# Fire Research Note
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## EXPERIMENTS ON SMOKE DETECTION

## PART 3: FIRES IN EXPANDED POLYSTYRENE, POLYURETHANE FOAM, AND COMPRESSED CORK.

by

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**SUMMARY**

This note describes experiments which measured the response of an ionization chamber smoke detector to smokes produced by burning or smouldering some thermal insulating materials. The response of the detector is given in terms of the optical density per metre of smoke required for an alarm signal. Detector performance is compared with the observed or estimated performance of other types of smoke detectors.

KEY WORDS: Detector, fire, smoke, insulation (thermal), plastics.



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## 1. INTRODUCTION

As part of a continuing programme of research into the detection of fire by smoke,[1,2,3] some preliminary measurements have been made of the response of a commercial ionization chamber smoke detector to the smoke produced during combustion of expanded polystyrene, polyurethane foam and compressed cork. These materials are commonly used as insulating materials in industrial cold stores. The first two materials are also used increasingly in domestic premises.

The experiments reported here were intended to establish:

(a) If the ionization chamber type smoke detector would respond to the smoke produced from these materials.

(b) The concentration of smoke required to give an alarm signal from the detector.

The concentration of smoke was not measured absolutely, but in terms of light transmission through a known path length of the smoke.

Some measurements were also made of the performance of an optical scattering smoke detector.

## 2. EXPERIMENTAL

2.1. Three ionization chamber smoke detectors A, B, C, from one manufacturer were mounted 4.6 m (15 ft) apart on the ceiling of a compartment 6.1 m (20 ft) high x 15.2 m (50 ft) x 11.0 m (36 ft) (see Fig 1). Optical density monitoring devices were mounted alongside each detector. These devices consist essentially of a tungsten filament lamp and a cadmium sulphide photocell, together with suitable collimating lens and a stop to reduce scattered light falling on the photocell. The spacing of lamp and photocell is such that the transmission of light over a metre path length through the smoke is measured.

The attenuation of light is preferably expressed as the optical density per metre, which, for these instruments, is:

$$\text{Optical density} = \log_{10} \frac{I_o}{I} \; ; \; m^{-1}.$$

where $I_o$ = illumination of the photocell when no smoke is present;

$I$ = illumination when smoke is present.

Alternatively, the attenuation may be expressed as the percentage obscuration, P, of the light in a metre path length through the smoke:

$$P = \frac{(I_o - I)\ 100}{I_o}$$

The estimated error of the optical density measurements was $\pm$ 0.005m$^{-1}$ ($\pm$ 1 per cent obscuration for a 1 m path length).

2.2. For the production of smoke, three methods were employed which roughly simulated different ways in which the materials might become involved in a fire:

(a) For the normal combustion of the material in air a pile of sticks of each material (referred to loosely as a crib) was burned. Ignition was facilitated by presoaking one of the sticks in methylated spirits. Sticks were typically 8 cm$^2$ (1.25 in$^2$) cross-section and 15 cm (6 in) long.

(b) Sticks of each material were placed in the flame of a 15 cm (6 in) diameter tray of burning methylated spirits. This was intended to simulate a situation in which the material was burned by the impingement of flame from another burning material. (Methylated spirits itself burns without producing smoke).

Fires (a) and (b) were at ground level, directly beneath either detector A or detector C.

(c) For smouldering combustion, each material was placed on a laboratory hotplate (temperature 450°C). The hotplate was 3 m (10 ft) below either detector A or detector C: insufficient heat was generated to carry the smoke from ground level to the 6 m high ceiling. For the same reason smoke reached only the detector directly above the hotplate.

2.3. A fire of cellulosic material (mainly cardboard but with some wood) was used to check the operation of the detectors and the optical density meters. Detector A, on the ceiling directly above the fire, gave an alarm signal when the optical density was $0.009 m^{-1}$ (2 per cent obscuration). Detector B, 4.6 m horizontal distance from the fire, gave an alarm 10 seconds later when the optical density at that position was $0.005 m^{-1}$ (1 per cent obscuration). These values are typical of the response of ionization chamber type detectors to fresh smoke from cellulosic material. Detector C, 9.2 m (30 ft) horizontal distance from the fire, did not give an alarm signal although the optical density in its vicinity reached $0.035 m^{-1}$ (8 per cent obscuration). Detector C was found to give erratic results in tests No.1 to 6 inclusive.

## 3. RESULTS

The results are summarized in Table 1.

### 3.1. Polyurethane foam

Polyurethane was rapidly consumed by methods (a) and (b), - as a crib or in a flame, - and produced copious black smoke in both cases. The optical density at the detector positions rose rapidly to a high value (80 - 100 per cent obscuration) very quickly after ignition of both fires.

Fire (a) was under detector C. All three detectors gave alarm signals within 1 minute of ignition. Fire (b) was under detector A. In this case detector C failed to give an alarm signal; the smoke was visually observed to be flowing downwards from the ceiling at a point between detectors B and C.

On the hotplate (3 m below detector A) polyurethane produced a yellowish, pungent smoke. Detector A gave an alarm signal when the optical density was $0.065 m^{-1}$ (14 per cent obscuration).

### 3.2. Expanded polystyrene

When the crib of polystyrene sticks, method (a), was ignited, the polystyrene melted/degraded to a black resin which continued to burn slowly producing a black smoke. All three detectors alarmed, the optical density at alarm being in the range 0.055 to $0.13 m^{-1}$ (12 to 26 per cent obscuration).

In the methylated spirits flame, method (b), the material was consumed without appreciable smoke production. The optical density at the three detector positions did not exceed 0.009 $m^{-1}$ (2 per cent obscuration); none of the detectors gave an alarm signal.

The smoke produced by placing polystyrene on the hotplate 3 m below detector C was detected when the optical density was 0.16 $m^{-1}$ (30 per cent obscuration).

3.3. Compressed cork

When burning in air, method (a), cork produced a greyish smoke. Detector A, under which the crib was placed, gave an alarm signal 40 seconds after ignition, and detector B gave a signal 1 minute later. There was no measurable optical density when detector A responded and the optical density at detector B was less than 0.009 $m^{-1}$ (2% obscuration) when that detector alarmed. Detector C did not give a signal, although the optical density at its position was about 0.018 $m^{-1}$ (4 per cent obscuration). The optical density did not exceed 0.025 $m^{-1}$ (6 per cent obscuration) at any of the three monitoring points.

This material was not burned in the methylated spirits flame.

When cork was placed on the hotplate, 3 m beneath detector A, the smoke produced was detected when the optical density was 0.03 $m^{-1}$ (6.5 per cent obscuration).

3.4. Observations with an optical smoke detector

The response of a commercially available smoke detector of the optical scattering type was also noted in some of the above experiments. This detector was found to respond to the dense smoke from polyurethane (either freely burning or burned in the methylated spirits flame). Because of the rapid rise of optical density from these fires (cf 3-1), it is not possible to quote the precise optical density at detector alarm. In the case of smoke from smouldering polystyrene, the optical scattering detector was found to alarm at an optical density of 0.06 $m^{-1}$ (13 per cent obscuration).

4. DISCUSSION AND CONCLUSIONS

The main conclusion from these experiments is that the ionization chamber type smoke detector will detect the smoke produced from polystyrene, polyurethane or cork, both when these materials are freely burning in air and when smouldering. However, polystyrene, if burned in an external flame, will not produce sufficient smoke to operate the detector.

The measured optical density at which the ionization chamber detector alarmed was, in general, higher for smoke from these materials than for wood or cardboard smoke: 0.03 to 0.17 $m^{-1}$ (6.5 to 32 per cent obscuration) for the former and 0.005 to 0.009 (1 to 2 per cent obscuration) for the latter. However the comparison must be seen in perspective. There is no universal relationship between optical density and smoke concentration, since the attenuation of light by a given mass concentration of smoke depends on the material constituting the smoke and the size of the particles in the smoke. It must also be remembered that, for early detection of fire, the important quantity is the mass of smoke produced per unit mass of material burned, and this quantity varies both from material to material and with the rate of burning of a particular material.

Nevertheless, the optical density measurements do suggest that a detector whose operating principle is the obscuration of light by smoke could be quite sensitive to fire in all the materials with the exception of cork (cf 3.3). In addition, it is known[2,3] that optical density values provide a good indication of the response to wood smoke of smoke detectors which work on a (forward) light-scattering principle. Although this correlation cannot be assumed to hold for all other types of smokes, the observations recorded in Section 3.4 suggest that it probably holds for smoke from polystyrene. More work, however, is needed on the response of both types of smoke detector to the smokes used in the present work.

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## TABLE 1 SUMMARY OF RESULTS

Polyurethane foam

| Test No. | Method of Combustion | Optical density per metre at alarm | | |
|---|---|---|---|---|
| | | Horizontal distance of fire from detector | | |
| | | 0 m. | 4.6 m | 9.2 m |
| 10* | a) Crib | $>$ 0.7 | $>$ 0.7 | $>$ 0.7 |
| 1 | b) Meths.Flame | $>$ 0.7 | $>$ 0.7 | No alarm |
| 7 | c) Hotplate | 0.065 | --- | --- |

Expanded Polystyrene

| | | | | |
|---|---|---|---|---|
| 4 | a) Crib | 0.055 | 0.10 | 0.13 |
| 3, 2 | b) Meths.Flame | No alarm | No alarm | No alarm |
| 8* | c) Hotplate | 0.15 - 0.17 | --- | --- |

Compressed Cork

| | | | | |
|---|---|---|---|---|
| 5 | a) Crib | 0 | $\leq$ 0.009 | No alarm |
| --- | b) Meths.Flame | | | |
| 9* | c) Hotplate | 0.02 - 0.04 | --- | --- |

Fire or hotplate was beneath detector A except in cases marked* when it was beneath detector C.

Fire was on ground 6.1 m beneath detector.

Hotplate was 3 m beneath detector.

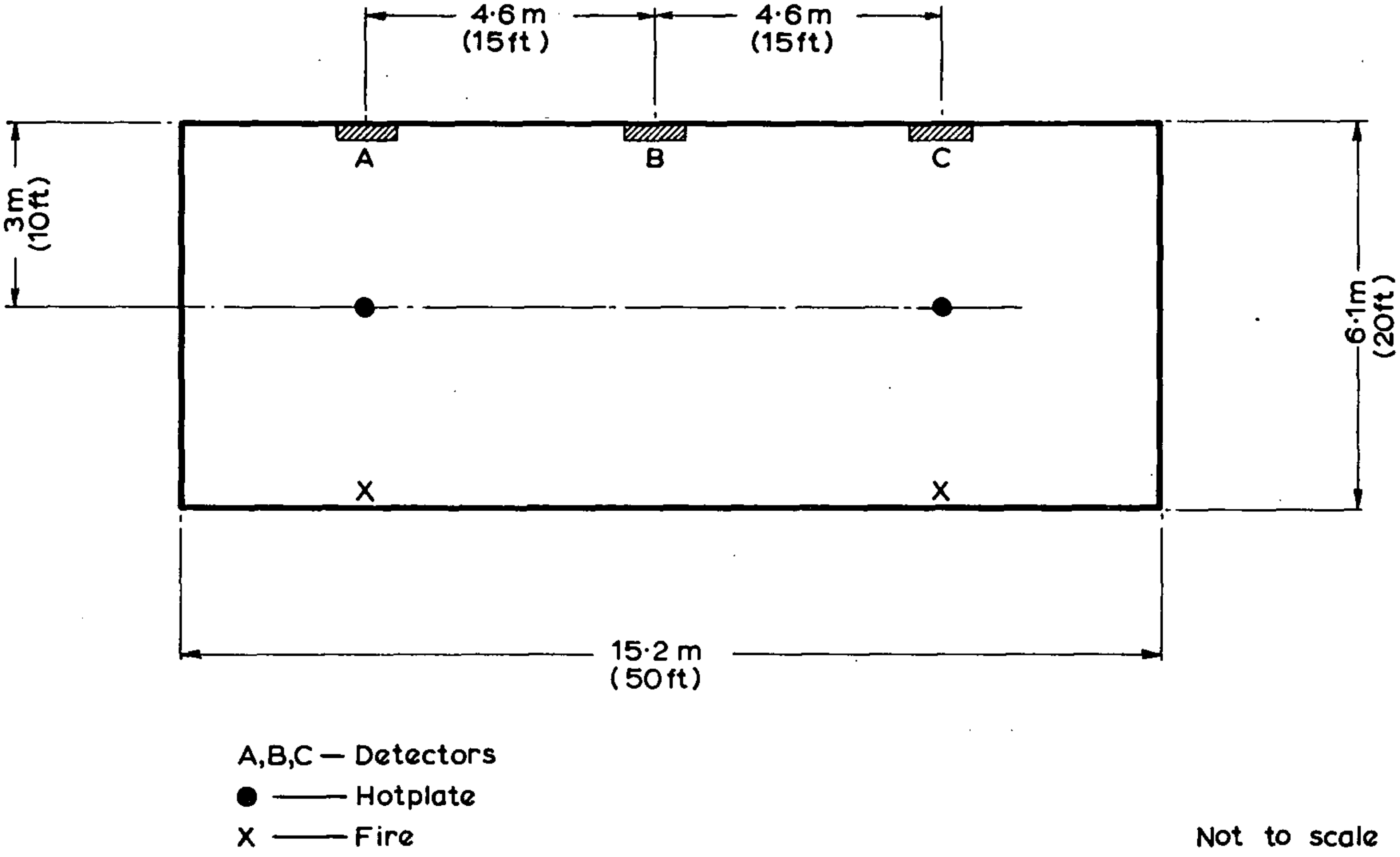


FIG. 1. CROSS-SECTION OF LABORATORY SHOWING POSITIONS OF DETECTORS RELATIVE TO THE VARIOUS SMOKE SOURCE LOCATIONS USED