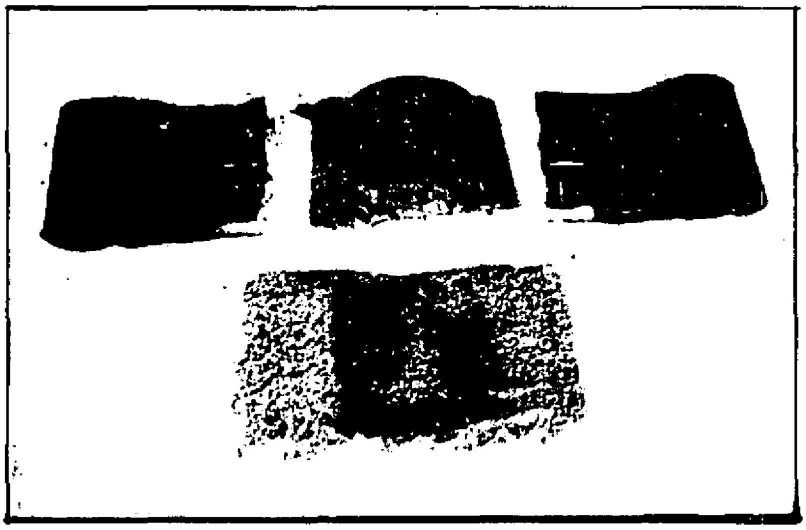

PLATE.8. FEARNOUGHT AND WOOL PILE
(NOTE SWELLING OF FEARNOUGHT)

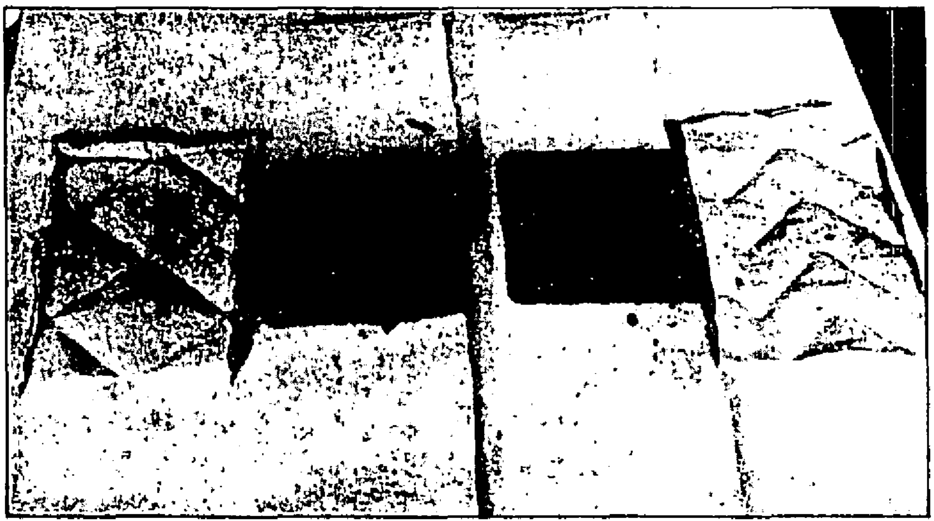

PLATE.9. FEARNOUGHT AND HEAVY QUILTED FIBREGLASS

FEARNOUGHT AND LIGHT QUILTED FIBREGLASS

ASSEMBLIES AFTER FLAME TESTS

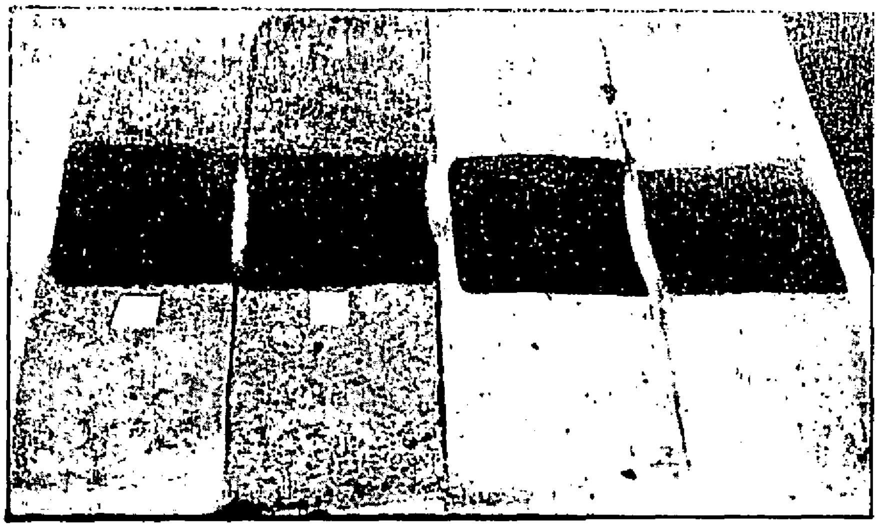

PLATE. 10. K_1 K_2 K_3 K_4

DOUBLE TEXTURE RUBBER BONDED MATERIALS

PLATE. 11. FEARNOUGHT, WOOL PILE AND STRING VEST

PLATE. 12. LASTING CLOTH, WOOL PILE AND STRING VEST

ASSEMBLIES AFTER FLAME TESTS

PLATE.13. COTTON FACED DOUBLE TEXTURE RUBBER BONDED FABRIC (K4) AND STRING VEST

ASSEMBLIES AFTER FLAME TESTS

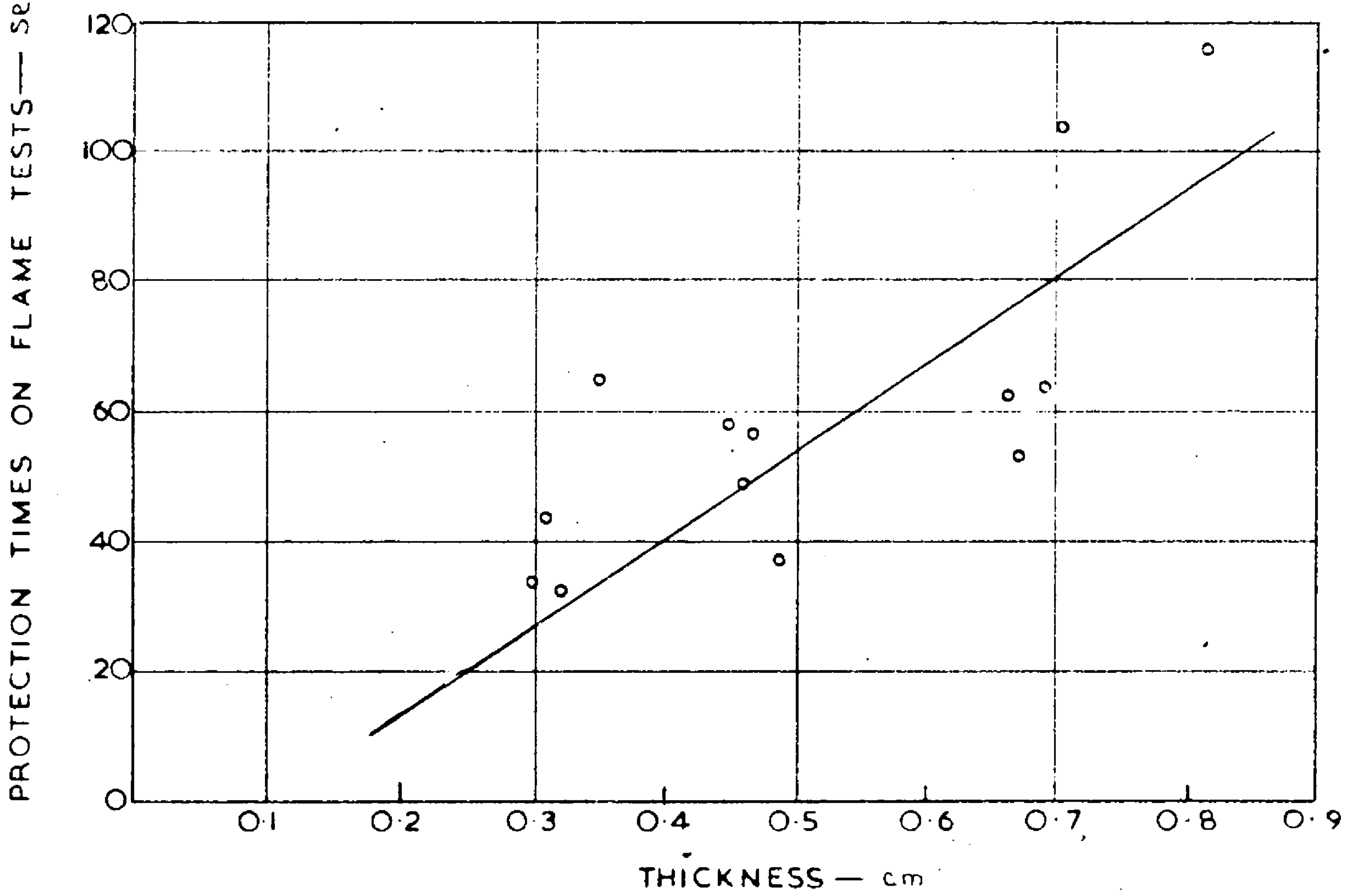

FIG.1. EFFECT OF THICKNESS ON PROTECTION TIMES OF FLAME TESTS

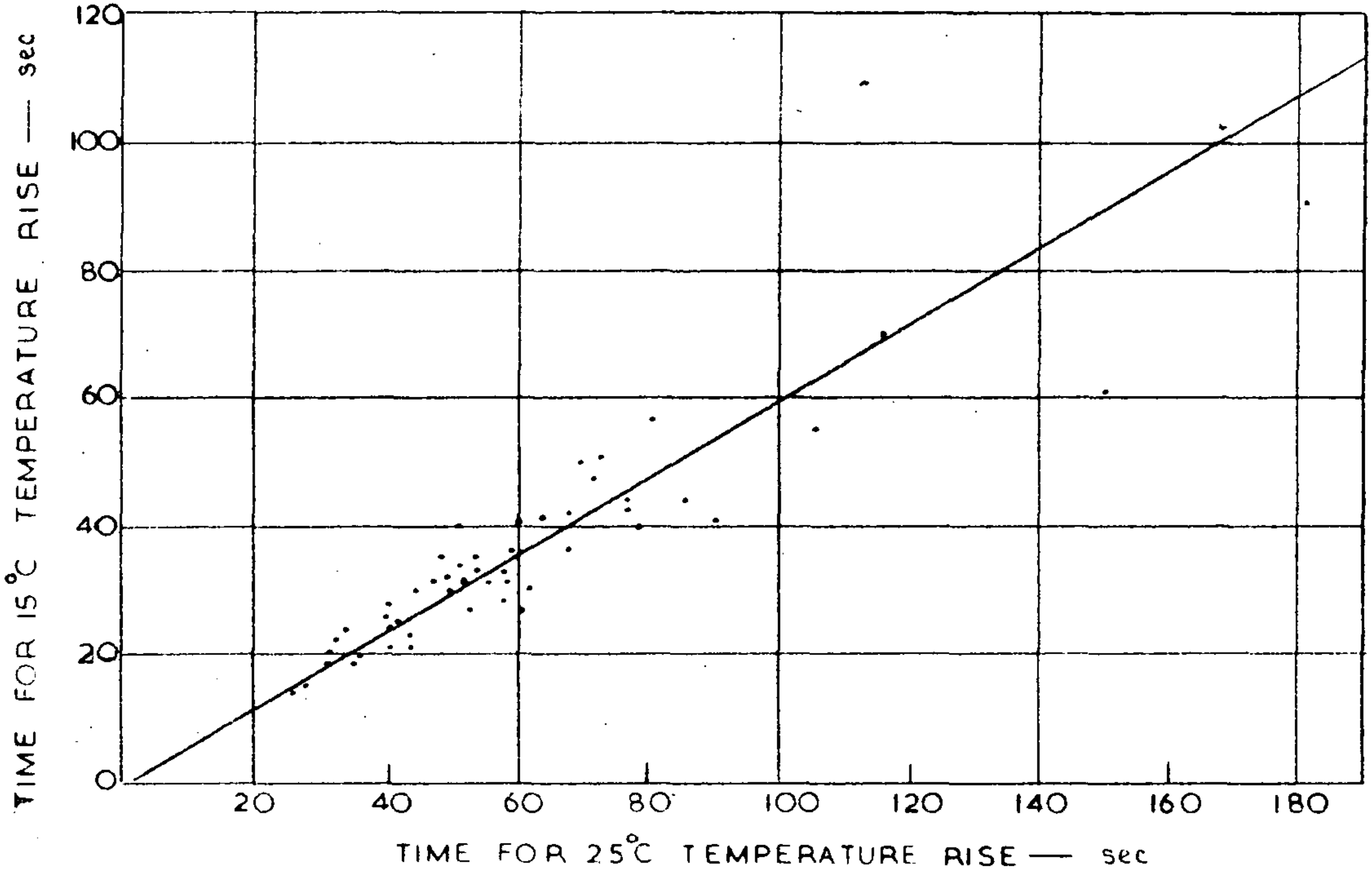

FIG. 2. TIMES FOR 15°C TEMPERATURE RISE AGAINST TIMES FOR 25°C TEMPERATURE RISE (FLAME TEST)

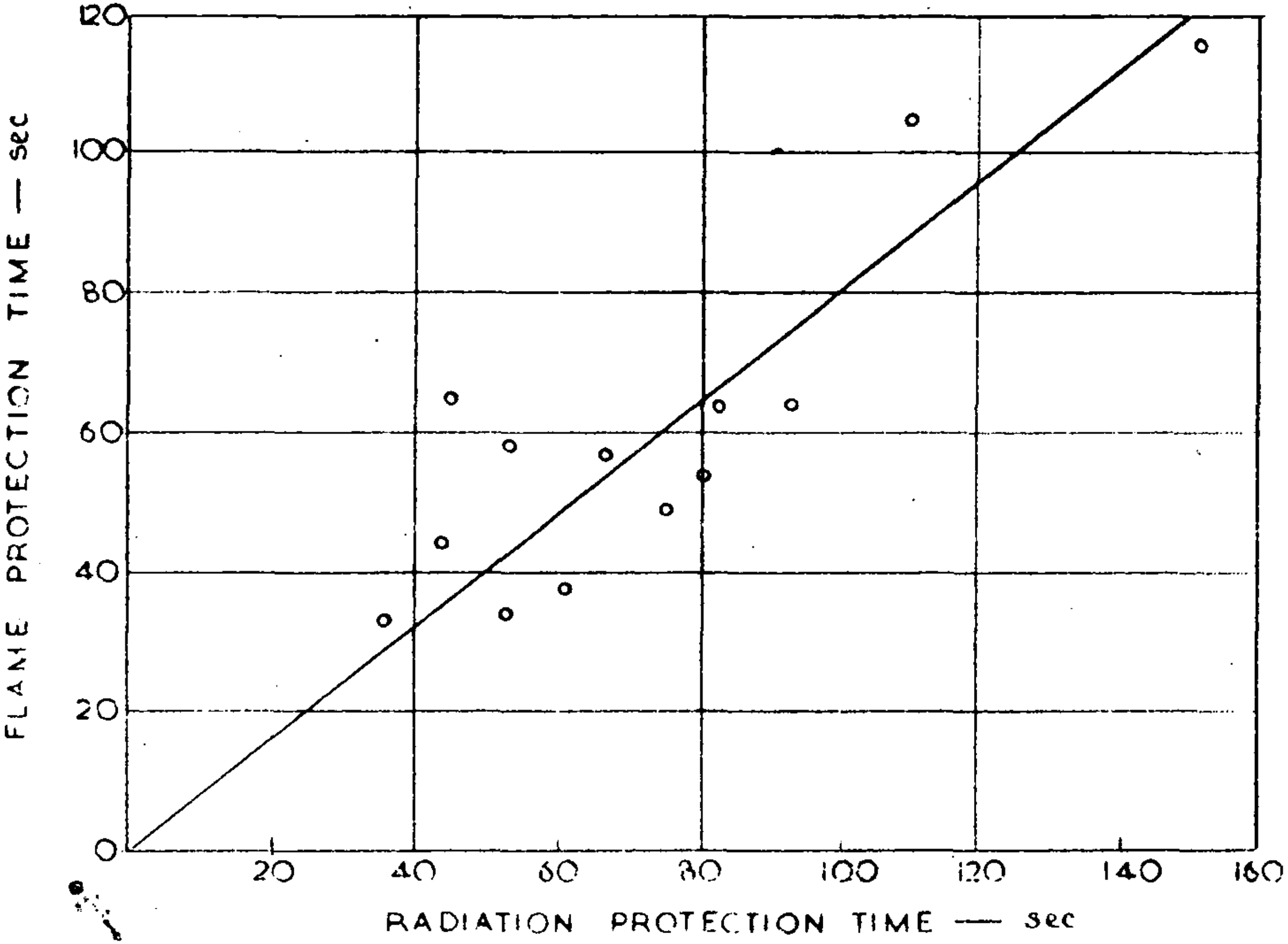

FIG. 3. FLAME PROTECTION TIME AS A FUNCTION OF RADIATION PROTECTION TIME