

DEPARTMENT OF SCIENTIFIC AID INDUSIRIAL RESEARCH AND FIRE OFFICES' COMMITTEE JOINT FIRE RESEARCH ORGNNIZATION

THE THERMAL RADIATION FROM SOME CORDITE FIRES
by
H. Wraight and J. H. McGuire

Summary
Total radiation, flame dimensions and thermal dosage have been measured for burning cordite stacks ranging in weight from 1,000 lb to $40,000 \mathrm{lb}$. Correlations have been derived between flame dimensions, time scale and weight of cordite, in order that maximum dosages could be predicted.

Fire Research Station, Boreham Yood, Herts.

H. Wraight and J. H. McGuire

## Introduction

In 1948 a number of experiments were caritied out by the Ministry of Supply to determine the size of flames from burning cordite, towards the final object of estimating safe distances between stores of this material.

To supplement this information with data on thermal radiation levels at various distances from a cordite fire, a second series of trials was carried out by the Proof and Experimental Establishment at Shooburyness in May, 1958. The principal object of this series was to relate radiation levels to distance from the source of the fire and to the quantity of cordite involved.

The Joint Fire Research Organization was asked to take part in the trials and this report is concerned with the Joint Fire Research Organization's contribution, which included the measurement of the blackbody temperatures of the fires and of the thermal dose at various distances from the fires.

A film record of the trials, made by the Proof and Experimental Establishment has been utilised to derive scaling relationships between the flame radius, time scale and the weight of cordite.

Experimental detail
The cordite stacks were cabical and ranged in weight from 1,000 to $40,000 \mathrm{lb}$.

The black-body flame temperatures were measured with a total radiation pyrometer sited to look across the top of the cordite stack so that the apparent aperture would be filled with radiating flame.

Thermal dose was measured with dosage meters $: \because$ consisting essentially of a sheet of metal blackened on the front surface and coated with temperature sensitive paint on the rear surface. A front shield ensures that only a central circular area is irradiated and the diameter of the paint which subsequently melts is a measure of the total thermal energy which has fallen on the plate. The meters were distributed as indicated in Fig. 1, the diatances given being those for the $40,000 \mathrm{lb}$ trial.

The distances chosen were such that the estimated minimum dose would lie in the range 1 to $10 \mathrm{cal} \mathrm{cm}^{-2}$, this being the order of dose likely to cause ignition of materials. For the remaining trials, ranges were suitably scaled.

All the trials were photographed on 16 mm film at 64 frames per second from two mutually perpendicular directions. The cameras were situated $1,665 \mathrm{ft}$ and 918 ft from the cordite.

The Proof and Experimental Establishment supplied the wind data. The wind direction was given by' a weather vane set up on the site and the wind speed was recorded electrically from a rotating cup anemometer at the same position.

## Dosage meter results

Measured thermal doses together with the distances at which they were obtained are given in Table, 1.

Table 1
Measured heat dosages

| Weight of cordite W 1b | Individual dosage meter results - cal $\mathrm{cm}^{-2}$ |  |  |  | wind speed $\mathrm{ft} / \mathrm{Bec}^{-1}$ |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  | Downwind | Upwind | Crosswind | In direction of camera |  |
| 1,000 | 5.1 at 50 ft | Dosage meter readings too small for conversion to thermal dose |  |  | 17 |
| 1,000 | $\left\lvert\, \begin{array}{ccc} 10.2 & \text { at } & 30 \mathrm{ft} \\ 7.2 \mathrm{n} & 40 \mathrm{ft} \\ 6.0 \mathrm{n} & 50 \mathrm{ft} \end{array}\right.$ | $3 \cdot 9$ at 40 ft |  | $4 \cdot 3$ at 40 ft | 17 |
| 1,000 | $\left\lvert\, \begin{array}{ccc} 15.2 & \text { at } 30 \mathrm{ft} \\ 9.0 & \mathrm{\prime} \mathrm{\prime} & 40 \mathrm{ft} \\ 6.8 \mathrm{\prime} \mathrm{\prime} & 50 \mathrm{ft} \end{array}\right.$ | 4.2 lat 40 ft | 27.0 and 4.4 at 40 ft | $4 \cdot 4$ at 40 ft | 19 |
| 2,500 | $17 \cdot 3$ at 40 ft | $\begin{array}{cc\|c} 14.9 \mid a t & 30 \mathrm{ft} \\ 8.0 & \text { " } & 40 \mathrm{ft} \\ 5.4 & \prime \prime & 50 \mathrm{ft} \end{array}$ | $\begin{gathered} 9.2 \text { and } \\ 14.4 \text { at } 40 \mathrm{ft} \end{gathered}$ | 14.4 at 40 ft | 20 |
| 5,000 | $15 \cdot 7$ at 40 ft 15.7 " 15.7 | 5.4 at 50 ft | $\begin{gathered} 8.6 \text { and } \\ 9.4 \text { at } 50 \mathrm{ft} \end{gathered}$ | 9.4 at 50 ft | 26 |
| 10,000 | $\begin{array}{r} 12.4 \text { at } 70 \mathrm{ft} \\ 8.0 \mathrm{ng} 80 \mathrm{ft} \\ 6.6 \mathrm{n} 90 \mathrm{ft} \end{array}$ | 6.3 at 70 ft | $12 \cdot 9 \text { at } 70 \mathrm{ft}$ | 6.0 at 70 ft | 32 |
| 20,000 ${ }^{\text {II }}$ | $\begin{aligned} & 9 \cdot 1 \text { at } 80 \mathrm{ft} \\ & 5 \cdot 7 \mathrm{nt} 90 \mathrm{ft} \\ & 5 \cdot 2 \mathrm{n} 100 \mathrm{ft} \end{aligned}$ | 27.0 at 80 ft | $\begin{aligned} & 7 \mathrm{I} \\ & 7.27 .0 \text { and } \\ & 7.2 \text { at } 80 \mathrm{ft} \end{aligned}$ | $27 \cdot 0$ at 80 ft | 17 |
| 40,000 | 23.0 at 00 ft 20.0 " 110 ft $15 \cdot 7$ " 120 ft | $25 \cdot 0$ at 100 ft | $15.7 \text { at } 100 \mathrm{ft}$ | 23.0 at 100 ft | 10 |

"It is presumed that the low "downwind" values are due to the wind changing direction between the time of measurement and the fire.

IThese high values are believed to be due to the envelopment of the meter in the fire-ball during gusting of the wind.

It can be seen that the direction of the prevailing wind has a very marked effect on the dosage values.

## Pyrometer results

The black-body flame temperatures were; calculated from the pyrometer readings for each trial. Values of between $1,330^{\circ} \mathrm{C}$ and $1,440^{\circ} \mathrm{C}$ were obtained, and the mean value was $1,390^{\circ} \mathrm{C}$. There was no observable correlation between the measured values and the size of fire. It would thus seem that the flames were thick enough to have an emissivity approaching unity.

## Film records

Measurements made from the 16 mm film records enabled estimations to be made of the flame dimensions. A summary of these is given in Table 2.

## Table 2

Maximum flame sizes in each trial estimated from film record

| Weight of cordite Ib | Estimated width at ground level ft | Estimated width at 20 ft above ground ft | Estimated maximum width ft | Estimated height of top of flame above 'ground ft |
| :---: | :---: | :---: | :---: | :---: |
| 1,000 | 90 | i. $\begin{array}{r}\text { Over } \\ 100\end{array}$ | $\begin{array}{r} \text { Over } \\ .100 \end{array}$ | $\begin{array}{r} \text { Over } \\ 60 \end{array}$ |
| 1,000 | 80 | 90 | 100 | $\begin{array}{r} \text { Over } \\ 80 \end{array}$ |
| 1,000 | 90 | $110$ | 110 | $\begin{array}{r} \text { Orer } \\ 80 \end{array}$ |
| 2,500 | 80 | 100 | 130 | $\begin{array}{r} \text { Over } \\ 80 \end{array}$ |
| 5,000 | 120 | 150 | 170 | 140 |
| 10,000 | 110 | 150 | 200 | 180 |
| 20,000 | 180 | 190 | 210 | 250. |
| 40,000 | 200 | 220 | 330 | 310 |

Examination of the photographs showed that the shape of the main fire ball was approximately spherical. The radius of this "ball" of flame was measured and radius-time curves obtained for each trial. The curves were normalized to the maximum radius reached in each trial, and also to the time at which the radius had reduced to half its peak value. These normalized curves are shown in Fig. 2.

There was in addition a subsidiary ground flame. A typical distribution is shown in Elate 1.

Derivation of an overall relationship
Because of the similarity of |the values of the normalized flame radius at corresponding times and the constancy of the black-body temperatures throughout the series of trials, an overall relationship between dosage and distance valid for any weight of cordite can be derived.

In Fig. 3 the maximum radius of the ball of flame and the time for the radius to fall to half its maximum value have been plotted on log-log paper against the weight of cordite, It can be seen that to a close approximation the flame. radius varies as pO 33 , and the pulse duration varies as $\mathrm{MO} \cdot 21$. Where $W$ is the weight of cordite.

The dosage received $D$ depend on the black-body intensity of the source $I$, the configuration factor $\varnothing$ and the time $t$ thus,

Since the temperature of the fire bail and its emissivity is constant $I$ is constant.
$\emptyset$ is a function of ratio of the diameter of the fire:ball (d) to its distance from the receiver ( $r$ )

$$
\text { thus } \emptyset=f\left(\frac{d}{r}\right)=f\left(\frac{w_{0} 0.33}{r}\right)
$$

The time scale of the radiation pulse from the fire ball varies as $\mathbf{F 0 . 2 1}$ and it follows therefore that the dosage data should be correlated by the functions $\frac{D}{T 0.21}$ and $\frac{T}{W_{0} .35}$ These have been plotted in Fig. 4. The curve calculated from the film dimensions of the fire ball assuming a temperature of $1,390^{\circ} \mathrm{C}$ is shown on the same graph.

In general the test results lie below the calculated curve which gives the total dosage received by a surface always facing the fire ball and a probable reason for this is that the experimental dosage meters faced in a horizontal direction and hence received lower doses. At the shorter. ranges some of the results are higher than the calculated values. This can be attributed to the contribution of radiation from a subsidiary flame volume which spread out horizontally and very close to the ground as shown in Plate 1.

In the $1,000 \mathrm{lb}$ trial two of the dosage results were anomalously high. This was probably due to the envelopment of the dosage meter in flame following a gust of wind.

The practical results plotted in Fig. 4 show no systematic variation with weight of cordite, which tends ito confirm the fire ball radius and time scale relationships which have beenlderived. The scatter can be attributed largely to the effect of wind but the data are insufficient to derive a correlation with wind conditions.

## Conclusions

Relations between weight of cordite and both fire ball radius and time scale have been derived and an estimate given for the maximumdose which might fall on a surface not enveloped in flame with winds of $20-30 \mathrm{ft} / \mathrm{s}$. Gusting may cause flame to come into contact with such a surface and cause doses about three times higher than this.

Wind conditions have a substantial effect on dose at points near to the fire ball but the available data are insufficient to derive a correlation.




FIG.2. NORMALISED CURVES FOR FLAME RADIUS


FIG.I. LAYOUT FOR 4O,OOO lb TRIAL (not to scale)



DOSAGE METER RESULTS
$+10001 \mathrm{~b}$
. 10000
x 2500Ib

- 20000
- 50001b
- 40000
:FIG. 4. MEASURED AND CALCULATED THERMAL DOSES FOR CORDITE FIRES

