NATIONAL BUREAU OF STANDARDS REPORT

10 806

HEAT FLUX DISTRIBUTIONS ON WALL AND FLOOR MOUNTED SPECIMENS

Effect of Angular Orientation in Flame Spread Test for
ISO/TC 92 WG 4

NBS

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

NATIONAL BUREAU OF STANDARDS

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[1] Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D.C. 20234.
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HEAT FLUX DISTRIBUTIONS ON WALL AND FLOOR MOUNTED SPECIMENS

Effect of Angular Orientation in Flame Spread Test for ISO/TC 92 WG 4

by
Edward K. Budnick, Jr.
General Services Administration*

*Temporary assignment to the
Fire Research Section
Building Research Division
Institute for Applied Technology
National Bureau of Standards
Washington, D. C. 20234

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ABSTRACT

Measurements are given of the incident heat flux distribution along the surface of wall and floor mounted specimens exposed to a gas-fired radiant panel heat source. The effect of angular orientation in the flame spread test for ISO/TC 92 WG 4 on five materials is summarized. It is shown that there are large effects due to turbulent convection and reradiation at small angles and at distances close to the radiant panel.

Comparisons are made with theoretical radiation levels and with experimental results from two other laboratories.

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1.0 INTRODUCTION

These preliminary tests were performed to determine the effect of orientation on the heat flux incident on the surface of a specimen when exposed to a radiant panel heat source. Primary concern was directed towards expansion of data in the previous report "Preliminary Spread of Flame Tests, ISO TC 92/WG4"[1] to include a variety of angular positions in regards to the "wall" orientation to analyze the effect on the heat flux distributed along the sample.

In conjunction with this, five materials supplied by ISO member countries and three types of carpet materials were tested. The ISO materials were tested in regards to the significance of the angular orientation of the materials in the wall position in regards to the rate of flame spread.

The carpet samples were tested in the floor position, again varying the angle of orientation.

2.0 TEST METHOD

The apparatus consisted of a natural gas-fired radiant panel (30 x 45 cm), and a "blank" specimen of asbestos cement board (15 x 100 cm) placed in a metal frame. The specimen was then tested in several positions with respect to the "wall" and "floor" orientations, as illustrated in Figure 1.

1 Unnumbered report. See also NBS Report No. 10327 "Spread of Flame Tests on Five Materials, ISO/TC 92 WG4", Aug. 1970.

The radiant panel was operated at a blackbody temperature of 750 °C, corresponding to 6.3 W/cm^2. This level was measured by a radiation pyrometer focused on a centrally located circle of 25 cm diameter. The blackbody temperature was recorded periodically to assure that a constant 750 °C temperature was maintained before each test.

3.0 HEAT FLUX MEASUREMENT

At this temperature of 750 °C a survey was made of the incident heat flux as a function of distance along the specimen for each position. The total heat flux (radiation and convection) was measured at 9 points along the samplesurface with commercially calibrated heat flux transducers of the Gardon gauge type. The receiving surface of the heat flux transducer is 2.5 cm in diameter.

4.0 TEST MATERIALS

The rate of flame spread (Dist. vs. Time) was determined for the test materials in the angular orientations. The ISO materials were tested in the 90°, 60°, 45° and 22°30' wall positions and the carpet samples were tested in the 90° and 45° floor positions. The sample edges were coated with sodium silicate and the samples were conditioned to constant weight at 23 °C and 50% R.H. prior to testing. The radiant panel temperature was maintained at 750 °C throughout the tests.

5.0 RESULTS AND OBSERVATIONS

5.1 Heat Flux Measurement

The test data recorded for each position is shown in Table 1 and Figure 2.

At the same distance measured along the specimen, the incident heat flux increases as the angle between the radiant panel and specimen decreases. At large distances from the radiant panel the effect of angle is minimized, inasmuch as the radiant panel represents nearly the same field of view to the viewing point.

At distances greater than 30 cm, energy is transferred exclusively by radiation. Closer to the panel, energy transfer by turbulent convection becomes an appreciable part of the total energy flux. This explains the high values and greater variability of flux very close to the radiant panel as shown in Figure 2.

5.2 Test Materials

The position of the radiant panel in regards to the specimen at extremely acute angles results in a more rapid decline of radiant energy as the distance along the specimen increases.

As the angle between the radiant panel and the specimen decreases from 90° to 45° the maximum distance of flame travel increases. However, at an angle of 22°30' the maximum distance of flame travel decreases, the distance being less than at 45°.

Rigid polystyrene melted in every test case. There was no flaming throughout the test period.

Although the actual flame front ceased, burning continued for the duration of the tests for both red oak and melamine-faced chipboard.

Polyurethane continued to crack and char after flame spread ceased.

In testing the carpet specimen in the floor position the 45° incline position resulted in an increase in the rate of flame travel over that at 90°.

6.0 DISCUSSION

6.1 Heat Flux Measurement

Conclusions from these tests were based primarily on comparison of the NBS test curves with those of other ISO members and with standard curves based on theoretical radiation configuration factors [1]. The three angles at which information was available to permit comparisons are: 90°, wall; 22°30', wall; and 90°, floor.

Variables in the test methods such as: position of the radiant panel, blackbody temperature, and position of the specimen relative to the radiant panel can be noted by reviewing Figures 3, 4, and 5.

Figure 3 represents the test curves at 22°30' in the wall orientation for both the French (CSTB) and NBS tests, and the theoretical curves corresponding to each of the two test methods (French Report 990 R 315, ISO/TC 92/WG4). There were three main differences between the NBS and CSTB test conditions:

a. the radiant panel was vertical in the NBS tests, horizontal in the CSTB tests,

b. the specimen was in contact with the radiant panel in the NBS tests, spaced 12 cm from the radiant panel in the CSTB tests,

c. the blackbody temperatures were different.

In comparing the US data with the theoretical curve based on simple radiation, it is clear that the divergence in the curves at distances less than 35 cm is due to turbulent convection and re-radiation. However, at distances greater than 35 cm along the specimen the convection becomes minimal and there exists a much closer agreement between the two curves for incident heat flux. The maximum difference between the two for any distance along the sample beyond 35 cm is 0.2 W/cm^2.

It should be noted that the decrease in incident heat flux from 6 to 0 cm is the result of the existence of a "cold" spot due to the metal framing around the radiant panel. Also, the geometrical position of the panel with respect to the specimen results in a rapid falling off of energy being radiated to distances beyond 35 cm as the angle of orientation decreases.

Some difficulty arises in comparing the CSTB test curves at 22°30' in the wall orientation with the theoretical curve established on the basis of radiation interchange. The original CSTB test report was based on data obtained from calorimeters and a standard blackbody temperature of 725 °C. A second report released by CSTB (990R 315 ISO/TC 92 WG4) utilized radiometers (fluxmeters) to obtain the test data. However, the blackbody temperature was established at 850 °C (~10 W/cm^2) with the inference that

that the blackbody temperature was identical with that of the first test.

In reviewing the two French test curves in respect to the theoretical curve, there arises a question of reliability of data as well as validity in test methods. The theoretical curve for a blackbody temperature of 725 °C lies below the test curve obtained with the calorimeter. However, the curve obtained from the fluxmeters at 850 °C (125 °C higher temperature) lies below the test curve for a blackbody temperature of 725 °C. Logic suggests that tests at the higher blackbody temperature would result in a higher curve than the test curve corresponding to 725 °C.

Figure 4 illustrates data from the NBS tests, the TNO tests, and the theoretical data for the 90° wall orientation. Here also, the NBS panel was oriented vertically while the TNO panel was horizontal. However, upon calculation of the theoretical curves corresponding to the two test methods, it was discovered that they are nearly coincident. Based on this, the analysis of the test results were based on the same theoretical curve. The NBS test curve lies above the theoretical curve due to the convected energy, but as the distance from the radiant panel increases the influence of convected energy decreases. Beyond 30 cm, the agreement between the theoretical and experimental results was very close, with the difference in incident heat flux between the curves in the order of 0.1 W/cm^2.

The TNO curve lies slightly below the theoretical curve from 20 cm to 80 cm along the specimen. This results from the lower blackbody temperature (727 °C) utilized in the TNO tests. However, it should be noted that the two curves parallel throughout the total distance (20-80 cm) with the difference in incident heat flux being less than 0.1 W/cm^2.

Figure 5 illustrates data obtained from NBS tests, and the initial CSTB report utilizing calorimeters, in the 90° floor orientation. Theoretical curves were determined for each test method. Again, the curves are nearly coincident, and therefore for purposes of analysis only one is shown. The CSTB curve obtained from fluxmeters resulted in virtually no change from that obtained by calorimeters and therefore was not included in Figure 5.

In this case the CSTB data compares reasonably well with the NBS test data. Convected energy affects both curves at distances less than 30 cm from the radiant panel. At points greater than 30 cm, the NBS curve approaches coincidence with the theoretical curve, with a maximum difference in incident heat flux of 0.1 W/cm^2. The CSTB curve is consistently above the NBS curve. Although the difference reduces slightly as the distance along the specimen increases, at 30 cm it is in the range of 43%. Although this appears to be high, the data is consistent, concluding that the variations are primarily due to the differences in test conditions.

6.2 Test Materials

The rate of flame spread (DISTANCE vs. TIME) has been plotted graphically on semilogarithmic paper for all specimens in each test position. (Fig. 6-11)

In regards to the rate of flame travel, rigid polyurethane was consistently the most rapid in all of the wall positions tested, whereas, melamine-faced chipboard was consistently the least rapid. Hardboard and red oak were fairly similar and intermediate in their flame spread behavior.

The positions which offered the maximum discrimination in rate of flame spread characteristics for the different ISO materials were the 90° and 45° wall positions.

Although all three carpet specimens had a maximum flame travel of approximately 525 mm at 45°, the time required for each varied considerably. The blue acrylic specimen burned the distance in the minimum time of 2 minutes. Whereas, the gold nylon carpet with integral pad took nearly 13 minutes to burn the same distance.

In the 90° position the rate of flame travel was less than for the same carpet materials in the 45° incline position. The actual time in which the material was flaming was significantly less.

The flame spread index was determined for each test position and recorded in Table 2a. The calculation for determining the flame spread index was:

$$I = 1 + \Sigma\frac{1}{\Delta T}$$

The value of distance traveled by the flame front at one minute was determined from Figures 6 through 11 and recorded in Table 3. The curves were extrapolated where necessary to obtain the value.

Also, a graphical analysis (Figures 12-15) was made of each ISO material in regards to the angular positions tested in the vertical (wall) orientation.

7.0 SUMMARY

The measured heat flux distributions are presented graphically in Figure 2 for each wall and floor orientation.

Based on analysis of the heat flux measurements by NBS, CSTB and TNO, and the theoretical radiation data, it is concluded that several possible configurations may be used in determining flame spread characteristics of materials using a radiant energy source.

It should be emphasized, however, that the energy is influenced to a great degree by convection at points close to the radiant panel. As the angle of the radiant panel decreases with respect to the specimen this factor becomes more significant (Figure 2 shows increases in incident heat flux when the angle is decreased). However, at points beyond a distance of 30 cm the data corresponds to the theoretical radiation levels, and it can be concluded that convected energy no longer influences the incident heat flux to a significant degree.

The effect of turbulent convection and reradiation is much greater at acute angles between the specimen and the radiant panel, compared to 90°. The effect of convection is less with the specimen in the 90° floor position than in the 90° wall (or 90° ceiling) position. Convection effects are also less when the specimen is spaced away from the radiant panel, e.g. 12 cm in the CSTB tests.

When the angle between radiant panel and specimen is 22°30', flame propagation was not as consistent as at the other angles studied. Whereas the flame spread index increased as the angular orientation decreased from 90° to 45° for all materials, at 22°30', the flame spread index decreased for some materials and increased for others.

Based on these tests, the most useful information for flame spread analysis was obtained for angular orientations between 90° and 45°.

Position	Distance (in)	Mv	Coeff. (1.137)	Calibration Factor	w/cm^2
Floor 90°	1	3.3		.89	3.34
	5	2.15	1.137	.87	2.13
	15	.75		.56	.48
	30	.55		.15	.09
Wall 90°	1	5.		.89	5.06
	3	3.2		.89	3.24
	5	2.3		.87	2.28
	8	1.5		.87	1.48
	13	.96		.56	.61
	15	.85		.56	.54
	17	.63		.56	.40
	28	.73		.15	.13
	30	.70		.15	.12
Wall 45°	1	10.5		.89	10.6
	3	9.0		.89	9.11
	5	6.8		.87	6.7
	8	4.55		.87	4.5
	13	2.85		.56	1.81
	15	1.7		.56	1.08
	17	1.24		.56	.79
	28	.9		.15	.15
	30	.725		.15	.12

Position	Distance	Mv	Calibration Factor	Coeff. (1.137)	w/cm^2
Wall 30°	1	11.6	.89		11.73
	3	13.2	.89		13.36
	5	9.6	.87		9.5
	8	6.9	.87		6.8
	13	2.95	.56		1.88
	15	1.75	.56		1.11
	17	1.18	.56		.75
	28	.60	.15		.10
	30	.47	.15		.08
Wall 22°30'	1	14.5	.89		14.7
	3	16.5	.89		16.7
	5	13.6	.87		13.5
	8	9.4	.87		9.3
	13	3.08	.56		1.96
	15	1.6	.56		1.02
	17	.94	.56		.6
	28	.34	.15		.06
	30	.26	.15		.04
Wall 60°	3	6.5	.89		6.58
	8	2.9	.87		2.87
	13	1.78	.56		1.13
	17	1.04	.56		.66
	28	.96	.15		.16

Table 1

Table 2

TEST MATERIALS

Material No.	Designation	Supplied By	Thickness (nominal)		Density	
			in	mm	pcf	kg/m^3
1	Rigid Polystyrene (FR)	Germany	3/4	20	1.0	16
2	Red Oak	U. S. A.	3/4	20	42	680
3	Melamine-faced Chipboard	U. K.	11/16	18	50	800
4	Panel Board (Hardboard)	Denmark	1/2	12	41	660
5	Rigid Polyurethane	Belgium	7/8	26	2.4	38

Material No.	Designation	in	oz/yd^2
6	Gold Nylon Carpet/Integral Pad	.375	89.0
7	Brown Acrylic (A-5)	.375	80.6
8	Blue Acrylic	.5	68.9
	Hair Pad (F-3)	.5	54.9

TABLE 3

Flame Spread Index / Distance at 1 Min*

	POSITION					
	Wall 90°	Wall 60°	Wall 45°	Wall 22°30'	Floor 90°	Floor 45°
Rigid Polystyrene**	1.0 / -	1.0 / -	1.0 / -	1.0 / -	1.0 / -	1.0 / -
Red Oak	5.5 / 138	16.7 / 240	17.8 / 249	32.8 / 280		
Melamine Faced Chipboard	2.14 / B 40	5.8 / 135	8.5 / 170	11.3 / 215		
Panel Board (Hardboard)	7.1 / 155	16.0 / 230	26.5 / 279	21.9 / 260		
Rigid Polyurethane	56.2 / 380	136.5 / B 470	244.2 / 540	82.3 / 380		
Gold Nylon Carpet					5.4 / 128	43.5 / 340
Brown Acrylic (A-5)					9.9 / A 180	118.9 / 440
Blue Acrylic					21.3 / A 250	89.5 / 450

* Distance measurement in mm

** No flame

A - Data obtained from ISO WG4 test 8/26/71 (Robinson)

B - Extrapolated value

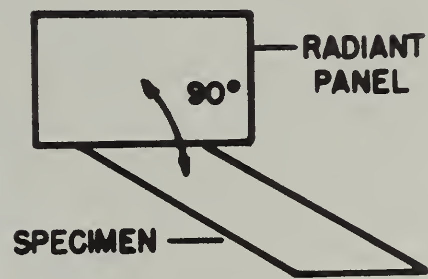
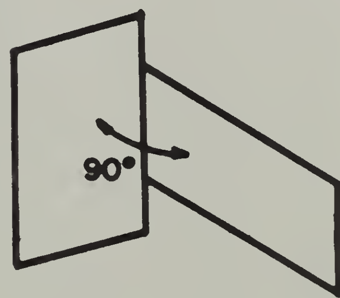
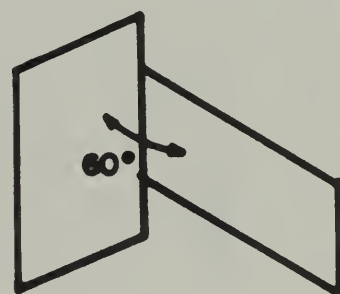
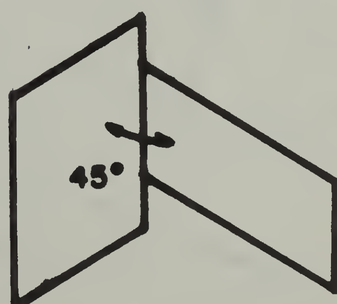
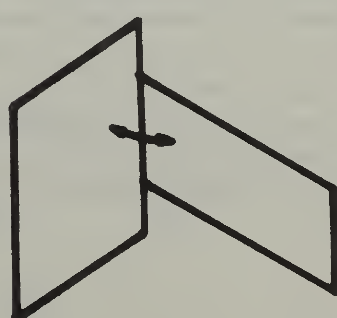
ORIENTATION	ANGLE BETWEEN RADIANT PANEL & SPECIMEN	ILLUSTRATION
FLOOR	90°	
WALL	90°	
WALL	60°	
WALL	45°	
WALL	30° 22°30'	

FIGURE I

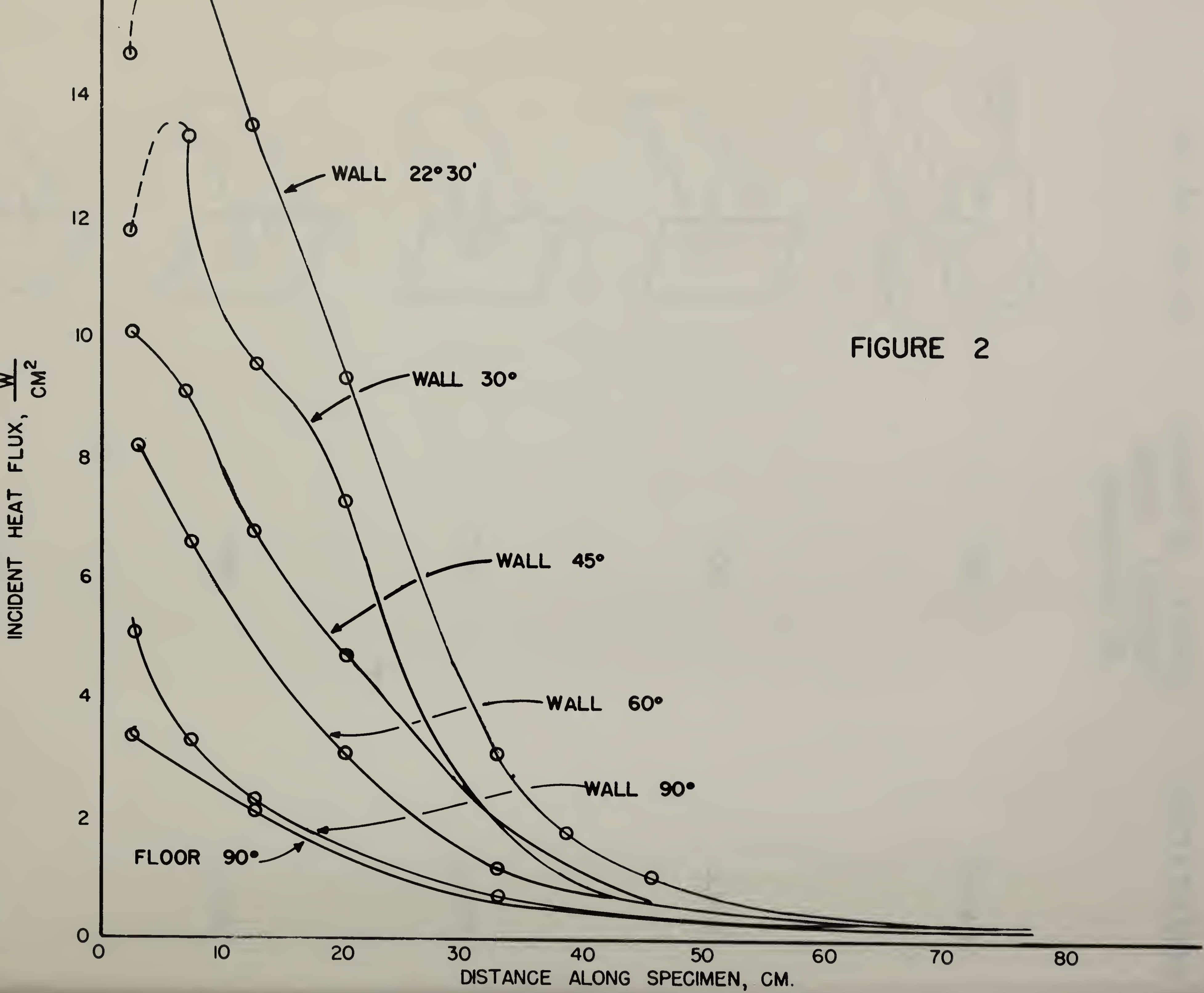

WALL 22° 30'
WALL 30°
WALL 45°
WALL 60°
WALL 90°
FLOOR 90°
INCIDENT HEAT FLUX, W/CM²
DISTANCE ALONG SPECIMEN, CM.
0
2
4
6
8
10
12
14
0
10
20
30
40
50
60
70
80

FIGURE 2

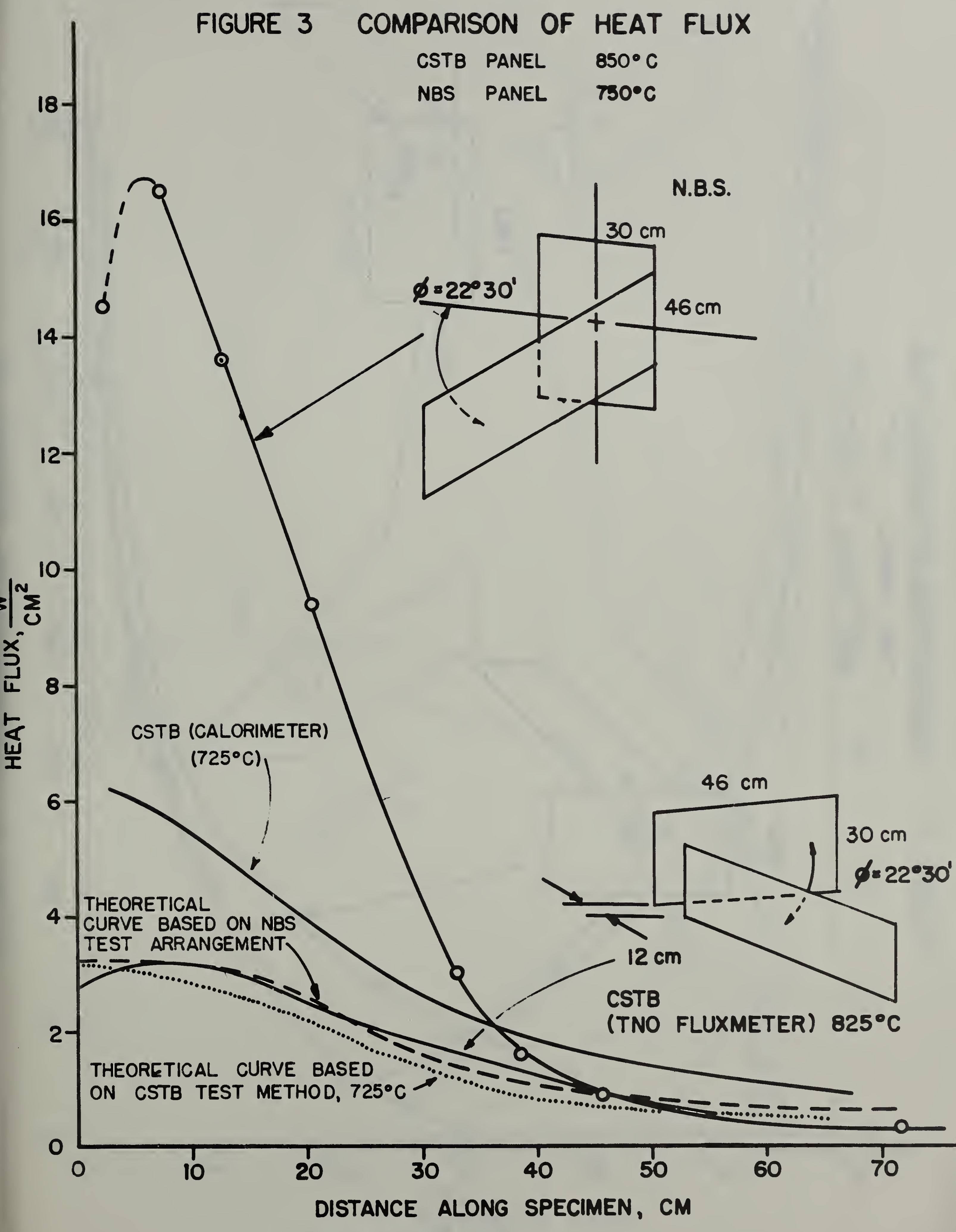


FIGURE 3 COMPARISON OF HEAT FLUX
CSTB PANEL 850° C
NBS PANEL 750°C
N.B.S.
30 cm
46 cm
ϕ = 22°30'
CSTB (CALORIMETER)
(725°C)
THEORETICAL CURVE BASED ON NBS TEST ARRANGEMENT
THEORETICAL CURVE BASED ON CSTB TEST METHOD, 725°C
46 cm
30 cm
ϕ = 22°30'
12 cm
CSTB
(TNO FLUXMETER) 825°C
HEAT FLUX, W/CM²
DISTANCE ALONG SPECIMEN, CM
0
2
4
6
8
10
12
14
16
18
0
10
20
30
40
50
60
70

FIGURE 4 COMPARISON OF HEAT FLUX

TNO PANEL 727°C

NBS PANEL 750°C

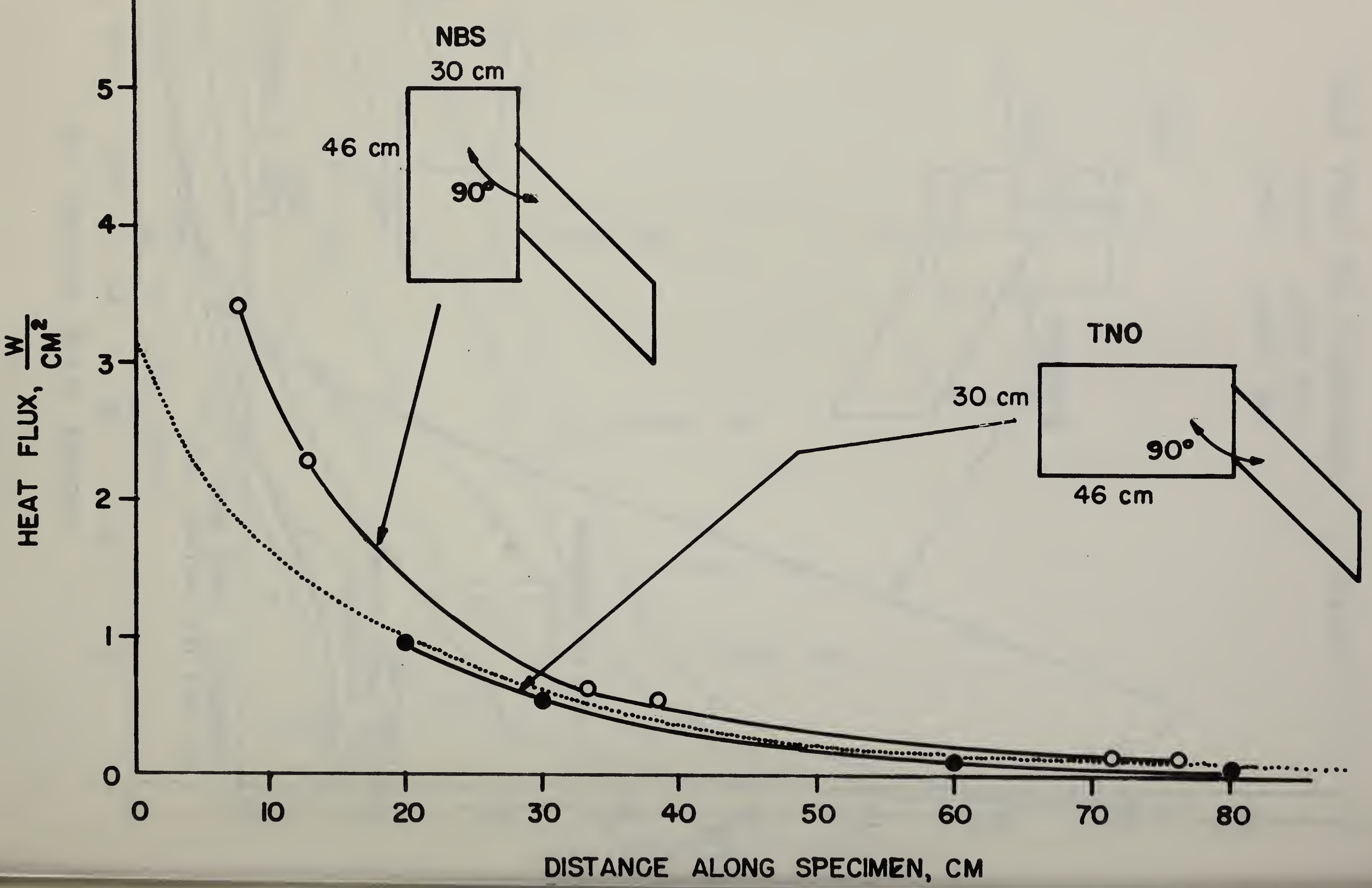


FIGURE 5 COMPARISON OF HEAT FLUX

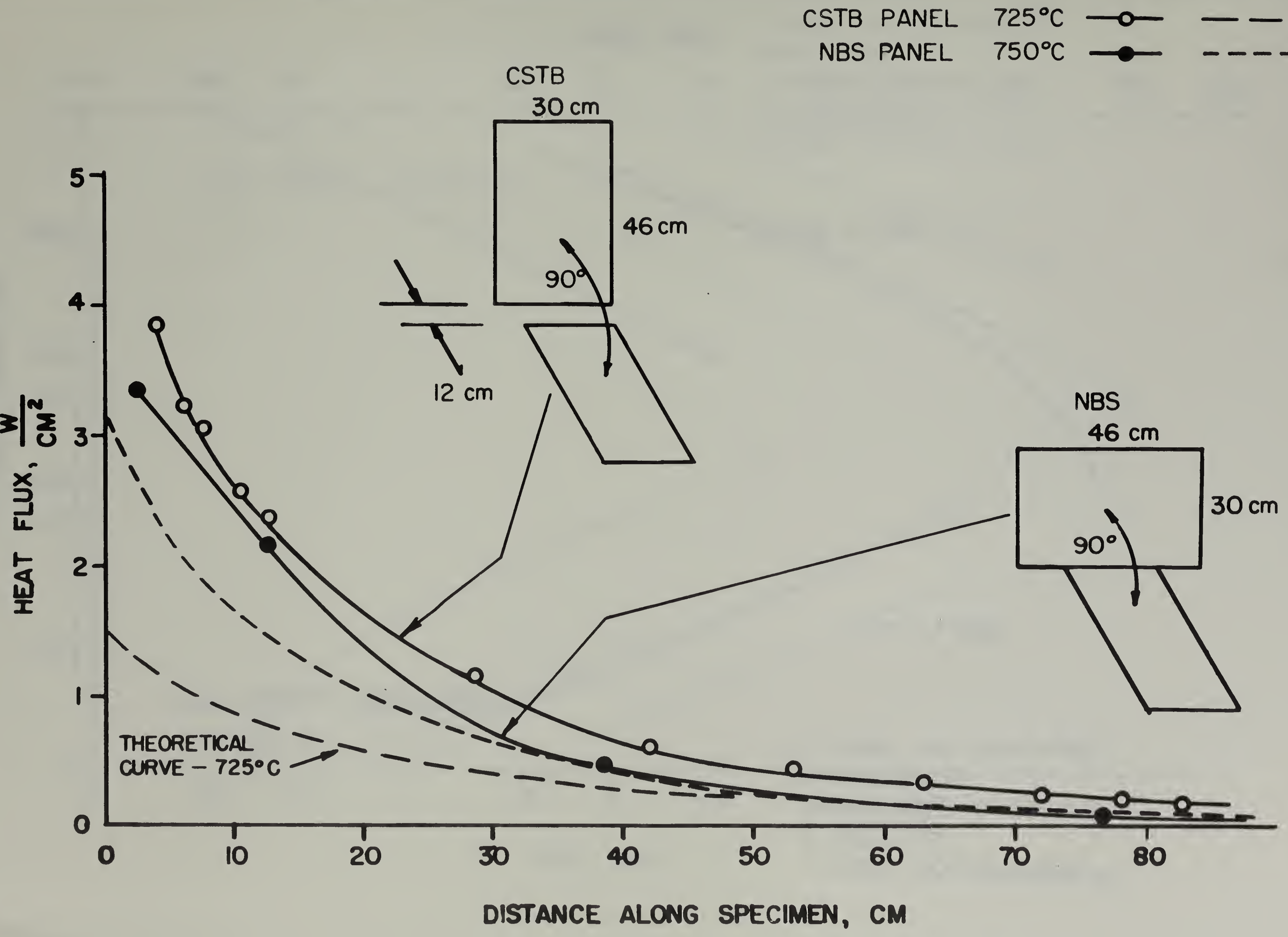


FIGURE 6
90° WALL POSITION

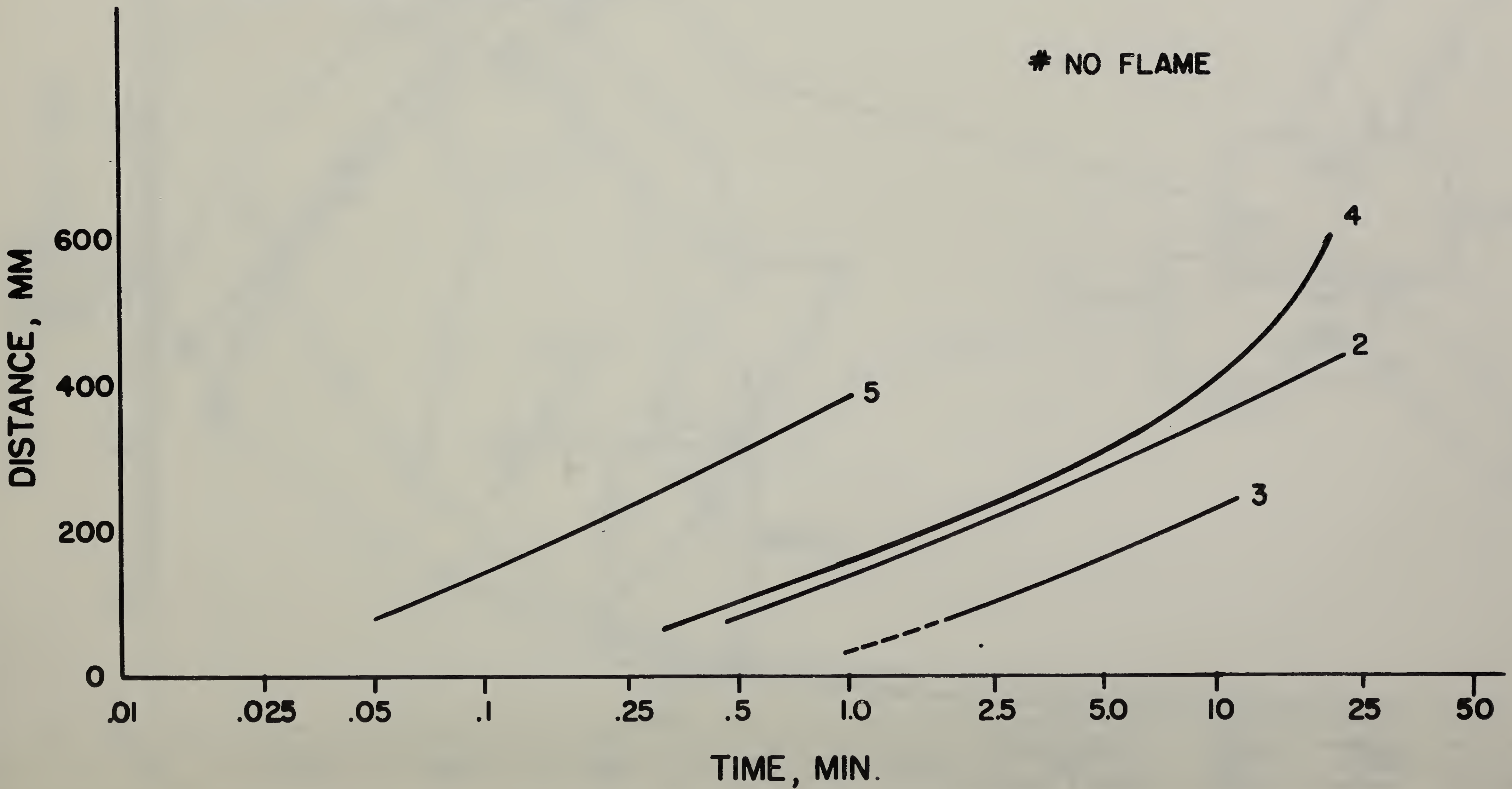


FIGURE 7

60° WALL POSITION

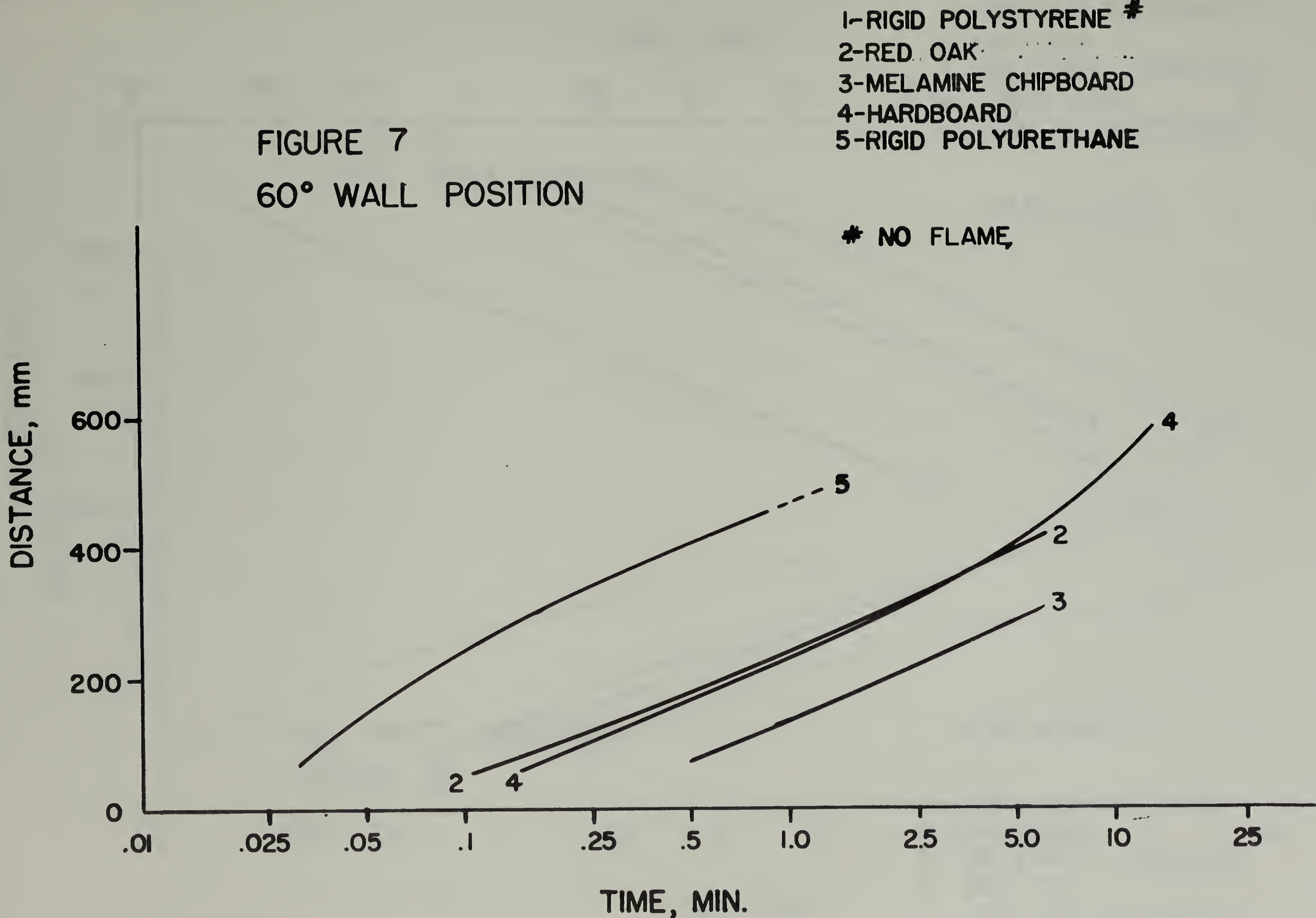


FIGURE 8
45° WALL POSITION

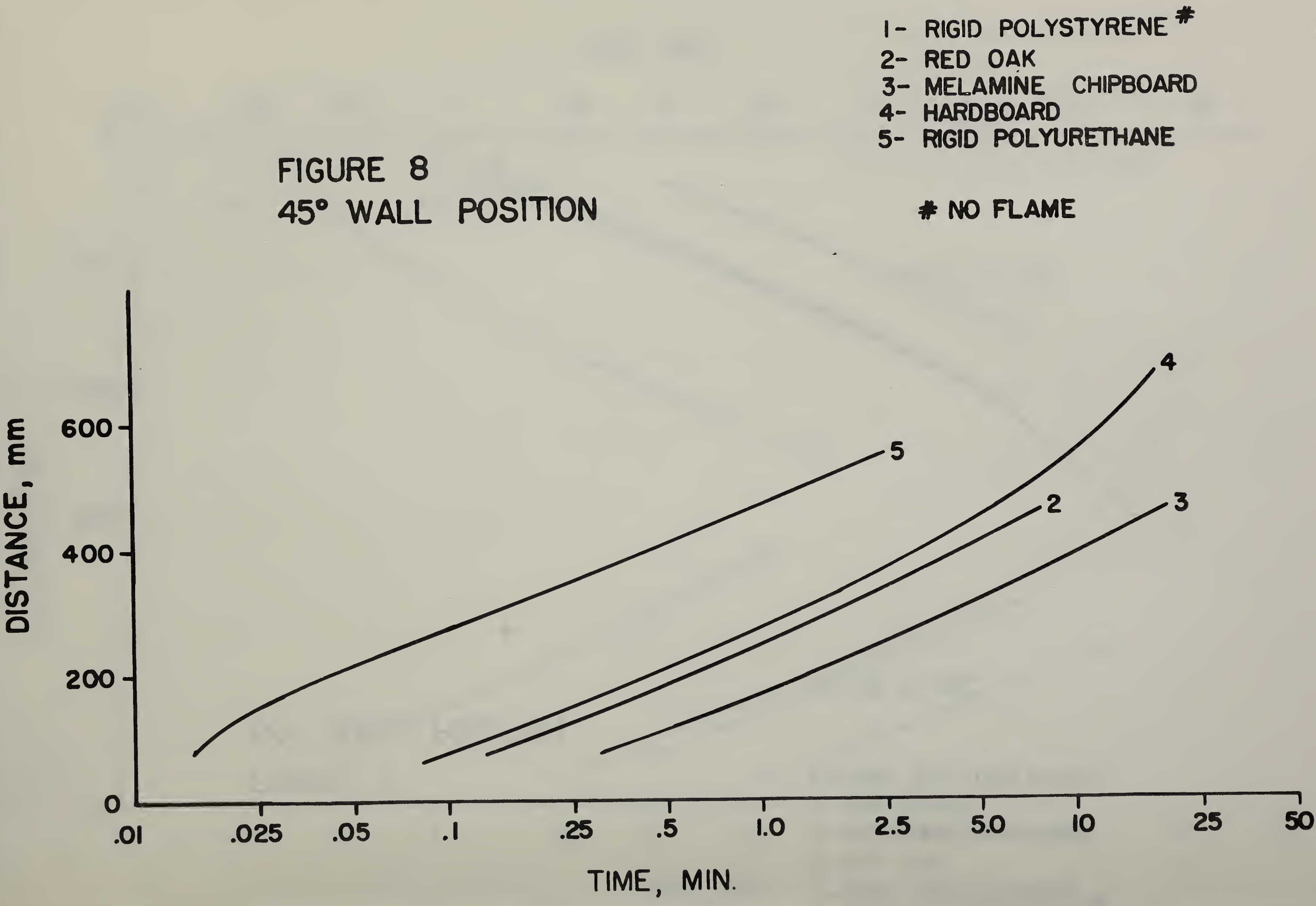


FIGURE 9
22°30' WALL POSITION

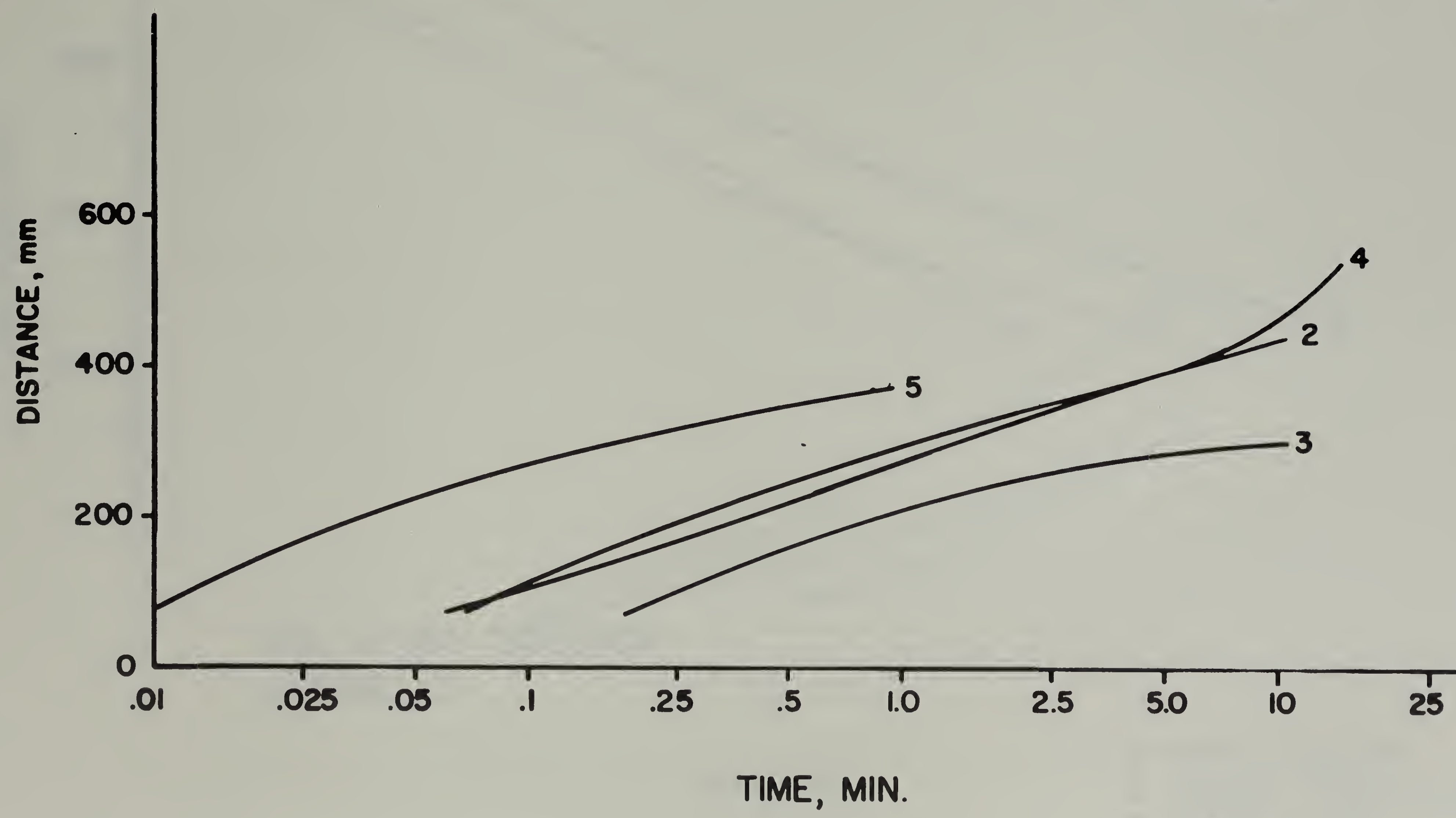


FIGURE 10
45° FLOOR POSITION

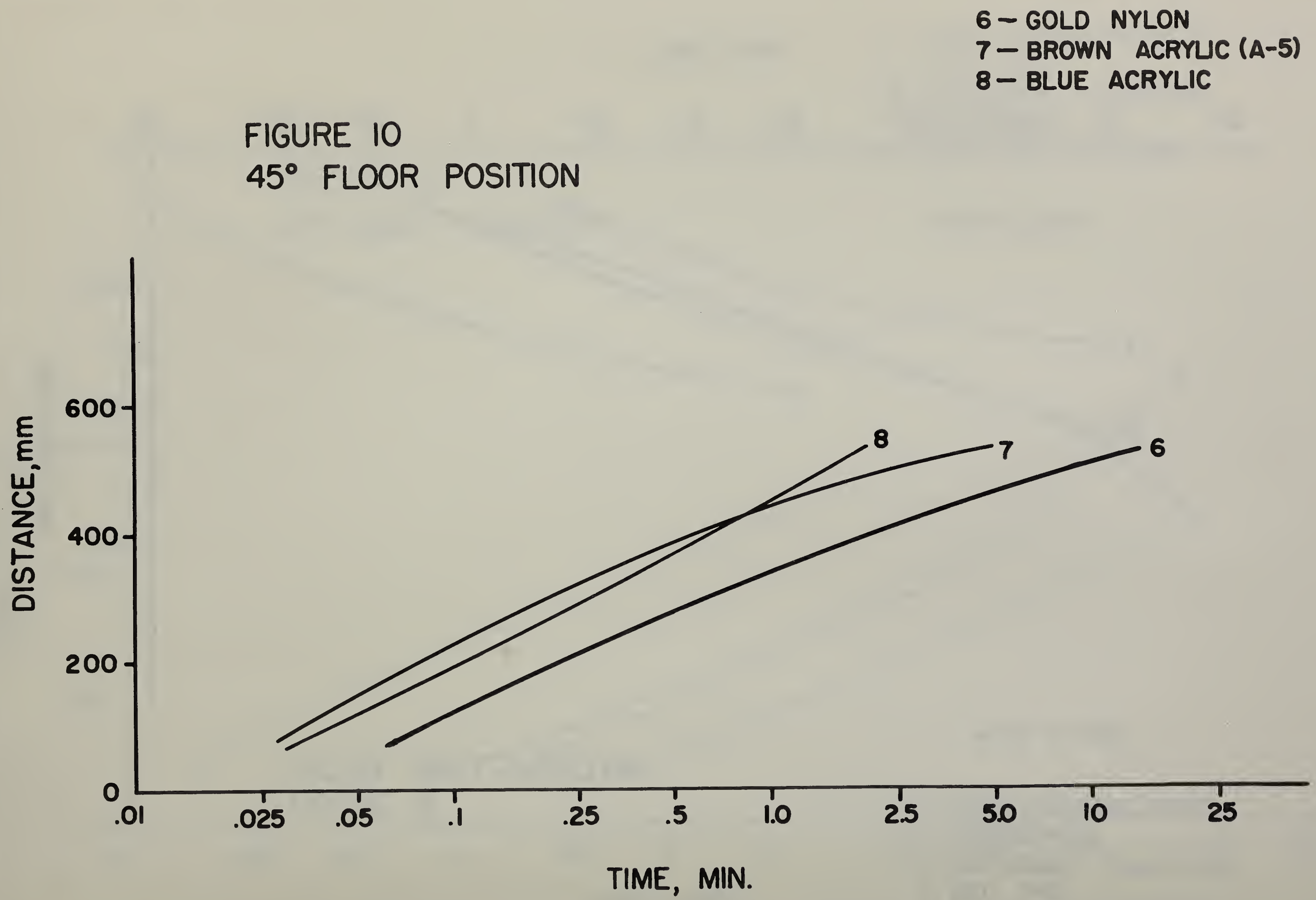


FIGURE 11
90° FLOOR POSITION

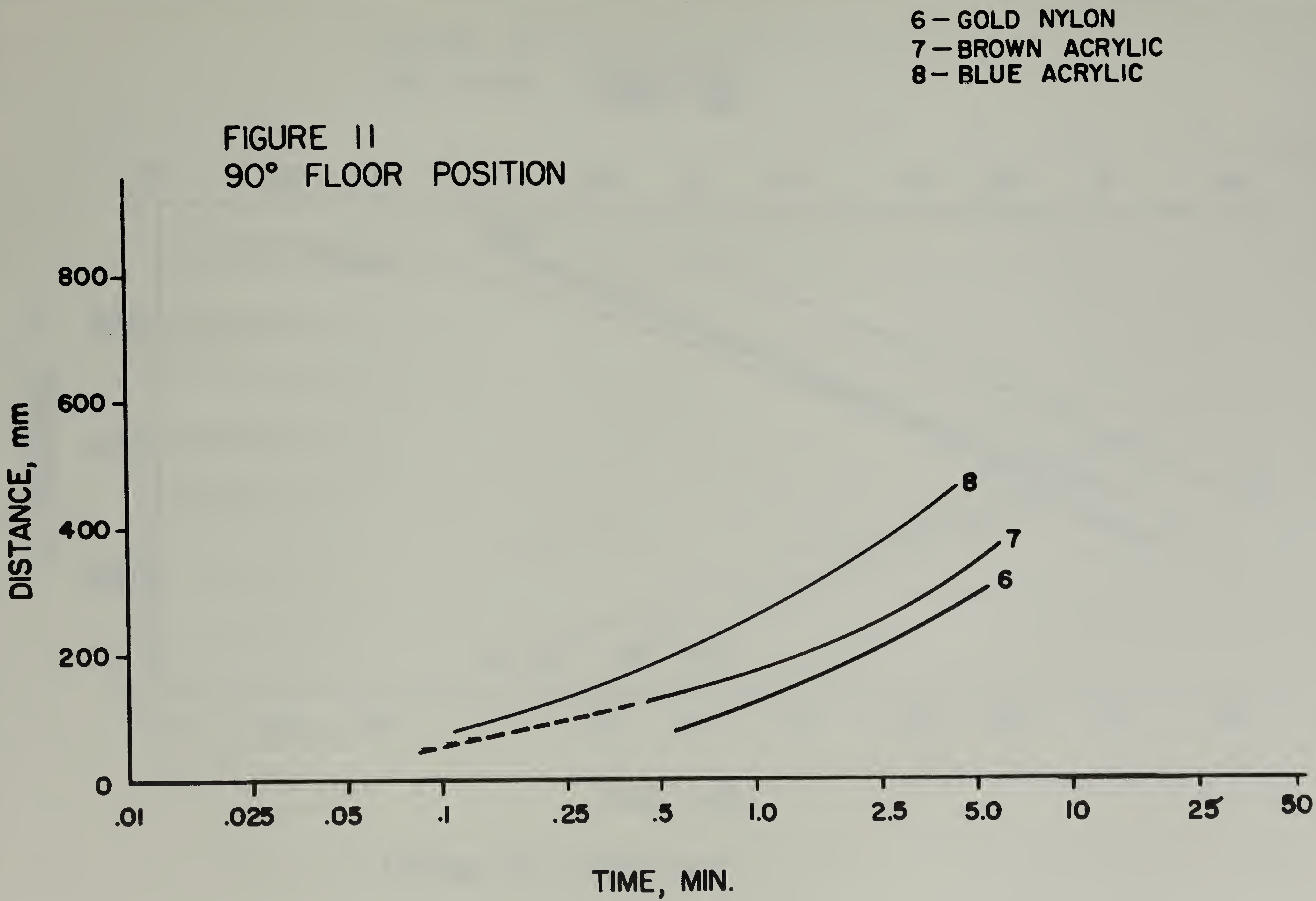


FIGURE 12 RED OAK

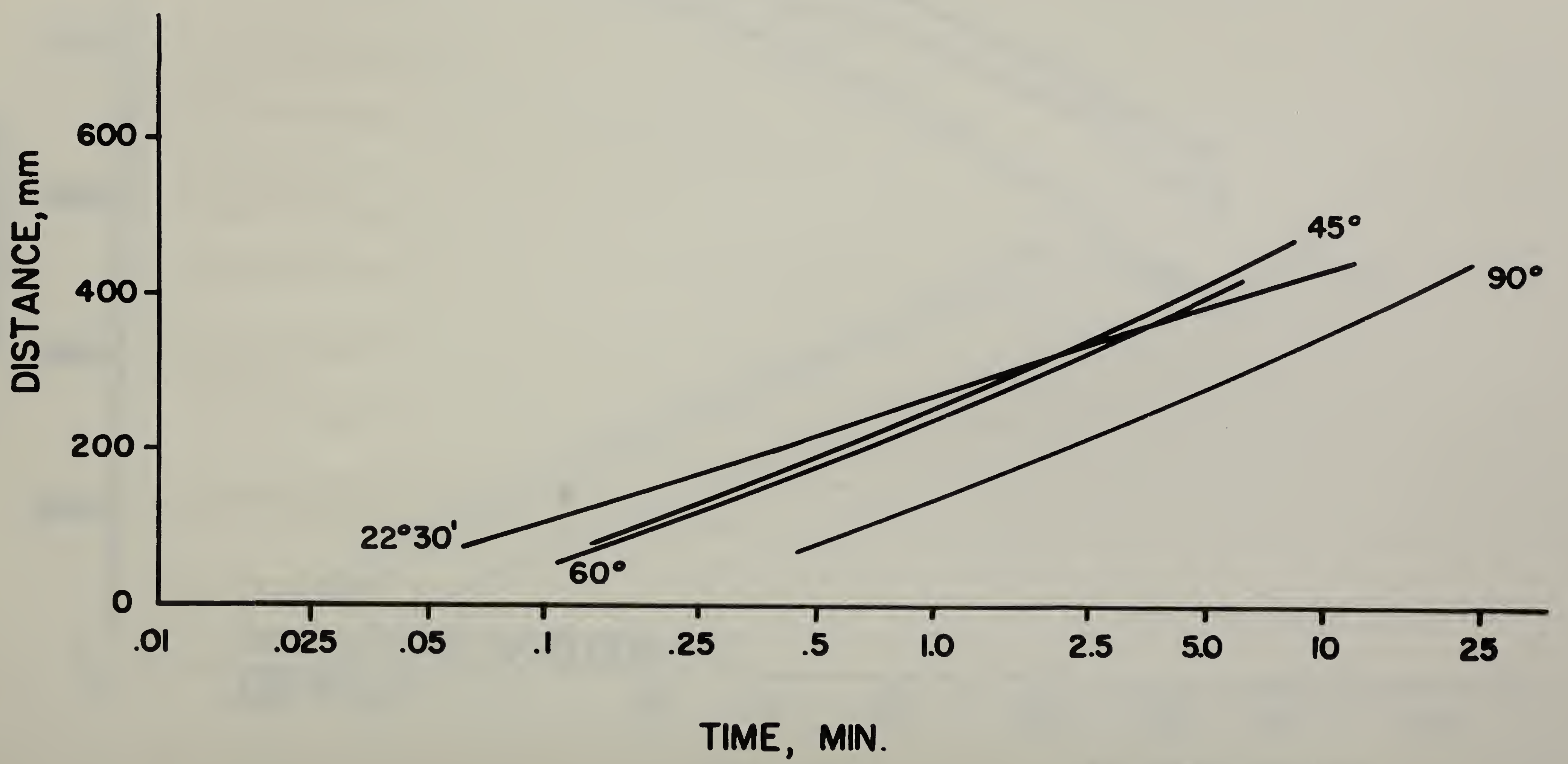


FIGURE 13
MELAMINE CHIPBOARD

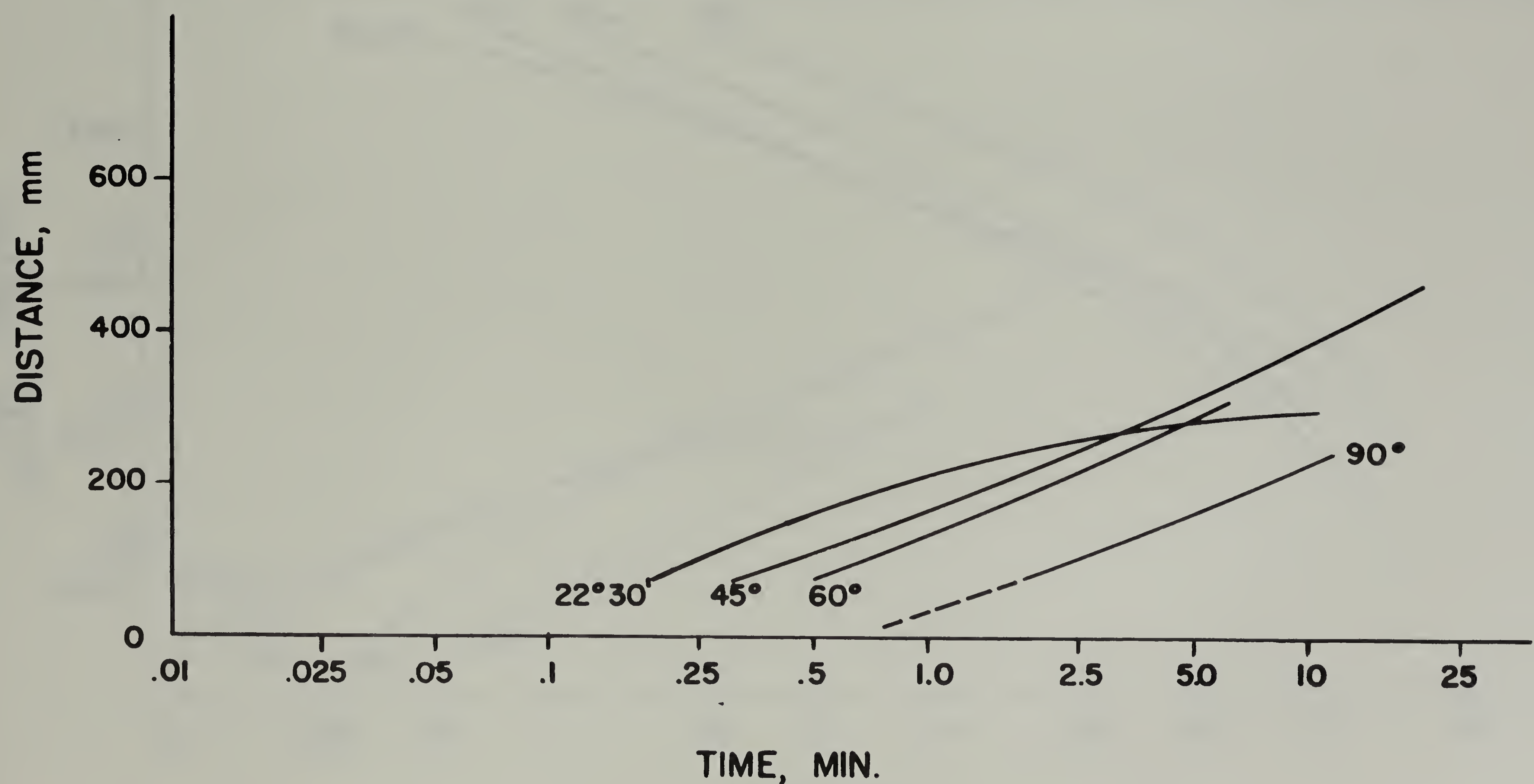


FIGURE 14 HARDBOARD

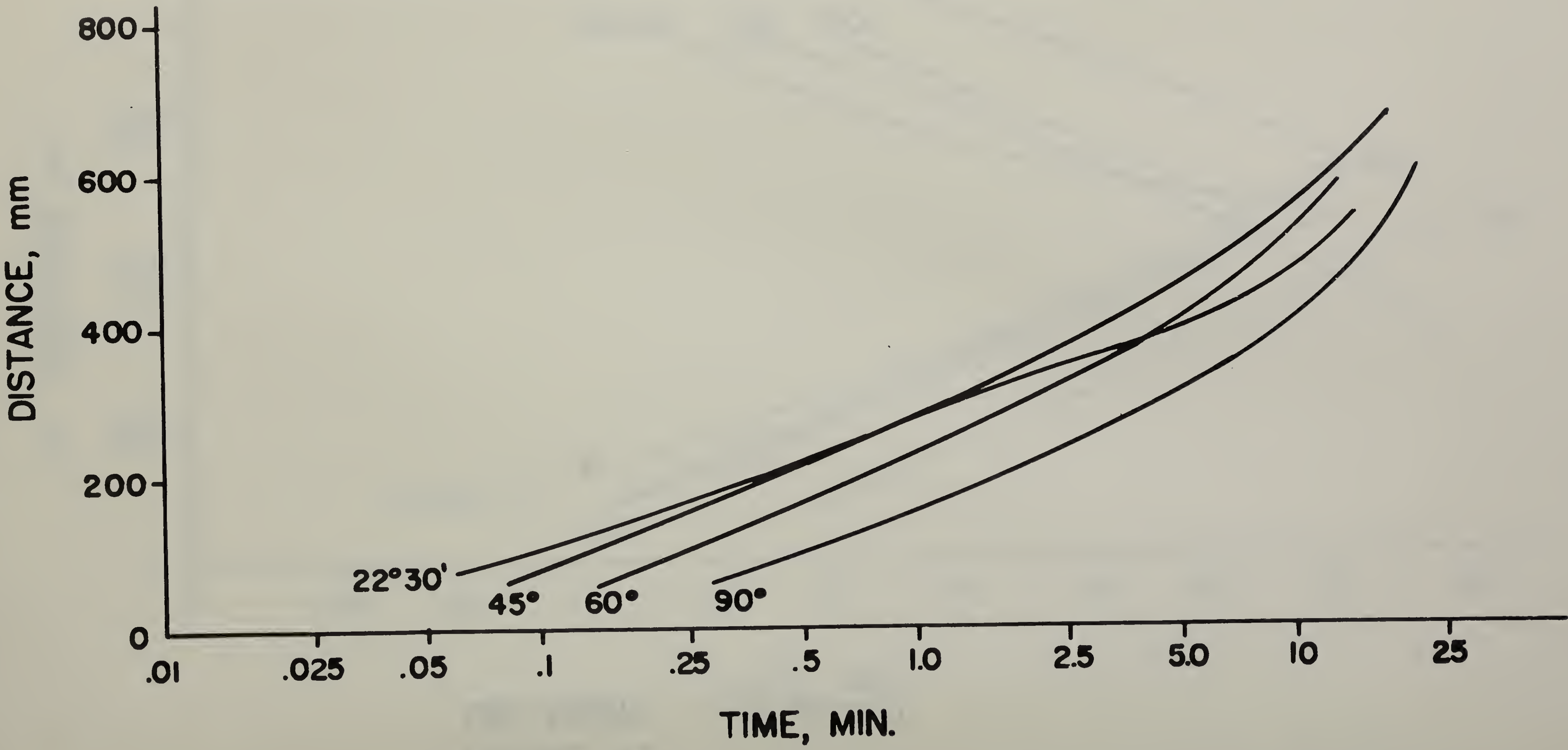


FIGURE 15 RIGID POLYURETHANE