DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

AND

FIRE OFFICES' COMMITTEE

JOINT FIRE RESEARCH ORGANIZATION

FIRE RESEARCH NOTE

NO. 578

THE BURNING OF WELL-VENTILATED COMPARTMENT FIRES
PART IV BRICK COMPARTMENT, 2.4m (8ft) CUBE

by

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F. R. Note No. 578

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SUMMARY

Experiments, in which wood cribs were burned in a well-ventilated brick compartment 2.4m (8ft) cube, are described. The rates of burning of these cribs were lower than those predicted from an extrapolation, from smaller scale, of the relationship between the rate of burning and the weight of the crib. However, the measurements of both the intensity of radiation from the opening and the ratio of flame height to a dimension of the compartment are consistent with predictions based on the smaller scale experiments.

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Introduction

Studies of the burning of well-ventilated compartment fires are being conducted to predict the fire resistance requirements of building structures[1], and to estimate the hazard to property exposed to radiation from a burning building[2].

From earlier experiments[3][4][5] with compartments up to 0.91 m (3 ft) cube it was found that:

(a) the rate of burning of a crib was independent of the size of the compartment (over the range considered) and was directly proportional to the initial weight of the crib,

(b) the radiation intensity in the plane of the window opening was directly proportional to the rate of burning per unit floor or window area, and

(c) the ratio of the flame height to a linear dimension of the compartment was proportional to a power of the rate of burning.

Three experiments on fires in a brick compartment about 2.4 m (8 ft) cube, described in this note, have been performed to increase the range of compartment size for which data are available, and also to find the temperatures within the walls of the compartment for a range of fire loads. These experiments were done on the same day and it was found that insufficient time had been allowed for the walls to cool down so that the wall temperatures were initially high enough above ambient to have serious effects on comparisons between measured and calculated temperatures within the walls during the fires, but it is not expected that even the maximum measured temperature of 90 degC would significantly affect the rate of burning or the radiation from the fire.

Two further experiments[6], carried out on successive days, gave measurements of the temperatures within the walls, which could be used in comparing measured and calculated temperature rises, but measurements of the flame height, the radiation intensity and the proportion of charcoal remaining when flaming had ceased suggested that the burning rate measurements were anomalous, and the results of these two tests have therefore been omitted from this report.

Experimental apparatus

The compartment used in this series of experiments had internal dimensions of 2.4 m (8 ft) cube, and was placed within a large, substantially draught-free building. This compartment consisted of three walls 2.4 m (8 ft) high (positioned as shown in Fig. 1) of brickwork 23 cm (9 in) thick supported by four concrete beams on four brick piers, with a roof of precast refractory concrete slabs 10 cm (4 in) thick. The floor, 1.37 m (4 ft 6 in) above the ground, was a weighing platform 2.4 m (8 ft) square; this consisted of a sheet iron tray 5 cm (2 in) deep with a layer of burnt clay aggregate 2.5 cm (1 in) deep and on this a layer of diatomaceous earth slabs 5 cm (2 in) thick to provide a hearth and thermal insulation. The platform, which was supported by two British Standard beams[7] 3.66 m x 7.5 cm x 3.8 cm (12 ft x 3 in x $1\frac{1}{2}$ in) spaced 1.22 m (4 ft) apart with their ends welded to upright joists, could move freely in the vertical plane. To restrict heat losses and air flow, the gap between the platform and the walls was partly filled by asbestos rope resting on the platform.

Any movement of the platform, due to a change in load, was transmitted by a wire to a mild steel cantilever 1.27 cm ($\frac{1}{2}$ in) x 0.16 cm ($^1/_{16}$ in), near the fixed end of which was attached a pair of resistance strain gauges forming two arms of a Wheatstone bridge. The out-of-balance voltage of this bridge was a measure of the load. The upper end of this wire was attached to the centre of the 1.22 m (4 ft) spacing rod fixed between the mid-points of the two beams. A knife-edge which rested in a V - groove mounted on the cantilever was fixed to the lower end (Fig. 2). From the knife edge a weight was hung which was just heavy enough to ensure that a deflection of the beam caused an equal deflection of the cantilever. If the weight had been heavier than this, the sensitivity of the apparatus would have been reduced unnecessarily.

The weighing machine was calibrated by running water from a 50 gallon tank placed on the platform. The output from the strain gauge system was directly proportional to the load to within ± 2 per cent and was unaffected by its position.

Experimental method

The cribs used for the fires in these experiments were made with 2.54 cm (1 in) square section sticks, 203 cm (80 in) long, spaced 7.6 cm (3 in) apart horizontally, with a measured moisture content of 10 per cent. Each crib was ignited by means of ten 244 cm x 5 cm x 1.3 cm (8 ft x 2 in x $\frac{1}{2}$ in) strips of fibre insulating board, each strip being soaked in 800 ml of kerosene (paraffin oil), placed under the crib at equal intervals at right angles to the plane of the opening.

The intensity of radiation from the open side of the compartment was measured by a radiometer[8] which was placed so that its configuration factor with respect to the opening was 0.24, compared with 0.56 in the earlier tests[3][4], in order to ensure that the maximum working intensity of the radiometer would not be exceeded. The radiation from the flames was measured by a similar radiometer placed 24 cm ($9\frac{1}{2}$ in) above the lower edge of the ceiling, with its receiver disc in the plane of the open side. The flame heights were determined from photographs taken at 5 s intervals.

Experimental results and analysis

Details of the cribs used and the principal results obtained are given in Table 1.

TABLE 1

CRIB DETAILS AND EXPERIMENTAL RESULTS

Test No.	Weight of fuel, W		No. of sticks	Density of wood		Area of wood exposed, A_w		Crib Height		Rate of weight loss $R_{90/20}$		Rate of weight loss $\frac{W_{90}-W_{60}}{\Delta t} = R_{90/60}$		Time taken for weight to drop from W_{90} to W_{60} (Δt)	Rate of weight loss / Area of wood exposed $\frac{R_{90/60}}{A_w}$		Maximum flame height above platform (L)		Maximum radiation from: Flame	Maximum radiation from: Opening (configuration factor = 1)
	kg	lb		g/cm^3	lb/ft^3	$cm^2 \times 10^5$	ft^2	cm	in	g/s	lb/min	g/s	lb/min	s	$mg\ cm^{-2}s^{-1}$	$lb\ ft^{-2}min^{-1}$	cm	in	$cal\ cm^{-2}s^{-1}$	$cal\ cm^{-2}s^{-1}$
222	99	218	126	0.60	37.3	2.3	245	15	6	120	16	140	19	207	0.63	0.077	No flames above compartment		0.020	0.54
223	145	320	210	0.53	33.0	3.8	408	25	10	170	23	230	30	190	0.60	0.074	No flames above compartment		0.110	1.32
224	217	478	315	0.53	32.8	5.7	613	38	15	270	35	350	46	186	0.61	0.075	409	161	0.170	2.84

Rate of burning

The weights of the burning cribs are shown plotted against time in Fig. 3.

The rates of burning ($R_{90/20}$) in g/s for test nos. 222-224 are shown plotted against the initial weights (W) of the cribs in Fig. 4 together with results from earlier experiments[3][4]. The equation of the regression line of $R_{90/20}$ on W is given by

$$R_{90/20} = 2.42\ W^{0.9} \qquad \text{..........(1)}$$

The 95 per cent confidence limits for the index are 0.83 to 0.97.

If the results from the 2.4 m (8 ft) cube compartment are omitted, the linear regression of $R_{90/20}$ on W for the remaining results (shown in Fig. 5) is

$$R_{90/20} = 2.17\ W \qquad \text{..........(2)}$$

In the range of the 2.4 m (8 ft) cube compartment experiments the value of $R_{90/20}$ obtained from equation (2) is higher than that from equation (1) by about 30 per cent for W = 100 kg and 35 per cent for W = 200 kg.

The rates of burning of cribs in the 2.4 m (8 ft) cube compartment therefore are significantly lower than those that would be predicted from the results of the previous experiments[3]. The disparity may be due to the largest compartment being constructed of brick, whilst the others were of asbestos wood sheets, thus affecting heat losses through the walls and ceiling of the compartments. Additionally, the ratio of height of crib to height of compartment was considerably different in the two series and this might also influence the air flow through the crib and hence its rate of burning.

Radiation from compartment opening

The variation with time of the intensity of radiation from the compartment opening is shown in Fig. 6 and the maximum intensity of radiation from the compartment opening is shown plotted against rate of burning per unit window or floor area in Fig. 7. The maximum rate of burning should be used here to correspond with the maximum intensity of radiation. However, the maximum rate is sensitive to small errors in weight measurement, and the mean rate over the 90/60 period was chosen since it gives a close approximation to the maximum rate of burning. Since the compartments are cubical and the window opening occupies the whole of one side, the window and floor area are equal and therefore these experiments alone cannot decide whether the floor or the window area is the more fundamentally important factor in this relationship. The regression line including all the results is not significantly different from that through the smaller scale results only, so that the large scale results can be predicted from the smaller scale results, implying that this relationship is substantially independent of the size and construction of the compartment and also of the heights of the cribs which differ considerably.

Flame heights

For the experiments in the 2.4 m (8 ft) cube compartment, the maximum mean flame height above the base of the compartment, L, was derived by averaging over 30 s periods the flame heights obtained from photographs taken at 5 s intervals. This result, together with those from earlier experiments[3][4] are shown plotted in Fig. 8. The line drawn has the equation

$$\frac{L}{D} = 47\left(\frac{\dot{m}''}{\rho (gD)^{\frac{1}{2}}}\right)^{\frac{2}{3}} \qquad \text{..........(3)}$$

where D is the length of a side of the compartment,
$\dot{m}''$ is the rate of burning ($R_{90/60}$) per unit area of the base of the compartment,
ρ is the density of the hot gases (taken as 1.3×10^{-3} g/cm^3),
and g is the acceleration due to gravity.

The constant in equation (3) was found from the average of the values of $(\frac{L}{D}) / \left(\frac{\dot{m}''}{\rho (gD)^{\frac{1}{2}}}\right)^{\frac{2}{3}}$. The equation is of the same form as that shown elsewhere[9][10].

The variation of flame height with time is shown in Fig. 9 for test no. 224.

Conclusions

Experiments with wood cribs of a particular design burning in a 2.4 m (8 ft) cube well-ventilated brick compartment have shown that

(i) the rate of burning and initial weight of crib are related differently to the data from previous smaller scale experiments[3], so that any such relationship can only be considered valid for sufficiently closely specified conditions, such as construction of compartment and relation of height of crib to height of compartment;

(ii) the measurements of radiation from the opening are consistent with the earlier relations[3] between the rate of burning per unit floor or window area and radiation;

(iii) the flame height is related to the rate of burning in a manner consistent with the earlier small scale experiments[3][4].

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(5) Fire Research 1961, p. 21, H.M.S.O. 1962.

(6) THOMAS, P. H., the late WEBSTER, C. T. and SMITH, P. G. Temperatures within the walls of a compartment containing a fire. F.R. Note No. 524/1963.

(7) Structural steel sections. Hot rolled sections. British Standard 4, Part 1, 1962.

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(9) THOMAS, P. H., WEBSTER, C. T. and RAFTERY, Monica M. Some experiments on buoyant diffusion flames. Combustion and Flame Vol. 5, December 1961, pp. 359-368.

(10) THOMAS, P. H. The size of flames from natural fires. pp. 844-59. Ninth Symposium (International) on Combustion. U.S. Combustion Institute, New York, 1963. Academic Press.

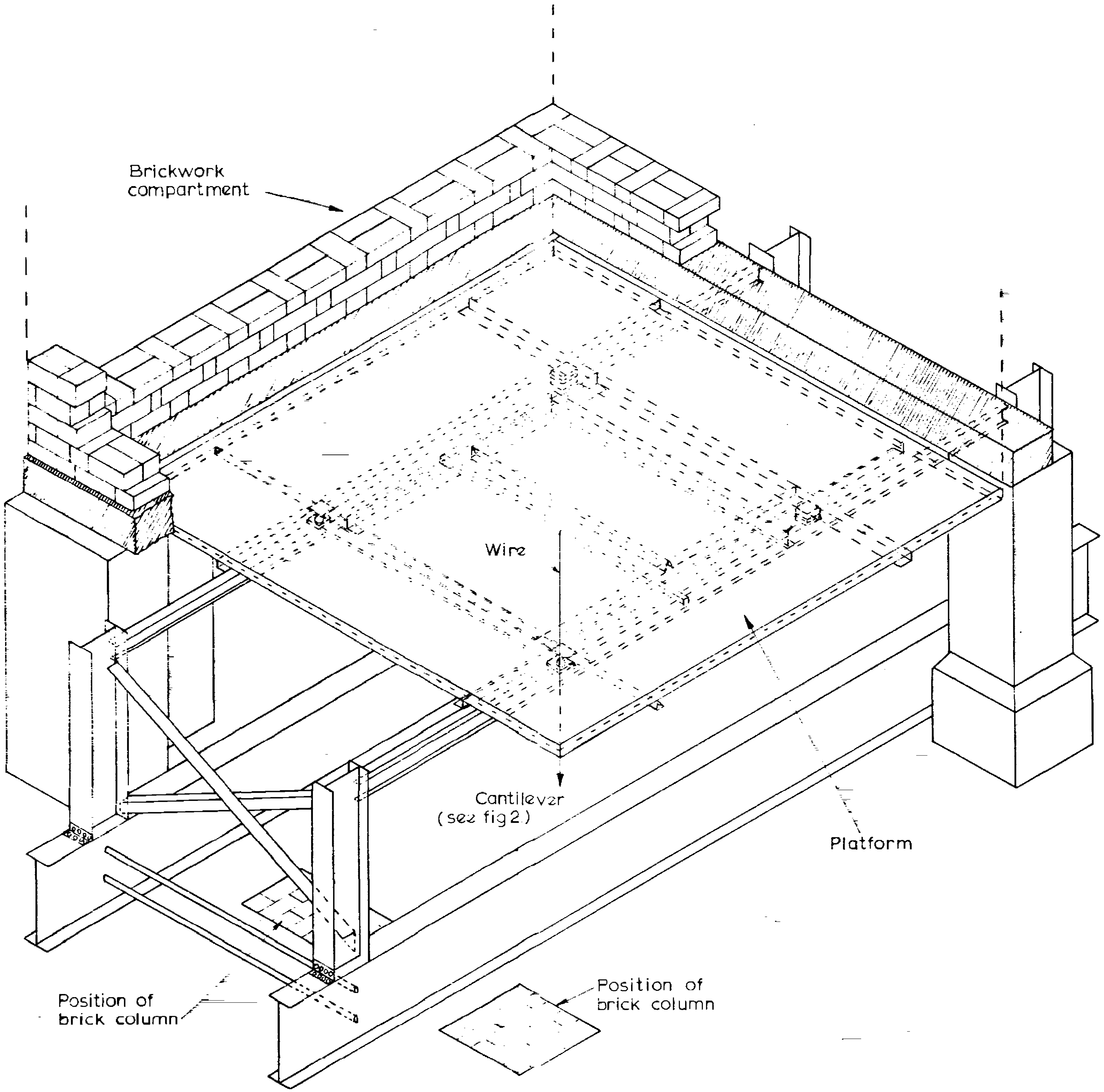

FIG.1. COMPARTMENT AND WEIGHING PLATFORM

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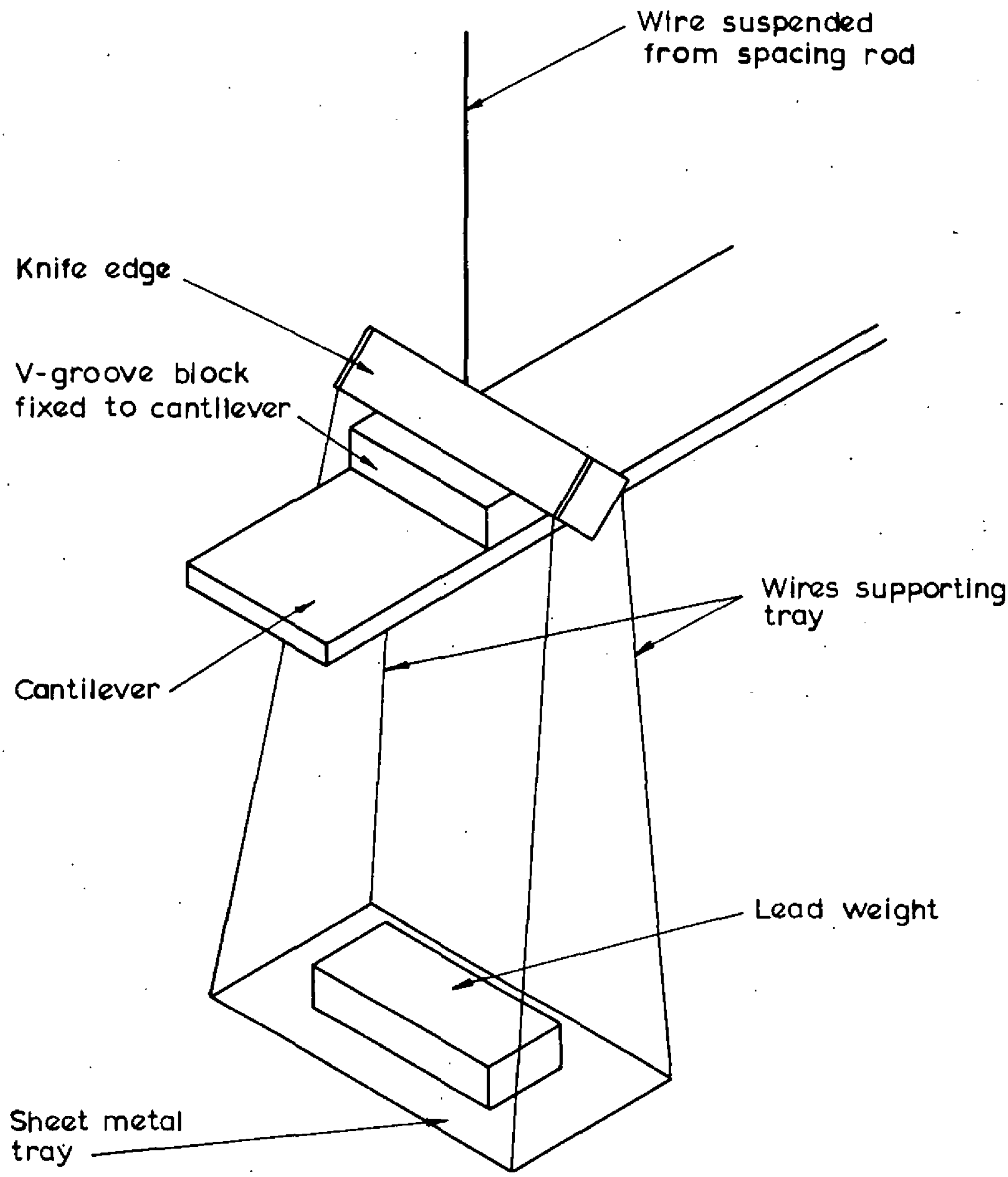

FIG.2. METHOD OF TRANSMITTING MOVEMENT OF BEAMS TO CANTILEVER

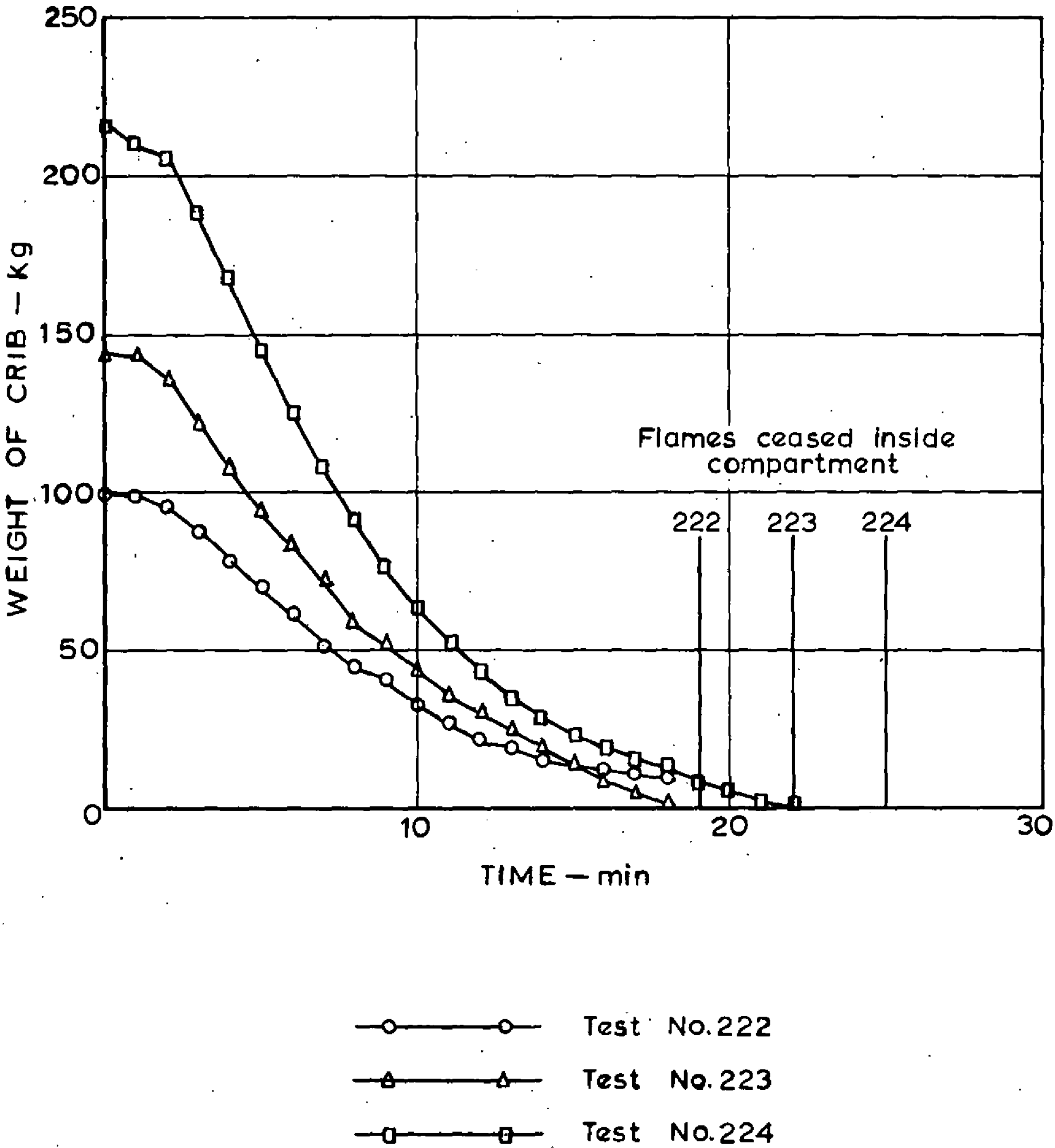

FIG.3. RATE OF BURNING

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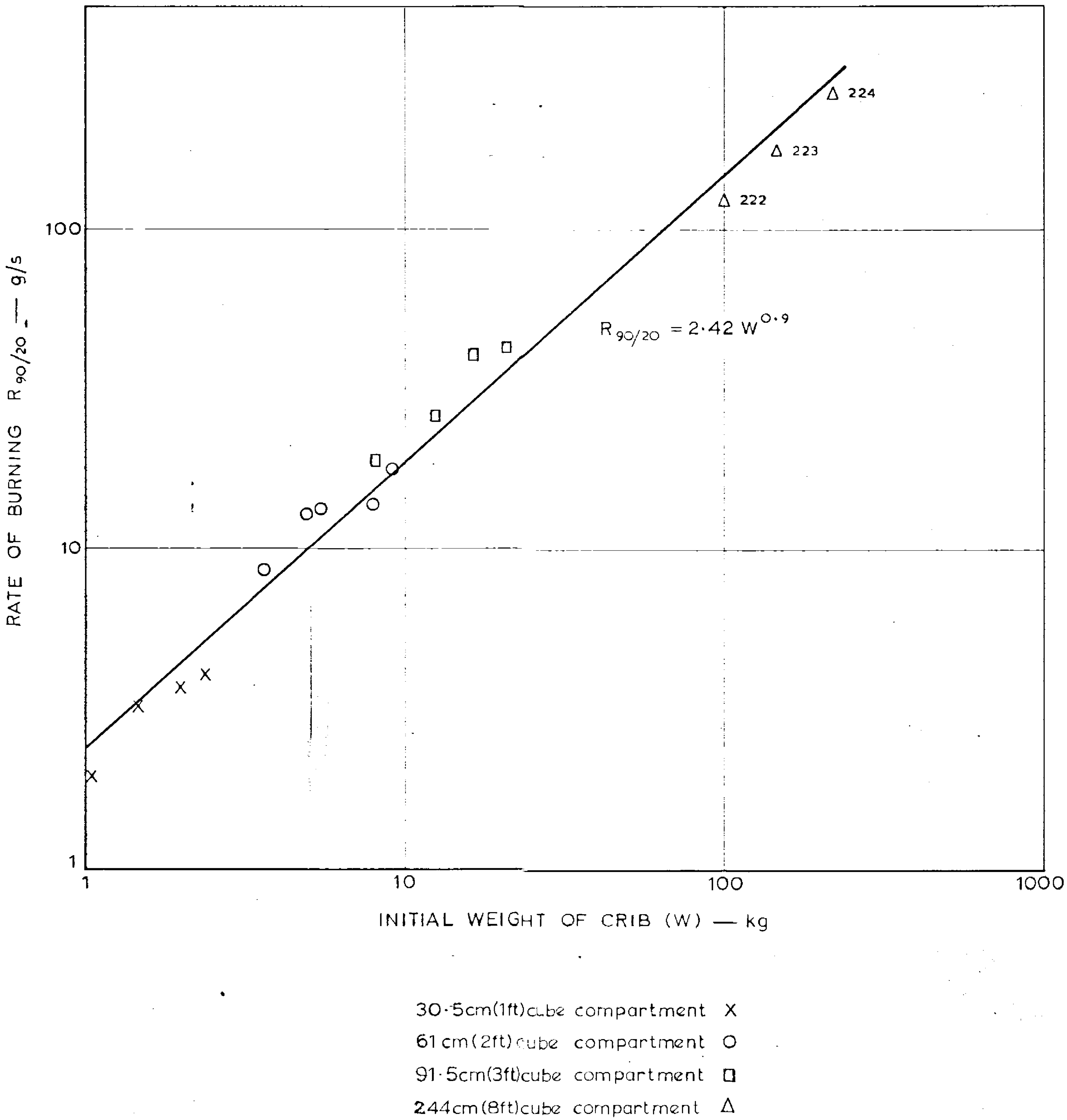

FIG.4. RATE OF BURNING

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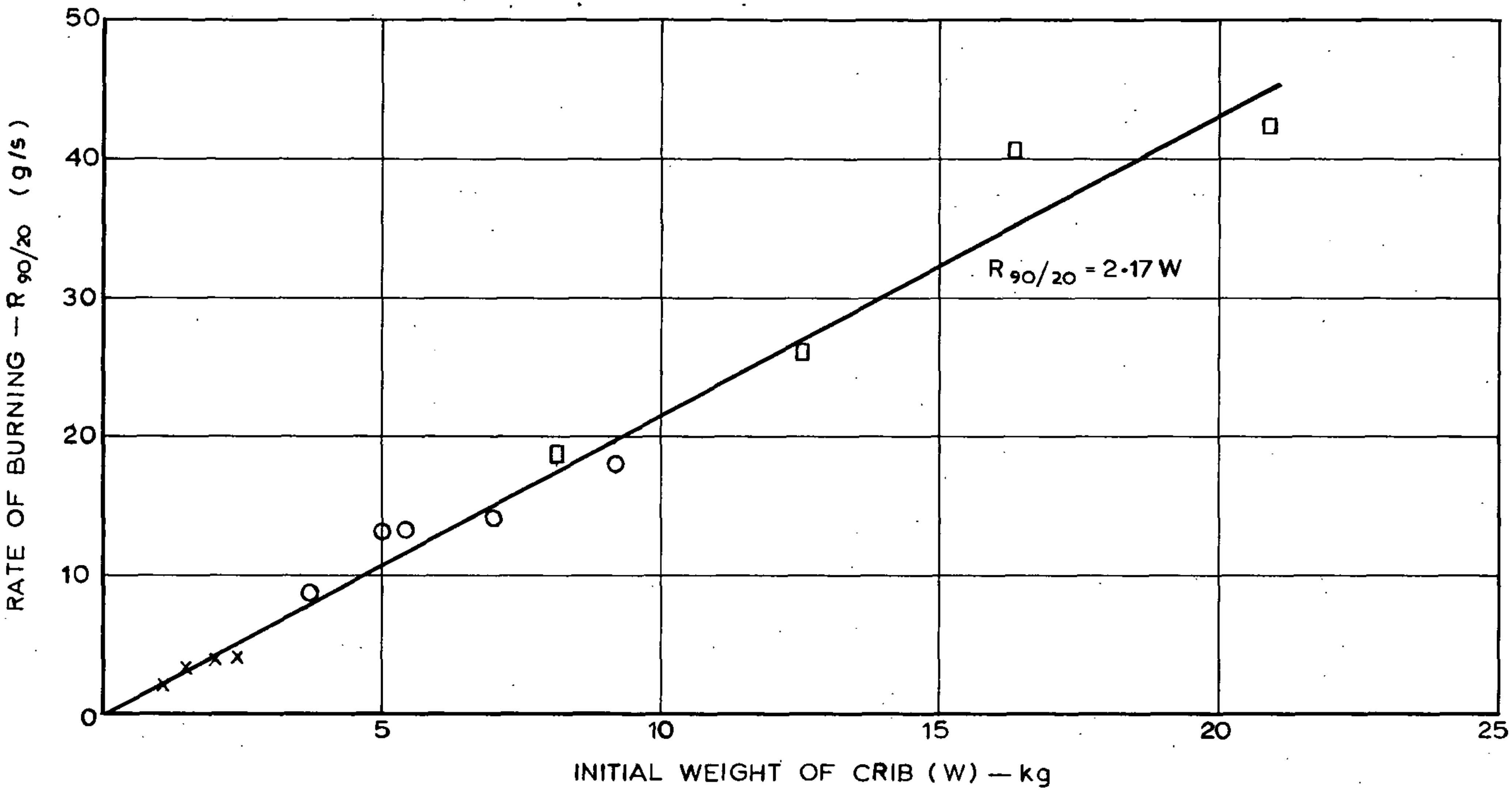


Compartment	Symbol
30·5cm (1 ft) cube	x
61cm (2ft) cube	O
91·5cm (3ft) cube	□

FIG. 5. RATE OF BURNING (1, 2 and 3 FT CUBE COMPARTMENT)

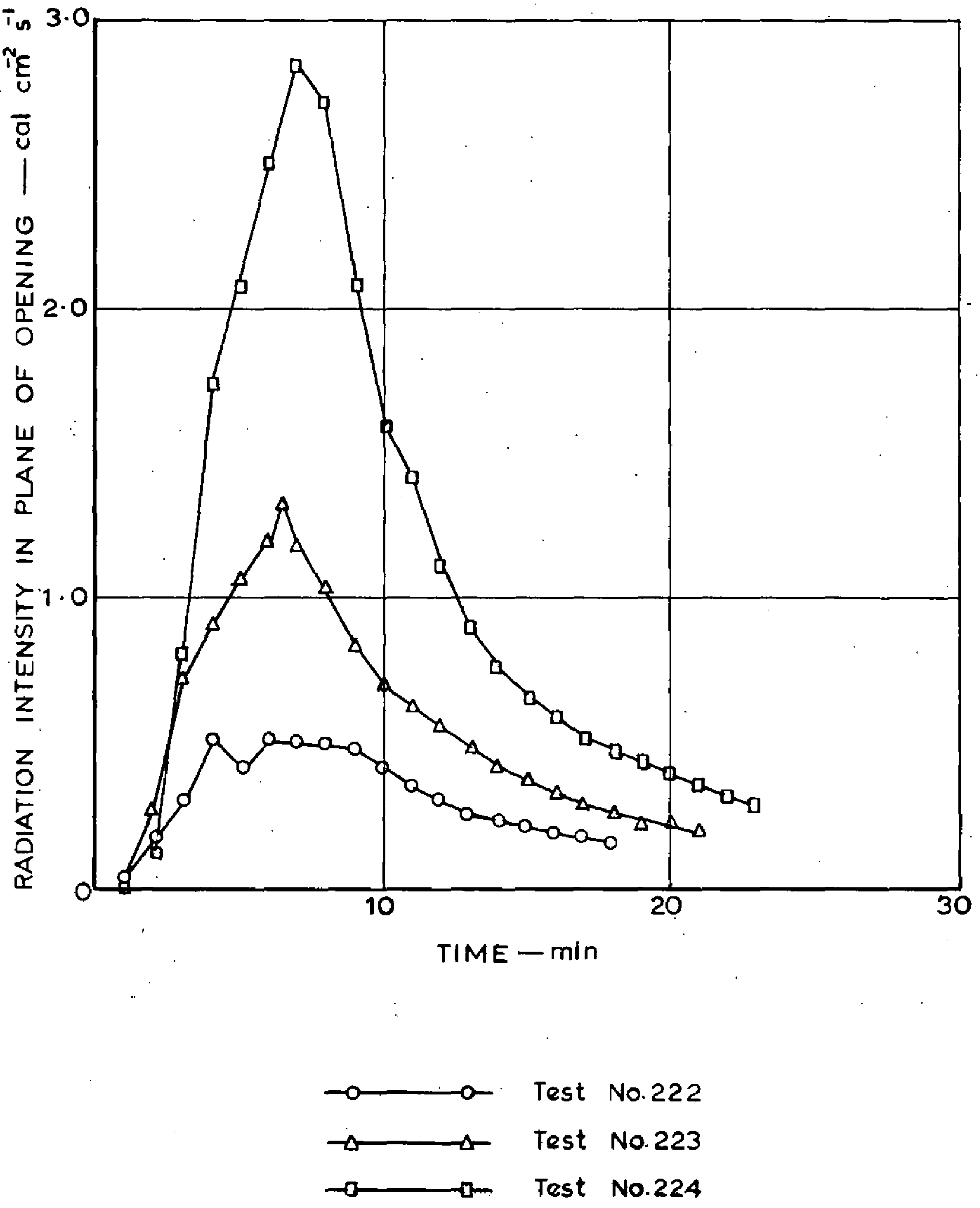


FIG. 6. RADIATION FROM OPENING

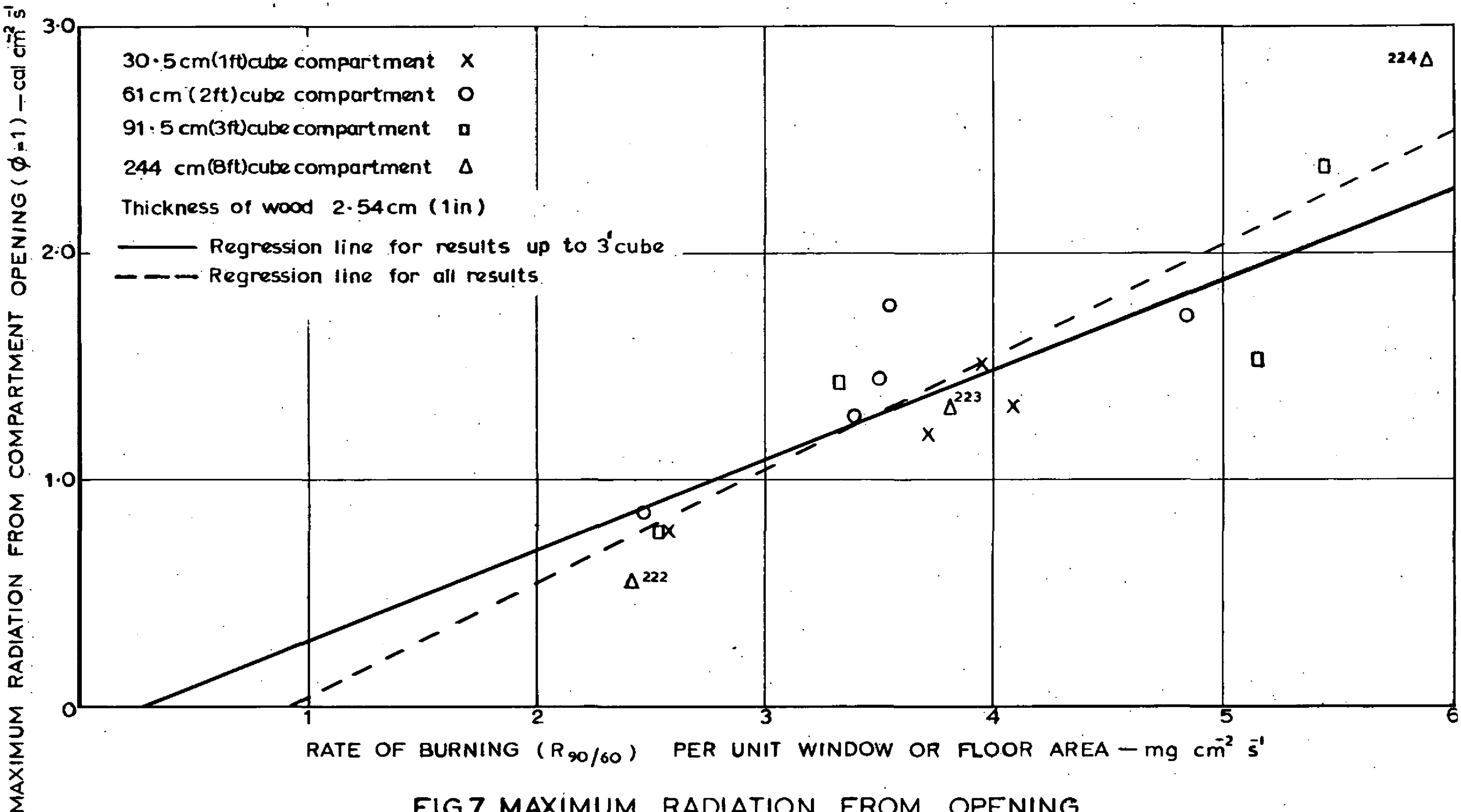
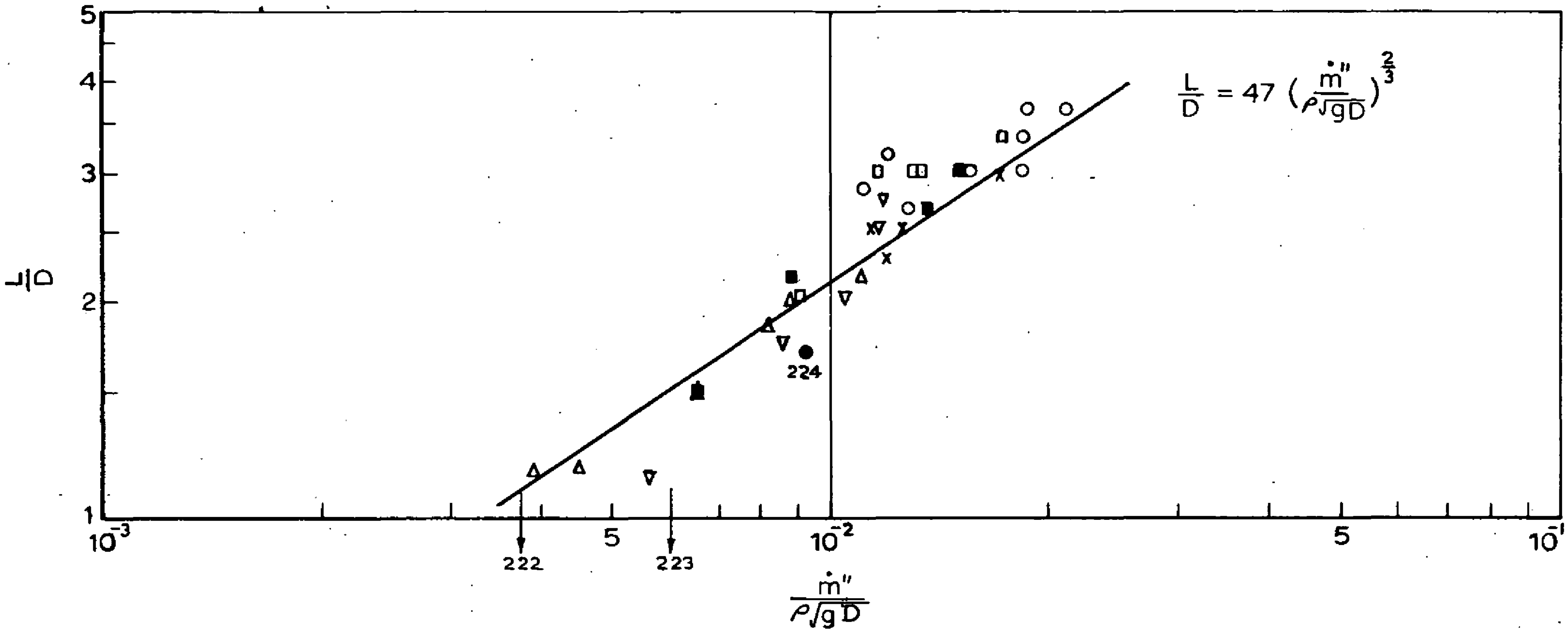


FIG.7. MAXIMUM RADIATION FROM OPENING



Thickness of wood cm		Dimension of compartment (D) ft	cm
○	1·27	3	91·5
□	2·54	3	91·5
△	5·08	3	91·5
▽	5·08	2	61·0
■	2·54	3	91·5
x	2·54	3	61·0
●	2·54	8	244·0

FIG.8. FLAME HEIGHT ABOVE BASE OF COMPARTMENT

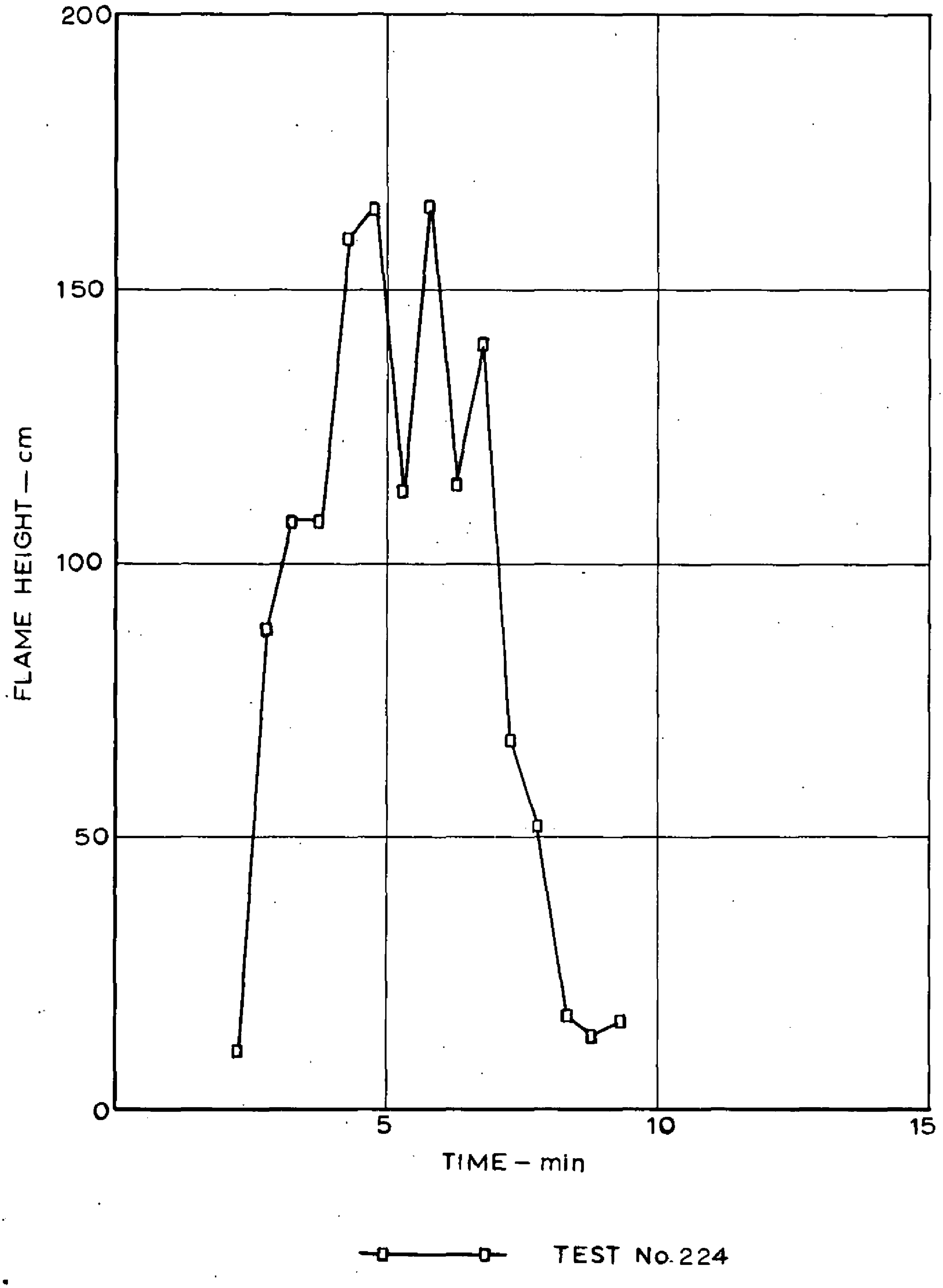


FIG. 9. FLAME HEIGHT ABOVE TOP OF COMPARTMENT

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