DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

AND

FIRE OFFICES' COMMITTEE

JOINT FIRE RESEARCH ORGANIZATION

FIRE RESEARCH NOTE

NO. 562

ON THE POSSIBILITY OF IGNITION OF MATERIALS BY RADIATION FROM NUCLEAR EXPLOSIONS

PART II - COMMENTS ON THE DATA FROM THE U.S. NAVAL MATERIALS LABORATORY

by

D. L. SIMMS AND MARGARET LAW

November, 1964.

Fire Research Station.
Boreham Wood.
Herts.
('phone ELStree 1341)

F. R. Note No. 562

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

ON THE POSSIBILITY OF IGNITION OF MATERIALS BY RADIATION FROM NUCLEAR EXPLOSIONS

PART II - COMMENTS ON THE DATA FROM THE U.S. NAVAL MATERIALS LABORATORY

by

D. L. Simms and Margaret Law

SUMMARY

The energies required for the sustained ignition of paper measured by Bracciaventi and De Bold at the Naval Materials Laboratory of New York and by Thomas, Simms and Law at the Fire Research Station, Boreham Wood have been compared. It is suggested that the higher energies measured by Bracciaventi and De Bold are due partly to their use of a smaller area of irradiation; they may also be partly due to their surrounding the irradiated specimen by an aluminium plate.

November, 1964.

ON THE POSSIBILITY OF IGNITION OF MATERIALS BY RADIATION FROM NUCLEAR EXPLOSIONS

PART II - COMMENTS ON THE DATA FROM THE U.S. NAVAL MATERIALS LABORATORY

by

D. L. Simms and Margaret Law

Introduction

The values given by Bracciaventi and De Bold of the Naval Materials Laboratory of New York[(1)] for the critical radiant exposures to produce spontaneous ignition followed by continued burning of cellulosic materials differ from those reported by Thomas, Simms and Law[(2)] of the Fire Research Station at Boreham Wood by a factor of 4 for some materials.

Apparatus used at Naval Materials Laboratory

The maximum intensity of radiation in the exposure plane is stated to be 65 cal $cm^{-2}s^{-1}$ over an area of $3/16$ cm^2 and 55 cal $cm^{-2}s^{-1}$ over an area of $\frac{3}{4}$ cm^2.

Specimens were exposed as sheets 3.1 cm square, mounted on 0.16 cm thick aluminium plates with an aperture 2.5 cm square, usually at three or four different intensities corresponding to different distances from ground zero. They were conditioned in atmospheres of 30, 50, 65 and 93 per cent humidity (giving moisture contents of 5 to 14 per cent for black α-cellulose paper) and exposed in draughts of 0, 44, 260 and 440 cm/s.

Comments on apparatus

1. Size of irradiated area

The size of the irradiated area produced by the carbon arc source at the Naval Materials Laboratory is small and this affects the flow patterns in the volatile stream; with small areas there is more rapid dilution by the surrounding air and consequently ignition is delayed.* The apparatus at the Fire Research Station had an effective irradiation area of 3 cm^2, and for this, it was estimated that the ignition time was 20 per cent too long for intensities above 3 cal $cm^{-2}s^{-1}$, and greater still for lower intensities[(4)]. For the source at the Naval Materials Laboratory, the heated area is smaller and the correction necessary for the area effect is much larger.

---

*Lateral conduction may also be significant, so that the temperature rise at the centre of the specimen is not characteristic of that of a large area[(3)]. The experiments at the Fire Research Station[(4)] were designed so that lateral conduction was negligible.

2. Specimen holder

The specimen appears to be flush with the aluminium plate. If this is so, then the volatiles may be cooled and ignition may be prevented or delayed[5].

3. Shape of irradiation pulse

The experimental intensity-time curves are intended to be based on the curve given in "Effects of nuclear weapons"[6]. Both fit this curve closely in the important region about the peak, but the total energies in the two curves are different.

For the source at the Naval Materials Laboratory[1]

$$E = 2.57\, I_p\, t_p \qquad \text{.........} (1)$$

For the source at the Fire Research Station

$$E = 2.4\, I_p\, t_p \qquad \text{.........} (2)$$

For the calculations made by Thomas, Simms and Law[2]

$$E = {}^{e^2}/_4\, I_p\, t_p = 1.85\, I_p\, t_p \qquad \text{.........} (3)$$

Martin and Lai[7] state that the simulated field pulse used in their experiments gives

$$E = 2.07\, I_p\, t_p \qquad \text{.........} (4)$$

Comments on results

1. Energy required for sustained ignition

Identical materials have not been tested by the two laboratories so that it is only possible to compare the experimental results obtained at the Naval Materials Laboratory with values calculated by Thomas, Simms and Law[2]. The lowest recorded values obtained by Bracciaventi and De Bold are those in a wind of 44 cm/s; their use in Table 1 minimises the difference between the two sets of data. Bracciaventi and De Bold found that the effect of a wind of velocity 44 cm/s was small but tended to reduce the total energy required for ignition; the presence of moisture was found to raise the total energy slightly.

Table 1

Energy required for ignition
Black α - cellulose
($\rho = 0.75$ g/cm^3, l = 0.03 cm)

Size of weapon - KT	Energy required - cal/cm^2	
	$E_{FRS}^{(2)}$ Oven dry (estimated)	$E_{NML}^{(1)}$ 30 per cent RH 44 cm/s wind
10	4.5	12
10^2	5.0	14
10^3	6.5	16
10^4	13	22

2. Effect of colour

The experiments and computations by Thomas, Simms and Law[2] suggest that white α-cellulose would require about 2.5 times as much energy as black α-cellulose at about 1 MT, the difference reducing with increasing size of explosion, whereas Bracciaventi and De Bold find a difference of about 5. Thus, comparing these results with those in Table 1, four times as much energy can be required to ignite white materials by the source at the Naval Materials Laboratory as by the one at the Fire Research Station.

3. Effect of wind

The only other experiments[5] reported on the effect of wind on spontaneous ignition showed that below an intensity of radiation of about 3 cal $cm^{-2}s^{-1}$ ignition would not occur unless turbulence were artificially induced. Above an intensity of 3 cal $cm^{-2}s^{-1}$, the turbulence induced by draughts of velocity 25 cm/s had no measurable effects on ignition time.

Bracciaventi and De Bold found an effect at comparable and higher intensities of radiation; there is a small decrease in the energy required for ignition in the presence of a wind of velocity 44 cm/s* but there are also increases in the presence of greater velocities. The effect apparently varies with the irradiation pulse length; with a 440 cm/s wind, twice as much energy is required for ignition at times corresponding to 10 MT as without, but very little difference was found at 250 KT. A difference of 50 per cent greater was found at 20 KT.

The effect of the wind is to increase turbulence and hence it may increase the possibility of a flammable mixture occurring, but it also increases the heat lost from the irradiated surface by forced convection. Rough calculations show that the heat lost by forced convection can be significant compared with the incident energy and, therefore, that one effect of the wind (forced convection) is to increase the energy required for ignition at any intensity of irradiation. The heat lost, and therefore the energy required for ignition, would also increase with wind velocity. The small reduction in energy required for ignition claimed at 44 cm/s may be due to increased turbulence; with the small plume produced by the radiation source at the Naval Materials Laboratory ignition times might be more sensitive to draught than with a larger plume[4][5].

---

*Even if the difference at low velocities is significant its practical importance in predicting threshold distances of ignition from ground zero would be small in view of the numerous other uncertainties in the information.

These effects are also sensitive to the size of the area irradiated as well as the proportion irradiated. With a larger specimen uniformly irradiated, the heat loss by forced convection will decrease relative to the radiation losses which increase uniformly with size and the experiments of Bracciaventi and De Bold may, therefore, overestimate the effect of wind velocity.

4. Effect of moisture content

Both sets of results(1)(2) agree that the effect of moisture content is usually small and that the results for some materials show considerable scatter.

5. Conclusions

Much greater energies for sustained or persistent ignition (spontaneous ignition with continued burning) are required according to Bracciaventi and De Bold than those predicted from calculations and experiments by Thomas, Simms and Law. It is suggested that the main reason for this is the small size of the area irradiated by the source at the Naval Materials Laboratory. An additional reason might be that the specimens were mounted immediately behind an aluminium plate, a method which has been shown to interfere with the ignition process. It is also possible that the results obtained by Bracciaventi and De Bold for the effect of wind are not independent of an area effect.

References

1. BRACCIAVENTI, J. and De BOLD, F. "Critical radiant exposures for persistent ignition of cellulosic target complex materials". Naval Material Laboratory Technical Report. New York, 1960.
2. THOMAS, P. H., SIMMS, D. L. and LAW, Margaret. "On the possibility of ignition of materials by radiation from nuclear explosions". Department of Scientific and Industrial Research and Fire Offices' Committee Joint Fire Research Organization. F.R. Note No. 561/1964.
3. THOMAS, P. H. Some conduction problems in the heating of small areas on large solids. Quart. J. Mech. and Applied Math., 1957, 10, Part 4, 482.
4. SIMMS, D. L. "Ignition of cellulosic materials by radiation". Combustion and Flame 1960, 4, (4) 293.
5. SIMMS, D. L. "Experiments on the ignition of cellulosic materials by radiation". Combustion and Flame 1961, 4, (5), 369.
6. GLASSTONE, S. (Ed.). Effects of nuclear weapons. United States Atomic Energy Commission, Washington, 1957.
7. MARTIN, S. B. and LAI, W. "Thermal radiation damage to cellulosic materials. Part III - Ignition of alpha cellulose by pulses simulating nuclear weapon air bursts". United States Naval Radiological Defense Laboratory, California, U.S.A. Technical Report USNRDL-TR-252, 1958.