NATIONAL BUREAU OF STANDARDS REPORT

6888

FIRES IN MODEL ROOMS

Results of Preliminary Experiments
Under an International Cooperative Program

by

D. Gross
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H. Shoub

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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ABSTRACT

The results of a preliminary series of model fire experiments performed under an international cooperative program are reported. Three parameters associated with the burning of a lattice-type fuel bed in a model room enclosure were varied, namely, the quantity of fuel, the dispersion or packing arrangement of the fuel and the area of the window opening. It was found that the area of the window opening had the largest effect, particularly with respect to the rate of weight loss of the fuel bed and the radiation from the window. The peak temperatures measured at two points within the enclosure ranged from 890°C to 1025°C and were found to be relatively unaffected by the range of parameters investigated. An evaluation of several types of thermal radiation detectors is included.

INTRODUCTION

In June 1959, a program for the systematic investigation of the growth of fires in rooms using small-scale models was suggested by the Joint Fire Research Organization (J.F.R.O.) of the United Kingdom.[1][1] The study took on an international character under the sponsorship of the Working Party on Fire Research of the Conseil International du Batiment (C.I.B.), and with the willingness of fire research laboratories in several countries to participate. Since the Fire Protection Section had for some time considered the need for engaging in model fire studies of this type, these tests provided an ideal means of becoming familiar with modelling techniques and instrumentation while at

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[1] Figures in brackets indicate the literature references at the end of the report.

the same time participating in a planned cooperative program, the results of which might not be otherwise obtainable. This report describes the results of a preliminary series of experiments performed for the purpose of cross-checking results and for establishing techniques on the basis of common experience among the various international participants.

2. EXPERIMENTAL PROCEDURE

2.1 Test Schedule

This series of tests was limited to a rectangular compartment in which only three parameters were varied, namely, the quantity of fuel, the dispersion or packing arrangement of the fuel, and the area of the window opening. The schedule of tests is listed in Table 1.

2.2 Test Compartment

The compartment was 1/2 meter wide by 1 meter long by 1/2 meter high, inside dimensions , and was constructed of one layer of asbestos millboard of 1/2 in. thickness (density $\sim$ 1.0 g/cc). This material was used in place of the suggested 3/8 in. thick "asbestos wood" material (density 1.3 to 1.5 g/cc, thermal conductivity 7 to $9 \cdot 10^{-4}$ cal sec^{-1} cm^{-1}°C^{-1}) which was unavailable at the time of the tests. The compartment was made with a detachable front panel containing a central window opening one-quarter of the box width and extending from the floor to the ceiling.

2.3 Wood Cribs

The amount of fuel was 20 and 30 kg per square meter of floor area or a fire load of 10 and 15 kg respectively. The fuel consisted of wood sticks of square section arranged in cribs with a lättice-type formation. The type of wood suggested was spruce fir (white deal, abies excelsa) having a density range of 0.45 to 0.55 g/cc. Since this species was not commonly available, the wood used was Douglas Fir (Pseudotsuga) which has a similar nominal density range. The sticks were smooth-sawed to 2-cm size and pre-assembled into cribs using a urea resin adhesive, the weight of which never exceeded 1% of the crib weight. The length of the sticks parallel to the long side of the compartment was 83.3 cm (5/6 meter) and the length of those parallel to the short side was 41.6 cm (5/12 meter). The "dispersion of the fuel" represented the

open space between adjacent sticks in both horizonatal dimensions expressed in terms of the stick width. The top layer contained the necessary number of sticks and a portion of a stick to yield the desired crib weight. The cribs were conditioned to a constant weight of 10 and 15 kg in an atmosphere maintained at 65 ± 2°F and 65 ± 3%rh prior to test.

2.4 Ignition

The ignition of the crib was accomplished with the aid of 1/2 in. by 1/2 in. by 83.3 cm long fiberboard wicks containing approximately 83 cc or about 1 cc of absorbed kerosene per cm length. One wick was placed in each bottom interstice, except that in the case of cribs constructed with "1" spacing, the wick was omitted from the center interstice to prevent interference with the lower thermocouple lead. The weight of the fiberboard, not including the absorbed kerosene, was a component of the total crib weight (10 or 15 kg).

2.5 Weight Measurements

The tests were performed near the center of a very large and essentially draft-free room. The compartment was supported over one sheet of asbestos millboard on an iron stand mounted directly on a platform balance scale. Weighing was accomplished by noting the time for balance after removing a small weight increment. In tests 1 through 8, a simulated floor was constructed around the compartment at the front and sides in the plane of the bottom surface of the compartment. The floor, which was elevated about 28 in., extended 4 feet in front and 3-1/2 feet at the sides of the compartment, and served as a convection baffle. In test 9, which duplicated test 1 in all other respects, the simulated floor was removed. Prior to each test, a preliminary fire was used to remove absorbed moisture from the compartment. The initial preliminary fire also served to remove the small amount of organic material contained in the asbestos millboard. Each test was started as soon as possible after placing the crib in the compartment. This was usually accomplished within 15 minutes after removal from the conditioning room.

2.6 Instrumentation

Thermocouples, of 0.020 in. dia. chromel-alumel wire, were used for measurement of the temperatures within the compartment, and were replaced for each test. One thermocouple was placed at the intersection of diagonals on the plan a quarter of the height (12.5 cm) below the ceiling (ceiling thermocouple) and another the same distance above the floor (floor thermocouple).

Measurement of the radiation from the windows was made by means of both "copper disc" radiometers and an enclosed radiometer. The copper disc radiometers, constructed from a published description 2 , were employed in all nine tests whereas the enclosed radiometer 3 , supplied by the J.F.R.O., was used from test 3 on. The copper disc radiometer actually consisted of a disc of phosphor bronze 0.0159 in. thick and 1 in. in diameter to one side of which chromel and constantan thermocouple leads (0.0253 in. dia. wire) were silver soldered. Sodium silicate adhesive was used to fasten a sheet of asbestos-base paper (0.008 in. thick, 6.48 oz/yd^2) to each face of the disc. Each copper disc radiometer was calibrated, see Fig. 1, by measurements using a copper slug calorimeter during exposure to several intensity levels of an extended area radiant energy source. For the intensity range of interest, the calibration curves were similar to those published. For the enclosed radiometer, the calibration curve furnished with the instrument was used.

One copper disc radiometer was placed centrally 5 cm above the top surface of the compartment and in the plane of the window opening to indicate the potential ignition hazard from flame radiation in an area above the burning compartment. A second copper disc radiometer was placed 50 cm centrally in front of the window and, in tests 3 to 9, the enclosed radiometer was placed adjacent to it.

3. Results

3.1 Weight Measurements

The weight-time records for all nine tests were plotted for direct comparison in Fig. 2. The total starting weight includes the weight of the kerosene primer. The curves consist essentially of three stages: a short period during which

the fire becomes established, the major period during which the weight decreases linearly with time, and a slow decelerating period corresponding to glowing embers and ultimate extinction. For the same initial crib weight, the most rapid burning arrangement was the full window opening and "3" spacing. Table 2 lists the tests in order of decreasing rapidity and tabulates the maximum rate of burning (i.e. the slope of the straight line portion) directly and as a percent of the initial crib weight.

3.2 Temperature Measurements

"Ceiling" and "floor" temperatures were automatically recorded on multi-point potentiometer recorders and are shown in Figs. 3 and 4. For convenience the data have also been summarized in Tables 3 and 4. It may be noted that the occurrence of the peak temperatures corresponds very closely in almost every case to the termination of maximum combustion and the beginning of the deceleration shown in Fig. 2.

3.3 Radiation Measurements

A record of the radiation intensities at the two locations is shown in Figs. 5 and 6. Compensation was provided for cold junction temperatures. An initial peak in several of the radiation curves at times less than ten minutes may be considered as due in part to the burning of the kerosene primer.

The curves of radiation from the window fall into two general groups according to the area of the window opening. The peak radiation for the tests employing the full window opening ranged from 0.43 to 0.70 cal sec^{-1} cm^{-2} while the range of maximum intensities for the one-quarter open window was from 0.21 to 0.27 cal $sec^{-1}cm^{-2}$. Since the "flame" copper disc radiometer was placed so as to indicate radiation from flames emerging from the compartment, it experienced a considerably greater range of fluctuations. These test results did not fall within distinct groups in the same manner as the window radiation curves.

3.4 Flame Height

In addition to the measurements specifically requested, several additional measurements were made and visual observations recorded during the progress of each test.

Flame height measurements were made visually with reference to a graduated rod placed along side the compartment and refer to the approximate maximum level of visible flames whether part of the primary body of flaming or separated from it. A typical record of flame height above the base of the compartment (for test 4) is shown in Fig. 7. The time at which the maximum flame height was observed for this and the other tests was considerably earlier than the time at which the maximum temperatures and radiation were obtained.

Some note was also taken of the extent of flaming in the window opening. The depth of flames measured below the top of the window may be expressed conveniently as a fraction of the total window or compartment height. The maximum flame "depth" was found to be approximately one-quarter for all the full window opening tests and about one-half for all the quarter window opening tests and remained fairly constant during the entire flaming period.

4. DISCUSSION

From a summary of the weight records, Table 2, it is seen that very nearly the same maximum rate of burning, expressed in kg/min, was obtained for both the 20 and 30 kg/m^2 loadings under the same conditions. The dispersion of fuel had only a slight effect upon the maximum rate of burning, ranging from 0 to 15 percent less with the "1" spacing than with the "3" spacing. The area of window opening had the greatest effect upon the slope of the weight-time curve. The maximum rate of burning with the one-quarter open window averaged approximately 40 percent less than the comparable test with the full open window. The maximum rate of burning when the compartment was tested without the simulated floor platform (test 9) was 21 percent greater than that obtained when the floor platform was used (test 1), indicating the strong dependence of the burning behavior on the convection pattern at the window opening.

From the temperature records, it was found that varying the quantity of fuel, the dispersion of the fuel and the area of the window opening affected the duration of test but had very little effect upon the maximum temperatures reached. The peak temperature range was 890 to 1025°C for the ceiling temperatures and 910 to 1025°C for the floor temperatures. However, the rate of temperature rise as well as the average temperature level during the early stages was generally higher for the ceiling than for the floor thermocouples. A comparison between the temperature histories of the ceiling thermocouple and the temperature-time curve of a standard fire test [4] , shows a general agreement up to about 25 to 30 minutes, at which time almost complete burnout had occurred in about half the tests.

The area of the window opening had a pronounced influence upon the radiation from the window, as seen in Fig. 5. This was not the case with respect to radiation from the flames extending above the compartment. With one exception, radiation from the window was generally greater with the "1" spacing than with the "3" spacing. The tests with the greater quantity of fuel did not result in a higher radiation level.

In connection with the fire model tests, evaluation of thermal radiation detectors was considered. The requirements of a good radiation detector for fire studies include mechanical strength, reasonable cost, simplicity of operation, adequate emf output and sensitivity to a substantial portion of the thermal spectrum. In addition, the detector should be unaffected by the extraneous effects of temperature and wind.

To evaluate the radiation detectors in terms of compensation for ambient temperature effects, a comparison test was performed using a gas fired radiant energy surface combustor. One copper disc radiometer, the enclosed radiometer and a thermopile radiation detector from a commercial radiation pyrometer were suddenly placed in a symmetrical pattern in front of the 12 by 18 in. radiating surface. The latter detector consisted of a multiple-junction total radiation thermopile with a wide-angle field of view and with a thin mica window added at this laboratory. From the manufacturer's specifications, its rate of response was 98% within 2 seconds and temperature compensation up to 250°F was achieved electrically

by means of a shunt nickel coil. The results of the comparison test are shown in Fig. 8, from which the following may be noted:

(a) The response of the enclosed radiometer and of the thermopile detector were comparable and considerably more rapid than the copper disc radiometer.

(b) The emf output was greatest for the enclosed radiometer and least for the thermopile detector. The low output of the thermopile detector may be due to the relatively short wave length cutoff of the laboratory-applied mica window.

(c) Whereas the emf output of the copper disc radiometer was fairly steady over a period of 25 minutes, the emfs of both the enclosed radiometer and the thermopile detector decreased approximately 7 percent. Based upon other tests, however, it should be noted that the unenclosed copper disc radiometer is subject to significant output variations due to ambient temperature, wind and shielding effects. The radiation records in Figs. 5 and 6 should be considered in terms of these results.

The progress of flaming in all tests was from front to rear. This is attributable to the ready access of air at the open front. From the readings of thermocouples placed at the floor level at positions one-quarter and three-quarters of the compartment depth in test 9, the progress of flames toward the rear was estimated to be on the order of 3.5 cm/min. Whether a different pattern of flaming would be obtained with ignition initiated solely at the center or at the rear of the compartment should be explored.

REFERENCES

[1] D. I. Lawson, "International Co-operation in Modelling Fires, A Suggested Programme", F.R.W.P./G.T.F. No. 59/11 (U.K.), June 1959.

[2] C. T. Webster and M. J. Gregsten, "A Disc Type Radiometer", Instruments in Industry, 3, No. 23, April 1956.

[3] J. H. McGuire and H. Wraight, "A Radiometer for Field Use", F.R. Note No. 394/1959.

[4] American Society for Testing Materials, "Standard Methods of Fire Tests of Building Construction and Materials", ASTM Designation E 110-55.

Table 1. SCHEDULE OF TESTS

Test No.	Designation	Amount of Fuel	Dispersion of Fuel	Window Opening	Remarks
		kg/m^2			
1	20-3-1	20	3 spacing	Full	False Floor Platform
2	30-1-$\frac{1}{4}$	30	1 "	Quarter	"
3	20-1-1	20	1 "	Full	"
4	30-1-1	30	1 "	Full	"
5	30-3-$\frac{1}{4}$	30	3 "	Quarter	"
6	20-3-$\frac{1}{4}$	20	3 "	Quarter	"
7	20-1-$\frac{1}{4}$	20	1 "	Quarter	"
8	30-3-1	30	3 "	Full	"
9	20-3-1	20	3 "	Full	No platform

Table 2. MAXIMUM RATE OF BURNING

10 kg Fuel Load				15 kg Fuel Load			
Test No.	Designation	Maximum rate of Burning		Test No.	Designation	Maximum rate of Burning	
		kg/min	%/min			kg/min	%/min
9	20-3-1	0.580	0.0580				
1	20-3-1	0.480	0.0480	8	30-3-1	0.470	0.0313
3	20-1-1	0.480	0.0480	4	30-1-1	0.445	0.0297
6	20-3-$\frac{1}{4}$	0.295	0.0295	5	30-3-$\frac{1}{4}$	0.305	0.0203
7	20-1-$\frac{1}{4}$	0.280	0.0280	2	30-1-$\frac{1}{4}$	0.255	0.0170

Table 3. CEILING TEMPERATURES

Time min	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9
0	20	20	20	20	↑	20	20	20	20
2	625	135	200	300		405	300	445	525
4	660	235	530	500	No	460	520	500	600
6	685	405	760	650		490	625	550	675
8	690	470	750	650	Data	515	635	600	690
10	750	540	750	725		540	625	575	715
12	775	615	800	765		570	650	625	755
14	825	590	900	775	↓	600	645	675	840
16	875	585	985	825		630	650	725	900
18	900	580	1000	850	490	655	675	780	895
20	890	575	1025	875	520	675	710	775	600
22	850	570	1020	900	540	740	740	830	500
24	700	565	900	935	580	770	780	840	465
26	565	575	645	975	595	790	820	880	405
28	480	590	575	985	600	825	875	890	365
30	415	630	490	990	625	840	890	800	285
35	275	662	400	950	660	895	945	505	135
40	175	725	330	805	745	700	985	425	
45		810	275	650	845	620	775	350	
50		850		465	920	575	640	225	
55		890		390	850		595	140	
60		925		300	705		535		
65		925		225	655		475		
70		730		135	630				
75		665			605				
80		600			570				
85		575							
Max. Temp.	900	925	1025	1000	920	935	985	890	900
Time	18	62	20	32	50	34	40	28	16

Table 4. FLOOR TEMPERATURES

Time min	1	2	3	4	5	6	7	8	9
0	20	20	20	20	↑	20	20	20	20
2	115	50	45	25		75	200	100	160
4	160	85	245	75	No	95	300	115	215
6	205	125	685	115		130	400	135	285
8	255	165	775	150	Data	190	450	180	450
10	525	215	825	215		250	480	205	675
12	830	290	850	275		390	550	315	875
14	990	342	900	360	↓	500	570	580	960
16	900	370	925	390		650	575	775	950
18	900	395	900	535	225	715	610	850	1000
20	850	420	925	575	250	775	640	910	950
22	850	435	975	610	275	950	690	900	825
24	750	455	965	695	300	800	725	860	710
26	600	465	910	755	320	925	820	930	625
28	520	475	855	835	350	910	880	975	500
30	415	525	830	925	400	875	875	925	385
35	150	575	850	930	560	890	940	600	125
40	75	700	700	915	800	865	870	425	
45		875	600	930	805	840	850	350	
50		910		865	900	655	830	180	
55		845		795	850		805	105	
60		820		705	875		730		
65		880		590	900		675		
70		880		280	840				
75		815			790				
80		722			720				
85		670							
Max. Temp	1025	910	975	940	950	950	960	975	1000
Time	$16\frac{1}{2}$	50	22	36	46	22	36	28	18

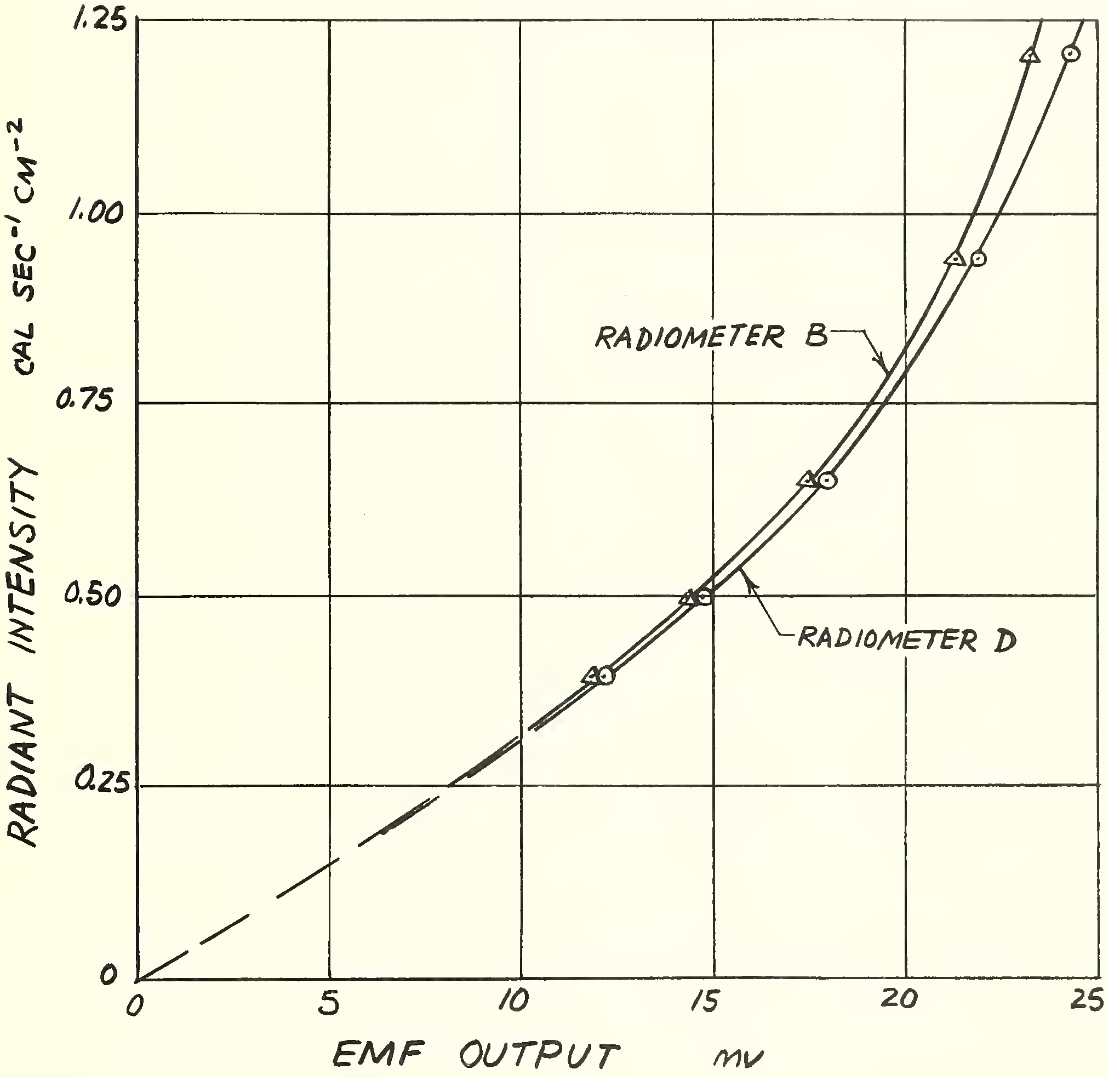
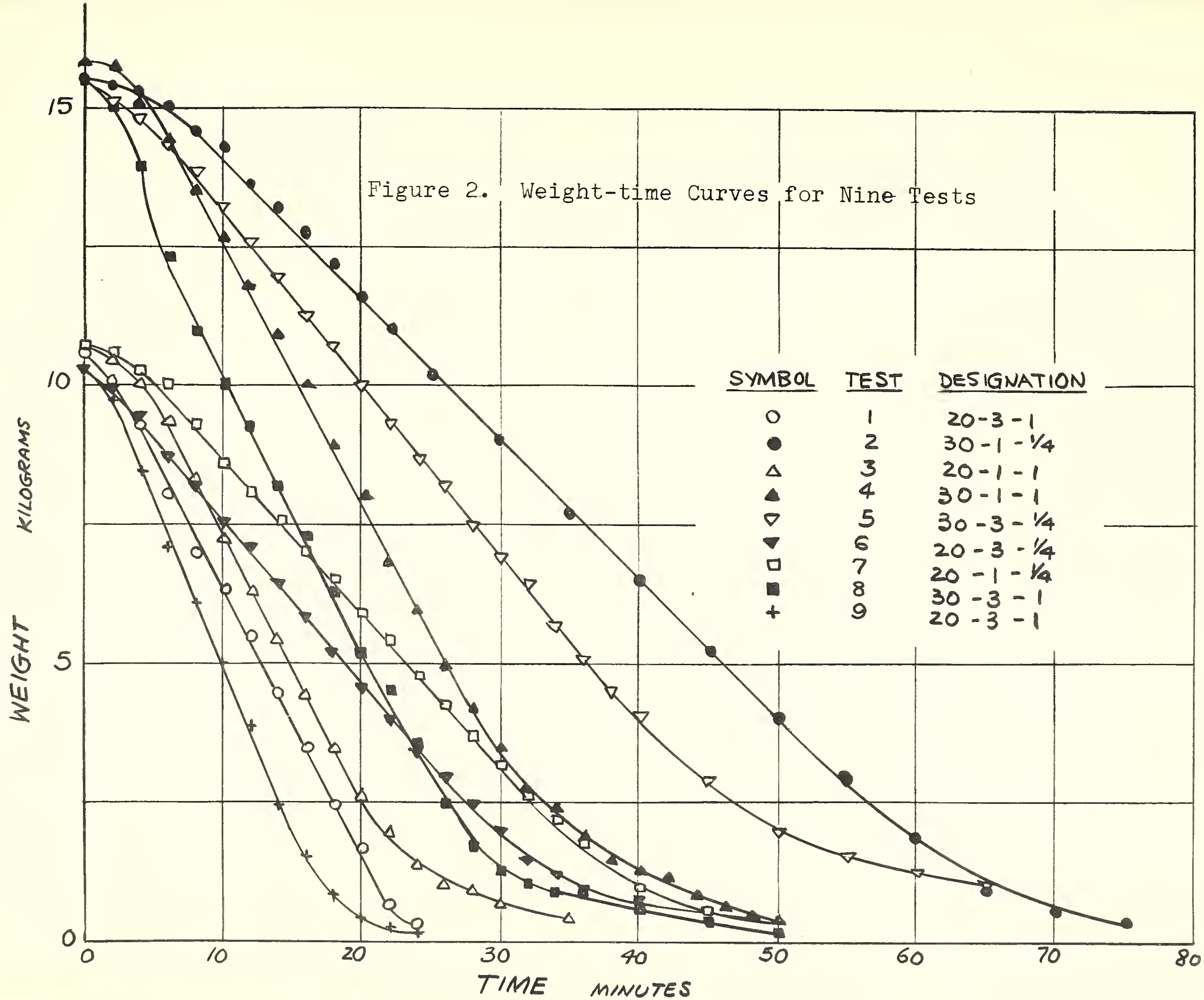


Figure 1. Calibration of Two Copper Disc Radiometers

Figure 2. Weight-time Curves for Nine Tests



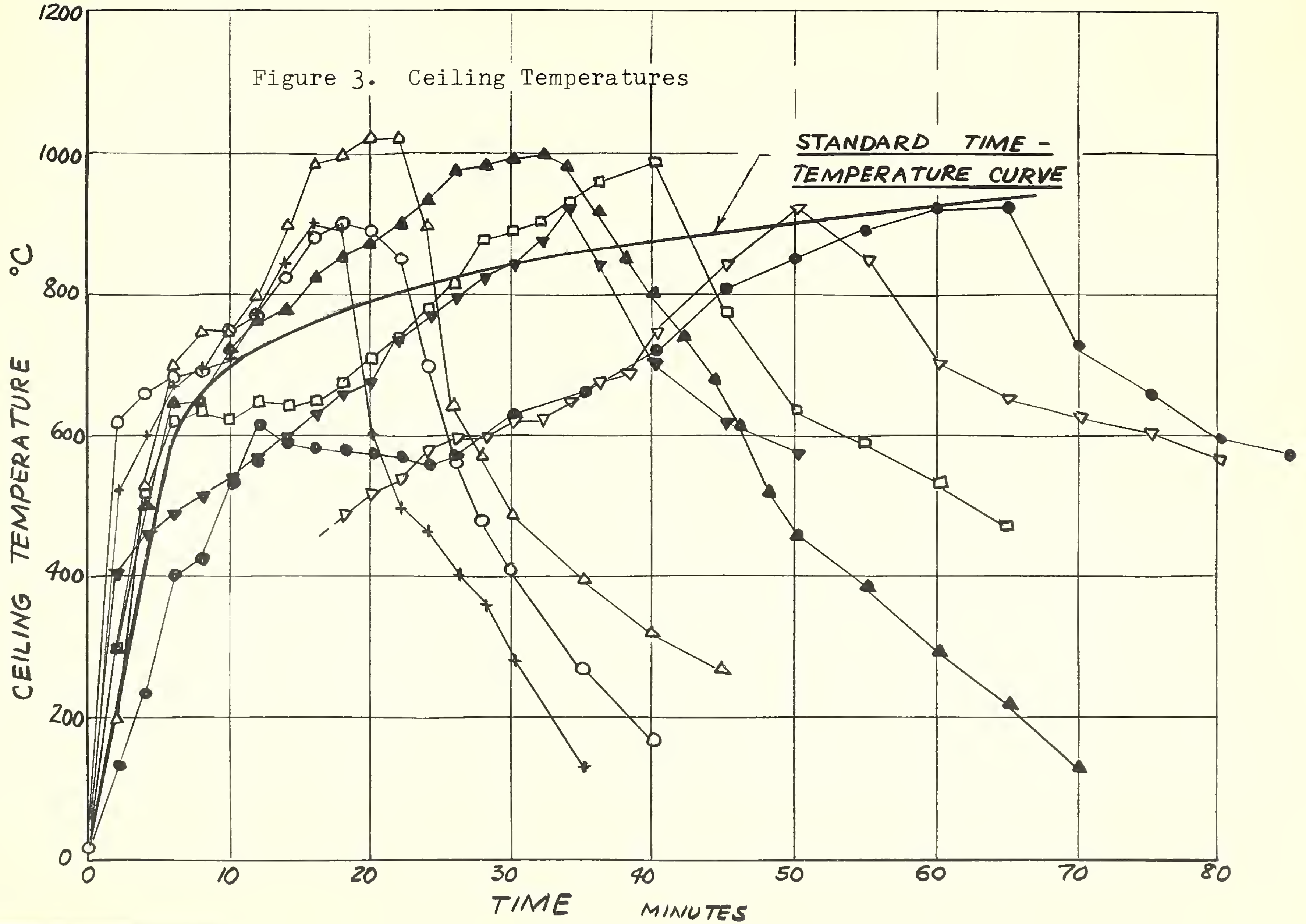
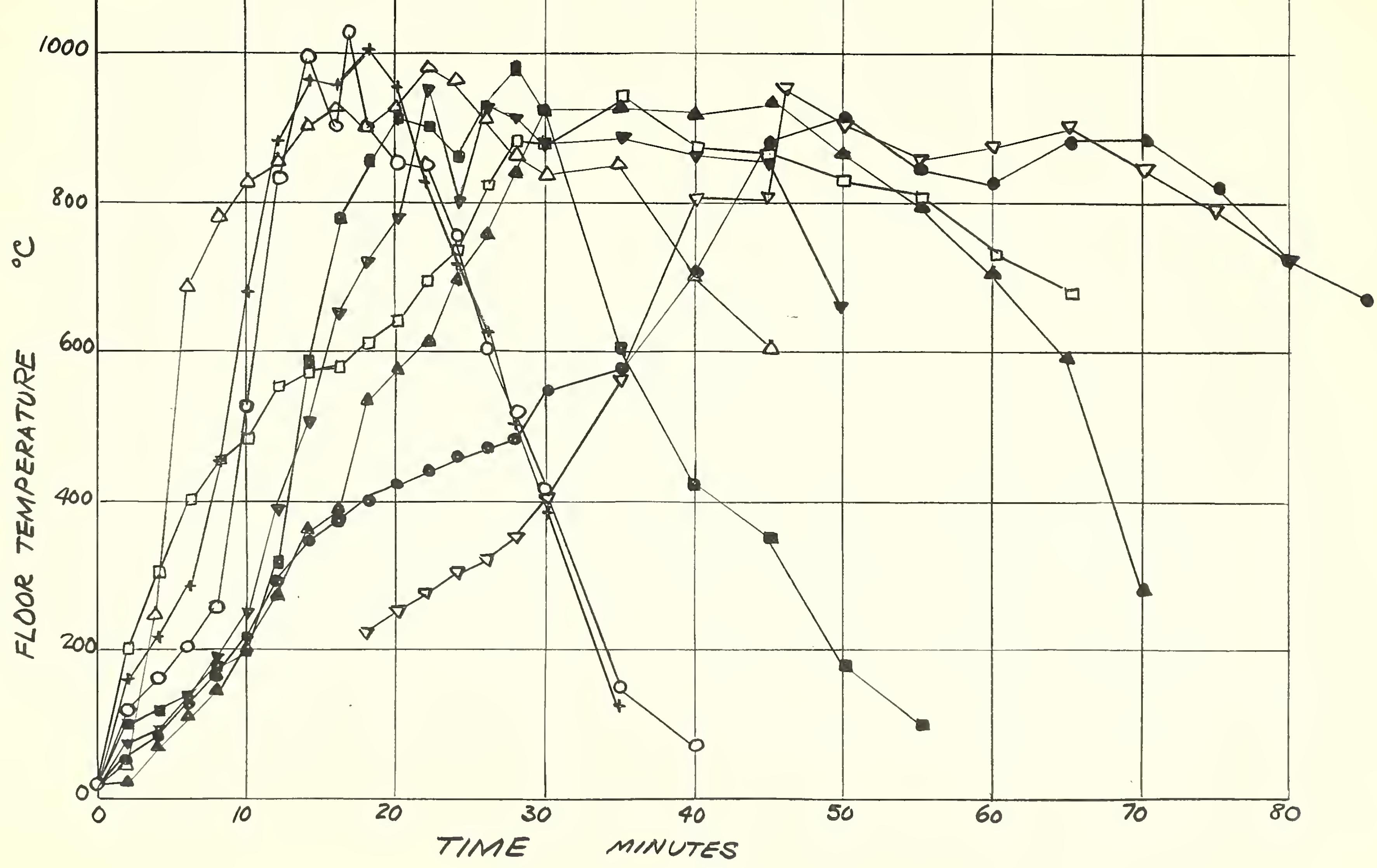


Figure 3. Ceiling Temperatures

Figure 4. Floor Temperatures



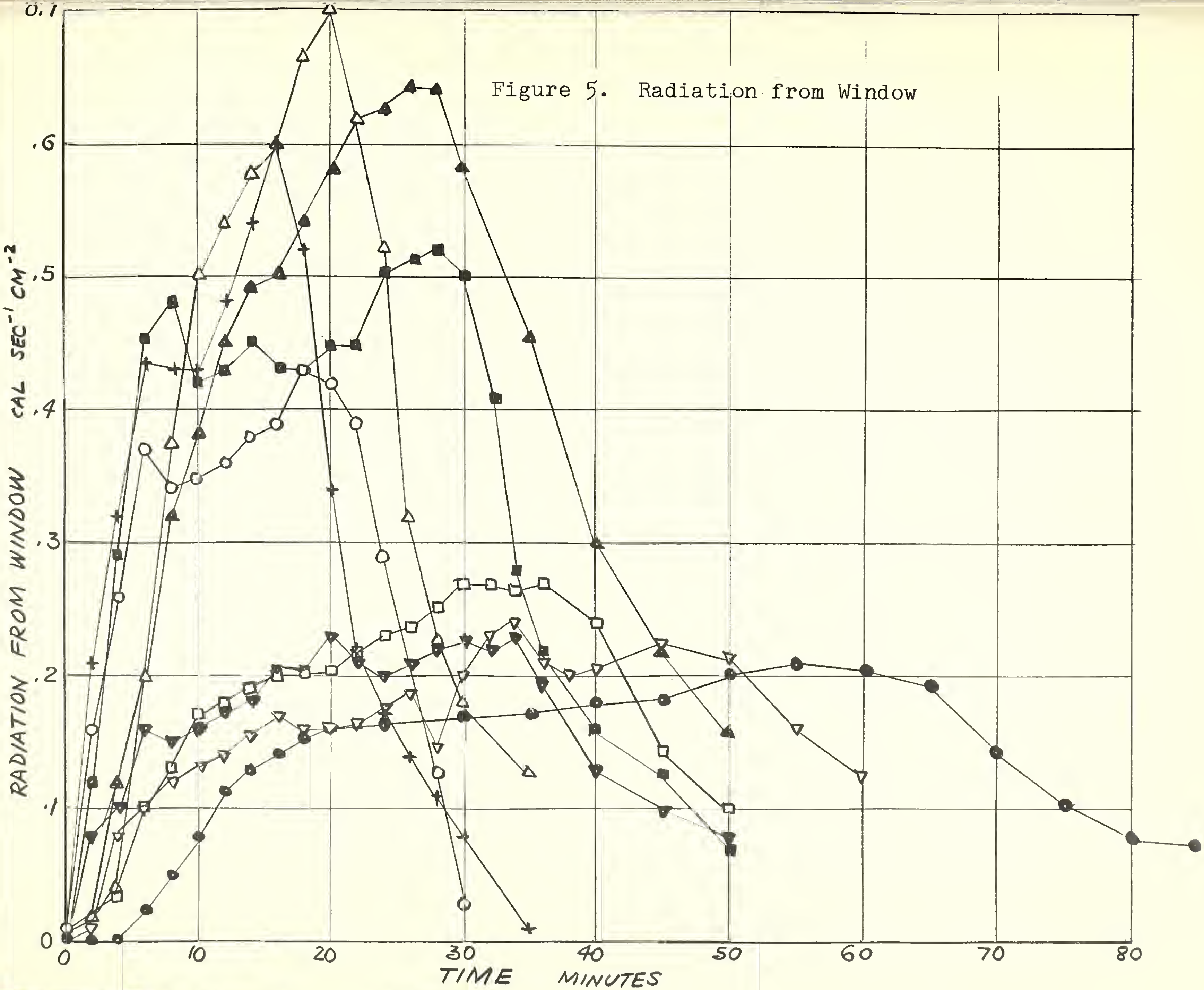


Figure 5. Radiation from Window

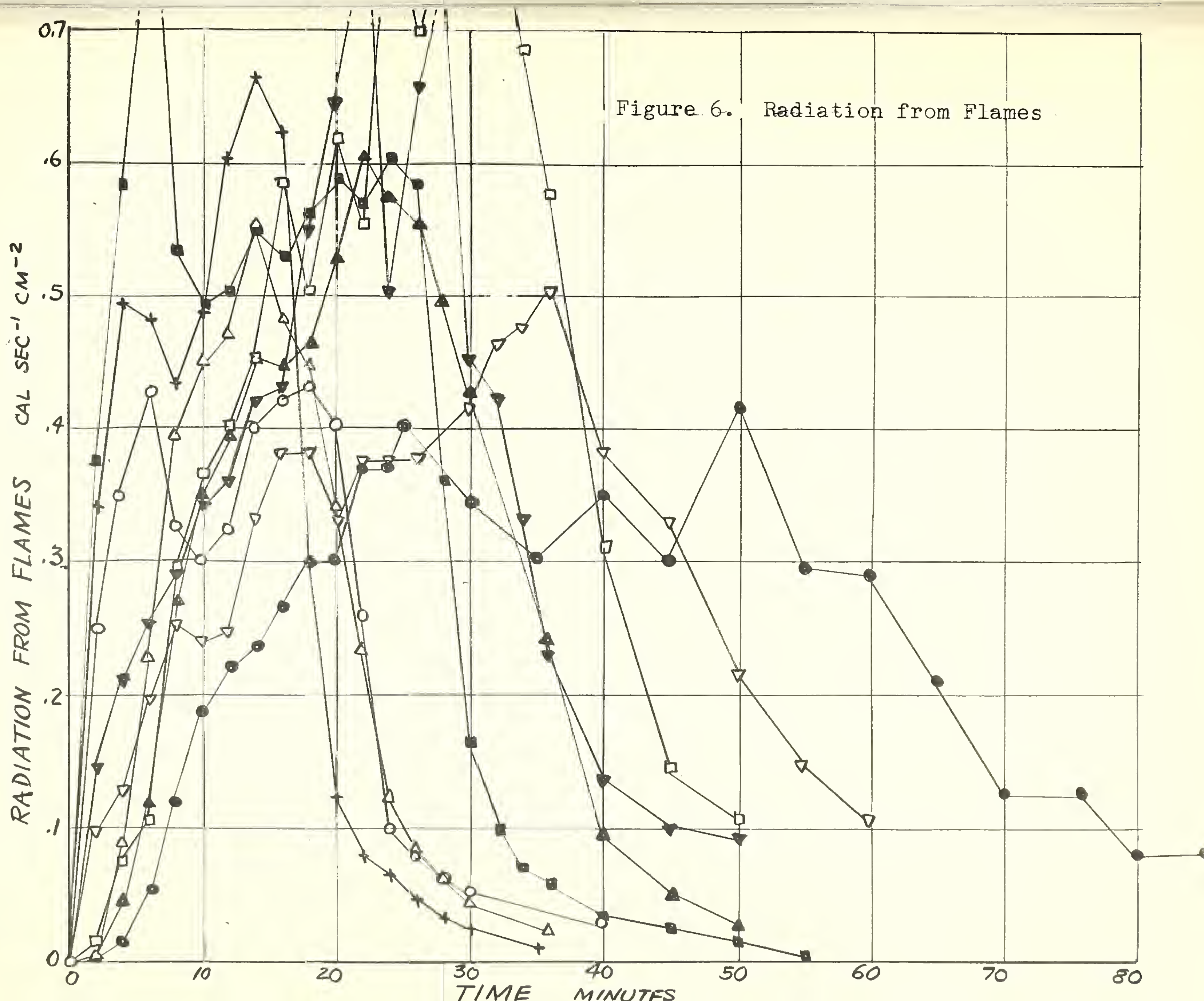


Figure 6. Radiation from Flames

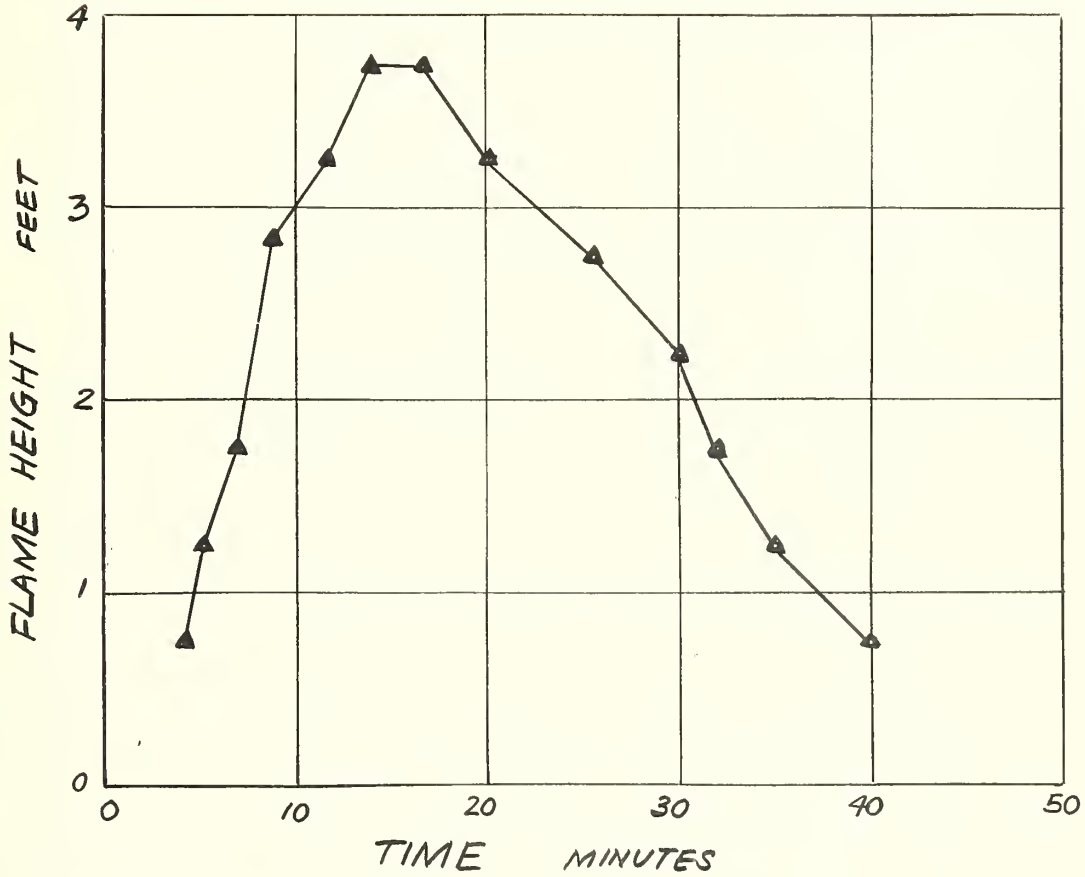


Figure 7. Flame Height - Measured above compartment base, Test No. 4

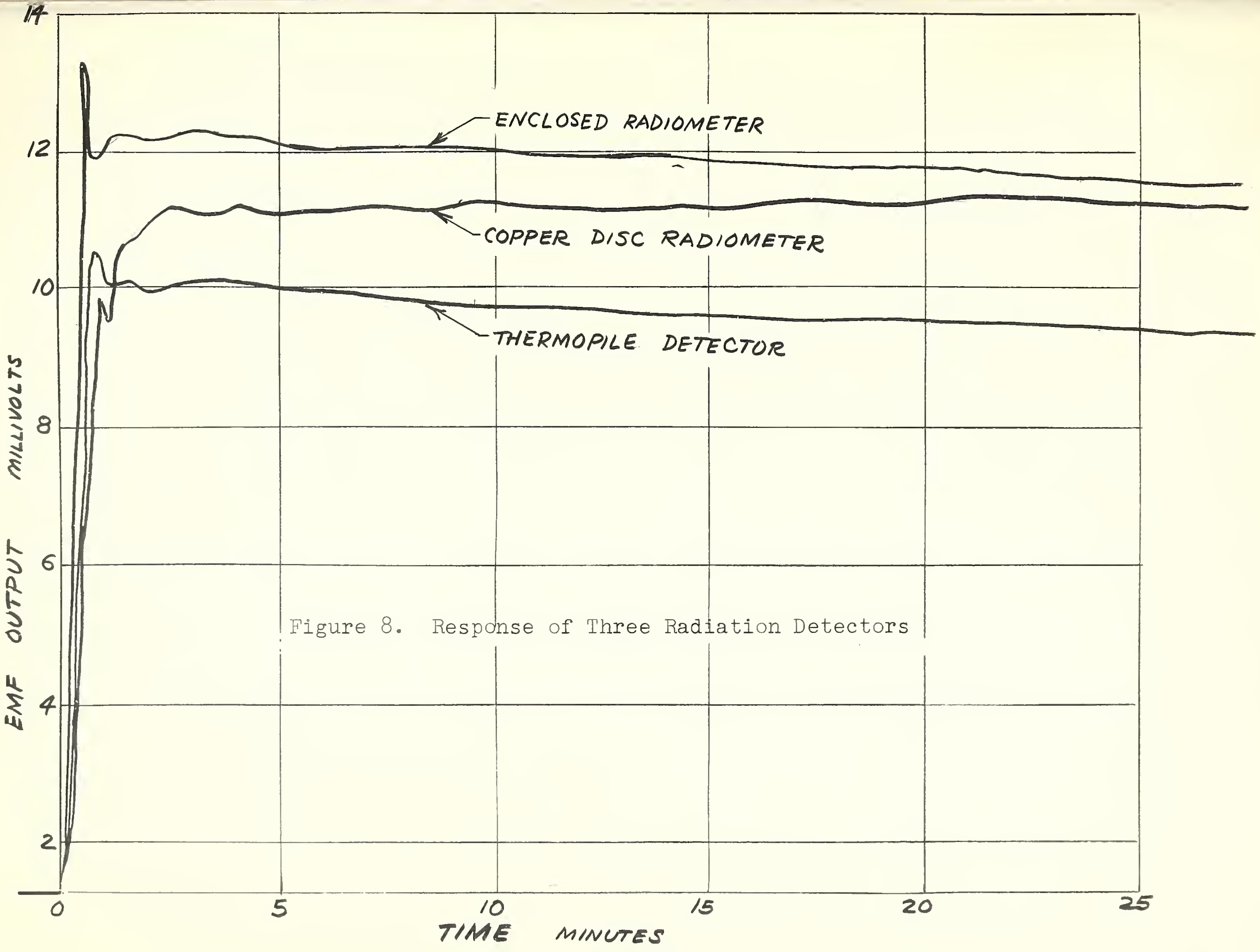


Figure 8. Response of Three Radiation Detectors

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