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# MATERIALS SUITABLE FOR CLOTHING AIRCRAFT FIRE CRASH RESCUE WORKERS

## PART X. THE EFFECT OF WATER ON CLOTHING

by

D. L. Simms and P. L. Hinkley

Summary

The effect of water content on the protection afforded by various clothing assemblies has been measured.

When clothing contains a moisture barrier a large increase in protection is obtained by wetting it. Without a moisture barrier, wet clothing gives less protection against radiant heat than dry clothing because of the inward diffusion of moisture; against flames the protection may be slightly higher for wet clothing than for dry. Possible reasons for this difference between flame and radiation exposure are discussed.

There is a large increase in protection if the clothing is wetted down continuously but there is a danger of scalding if permeable clothing is wetted down when it is hot.

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### 1. Introduction

Previous investigations (1) into the protection afforded by clothing for aircraft fire crash rescue workers have been carried out at moisture contents found in the laboratory. In practice, the moisture content may be very different as the clothing may be worn in differing climates or it may be wet with rain.

The water content of clothing could influence the protection given by:-

(a) the cooling effect of the evaporation of water from the surface:

(b) the heat transfer through the clothing due to the inward diffusion hot vapour:

(c) the change of the thermal properties of clothing materials; the thermal resistance may be reduced and the thermal capacity will be increased.

The relative importance of these effects is likely to vary according to the severity and duration of the exposure. This report describes experiments to determine the effect of the moisture content on the protection afforded by clothing against radiant heat and against flame licks under the same conditions as previous work (1). This has led to the modification of some of the conclusions of an earlier report (2), and the assumption that the results of the flame tests were applicable to the radiation tests has been shown to be incorrect.

A rescue worker may be wetted down after his clothing has become hot; for instance, it is common practice to wet down a man who has become overheated in order to provide relief, but because a large volume of steam may be produced rapidly if the clothing is above 100°C, experiments were carried out to find whether this could penetrate the clothing and scald the wearer.

Some of these experiments were repeated with a thin polythene layer interposed between the outer garments and the interlining. This was thin enough not to have a significant effect on the protection given by a dry assembly but it provided a barrier to heat transfer by diffusion of water or water vapour and thus made it possible to demonstrate the importance of this effect upon the protection afforded by wet garments.

### 2. Experimental procedure and results

#### 2.1. Materials used in experiments

The materials used are listed in table 1.

TABLE I

| Part of clothing assembly | Description | Surface colour | J.F.R.O. ref. no. | Thickness mm | Weight per unit area g/cm$^2$ |
|---|---|---|---|---|---|
| Outer materials | Aluminised asbestos | aluminium | R.165 | 1.3 | 0.10 |
| | Aluminised cotton | aluminium | R.166 | 0.4 | 0.05 |
| | Fearnought (wool, not flameproofed or water proofed). | white | R.154 | 2.9 | 0.08 |
| | Lasting cloth (wool, not flameproofed). | white | R.178 | 1.1 | 0.05 |
| | Asbestos cloth | white | R.179 | 1.3 | 0.08 |
| Inter-lining | Wool pile (cotton backed). | white | R.177 | 4.0 | 0.045 |
| | Open mesh fabric (cotton) | white | R.148 | 3.0 | 0.05 |
| | Polythene | transparent | R.249 | 0.04 | 0.0035 |
| Lining | Cotton poplin | cream | R.147 | 0.01 | 0.012 |

## 2.2. Conditioning of assemblies

Assemblies were tested in all the following conditions:-

(a) Oven dry : All materials oven dried.

(b) Wet : All materials soaked in water containing a little wetting agent rinsed in clean water and wrung out. This resulted in a moisture content of the order of 100 per cent. of dry weight.

(c) Normal : All materials conditioned in an oven at 40-60 per cent. humidity and about 25°C for 24 hours resulting in a moisture content of the order of 10 per cent. The moisture content was determined by weighing.

## 2.3. Experiment on the effect of moisture on protection

### 2.3.1. Flame tests

Details of the experimental method have been described previously[3] except that in these experiments the backing material was a ½ in. thick piece of asbestos wood which is more convenient to use than the horse-meat used previously. Comparative experiments show that the protection times obtained using asbestos wood are 2/3 of those obtained using horsemeat. The temperature of the surface of the asbestos wood in contact with the back of the assembly was measured by a 38 s.w.g. copper-constantan thermocouple soldered to a copper disk ½ in. in diameter. The front face of the assembly was exposed to flames from a small petrol fire and the time taken for the surface of the asbestos wood to rise in temperature by 25°C was noted. Tests were carried out on a number of assemblies with and without moisture barriers in the oven dry, normal and wet conditions.

The results are shown in Figs. 1a, 1b, and 2.

2.3.2. Radiation tests

The radiation test [3] was similar to the flame test except that the front face of the assembly was exposed to radiation approximately characteristic of a black body at 1000°K at an intensity of 0.5 cal $cm^{-2}s^{-1}$. This was provided either by an electric heater or a gas fired radiant panel. Experiments were carried out on two assemblies both with and without a moisture barrier in the oven dry, normal and wet conditions, the results being shown in Figs. 1a and 1b.

2.3.3. Wetting down tests

The radiation test was used for these experiments which were carried out on oven dry assemblies with and without a moisture barrier at intensities of radiation of 0.5 cal $cm^{-2}s^{-1}$ and 1 cal $cm^{-2}s^{-1}$. When the temperature of the surface of the asbestos wood rose by 25°C a spray of water was applied to the outer face of the clothing from a batswing burner at the rate of 750 ml/min. (plate I).

With some materials, but not with fearnought nor any assembly with a moisture barrier, there was often a sharp rise in temperature when water was sprayed on to the hot assembly. Typical results are shown in fig. 3 and discussed below.

A few experiments were carried out on assemblies without moisture barriers in which the clothing was wetted by a water spray applied continuously while the assembly was exposed to radiation. No rise in temperature was observed.

2.3.4. Effect of diathermancy on the protection given by wet clothing

As the effect of moisture on the protection given against flames and against radiation differed considerably, some experiments were carried out to test whether part of this effect was due to diathermancy (partial transparency of material to radiation) of the water and of the fabric. These used water and indian ink to wet black and white cotton of similar weights, the backing material being wool pile. The results are given in Table II.

TABLE II

PROTECTION GIVEN AGAINST RADIATION

| Wetting liquid \ Outer material | Protection Times s | |
|---|---|---|
| | Black cotton | White cotton |
| Water | 17, 17, 23, 26<br>mean 20.75 | 15, 23, 19. 17<br>mean 18.5 |
| Indian ink | 30, 21, 21, 28<br>mean 25 | 25, 23, 25, 22<br>mean 23.75 |

There is a slight but significant difference between cloth soaked in water and cloth soaked in indian ink, but no significant difference between the results for black and white cloth. These results are discussed below.

2.3.5. Other observations during experiments

When the garments were wet, moisture condensed on the surface of the asbestos wood except when the polythene layer was present.

Both normal and oven dry outer clothing, unless made of asbestos, were often considerably damaged and the underwear scorched before the end of the protection time, whereas when the clothing was wet there were few signs of damage to the outer garment and none to the underwear showing that heat is transferred by diffusion of water.

## 3. Discussion of results

### 3.1. The effect of water content on protection time

The protection given by moisture permeable clothing against radiation decreases with increasing moisture content. The protection against flames at first decreases with increasing moisture content but then rises and, at moisture contents of about 100 per cent. may be greater than that for dry garments. When a moisture barrier is included in clothing, the protection time always increases with increasing moisture content; with a high moisture content the protection against radiation or flames may be at least twice as high as for dry clothing.

The effects are shown diagrammatically in fig. 4.

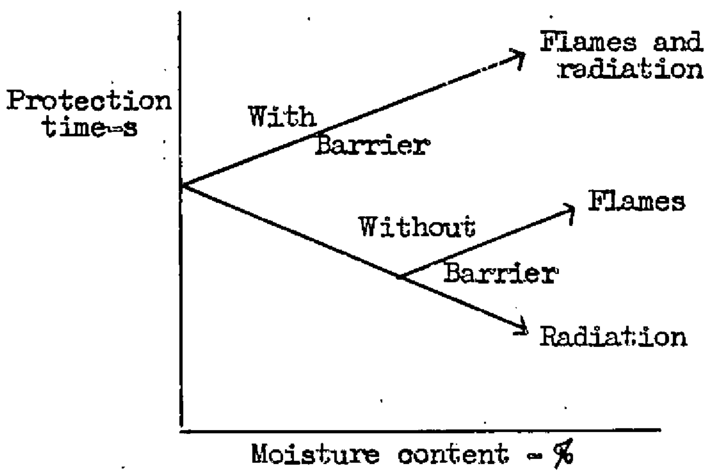


Fig. 4. Diagram of results

With a moisture barrier, the inward diffusion of moisture is restricted and the increased protection results from increased thermal capacity and latent heat. Without a moisture barrier, the inward diffusion of vapour usually reduces protection below the level of that for dry materials. The differences between the behaviour of materials exposed to radiation and flames may arise from either or both of the following effects:-

(a) Table II shows that there is some effect due to diathermancy; radiation penetrates into the body of the wet assembly and this results in a lowered protection time. The effect is slight but significant. Heating in the flame test is more by convection than by radiation so that the greater part of the heat is absorbed directly on the surface and any diathermancy due to water content would have little effect.

(b) The convective flow of water from the hot surface tends to reduce the net heat transfer from the flames; there is no similar effect with radiation transfer.

Thus for small increases in moisture content, the heat transfer by diffusion reduces the protection, but as the moisture content increases, the evaporative effect reduces the effective rate of heat transfer from the flame so that the protection time is correspondingly increased.

### 3.2. The wetting of hot clothing

With assemblies other than those incorporating an impermeable layer the temperature generally rose suddenly when water was applied. This rise in temperature depended on the outer material, being much less for heavy woollen or tightly woven materials than for asbestos. It is probably due to the passage of steam formed in the outer layers of the clothing expanding inwards through the air spaces in the clothing. Some of the differences between materials may be due to differences in "wettability". (Plates 1 and 2).

## 4. Practical Implications and Conclusions

In use, the most likely severe exposure is to heating by radiation so that the protection afforded by wet clothing is likely to be less than that afforded by dry clothing, although not much less than that afforded by slightly damp clothing. Continuous wetting down of the clothing when exposed to flames or radiation will, by maintaining the outer surface at less than 100°C, tend to improve the protection whether or not there is a moisture barrier, but this is not always practical.

If the clothing does not incorporate a moisture barrier, "wetting down" a rescue worker before he enters the fire zone may reduce the protection afforded, although it delays the onset of charring and so reduces the tendency for clothing to lose its strength on heating. The danger of scalding from initially wet clothing is much less than from clothing which is wetted when it is hot, particularly if the clothing is made of asbestos. If there is a danger of accidental wetting, clothing should be "wetted down" before the wearer enters the fire zone.

If the clothing incorporates a moisture barrier "wetting down" will greatly increase the protection. Such clothing is, however, uncomfortable to wear for long periods "at the ready" except in cool conditions and is generally only suitable for "quick donning" garments.

## References

1. HINKLEY, P. L. SIMMS, D. L. and PICKARD, R. W. Materials suitable for clothing aircraft fire crash rescue workers. Part IX. Joint Fire Research Organization, F. R. Note No. 323/1957.

2. SIMMS, D. L. and KARAS, G. C. ibid Part VI. Joint Fire Research Organization, F. R. Note No. 268/1956.

3. PICKARD, R. W. and SIMMS, D. L. ibid Part I. Joint Fire Research Organization, F. R. Note No. 153/1955.

4. HINKLEY, P. L., SIMMS, D. L. and MILLAR, D. W. ibid Part II. Joint Fire Research Organization, F. R. Note No. 220/1955.

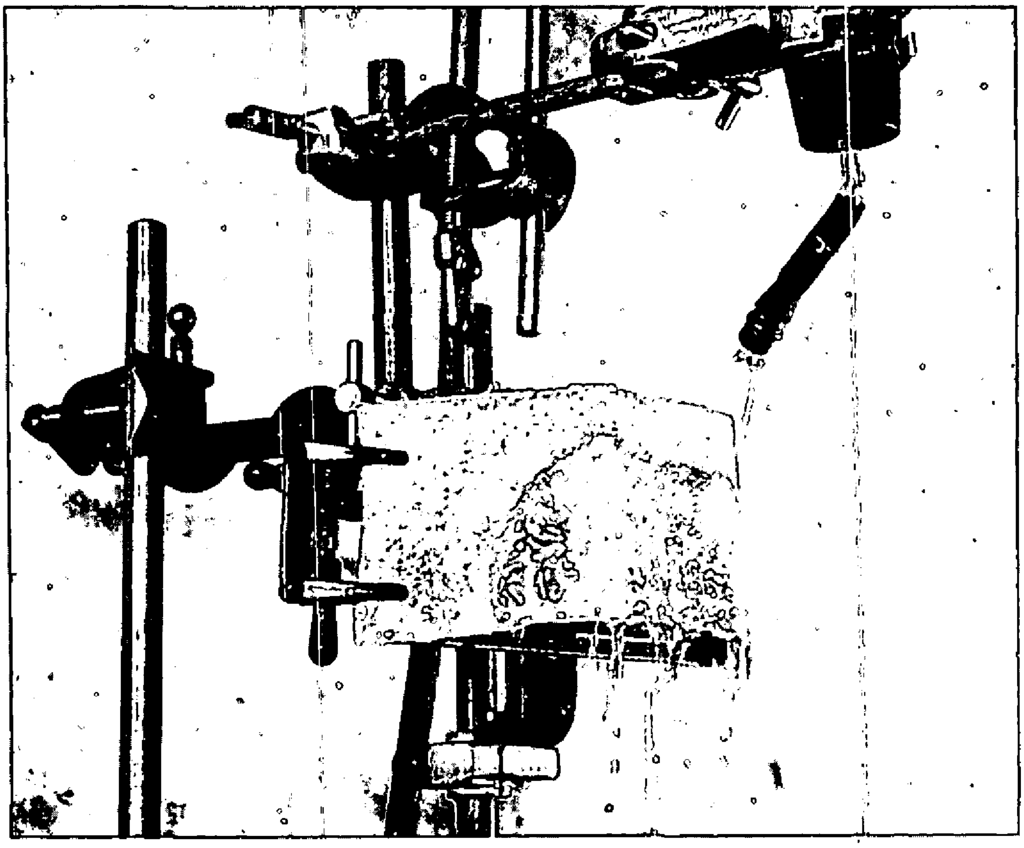

PLATE. I. THE APPLICATION OF WATER SPRAY TO ASBESTOS CLOTH

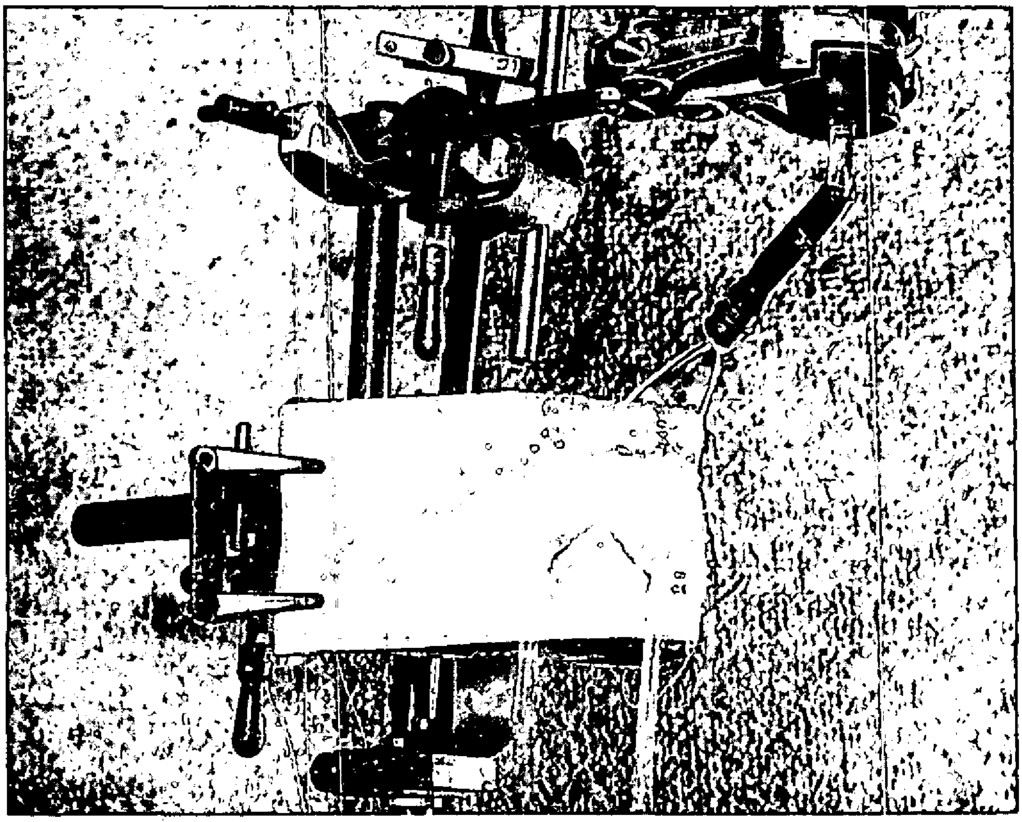

PLATE. 2. THE APPLICATION OF WATER SPRAY TO LASTING CLOTH

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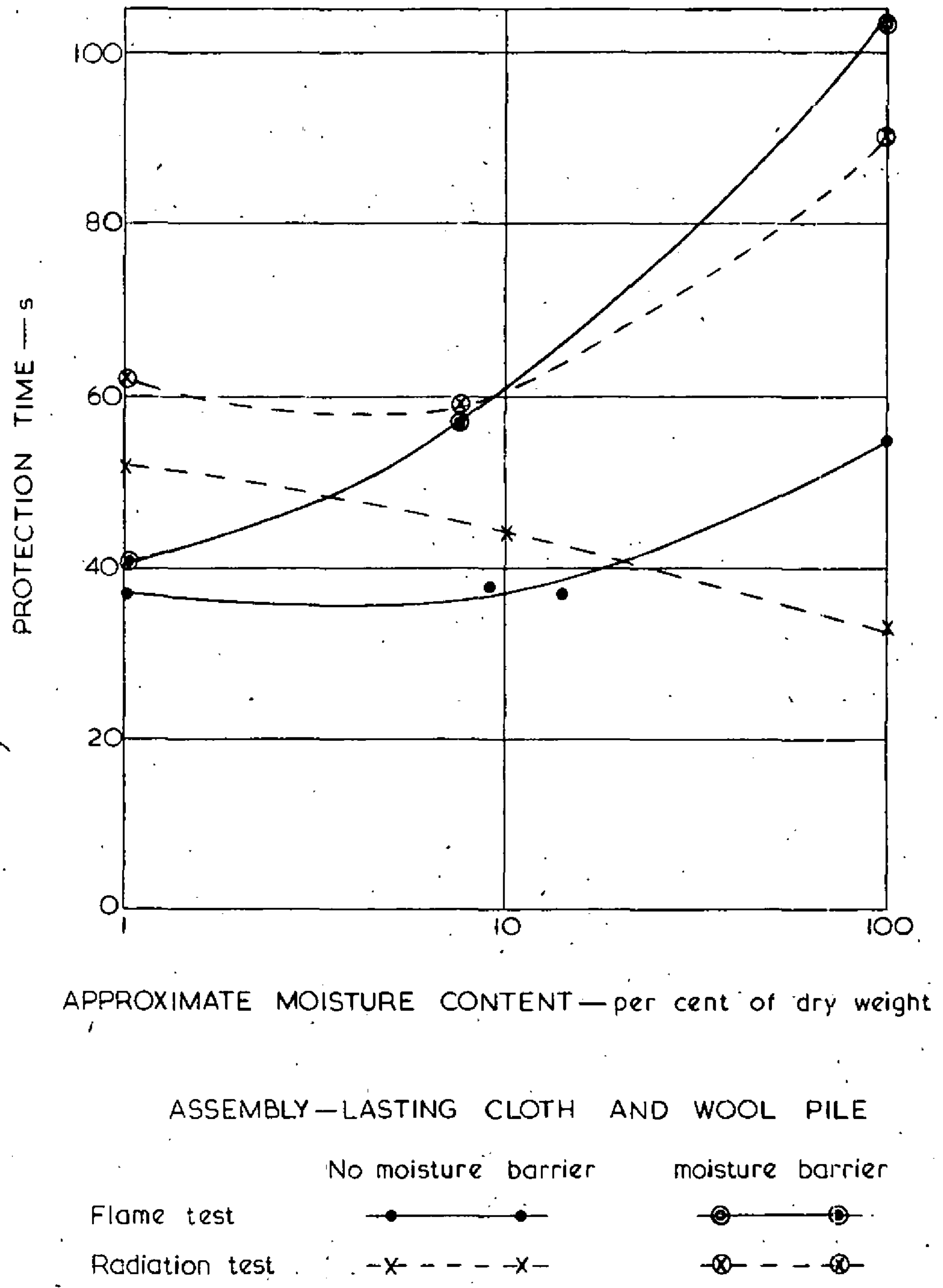


FIG. 1a. EFFECT OF WATER CONTENT ON PROTECTION AGAINST FLAMES AND RADIATION TIMES

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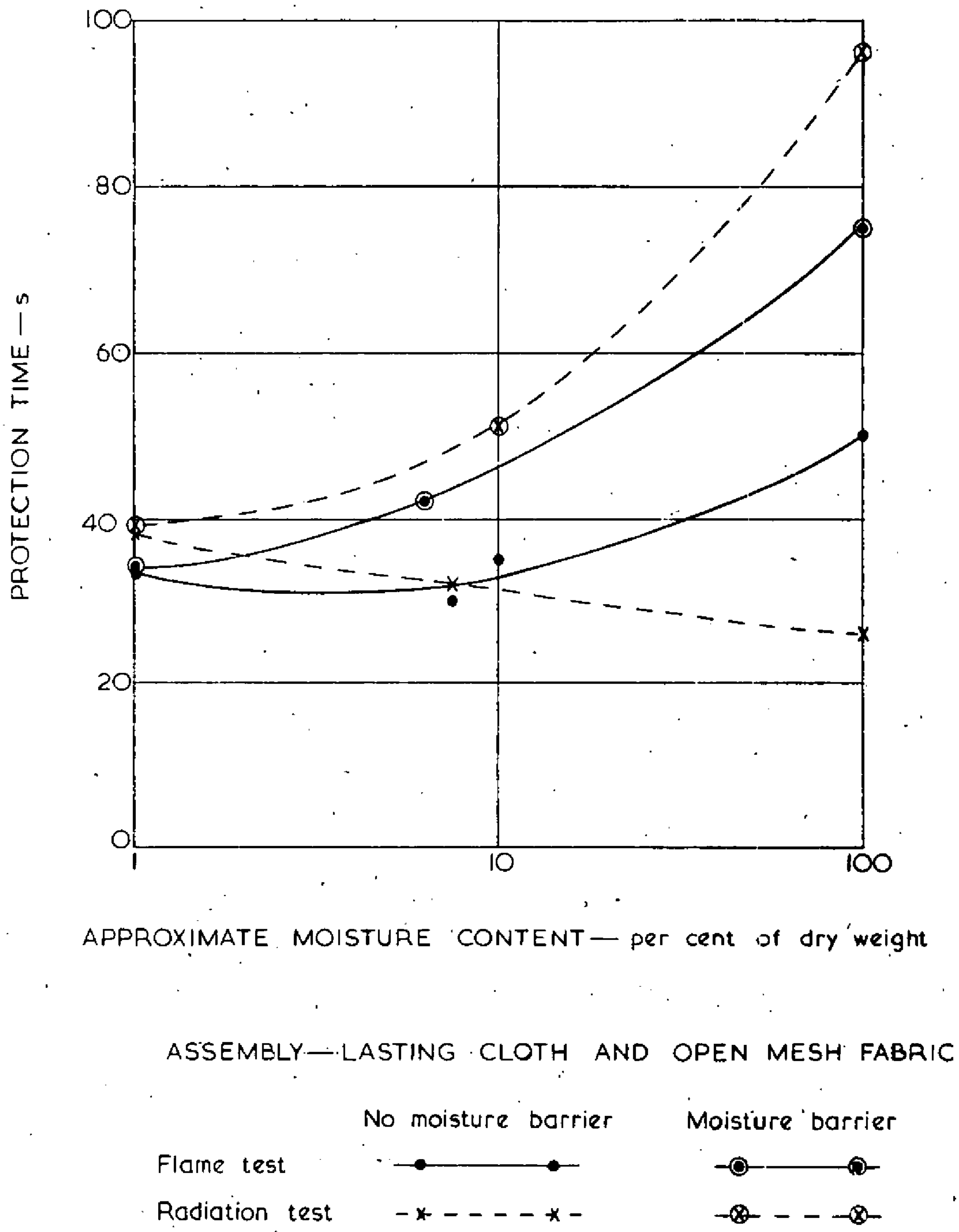


FIG. Ib. EFFECT OF WATER CONTENT ON PROTECTION AGAINST FLAMES AND RADIATION

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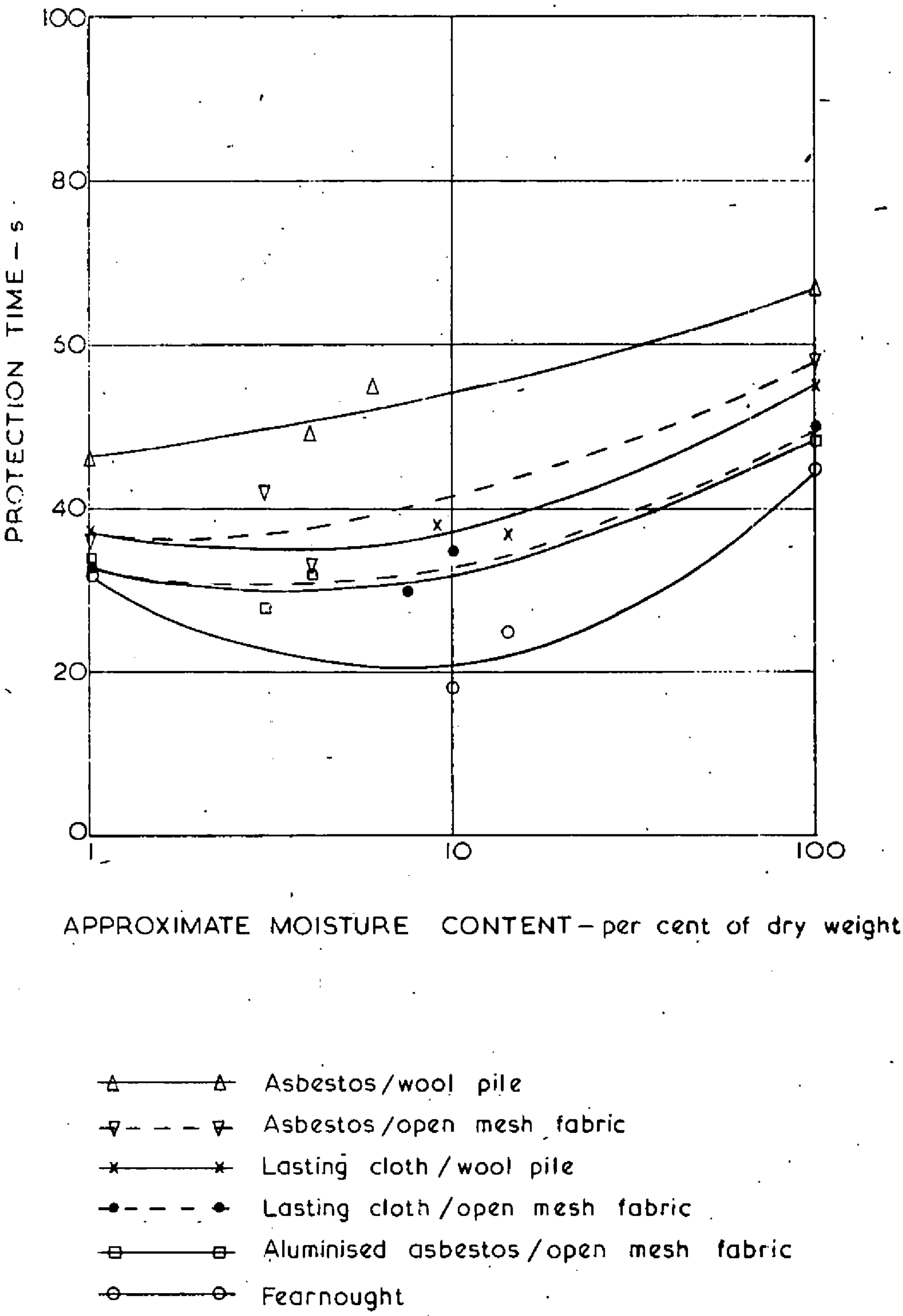


FIG. 2. EFFECT OF WATER CONTENT ON PROTECTION AGAINST FLAMES (NO MOISTURE BARRIER)

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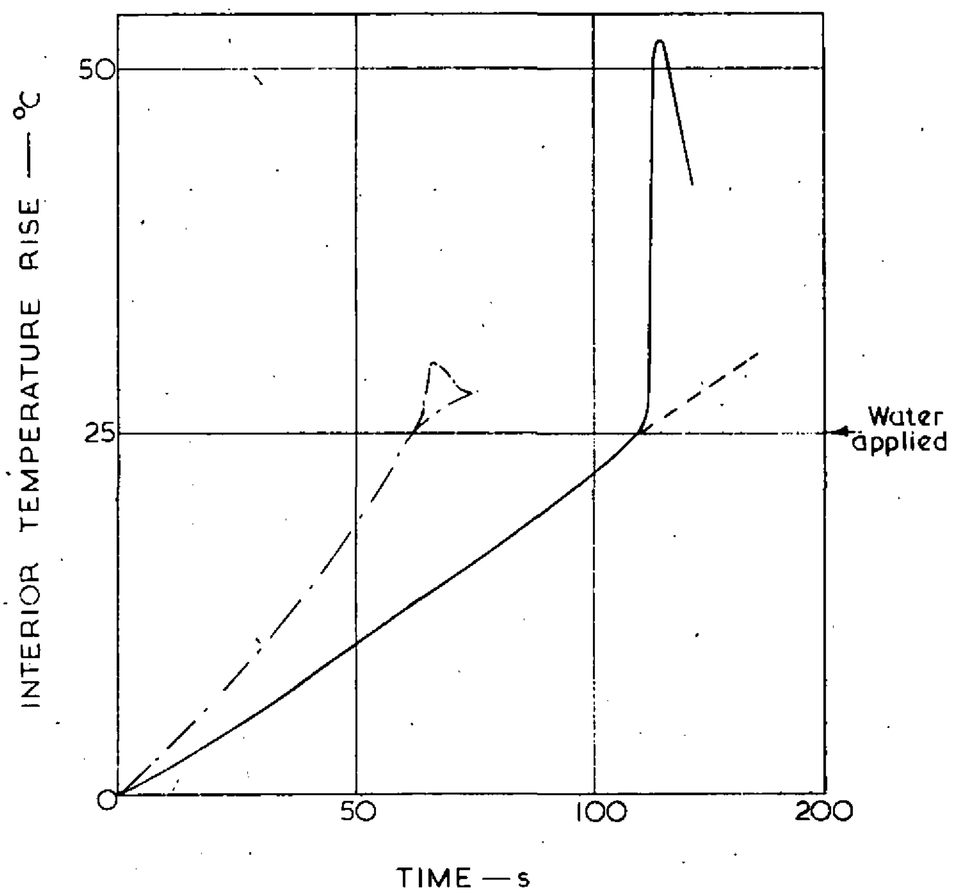


FIG. 3. EFFECT OF SPRAYING WATER ON TO HOT DRY CLOTHING

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