NATIONAL BUREAU OF STANDARDS REPORT

10 471

EXPERIMENTAL FIRES IN ENCLOSURES
(GROWTH TO FLASHOVER)
C.I.B. COOPERATIVE PROGRAM (CIB 2)

NBS

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

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EXPERIMENTAL FIRES IN ENCLOSURES
(GROWTH TO FLASHOVER)
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ABSTRACT

Data are reported on the growth of fire in small-scale compartments performed under a C.I.B. international cooperative program. The results of the statistically designed program include measurements of flame spread time, flame height, weight loss, temperature, radiation intensity and gas concentration.

1.0 INTRODUCTION

Proposals were made in C.I.B. Paper No. CIB/CTF 66/11 (UK) for a co-operative experimental program to study the growth of fire in small-scale compartments from ignition to a "flashover" or full-involved condition. A total of eight international laboratories agreed to participate. To permit evaluations to be made of the effects of eight main variables, each at two levels, and most first order interactions, a statistical design based on a half replicate was chosen. This required that each laboratory, including NBS, perform a series of 32 tests. The data will be analyzed in combination with the data from the seven other laboratories, comprising a total of 256 tests. The independent variables were the shape, ventilation and lining of the compartment, the size, shape and distribution of the fuel, and the size and position of the ignition source. (See Table I).

Based on the results of preliminary experiments by the Joint Fire Research Organization, certain experimental details were revised in June 1967. Additionally, revisions were suggested in the standardized form of data presentation in a letter of October 1968.

This report contains a summary of the 32 tests performed by the Fire Research Section, Building Research Division, NBS. Included are series of graphs showing the following variables as a function of time:

Flame Spread and Flame Height

Weight

Temperature

Radiation Intensity

Gas Concentration

Similar data were collected from five supplemental tests, in which additional types of linings were used, all other conditions remaining the same.

This study extends and supplements the C.I.B. first phase cooperative program on fully-developed fires in compartments. The results of NBS tests for the earlier study were reported in TR 8131; a summary report giving results for all eight participating laboratories, and a comprehensive analysis is being prepared under the auspices of the Fire Research Working Group (W 14) of C.I.B.

2.0 EXPERIMENTAL DETAILS

2.1 Compartment

Two compartments were constructed for ease in performing tests in the two assigned shapes. The frames of the compartments were made of hot-rolled steel angle welded together such that one box had the 121 configuration and the other box had the 211 configuration. The inside dimensions were 2 meters by 1 meter by 1 meter high. Each compartment was lined with a single layer of 10 mm thick asbestos millboard (type M4 purchased from Bell's Asbestos and Engineering, Ltd., England, in 40 in. square sheets). A loose board of the same material was laid on the floor to provide a double thickness. The nominal density was 1.1 g/cm^3 and thermal conductivity at room termperature 3.8×10^{-4} cal/s cm °C.

Observation windows in the sides of the compartment were 10 cm square and were made of a high-temperature fused silica glass. The compartment was positioned so that its floor was above the laboratory floor by a distance equal to the compartment height (1 meter).

2.2 Ventilation

The ventilation window was either completely open or only 1/4 open. In the latter case, two sheets of asbestos millboard of the correct size were bolted on either side of the frame to provide the required window opening at the center. When the compartment was required to be lined, the window-limiting asbestos boards were also lined.

2.3 Wall Lining

The lining used in the tests was purchased from Evans Products Co., Chesapeake, Va., according to the prescribed specification:

"Golden Royal Board, manufactured by Aktiebolaget Statens Skogsindustrier, Stockholm. Thickness 5 ± 0.5mm, weight 5.0 ± 0.2 kg/m^2 thermal conductivity 0.026 ± 0.002 cal/s cm °C, smooth one side, untreated."

The material received was of the same thickness and weight, marked "TIMBERIT STD-WGR-SBS Made in So. Africa." In the five additional tests, five different linings were used and are noted in the data (Tables IV and V). The linings were not conditioned before testing.

2.4 Fuel

The fuel used was Ponderosa Pine, which had a density of between 0.44 and 0.53 g/cm^3. The fuel used in the tests was conditioned for at least 14 days prior to use. The moisture content generally varied between 8 and 12.3% (see Table III), but were occasionally higher when the prescribed humidity level could not be maintained by the air conditioning system. The sticks had a cross section 2 cm square and were planed smooth top and bottom and fine sawn on the sides.

The cribs were 8 or 16 layers high with alternate layers perpendicular to each other. The spacing between sticks was either 2 or 6 cm. The sticks were glued together with urea - formaldehyde thermosetting adhesive.

There were eight different types of crib arrangements, four for tests with multiple, separated cribs and four for tests with a single continuous crib. See Table II for details. This number of arrangements allowed for examination of the interaction between the spacing of sticks and the size and height of the cribs.

The large cribs were made of sticks 68 cm and 168 or 164 cm long, the latter depending on the spacing, 2 or 6 cm respectively.

In every case, the top layer of the crib over the ignition source was parallel to the opening in the compartment.

2.5 Ignition Source

The cribs were ignited by either a "small" source, consisting of 3 ml of ethyl alcohol in a 4 cm x 4 cm tray or a "large" source, 25 ml of ethyl alcohol in a 12 cm x 12 cm tray. The alcohol was placed in the recessed tray, either in a back corner or in the center of the compartment.

2.6 Extinguishment

After flaming had covered the top(s) of the crib(s), the fire was extinguished. Two methods were used. The first method was to knock down the fire with a hand-held CO_2 extinguisher, and then close the compartment with an asbestos door and pump in nitrogen gas. The second, which proved to be much more effective, was to shovel dry ice (solid CO_2), into the compartment and then close the door over the opening.

3.0 TEST RESULTS

3.1 Flame Spread

The progress of the flames across the sticks and the cribs was measured visually using a stop watch.

In all cases, the spread along the length of the box was measured; in some cases it was also possible to measure the flame spread laterally. The times at which ignition was observed in tests with 21 small cribs are given in Figures 1 - 16.

There is a graph of distance spread vs. time for each test (see Figs. 17 - 21). From the graphs it was generally easy to find T_2, the time of the final transition when the spread suddenly increases. However, in several tests, no sharp transition was noted and the "final transition time, T_2," was arbitrarily assumed to be the time at which the rate of flame spread exceeded 10 cm/min.

3.2 Flame Height

The flame height is represented on the same graphs as the flame spread (Figs. 17 - 21) and was also measured visually.

3.3 Weight

During the test the whole compartment was suspended from a load cell which provided a continuous weight record. The cribs were weighed separately on a platform balance before the test. If the test included a compartment lining, the weight of the lining was estimated after it had been fit and installed. The weight-time curves (Figs. 22 - 23) are based on the original crib weight, although the loss in weight includes that due to the combustible lining (where used), and moisture in the box. Figure 24 shows the weight records for the five additional tests, two of which were permitted to continue through the fully-developed stage.

3.4 Temperature

The temperature was measured by bare 0.020 in. dia. chromel-alumel thermocouples at three heights located along the central axis and 3/4 of the length of the box: at the ceiling (TC1), 25 cm from the ceiling (TC2), and 75 cm from the ceiling (TC3). A graph of the temperatures at TC1, TC2, and TC3 vs. time is given for each test. (See Figs. 25 - 61).

3.5 Radiation Intensity

Two radiometers were placed side-by-side outside the box facing the opening. One was unshielded and the second was shielded by an aluminum plate which restricted the field of view of the radiometer to the area below the top opening in the compartment so as not to include the flames above. A graph of radiation intensity vs. time is given for each test (see Figs. 62 - 98).

3.6 Gas Concentrations (O_2, CO_2, CO)

To take the gas sample, a hole was drilled through the top of the compartment 15 cm from the opening and a stainless steel tube was positioned in the hole so that the tip was 5 cm below the ceiling. The gas was drawn through a trap lined with glass wool and cooled with dry ice to remove smoke particles and water vapor.

The gas was divided into three streams which passed through individual instruments of the following types: non-dispersive infrared analyzers for CO and CO_2, and a magnetic susceptibility analyzer for O_2. The concentrations were calculated and plotted in Figs. 99 - 134.

3.7 Lining

The time at which the lining ignited was noted and was included in Table III where applicable.

4.0 DISCUSSION

A table of symbols precedes the graphs. These symbols are only used where clarification is needed to help interpret the graphs and do not necessarily represent data points. The graphs of flame spread and flame height and the graphs of weight vs. time are presented with replicates on the same graph. The graphs of radiation intensity, temperature, and gas concentration are presented individually in order of test number (1 through 37).

The tests were performed in a random order (selected from random order tables), except for the following sequence according to compartment shape:

Compartment	Tests
121	1-8
211	9-24
121	25-37

There was no pattern which could be attributable to the order of testing.

Five additional tests were included to examine whether a relation exists between the flame spread rating, or the thermal properties ($k\rho c$), of the lining material, and the time for flames to spread within a compartment under a given set of conditions. The principal test results from this comparison are given in Table V. The anticipated qualitative relation with thermal inertia was noted, although the difference in T_2 (final transition time) only ranged between 7.33 min. (fiberboard) and 9.72 min. (plastic-coated hardboard). (See Fig. 135).

TABLE I

Test Variables

Variables		Condition 1		Condition 2	
Compartment Shape - (S)	width	1 m		2 m	
	depth	2 m	121	1 m	211
	height	1 m		1 m	
Position of Ignition Source - (P)		corner		center	
Fuel Height - (F)		16 cm		32 cm	
Ventilation - (V)		1/4		full	
Spacing Between Sticks (Bulk Density) - (B)		2 cm		6 cm	
Fuel Distribution (Continuity) - (C)		1 large crib		21 small cribs	
Wall Lining - (L)		no lining		lined with hardboard	
Area and Amount of Alcohol - (A)		16 cm^2; 3 ml		144 cm^2; 25 ml	

TABLE II

Types of Cribs and Distribution

Type	Length of Sticks, cm	Number of Layers	No. Sticks per Layer	Spacing, cm	Number of Cribs
A	20	8	5	2	21
B	20	8	3	6	21
C	20	16	5	2	21
D	20	16	3	6	21
E	168 68	4 4	17 42	2	1
F	164 68	4 4	9 21	6	1
G	168 68	8 8	17 42	2	1
H	164 68	8 8	9 21	6	1

TABLE III   Test Results - Compartment Shape 121

Test Number	S	P	F	V	B	C	L	A	Fuel Density g/cm^3	Fuel Moisture %	Room Temp °C	Relative Humidity %	Times, min. Lining Ignited T_{L_1}	Flames Touched Ceiling T_f	Flames Out Window T_w	Flames Over Whole Ceiling T_{L_2}	Time Final Transition T_2	Time Ignition 1st ADJ Crib T_a	Flaming Whole Top Crib T_3	Weight Loss At T_3 kg
1	1	2	2	2	2	1	1	1	0.45	12				2.2	6.0		6.2		7.6	11.8
31									0.47	11.6	17	28		2.9	5.0	7.3	5.8@		7.3	5.0
2	1	1	1	1	2	2	2	2	0.49	8			9.8	9.7	10.8	11.8	9.8	6.0	11.6	6.8
3									0.46	9			6.9	6.2	7.7	7.1	7.0	5.9	8.3	6.2
4	1	2	2	2	2	2	2	1	0.46	11			7.0	5.1	8.2	8.9	8.2	7.9	9.8	8.8
7									0.44	11			5.0	3.5	6.8	7.4	7.2	6.5	8.3	13.0
5	1	1	1	2	1	1	2	1	0.46	10			14.2	9.2	14.8	15.0	14.4		15.5	6.3
32									0.49	11.8	15	62	16.9	9.5	17.5	17.9	17.3		18.3	5.0
6	1	2	2	1	1	2	1	2	0.47	12				6.0	11.7		11.3	10.8	13.5	4.8
25									0.47		13	44		7.5	11.0		>10.3	9.8	13.1	5.0
8	1	1	1	2	1	2	1	1	0.53	10				10.4	35.0		33.2	16.4	36.3	18.5
30									0.53	14.2	24	38		25.2	39.0	39.7	37.0@	20.0	40.4	14.2
26	1	2	2	1	1	1	2	2	0.48	12.2	10	61	10.8	10.5	10.5	11.2**	>11.8		14.1	6.8
27									0.48	11.6	23	42	9.5	9.5	9.9	10.5**	12.3		14.2	14.5
28	1	1	1	1	2	1	1	2	0.49	12.2	20	58		9.0	13.8	15.2	12.6		15.2	7.0
29									0.46	12.3	22	48		8.0	11.5	12.8	12.1		13.2	6.3

+ Ventilation - Limited at 14 min.
* Estimated; all cribs not ignited.
** Estimated; part of ceiling not involved.
@ Based on 10 cm/min

TABLE III (Cont.) Test Results - Compartment Shape 211

Test Number	S	P	F	V	B	C	L	A	Fuel Density g/cm^3	Fuel Moisture %	Room Temp °C	Relative Humidity %	Times, min. Lining Ignited T_{L_1}	Flames Touched Ceiling T_f	Flames Out Window T_w	Flames Over Whole Ceiling T_{L_2}	Time Final Transition T_2	Time Ignition 1st ADJ Crib T_a	Flaming Whole Top Crib T_3	Weight Loss At T_3 kg
9	2	2	1	2	1	2	1	1	0.46	13.3	23	61		6.5	20.0		~22.5@	11.8	23.7	15.5
13	2	2	1	2	1	2	1	1	0.49		24	54		8.0	19.1		~24@	13.9	25.4	15.1
11	2	2	1	1	2	2	2	2	0.45	8.9				8.2	9.2		8.5@	4.4	~10*	8.1
16	2	2	1	1	2	2	2	2	0.46	29.6	14	66		>12	>12		~13@	9.2	~14*	5.9
15	2	1	2	1	1	1	2	2	0.45	9.8	20	71	8.7	5.1	9.7		10.4		11.5	6.5
19	2	1	2	1	1	1	2	2	0.48	11.4	14	56	11.3	6.5	12.0	13-14	12.5		~13.0	
14	2	2	1	2	1	1	2	1	0.46	20.4	26	63	12.1	7.2	10.8	14.2	13.4		15.0	9.1
20	2	2	1	2	1	1	2	1	0.47	(13.2)	11	51	9.8	6.0	9.8	12.0	11.4		12.8	6.0
17	2	2	1	1	2	1	1	2	0.45	17.4	18	51		4.5	6.5		5.7@		7.8	5.0
21	2	2	1	1	2	1	1	2	0.44	13.2	13	43		5.0	7.9	8.5	5.3@		8.5	5.1
12	2	1	2	2	2	2	2	1	0.46	11.7	25	39	6.5	4.5	7.2	8.5	8.6	7.5	9.3	9.1
22	2	1	2	2	2	2	2	1	(0.46)	11.4	13	44	7.1	5.5	7.8	9.2	8.8	8.6	~10.3*	9.1
18	2	1	2	1	1	2	1	2	0.47	14.8	14	37		3.8	10.0		10.8	9.8	>14+	>11
23	2	1	2	1	1	2	1	2	0.47	11.4	13	44		8.9	20.1		21.3	17.2	23.6	8.8
10	2	1	2	2	2	1	1	1	0.45	13.3				5.6	11-13		8.8		13.0	9.5
24	2	1	2	2	2	1	1	1	0.44	11.6	18	56		5.8	9.2	13.7	8.2		13.2	8.9

\+ Ventilation - Limited at 14 min.
* Estimated; all cribs not ignited.
** Estimated; part of ceiling not involved.
@ Based on 10 cm/min

TABLE IV Test Results - Effect of Wall Lining

Test Number	S	P	F	V	B	C	L	A	Fuel Density g/cm^3	Fuel Moisture %	Room Temp °C	Relative Humidity %	Lining Ignited T_{L_1}	Flames Touched Ceiling T_f	Flames Out Window T_w	Flames Over Whole Ceiling T_{L_2}	Time Final Transition T_2	Time Ignition 1st ADJ Crib T_a	Flaming Whole Top Crib T_3	Weight Loss at T_3 kg
33 Hardboard	1	1	1	1	2	1	2	2	0.472	10.8	-	36	7.12	7.50	8.50	8.50	7.75		9.78	(15)
34 Fiber-board	1	1	1	1	2	1	2	2	0.462	9.5		36	7.33	7.50	7.83	7.83	7.33		8.50	(10)
35 Plastic-Coated Hardboard	1	1	1	1	2	1	2	2	0.492	10.8		36	10.63	9.00	10.87	11.00	9.72		11.92	(12)
36 Gypsum board	1	1	1	1	2	1	2	2	0.529			47	9.00	8.00	9.83	10.25	8.75		11.67	22
37 Plywood	1	1	1	1	2	1	2	2	0.520			50	8.83	9.00	9.30	9.50	9.25		10.10	11

TABLE V

Effect of Lining on Growth to Flashover

Test No.	Lining	Thickness mm	Thermal Inertia $k\rho c$ $\frac{W^2\ sec}{°C\ cm^4}$ x 10^4	Flame Spread Index (ASTM E162)	Characteristic Times T_{L_1}	T_w	T_2	T_3
						min.		
28	None	-	6.9	-	-	13.75	12.60	15.00
29	None	-	6.9	-	-	11.50	12.10	13.23
33	Hardboard	5	20.0	203	7.12	8.50	7.75	9.78
34	Fiberboard	12	3.7	45	7.33	7.83	7.33	8.50
35	Plastic-Coated Hardboard	3	~20	122	10.63	10.87	9.72	11.92
36	Gypsum Board	10	7.4	~10	9.00	9.83	8.75	11.67
37	Plywood, Exterior Grade	6	13.0	120	8.83	9.30	9.25	10.10

GRAPHS - KEY

FLAME SPREAD & FLAME HEIGHT

16 Test number, see Tables III, IV

○ Flame spread, long side

△ Flame spread, short side

+ Flame height

WEIGHT

7 Test number, see Tables III, IV

• Weight

TEMPERATURE

× TC 1, thermocouple 1, top of box

○ TC 2, thermocouple 2, 25 cm down from top

□ TC 3, thermocouple 3, 75 cm down from top

RADIATION

□ Unshielded

○ Shielded

GAS CONCENTRATION

○ O_2, oxygen

△ CO_2, carbon dioxide

□ CO, carbon monoxide

9 min 30 sec	10 min 05 sec					11 min 25 sec
6 min 00 sec	8 min 50 sec	10 min 06 sec	10 min 25 sec		11 min 00 sec	
LIT	6 min 05 sec	9 min 03 sec				

1/4 VENT

FIG. 1 Time to ignition of 21 small cribs.

TEST #2 (S_1 P_1 F_1 V_1 B_2 C_2 L_2 A_2)

7 min 15 sec						
5 min 55 sec	6 min 30 sec					8 min 20 sec
LIT	5 min 56 sec					

1/4 VENT

FIG. 2 Time to ignition of 21 small cribs.

TEST #3 (S_1 P_1 F_1 V_1 B_2 C_2 L_2 A_2)

		8 min 45 sec	7 min 55 sec			9 min 25 sec	FULL VENT
		8 min 35 sec	LIT	8 min 10 sec		9 min 26 sec	
			8 min 20 sec			9 min 25 sec	

FIG. 3 Time to ignition of 21 small cribs.

TEST #4 (S_1 P_2 F_2 V_2 B_2 C_2 L_2 A_1)

		11 min 30 sec	10 min 45 sec		12 min 25 sec		
		11 min 31 sec	LIT	11 min 20 sec	12 min 18 sec	12 min 45 sec	1/4 VENT
		11 min 32 sec	11 min 00 sec				

FIG. 4 Time to ignition of 21 small cribs.

TEST #6 (S_1 P_2 F_2 V_1 B_1 C_2 L_1 A_2)

			7 min 08 sec			7 min 50 sec	F U L L
		7 min 09 sec	LIT	7 min 10 sec		7 min 55 sec	V E N T
			6 min 30 sec			7 min 55 sec	

FIG. 5 Time to ignition of 21 small cribs.

TEST #7 (S_1 P_2 F_2 V_2 B_2 C_2 L_2 A_1)

LIT	16 min 22 sec	27 min 10 sec	33 min 11 sec	34 min 14 sec	35 min 38 sec	36 min 17 sec	F U L L
16 min 55 sec	19 min 10 sec	27 min 00 sec	32 min 27 sec	34 min 25 sec	35 min 20 sec	35 min 59 sec	V E N T
28 min 54 sec	29 min 03 sec	30 min 13 sec	33 min 15 sec	34 min 35 sec	35 min 45 sec	36 min 05 sec	

FIG. 6 Time to ignition of 21 small cribs.

TEST #8 (S_1 P_1 F_1 V_2 B_1 C_2 L_1 A_1)

22 min 25 sec	18 min 50 sec	15 min 00 sec	11 min 50 sec	14 min 20 sec	19 min 00 sec	23 min 10 sec
22 min 30 sec	19 min 10 sec	11 min 52 sec	LIT	12 min 30 sec	20 min 00 sec	23 min 18 sec
22 min 55 sec	20 min 10 sec	14 min 45 sec	12 min 06 sec	14 min 40 sec	20 min 10 sec	23 min 34 sec

FULL VENT

FIG. 7 Time to ignition of 21 small cribs.

TEST #9 (S_2 P_2 F_1 V_2 B_1 C_2 L_1 A_1)

		7 min 08 sec	6 min 25 sec	7 min 55 sec		
	8 min 30 sec	4 min 22 sec	LIT	6 min 10 sec	8 min 46 sec	
	9 min 20 sec					

1/4 VENT

FIG. 8 Time to ignition of 21 small cribs.

TEST #11 (S_2 P_2 F_1 V_1 B_2 C_2 L_2 A_2)

LIT	7 min 30 sec		8 min 50 sec			
8 min 25 sec	8 min 40 sec	8 min 45 sec	9 min 00 sec	9 min 05 sec	9 min 12 sec	9 min 15 sec
						9 min 20 sec

FULL VENT

FIG. 9 Time to ignition of 21 small cribs.

TEST #12 (S_2 P_1 F_2 V_2 B_2 C_2 L_2 A_1)

24 min 00 sec	21 min 14 sec	16 min 07 sec	15 min 24 sec	17 min 30 sec	21 min 42 sec	25 min 14 sec
23 min 54 sec	20 min 49 sec	13 min 55 sec	LIT	14 min 43 sec	21 min 42 sec	25 min 21 sec
23 min 52 sec	20 min 59 sec	15 min 45 sec	12 min 52 sec	15 min 30 sec	21 min 54 sec	25 min 24 sec

FULL VENT

FIG. 10 Time to ignition of 21 small cribs.

TEST #13 (S_2 P_2 F_1 V_2 B_1 C_2 L_1 A_1)

		11 min 34 sec	9 min 10 sec	10 min 39 sec		
	13 min 00 sec	9 min 49 sec	LIT	10 min 15 sec	13 min 00 sec	
		12 min 29 sec		12 min 37 sec	13 min 15 sec	

1/4 VENT

FIG. 11 Time to ignition of 21 small cribs.

TEST #16 (S_2 P_2 F_1 V_1 B_2 C_2 L_2 A_2)

LIT	9 min 52 sec	11 min 20 sec	11 min 37 sec	12 min 00 sec		
9 min 48 sec	10 min 40 sec	11 min 15 sec	11 min 45 sec	12 min 00 sec		
	11 min 30 sec		11 min 47 sec		12 min 15 sec	

1/4 VENT

FIG. 12 Time to ignition of 21 small cribs.

TEST #18 (S_2 P_1 F_2 V_1 B_1 C_2 L_1 A_2)

LIT	8 min 47 sec	9 min 37 sec				
8 min 37 sec	9 min 07 sec	9 min 40 sec	9 min 49 sec	10 min 05 sec		
9 min 40 sec	9 min 49 sec	9 min 49 sec		10 min 12 sec		10 min 20 sec

FULL VENT

FIG. 13 Time to ignition of 21 small cribs.

TEST #22 (S_2 P_1 F_2 V_2 B_2 C_2 L_2 A_1)

LIT	17 min 10 sec	21 min 42 sec	22 min 15 sec	22 min 45 sec	22 min 52 sec	23 min 10 sec
18 min 06 sec	19 min 20 sec	21 min 25 sec	22 min 34 sec		22 min 55 sec	
21 min 45 sec	21 min 50 sec	22 min 05 sec	22 min 36 sec	22 min 50 sec	22 min 57 sec	23 min 35 sec

1/4 VENT

FIG. 14 Time to ignition of 21 small cribs.

TEST #23 (S_2 P_1 F_2 V_1 B_1 C_2 L_1 A_2)

	12 min 26 sec	11 min 17 sec	10 min 47 sec	11 min 31 sec		13 min 06 sec	
		10 min 50 sec	LIT	10 min 20 sec		12 min 45 sec	1/4 VENT
		10 min 10 sec	9 min 52 sec	11 min 27 sec		13 min 00 sec	

FIG. 15 Time to ignition of 21 small cribs.

TEST #25 (S_1 P_2 F_2 V_1 B_1 C_2 L_1 A_2)

LIT	20 min 05 sec	31 min 00 sec	36 min 30 sec	38 min 45 sec	39 min 55 sec	40 min 25 sec	
20 min 00 sec	22 min 28 sec	30 min 48 sec	36 min 24 sec	38 min 40 sec	39 min 30 sec	40 min 25 sec	1/4 VENT
30 min 42 sec	30 min 48 sec	31 min 20 sec	36 min 35 sec	38 min 00 sec	39 min 50 sec	40 min 20 sec	

FIG. 16 Time to ignition of 21 small cribs.

TEST #30 (S_1 P_1 F_1 V_2 B_1 C_2 L_1 A_1)

Fig. 17 Flame Spread and Flame Height
Compartment Shape 121
Stick Spacing 6 cm

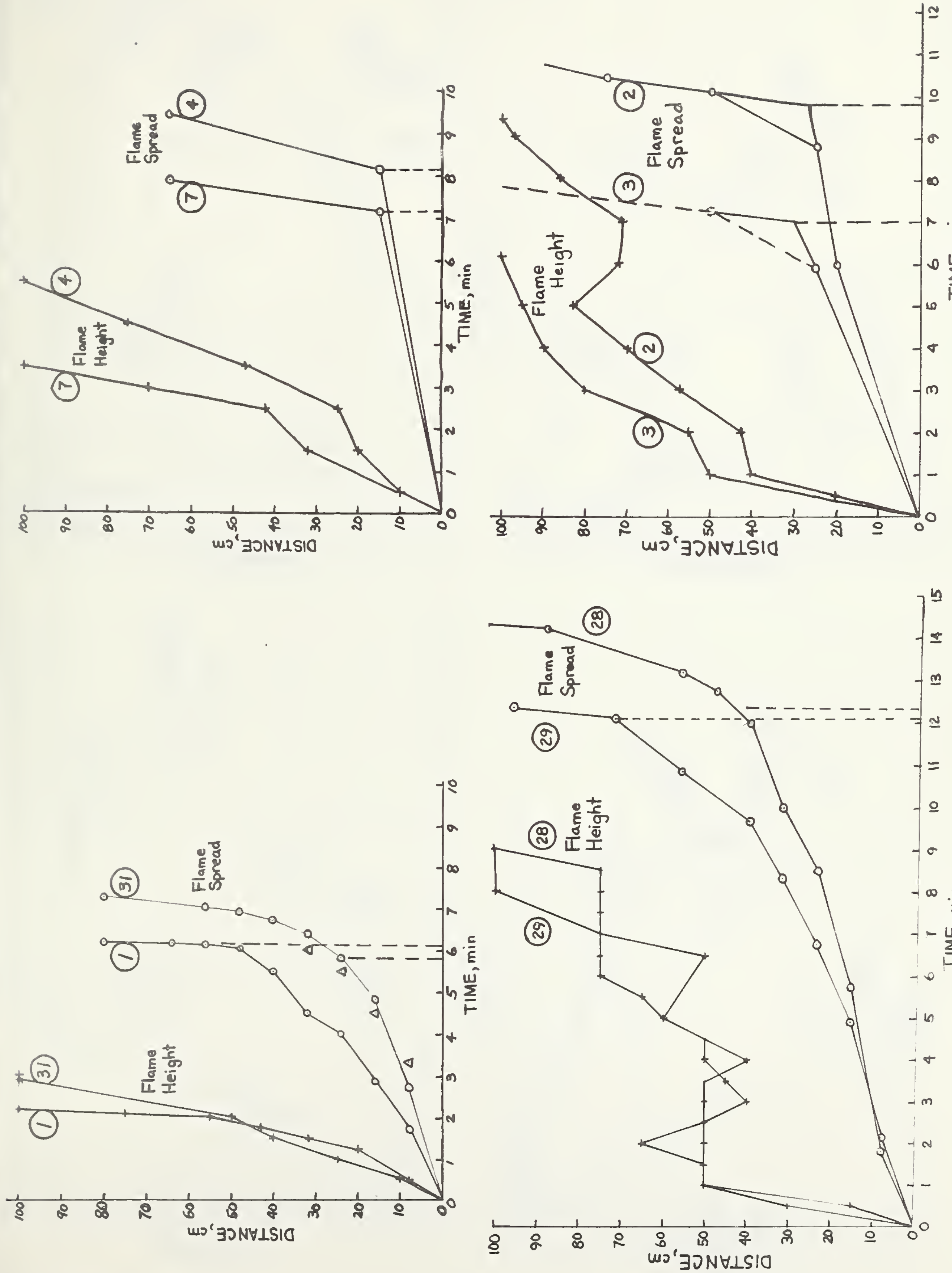
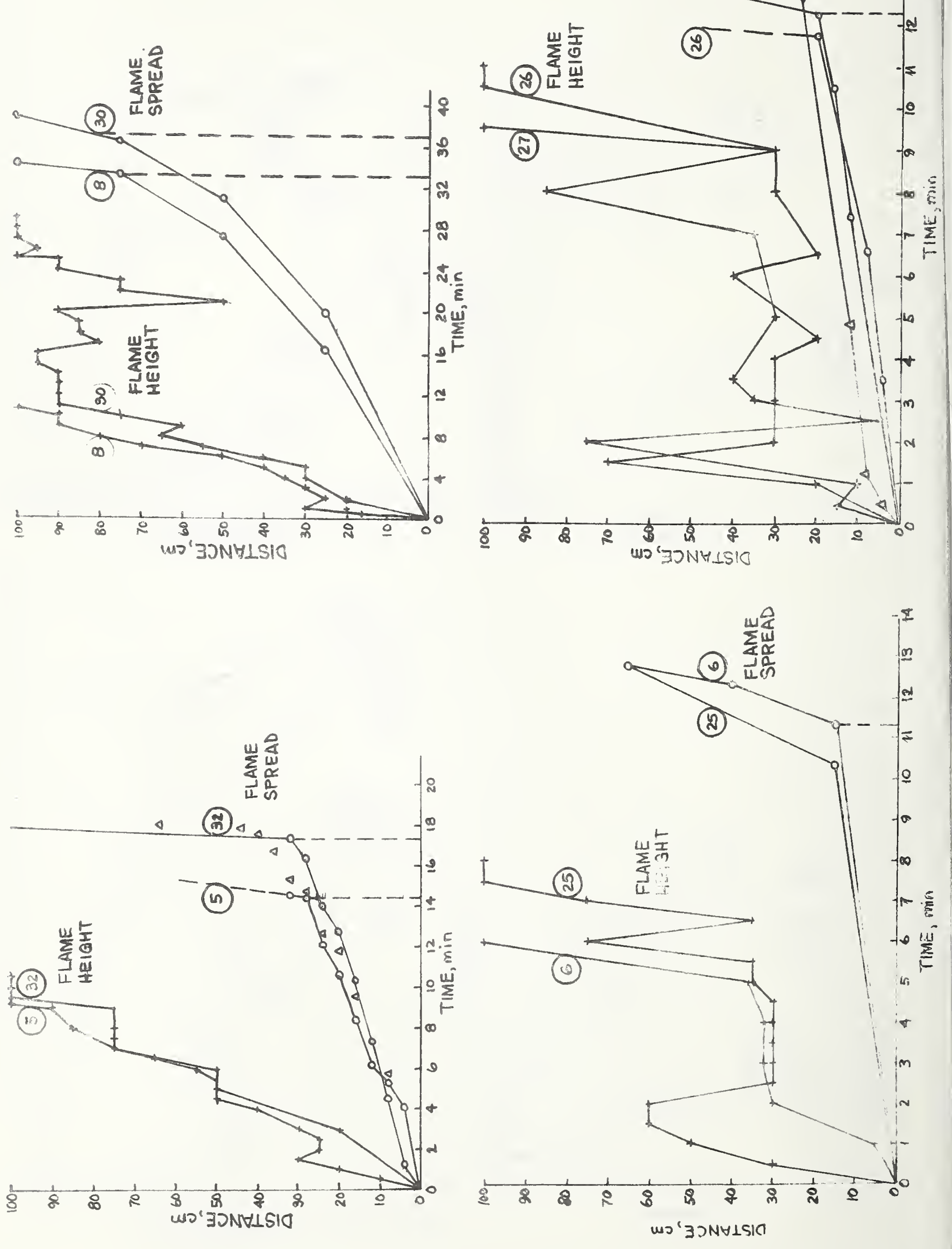


Fig. 13 Flame Spread and Flame Height

Compartment Shape 121

Stick Spacing 2 cm



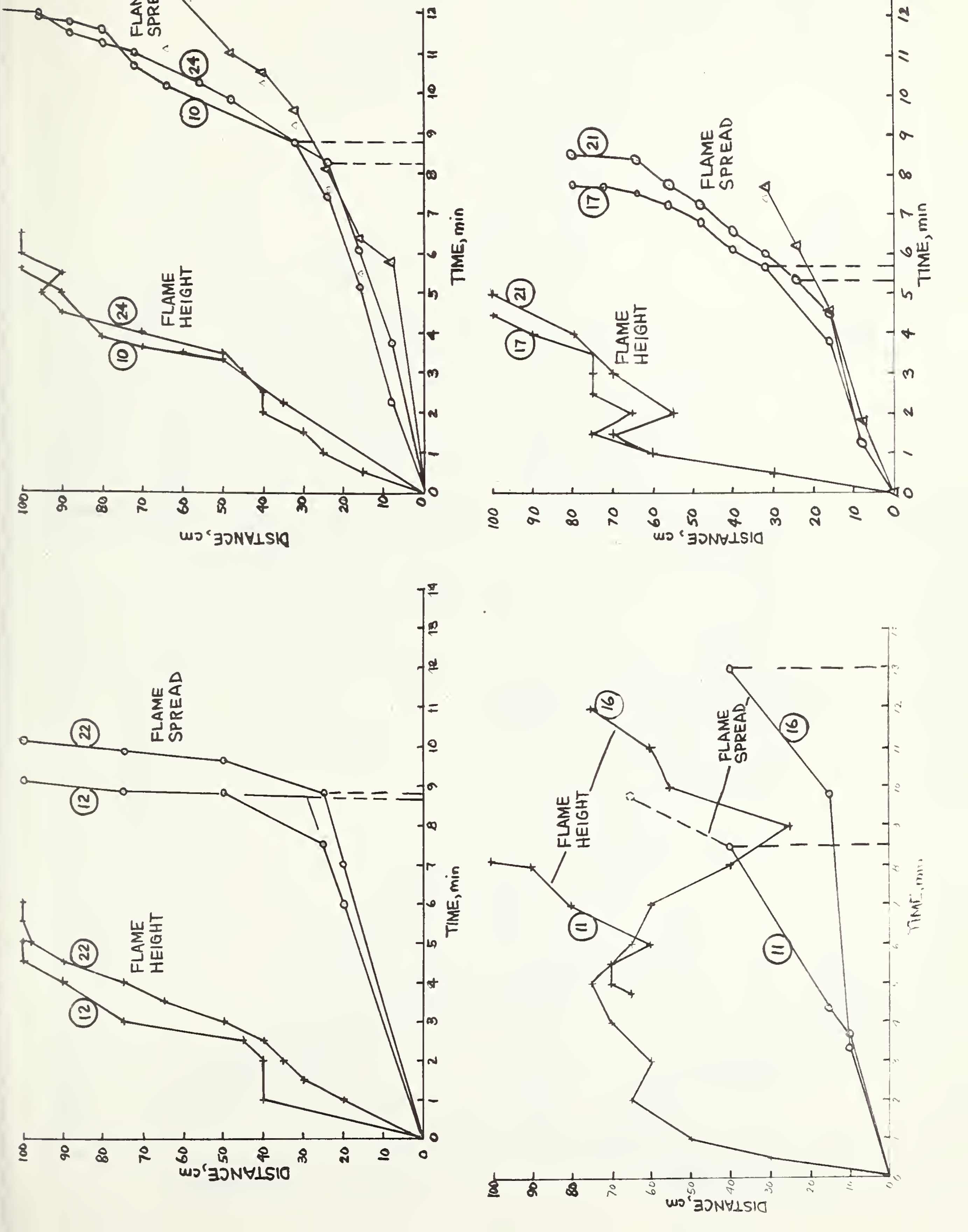


FIG. 19 FLAME SPREAD AND FLAME HEIGHT
COMPARTMENT SHAPE 211
STICK SPACING 6 CM

Fig. 20 Flame Spread and Flame Height
Compartment Shape 211
Stick Spacing 2 cm

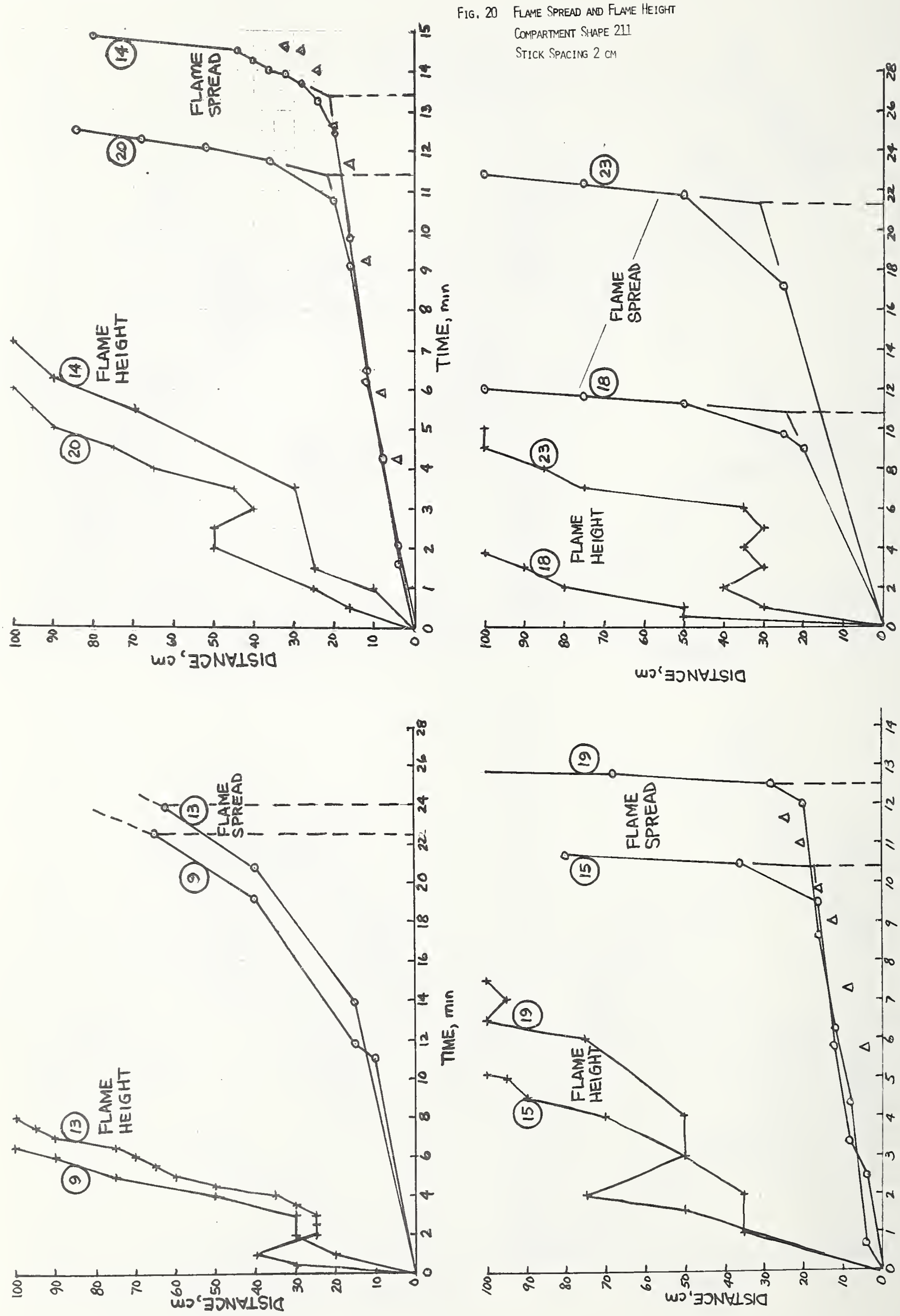
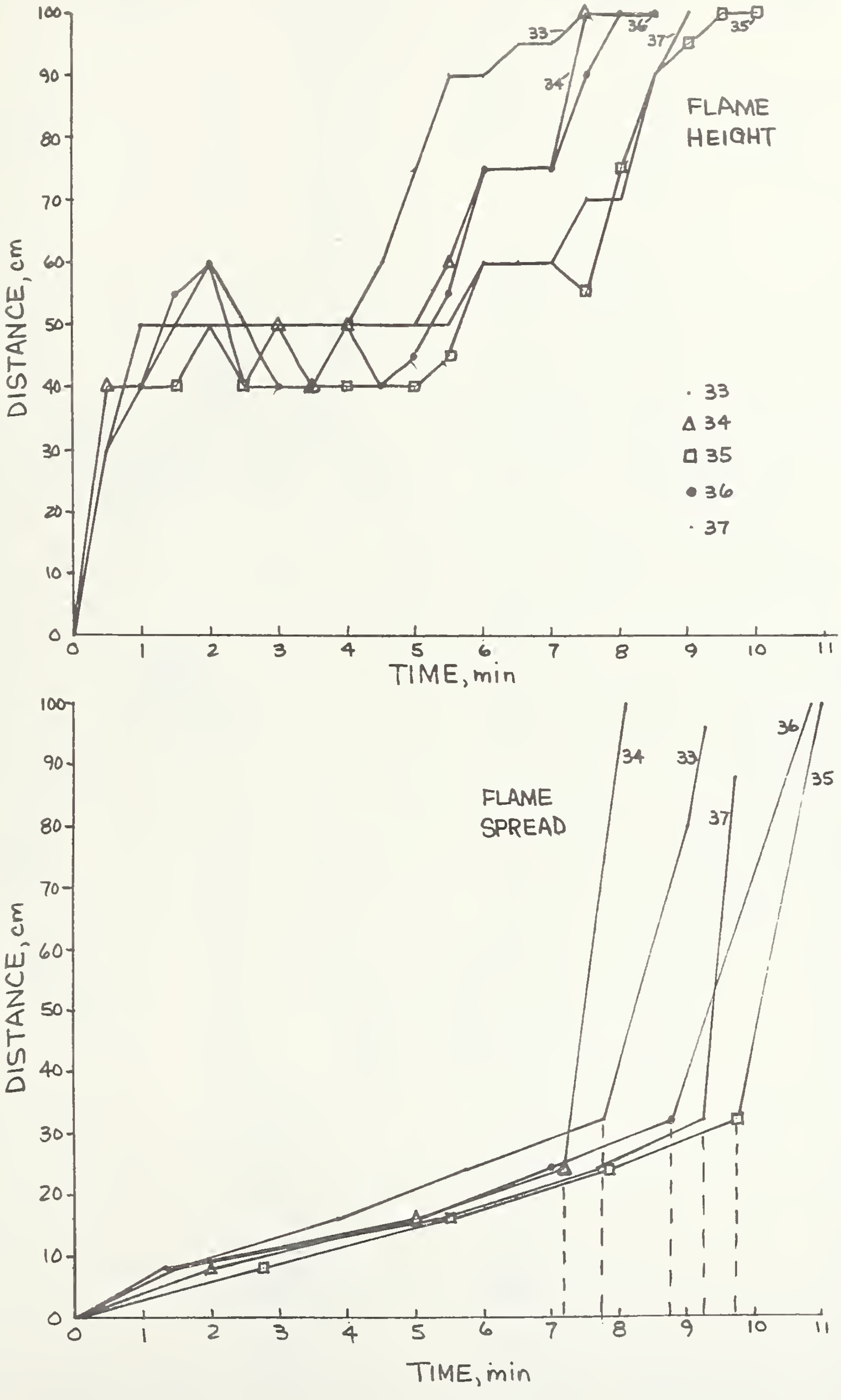


Fig. 21 Flame Spread and Flame Height
Five Additional Types of
Lining
Compartment Shape 121
Stick Spacing 6 cm



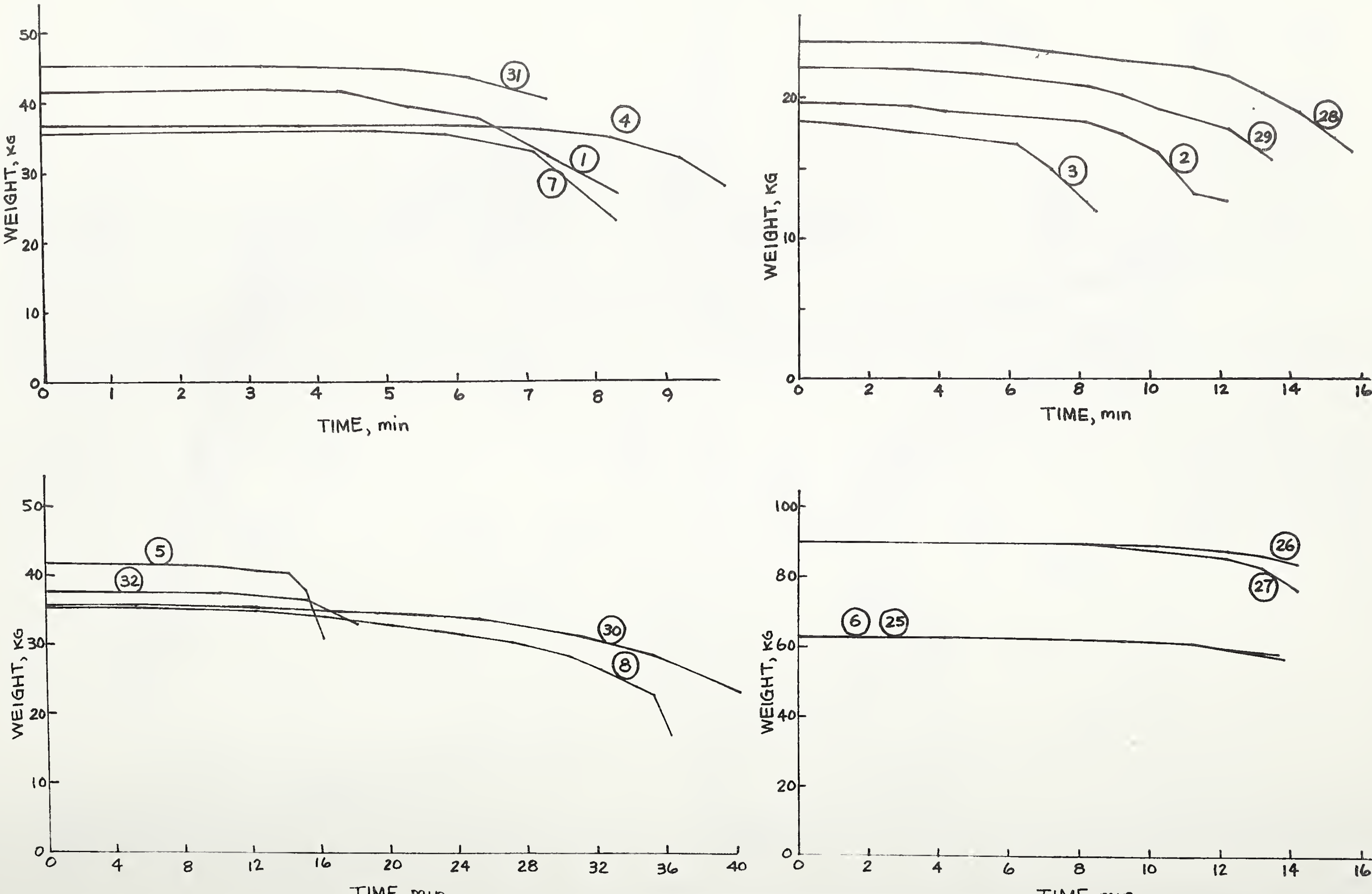


Fig. 22 Weight - Compartment 121

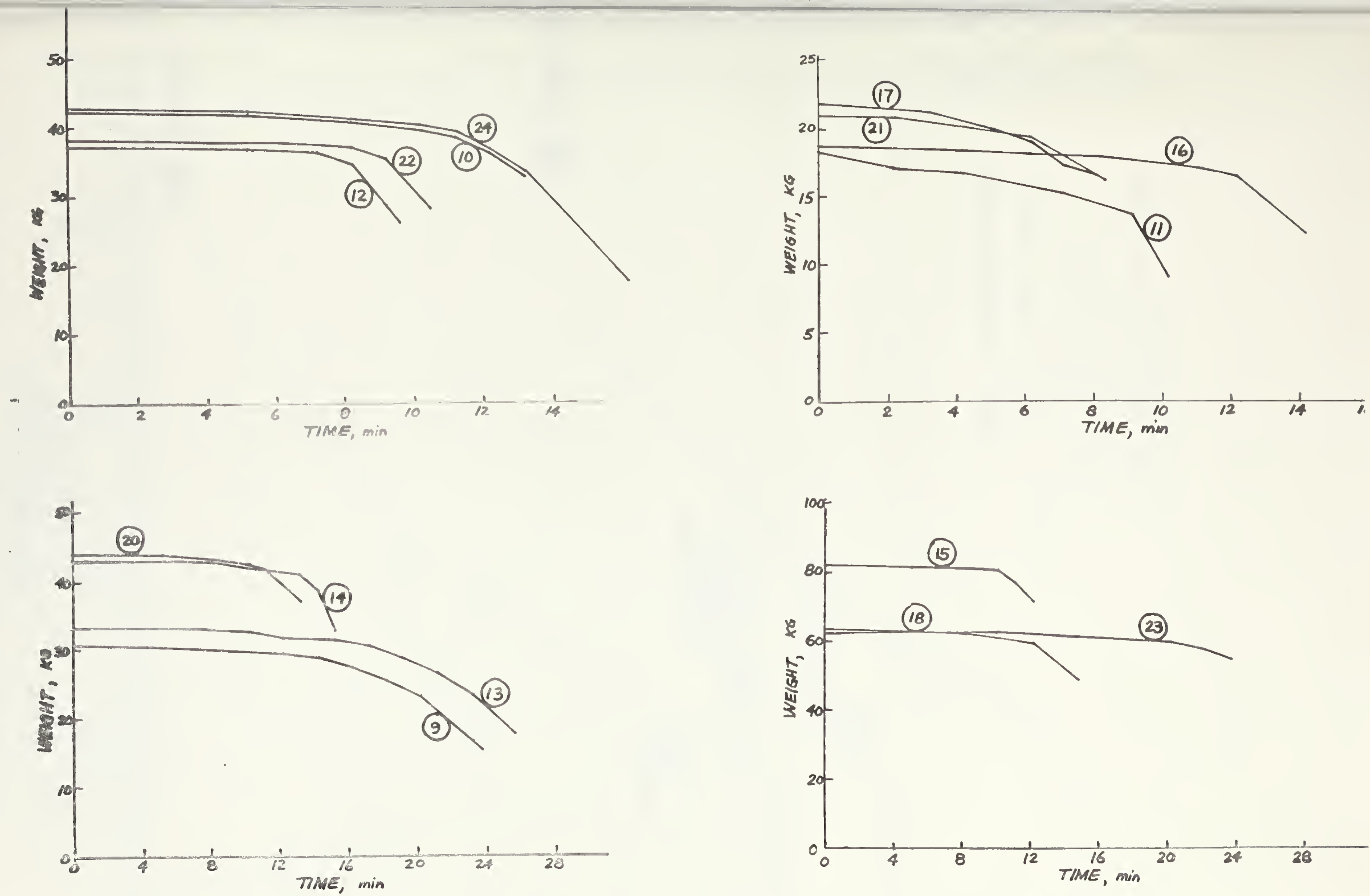


Fig. 23 Weight - Compartment 211

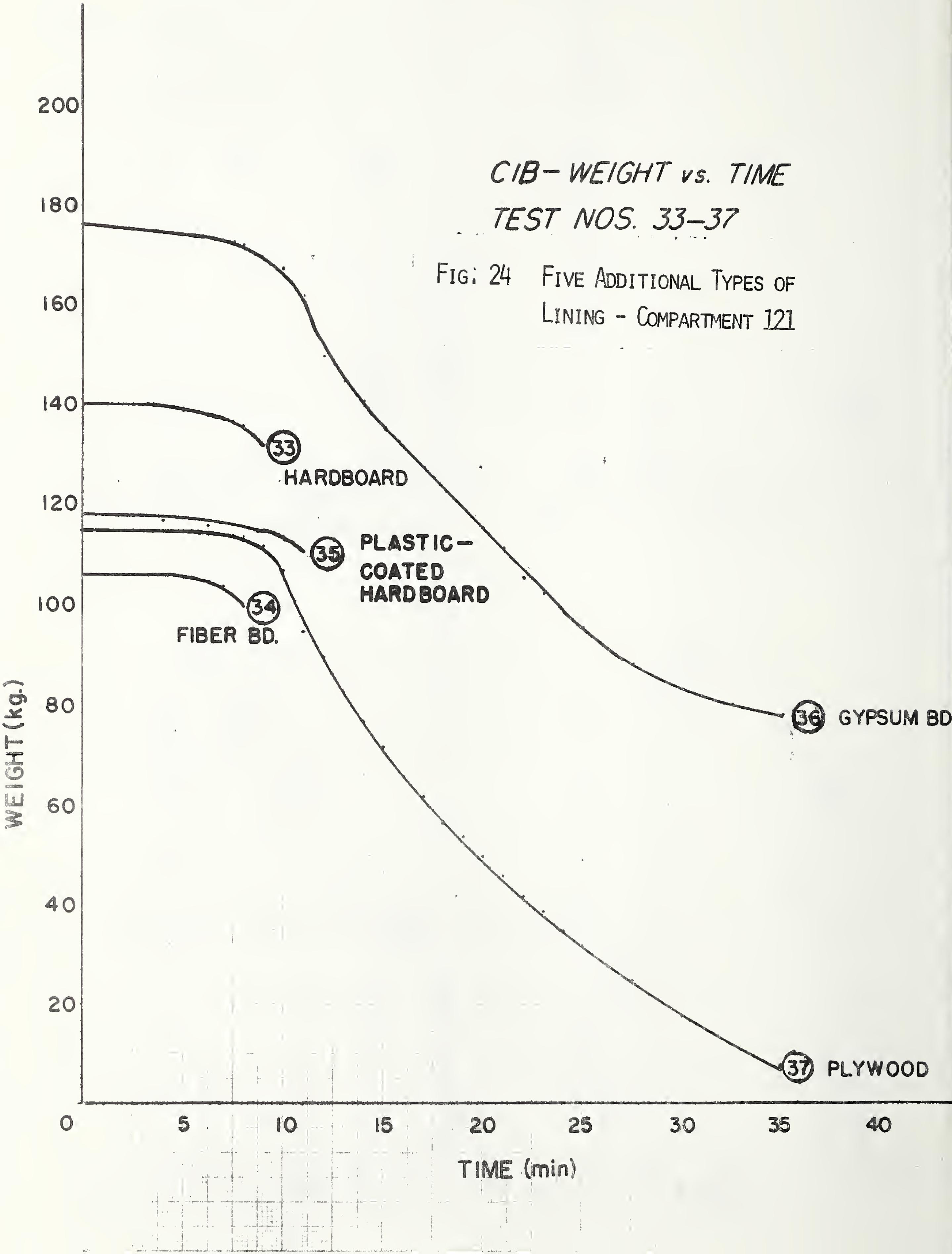

CIB-WEIGHT vs. TIME
TEST NOS. 33-37
FIG. 24 FIVE ADDITIONAL TYPES OF LINING - COMPARTMENT 121
WEIGHT (kg.)
TIME (min)
200
180
160
140
120
100
80
60
40
20
0
5
10
15
20
25
30
35
40
33
HARDBOARD
35
PLASTIC-COATED HARDBOARD
34
FIBER BD.
36
GYPSUM BD.
37
PLYWOOD

FIG. 25 TEST NO. 1

TEMPERATURE

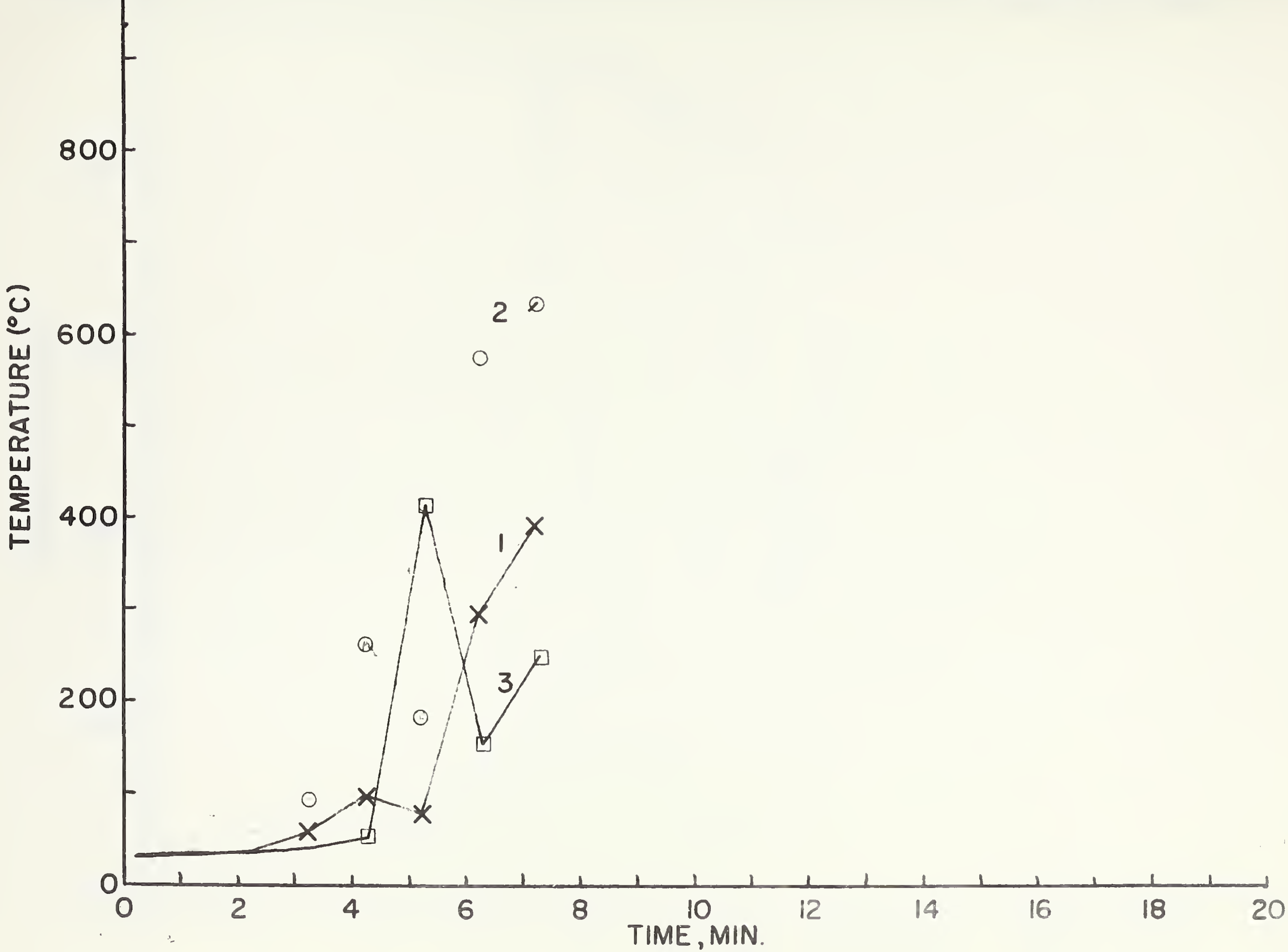


FIG. 26 TEST NO. 2
TEMPERATURE

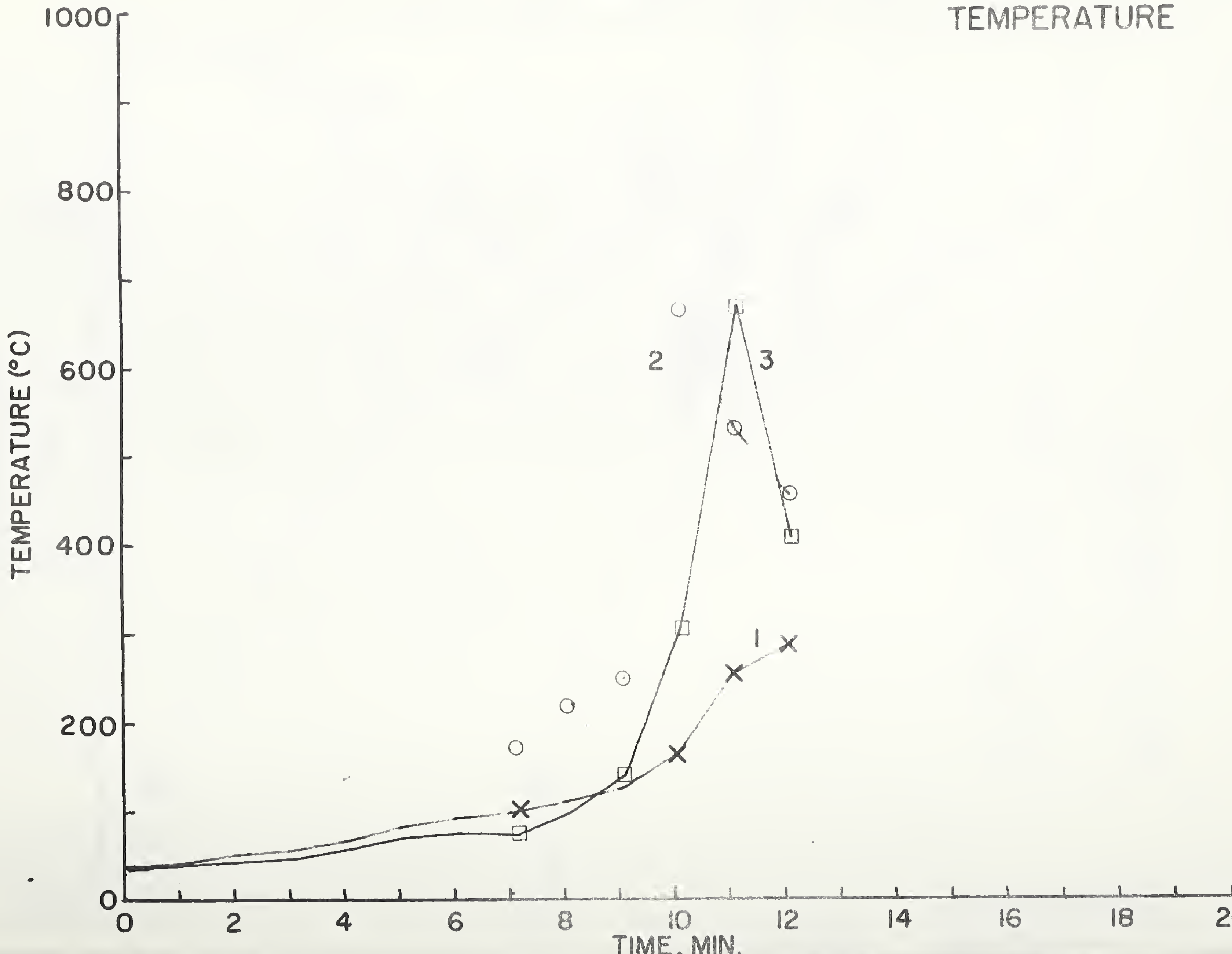


FIG. 27 TEST NO. 3

TEMPERATURE

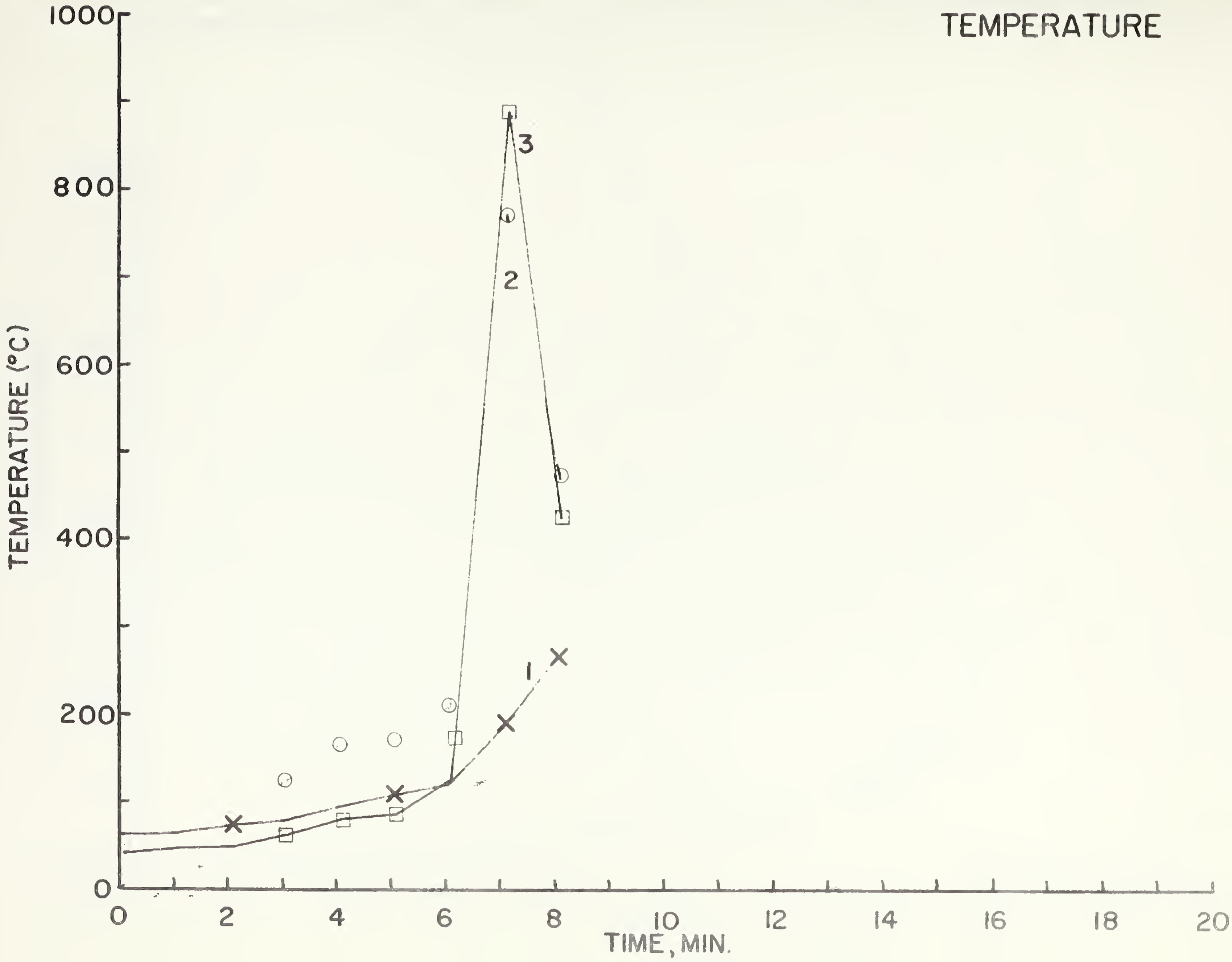


FIG. 28 TEST NO. 4
TEMPERATURE

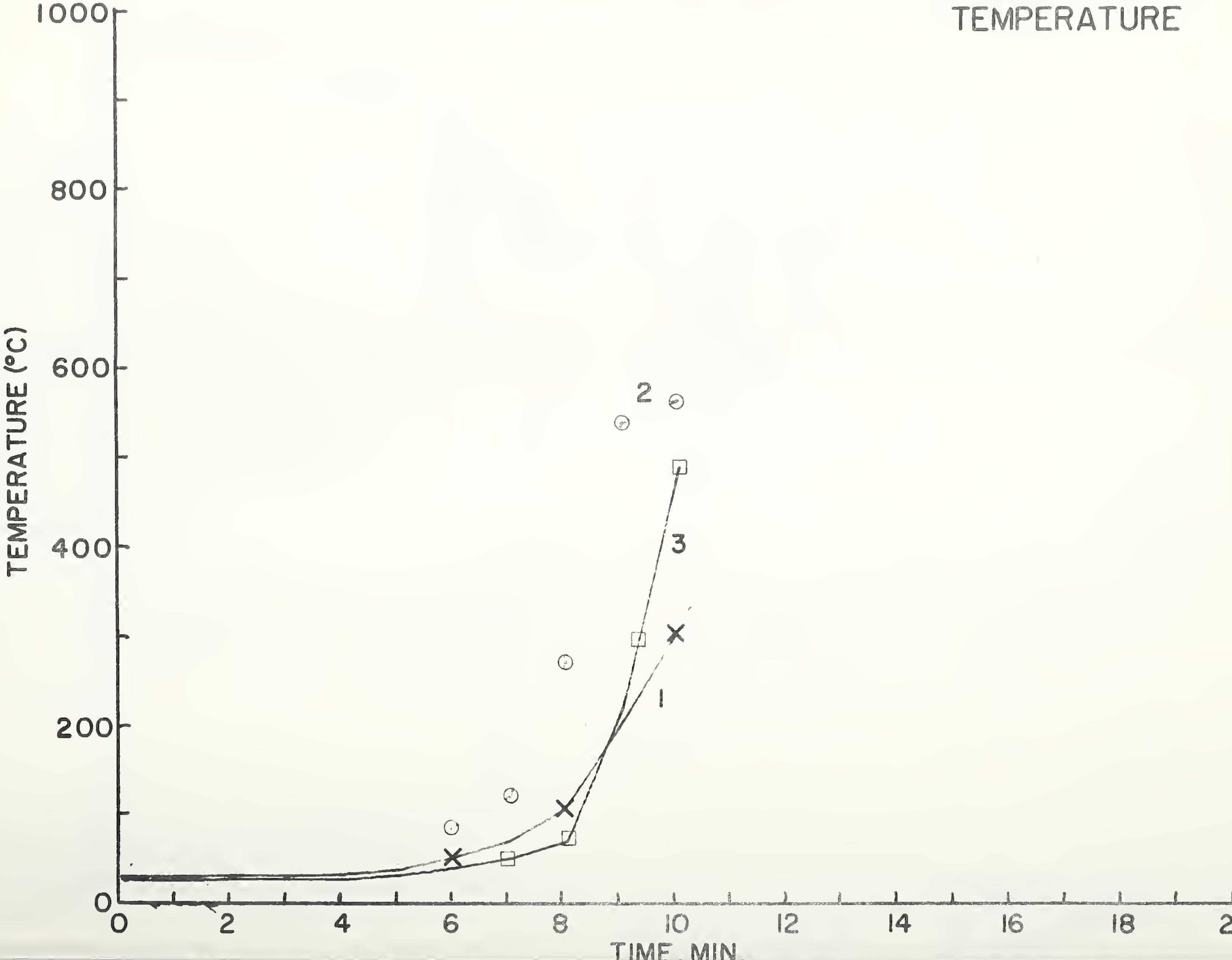


FIG. 29 TEST NO. 5

TEMPERATURE

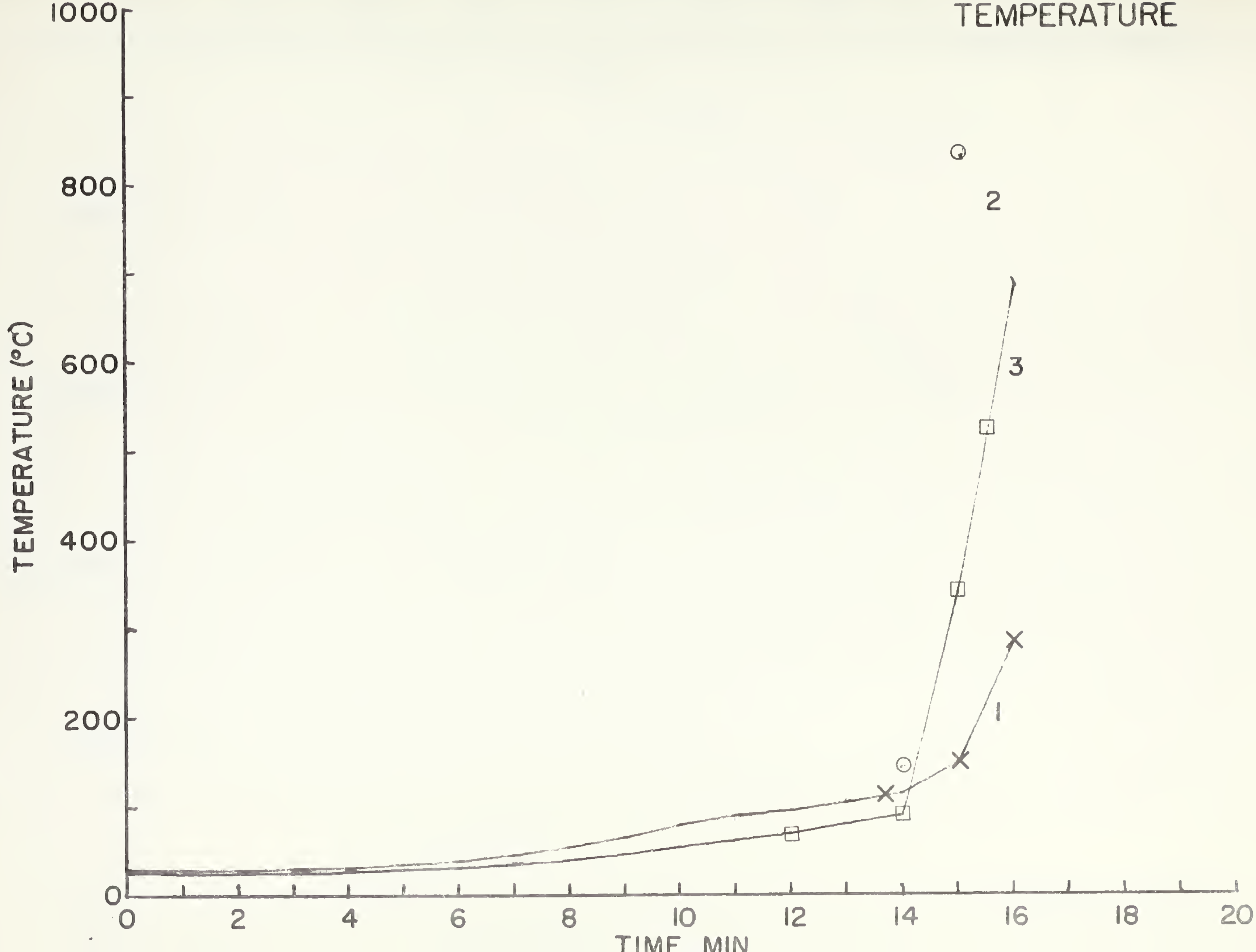


FIG. 30 TEST NO. 6

TEMPERATURE

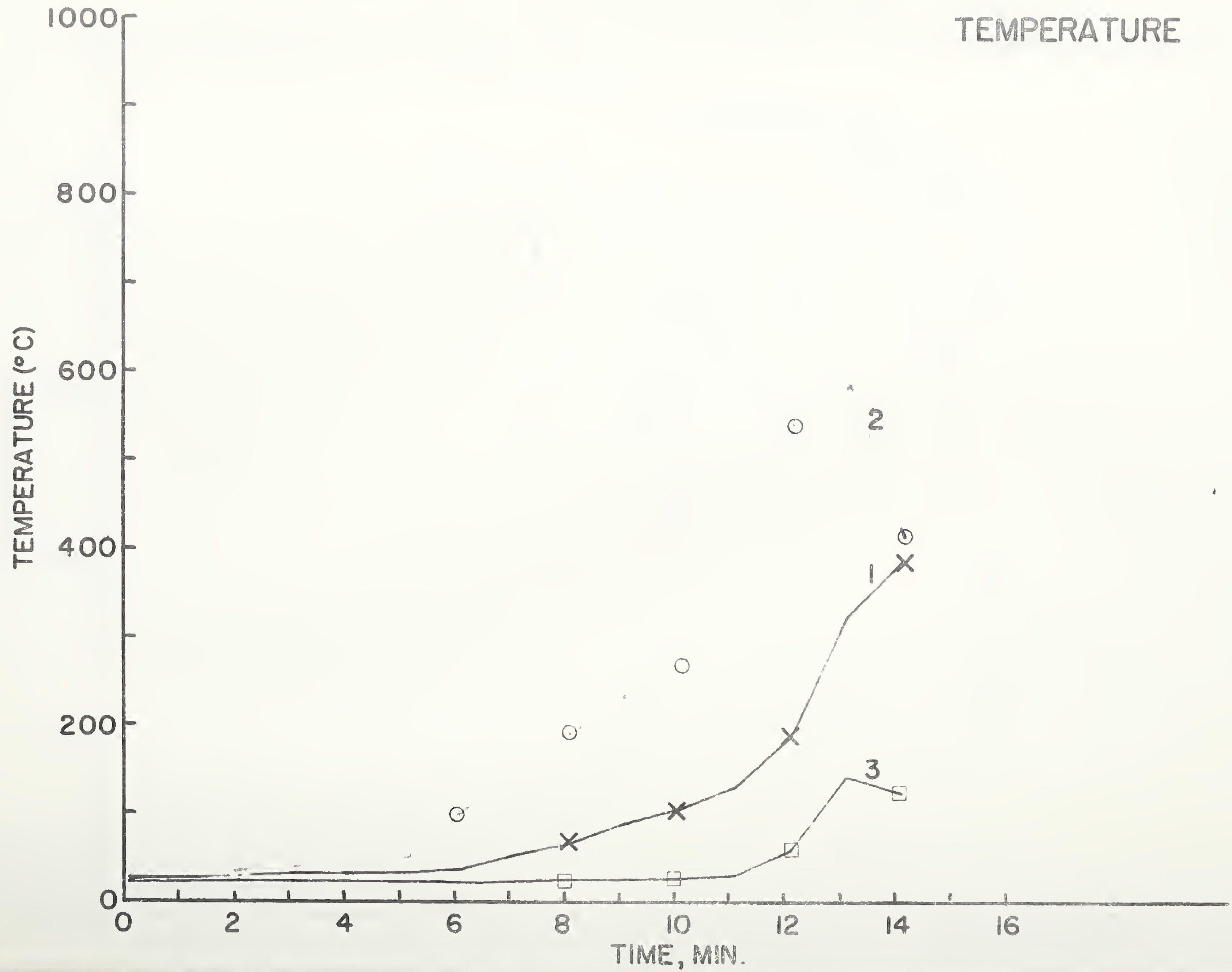


FIG. 31 TEST NO. 7

TEMPERATURE

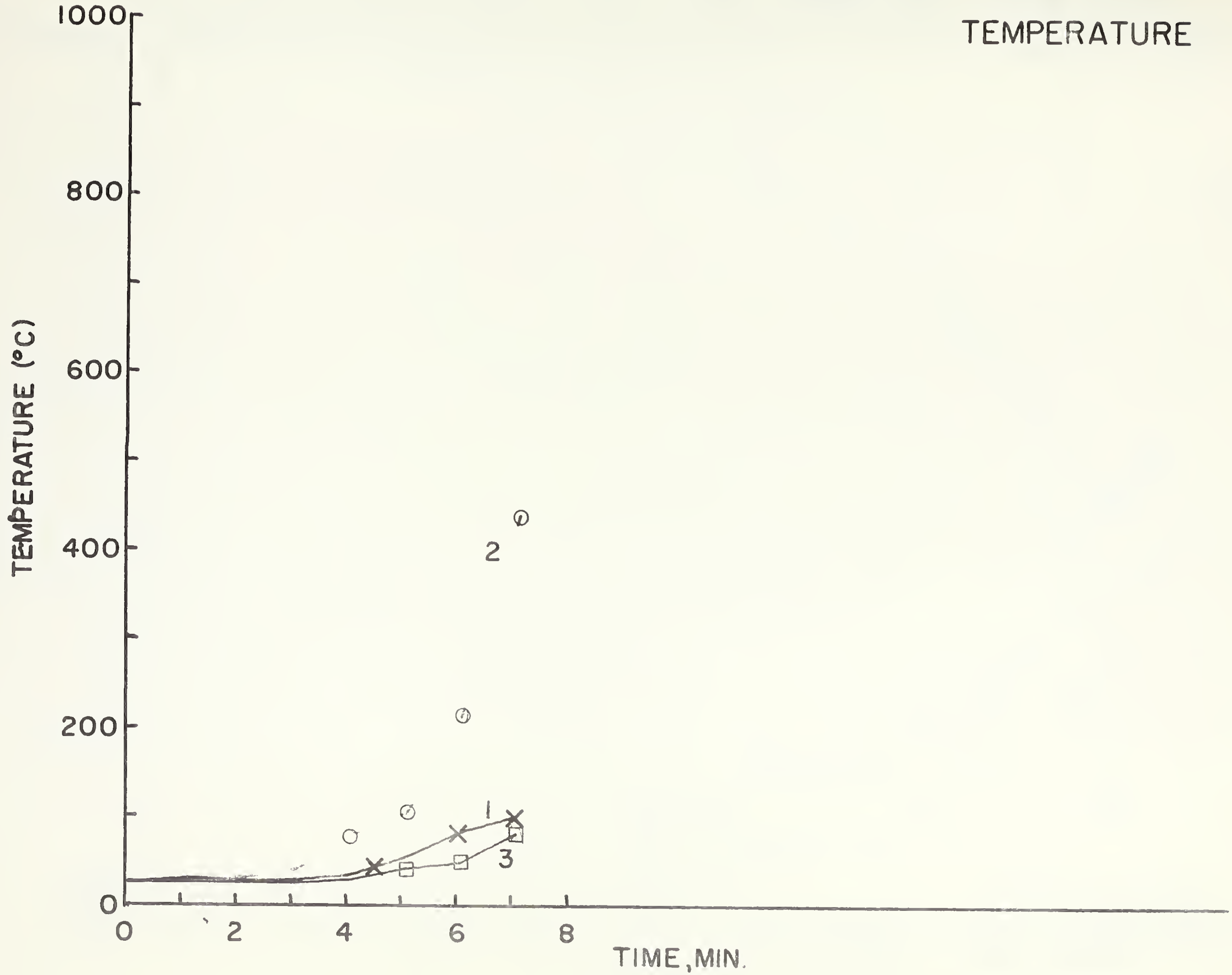


FIG. 32 TEST NO. 8 TEMPERATURE

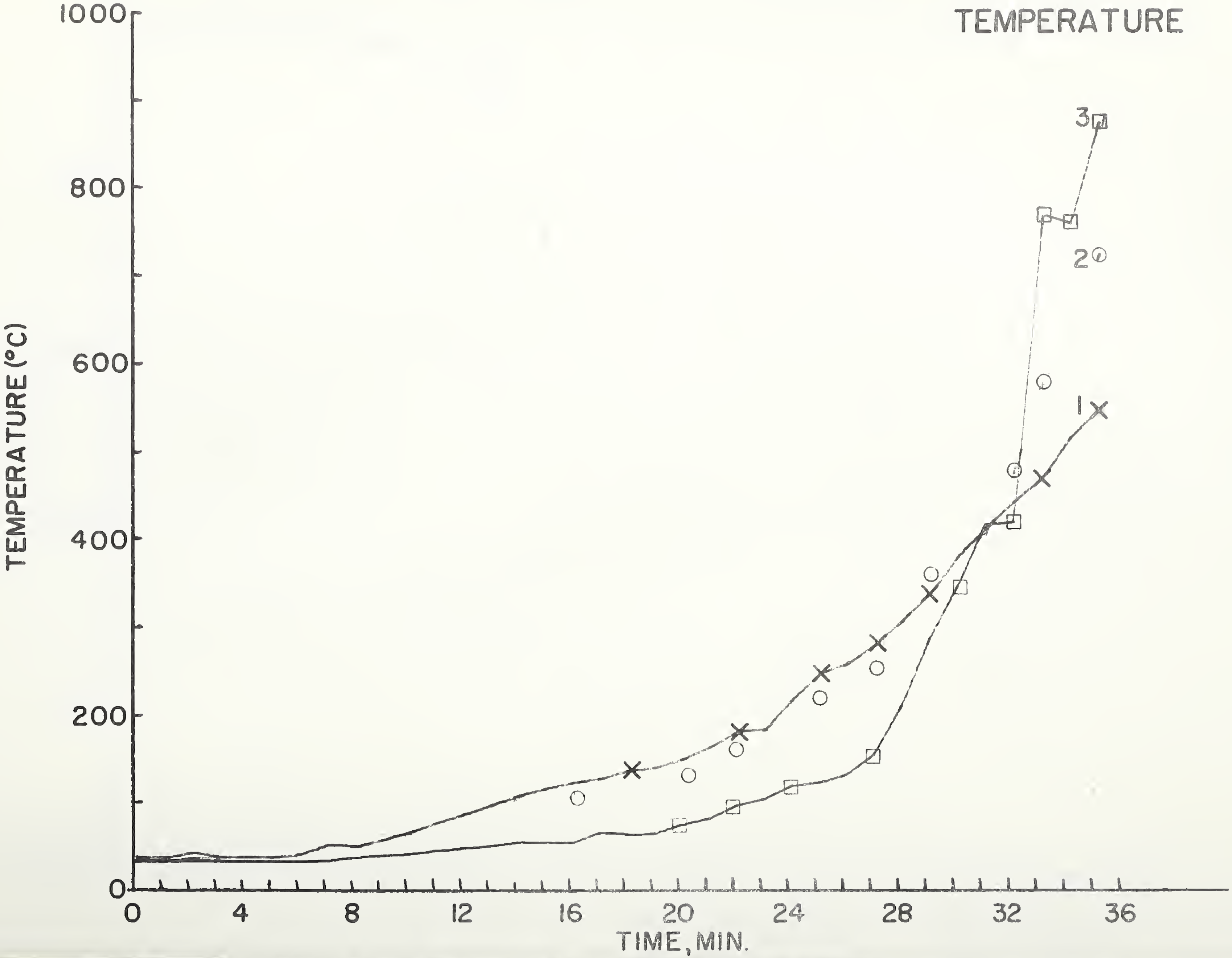


FIG. 33 TEST NO. 9
TEMPERATURE

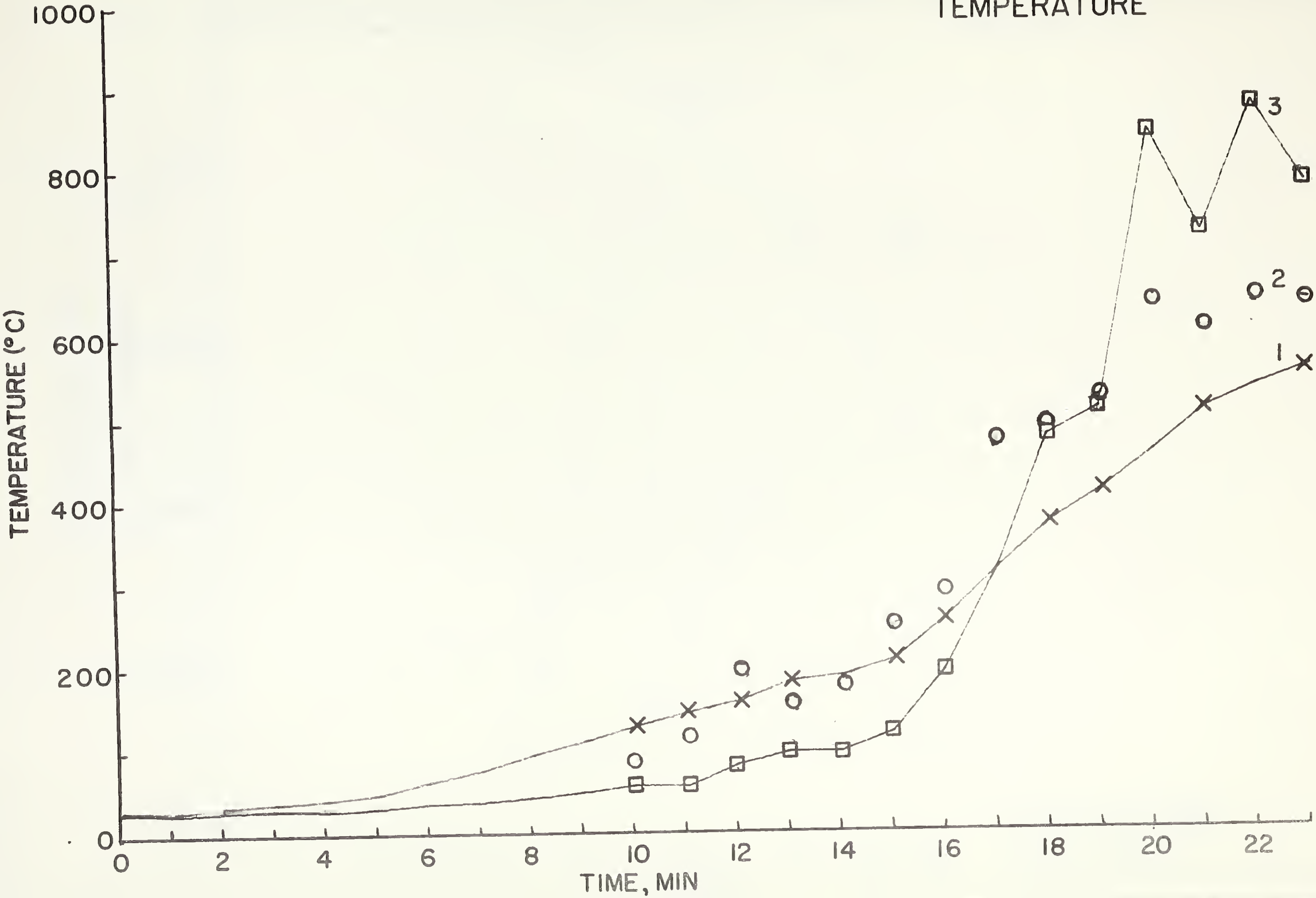


FIG. 34 TEST NO. 10
TEMPERATURE

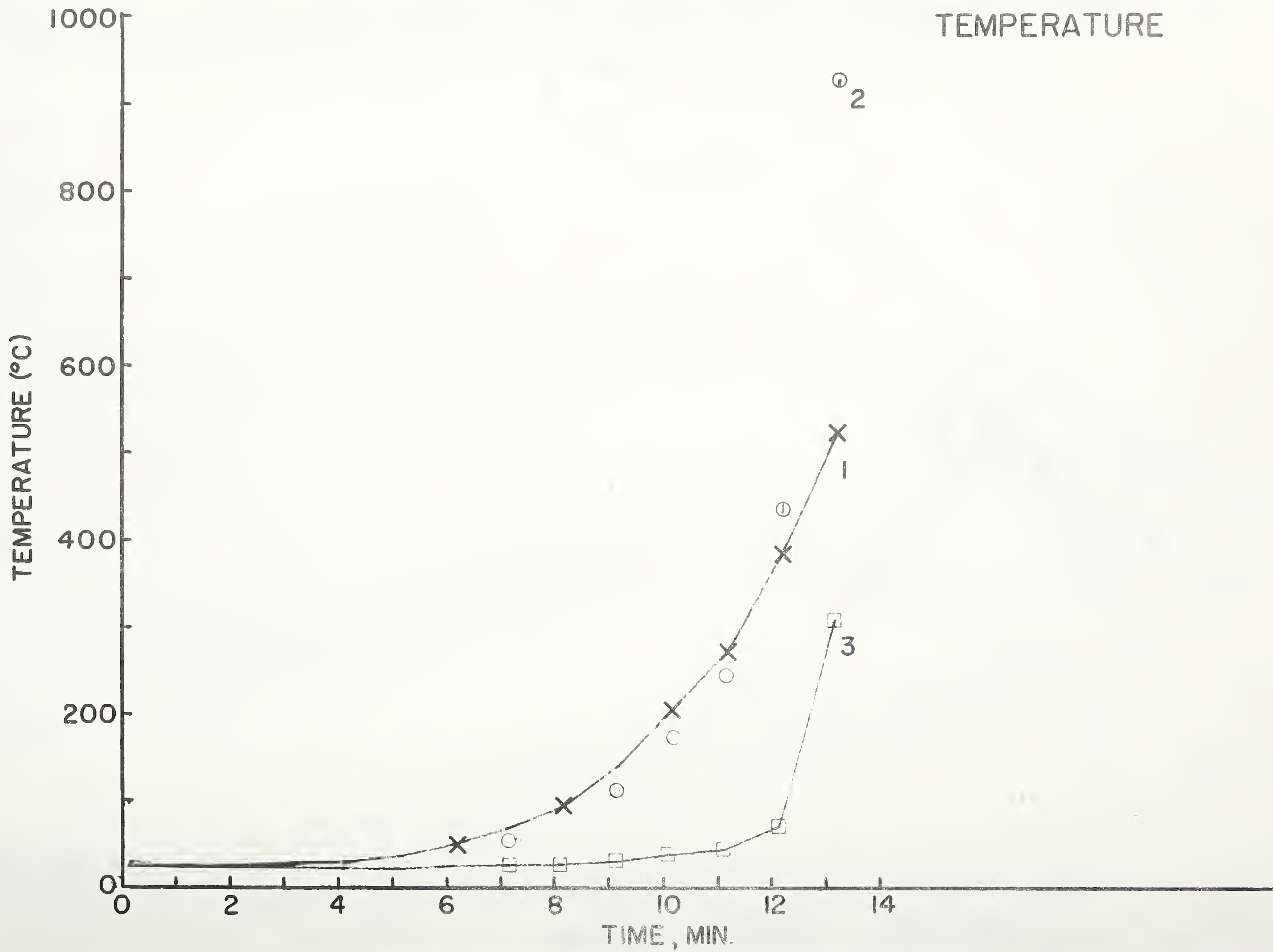


FIG. 35 TEST NO. 11
TEMPERATURE

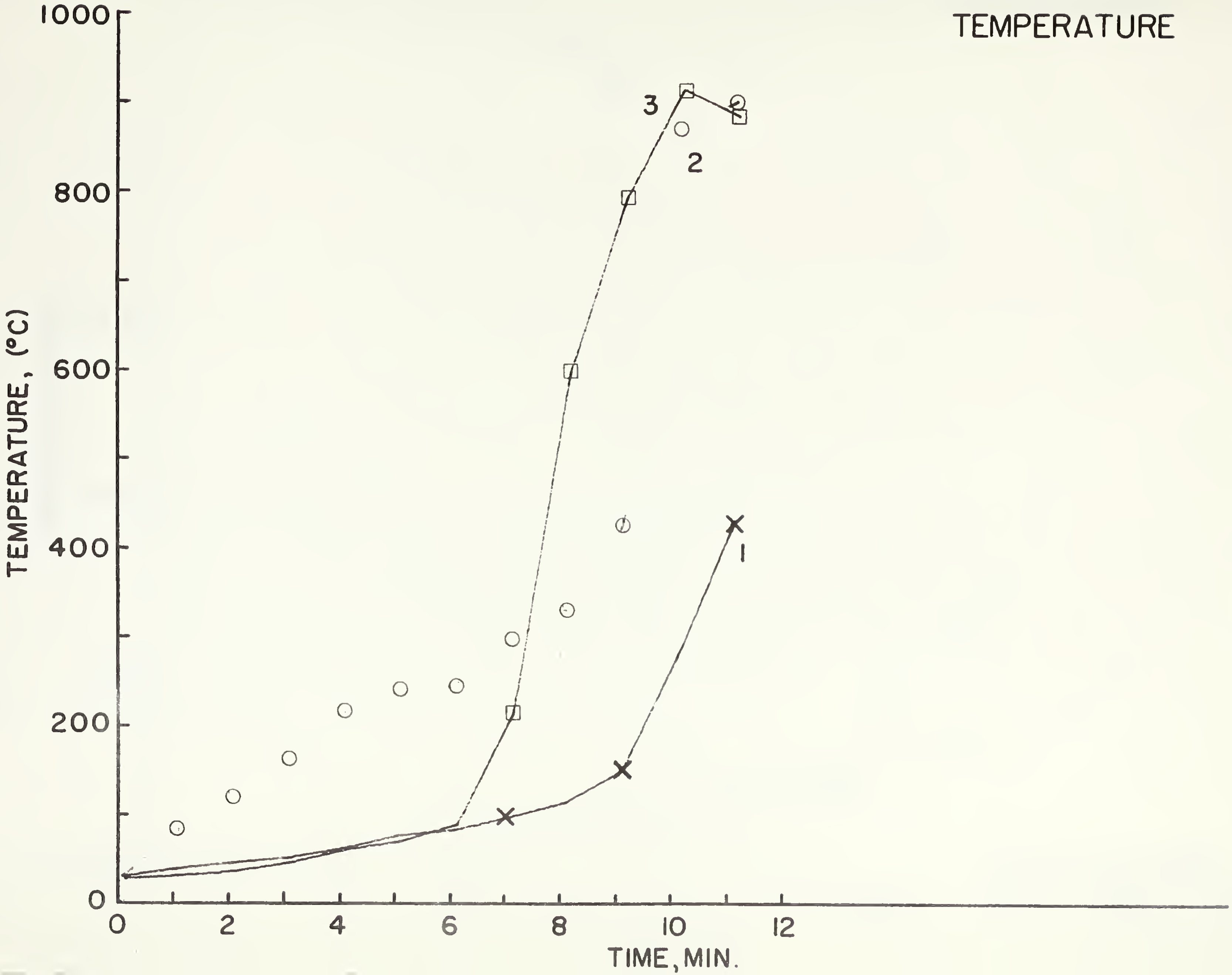


FIG. 36 TEST NO. 12
TEMPERATURE

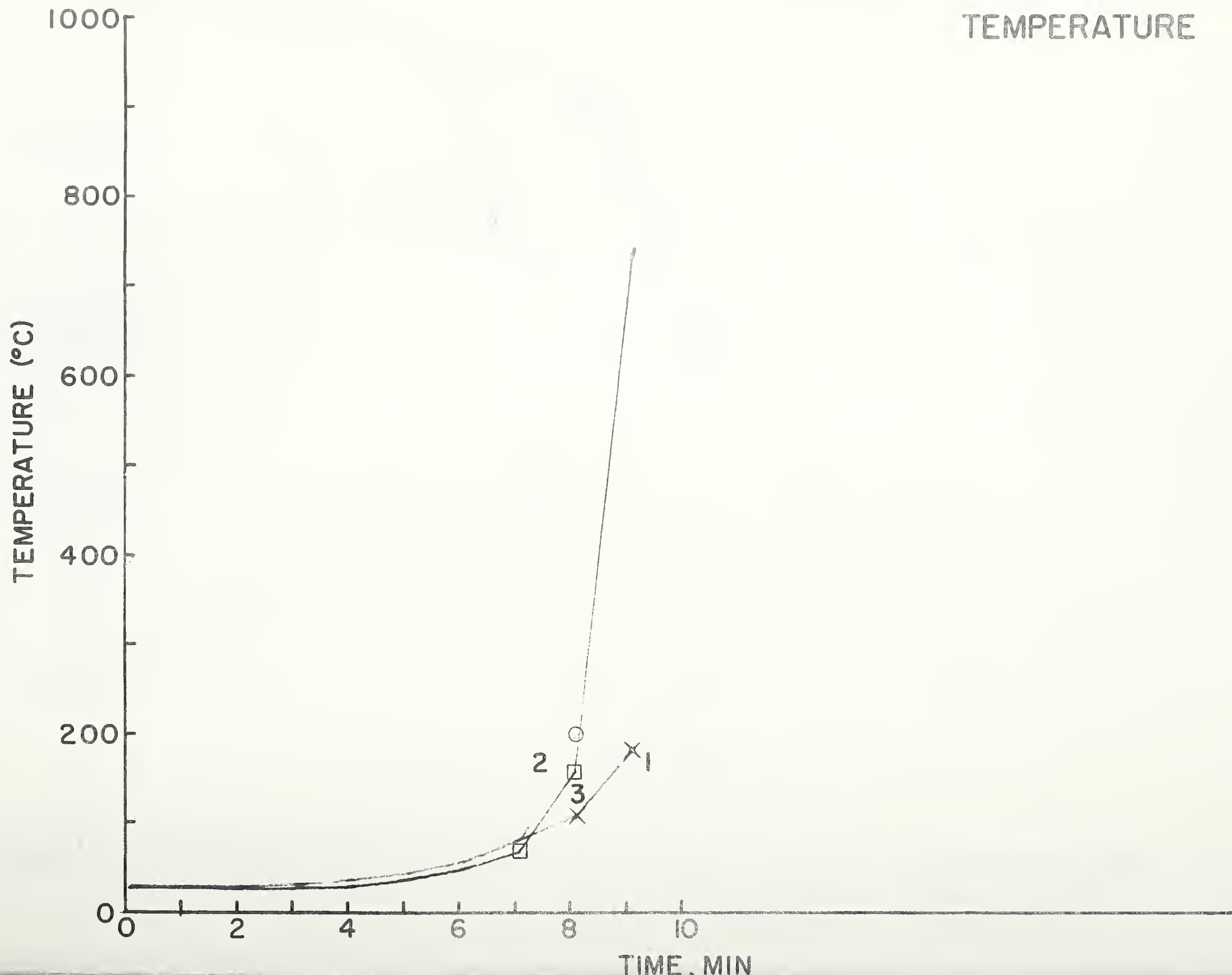


FIG. 37 TEST NO. 13
TEMPERATURE

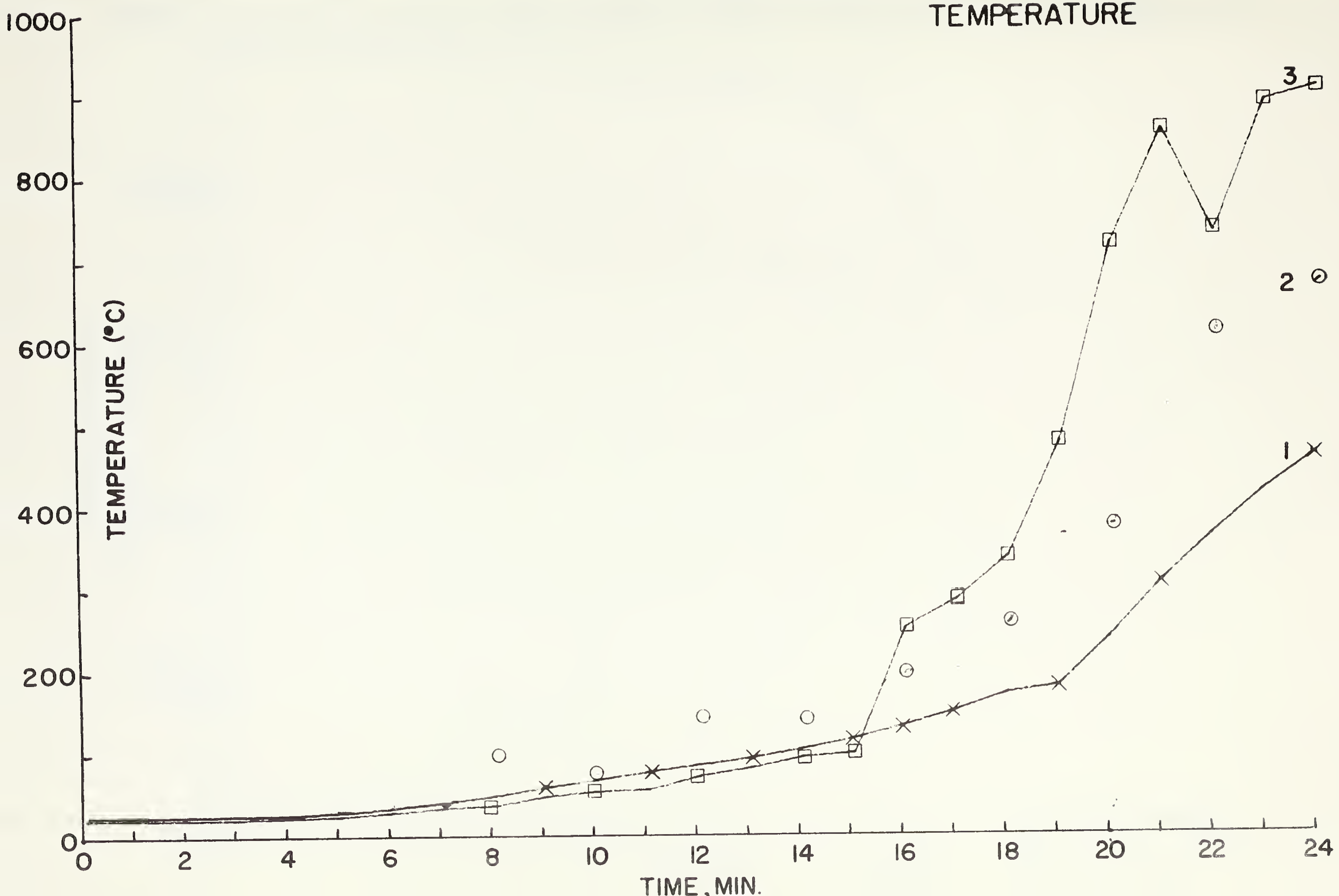


FIG. 38 TEST NO. 14
TEMPERATURE

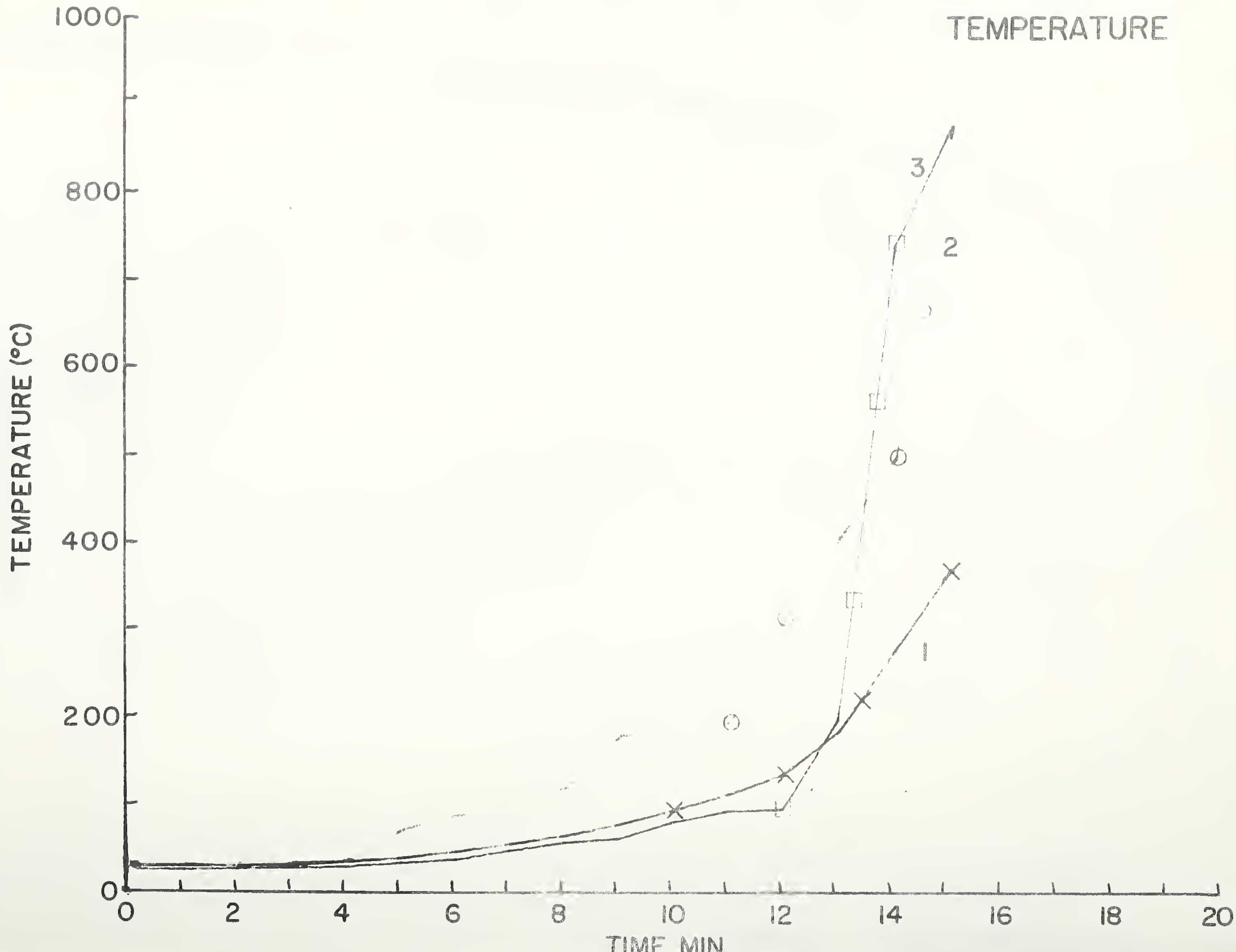


FIG. 39 TEST NO. 15

FIG. 39 TEST NO. 15

TEMPERATURE

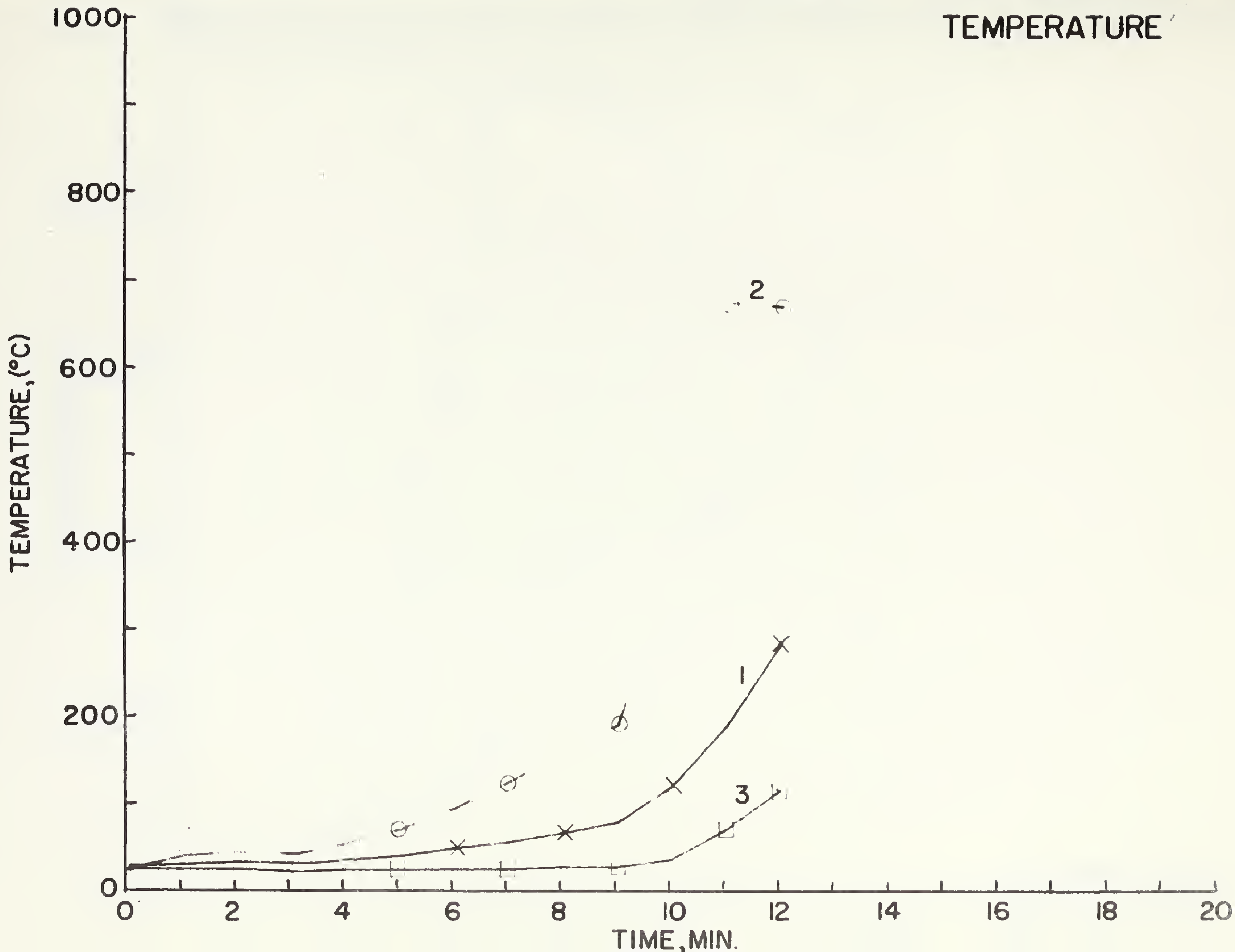


FIG. 40 TEST NO. 16
TEMPERATURE

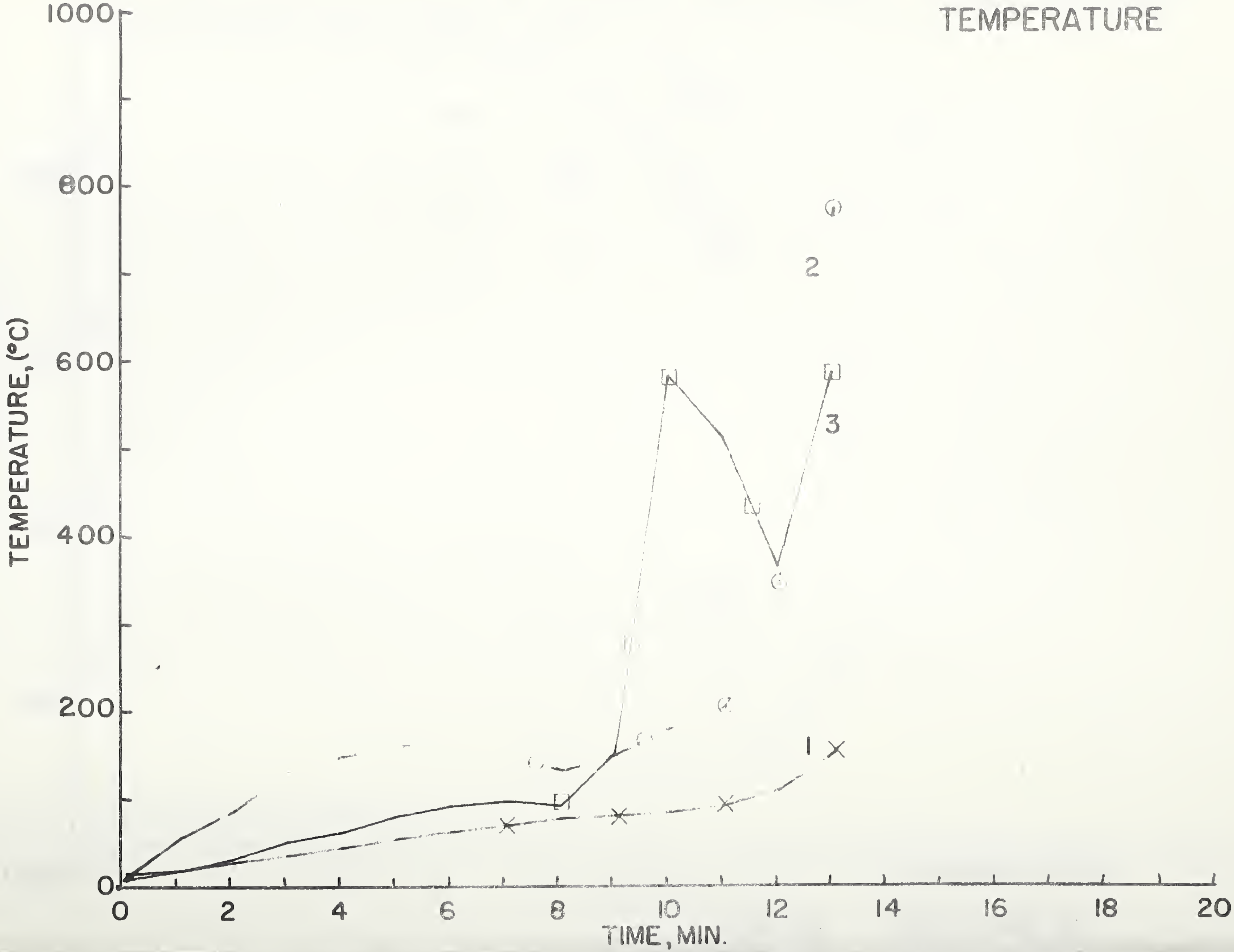


FIG. 41 TEST NO. 17

TEMPERATURE

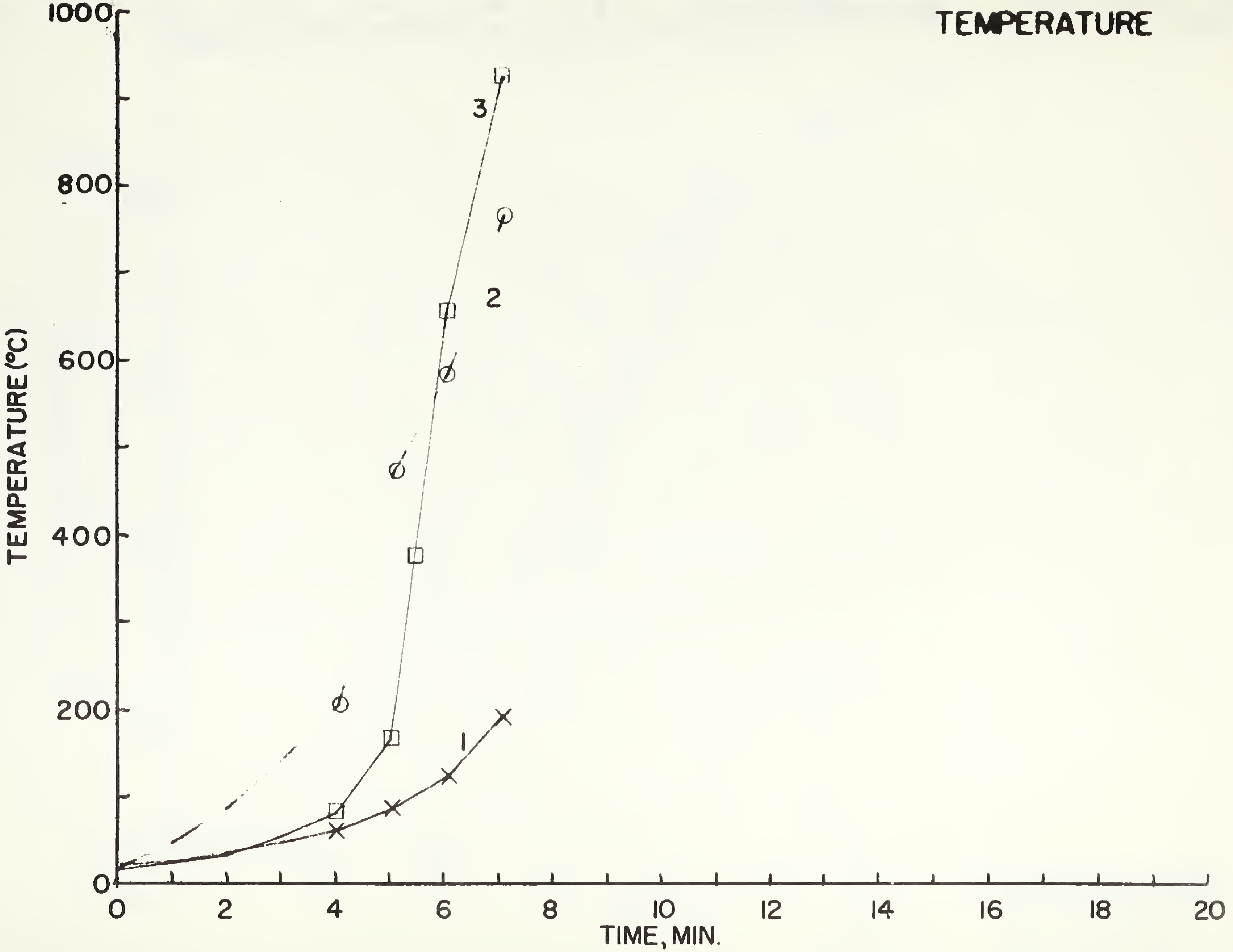


FIG. 42 TEST NO. 18
TEMPERATURE

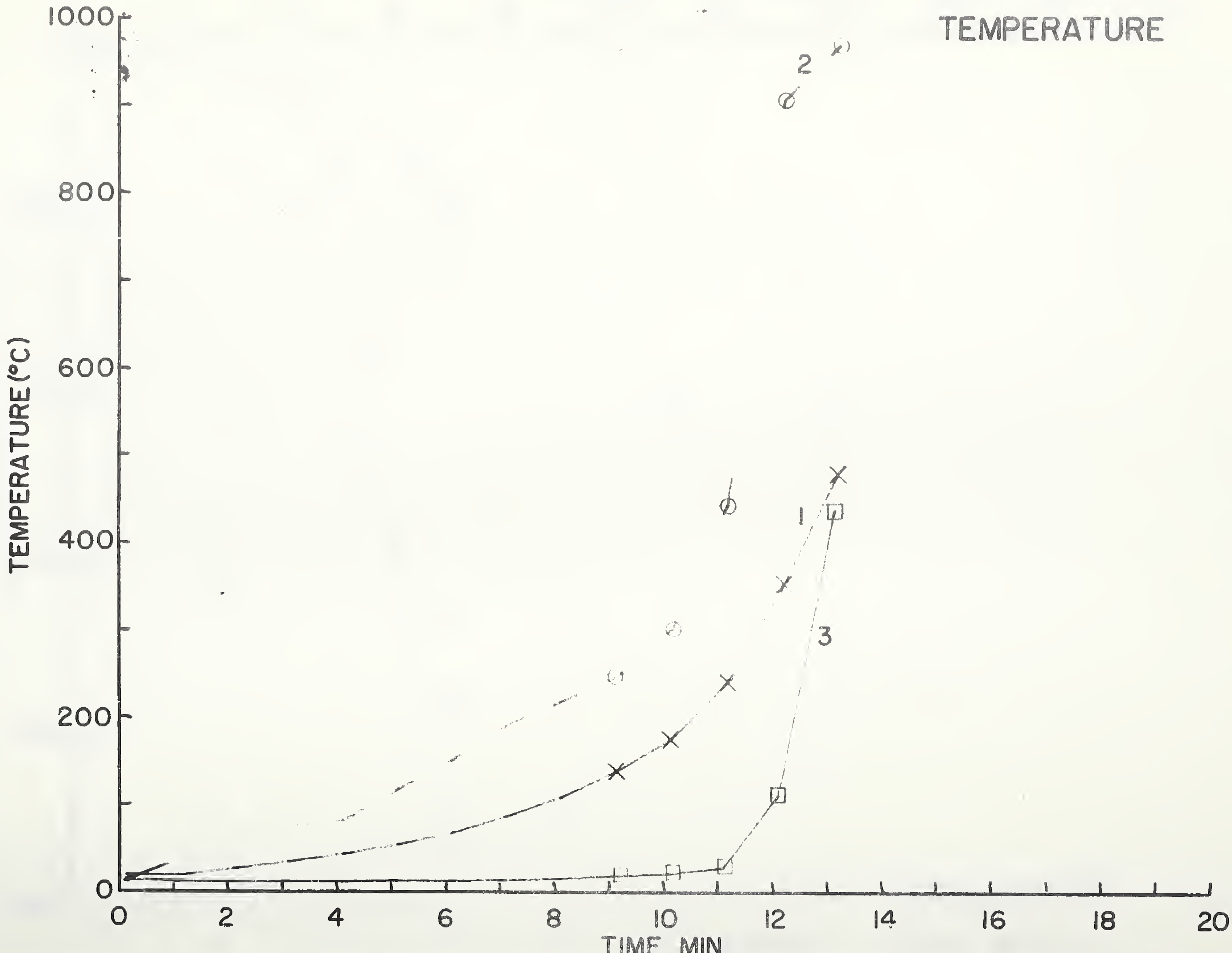


FIG. 43 TEST NO. 19

TEMPERATURE

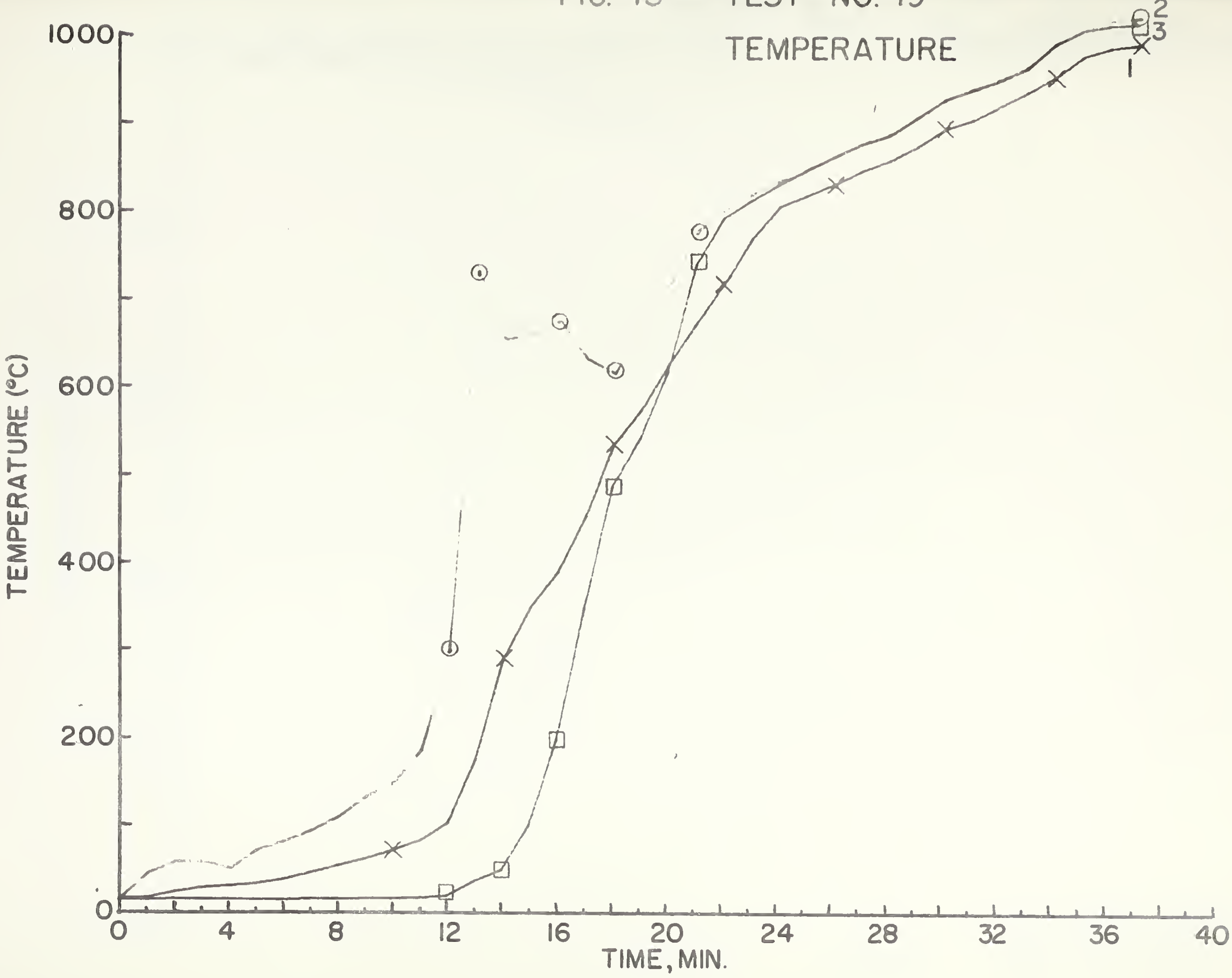


FIG. 44 TEST NO. 20

TEMPERATURE

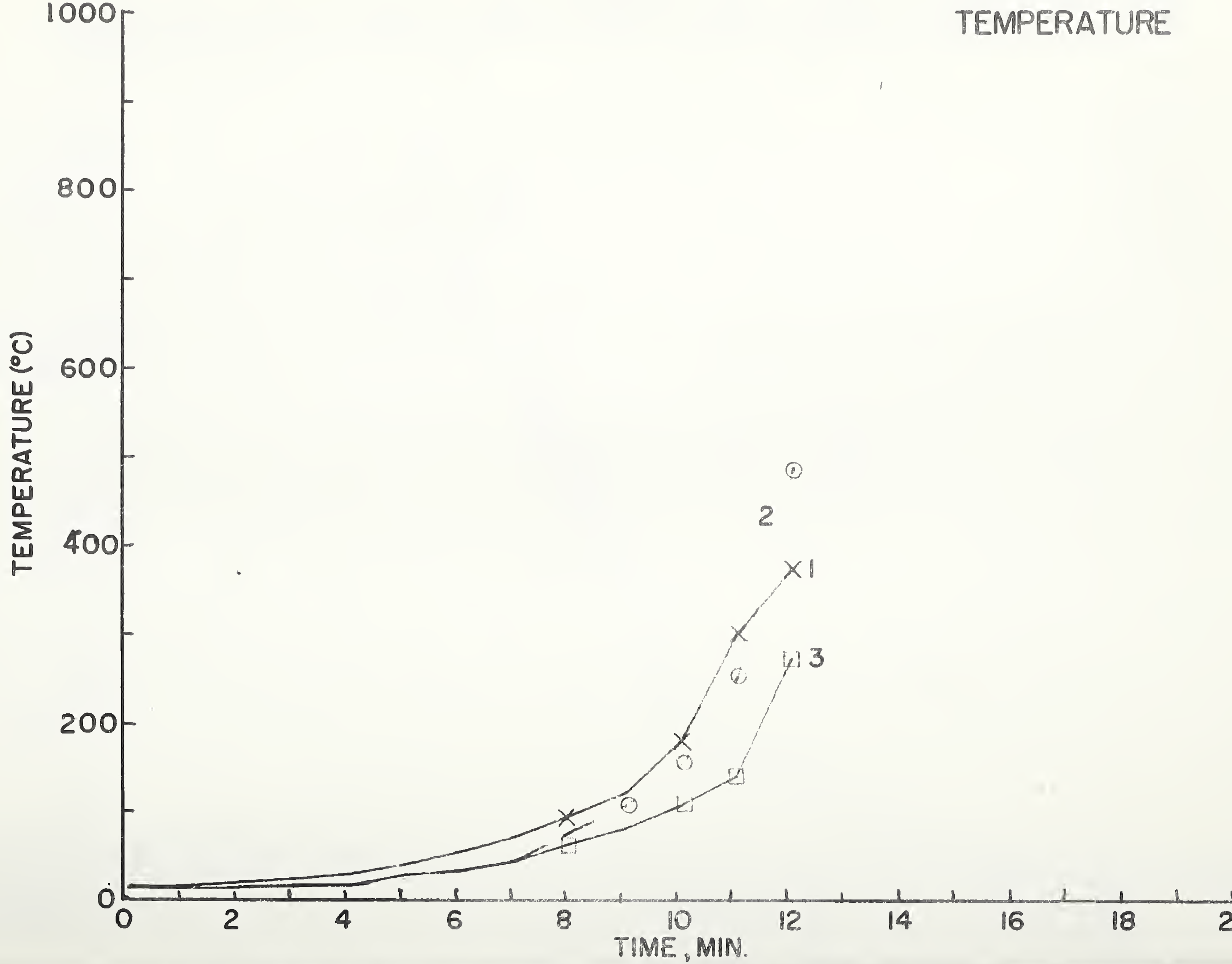


FIG. 45 TEST NO. 21

TEMPERATURE

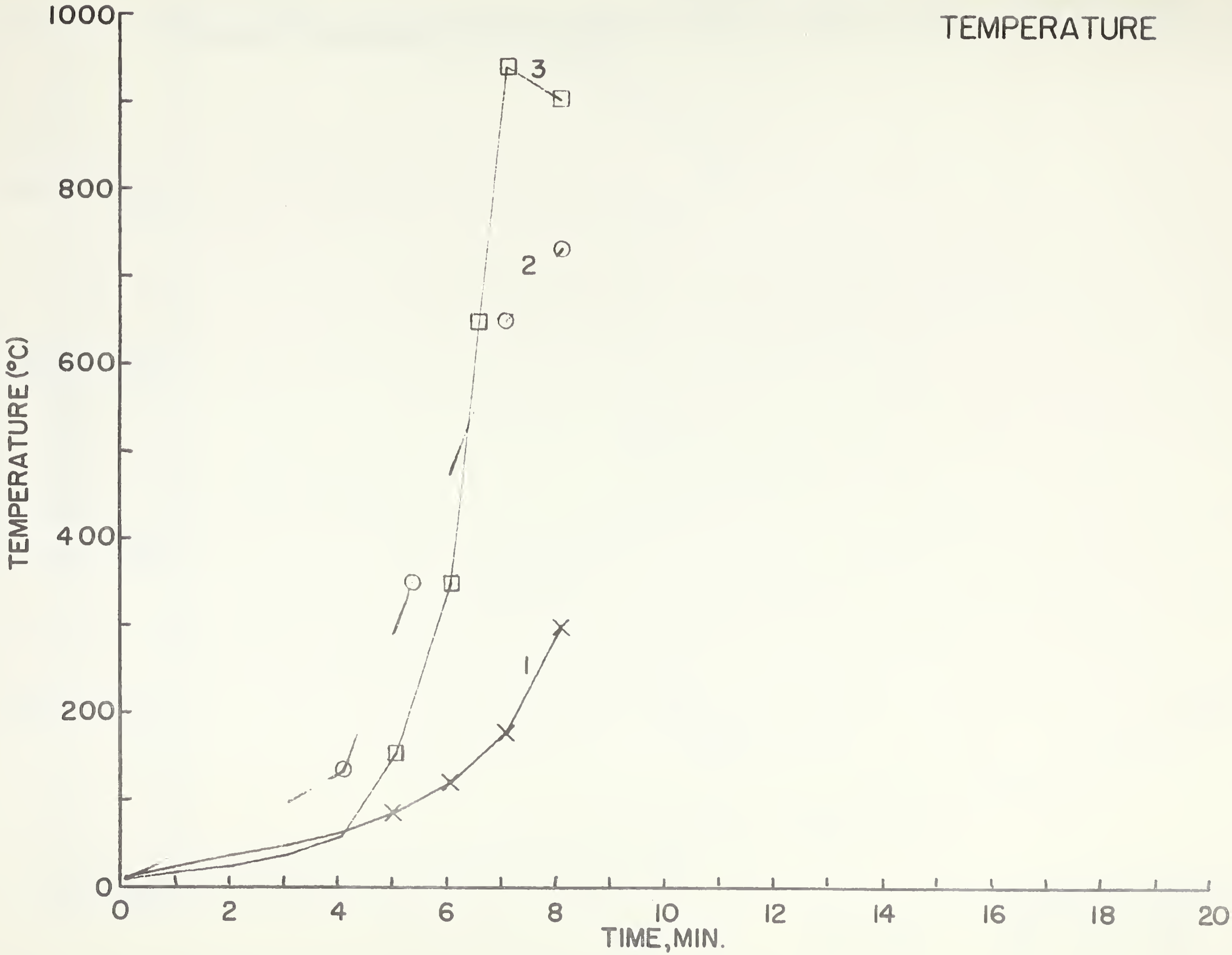


FIG. 46 TEST NO. 22
TEMPERATURE

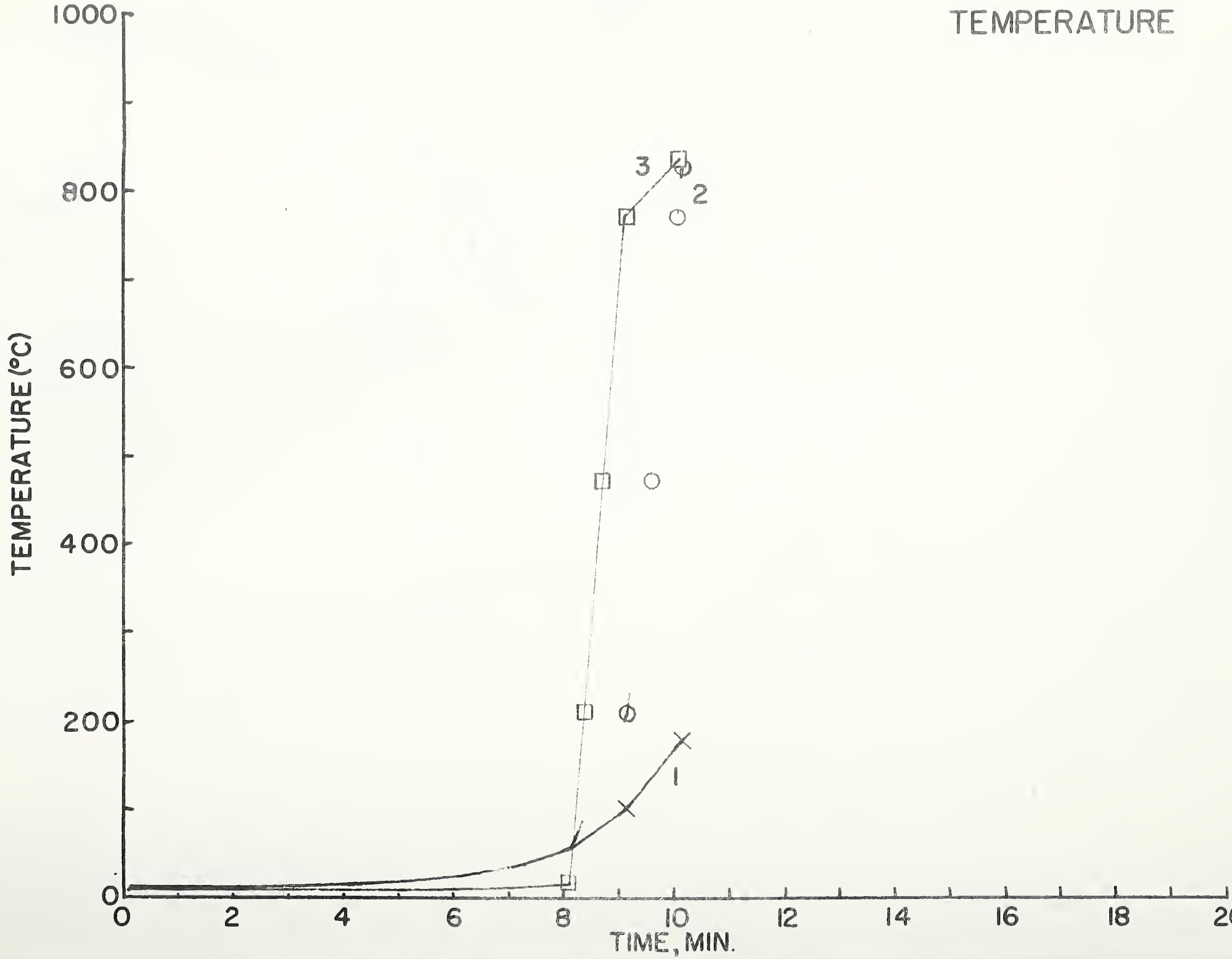


FIG. 47 TEST NO. 23

TEMPERATURE

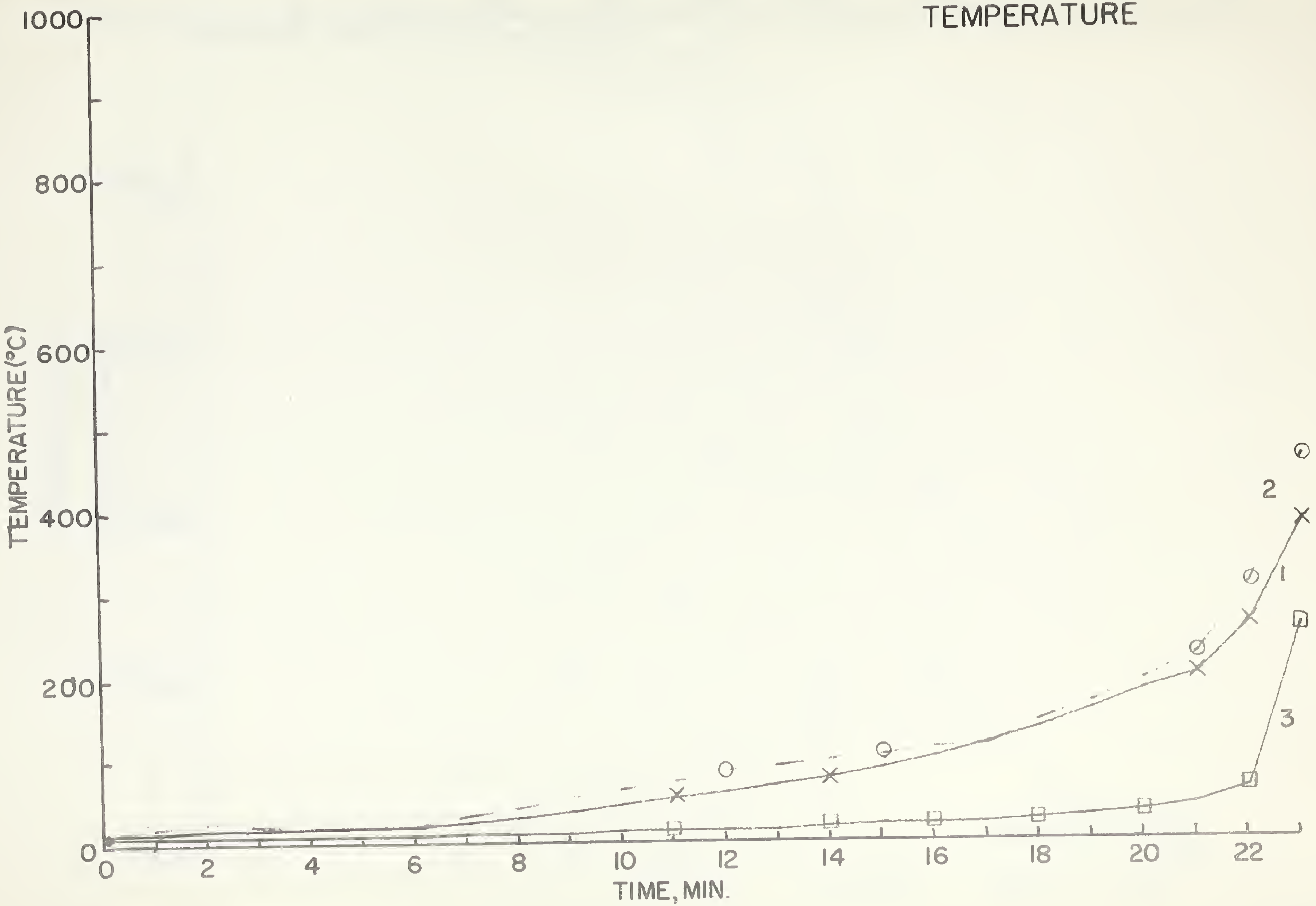


FIG. 48 TEST NO. 24

TEMPERATURE

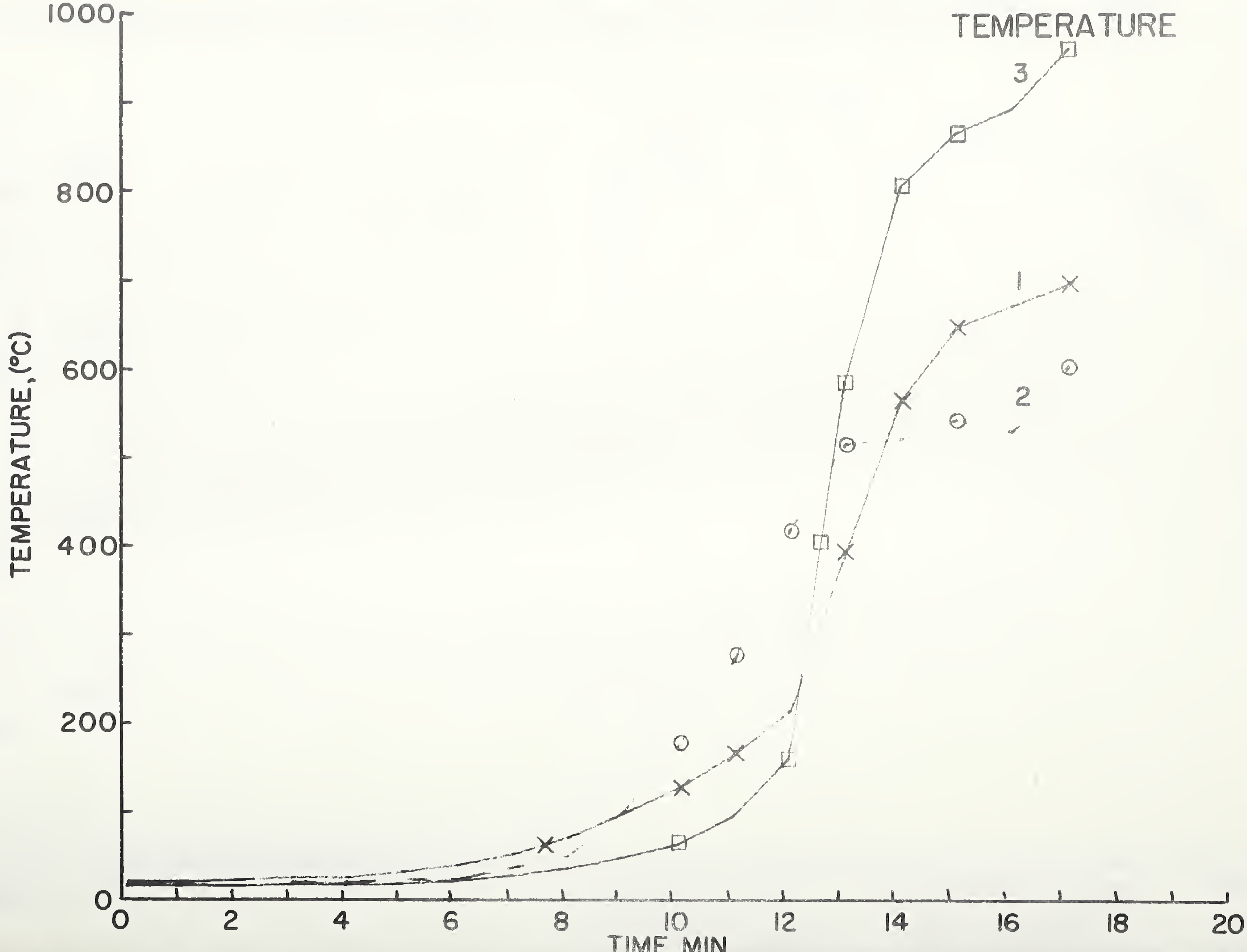


FIG. 49 TEST NO. 25

TEMPERATURE

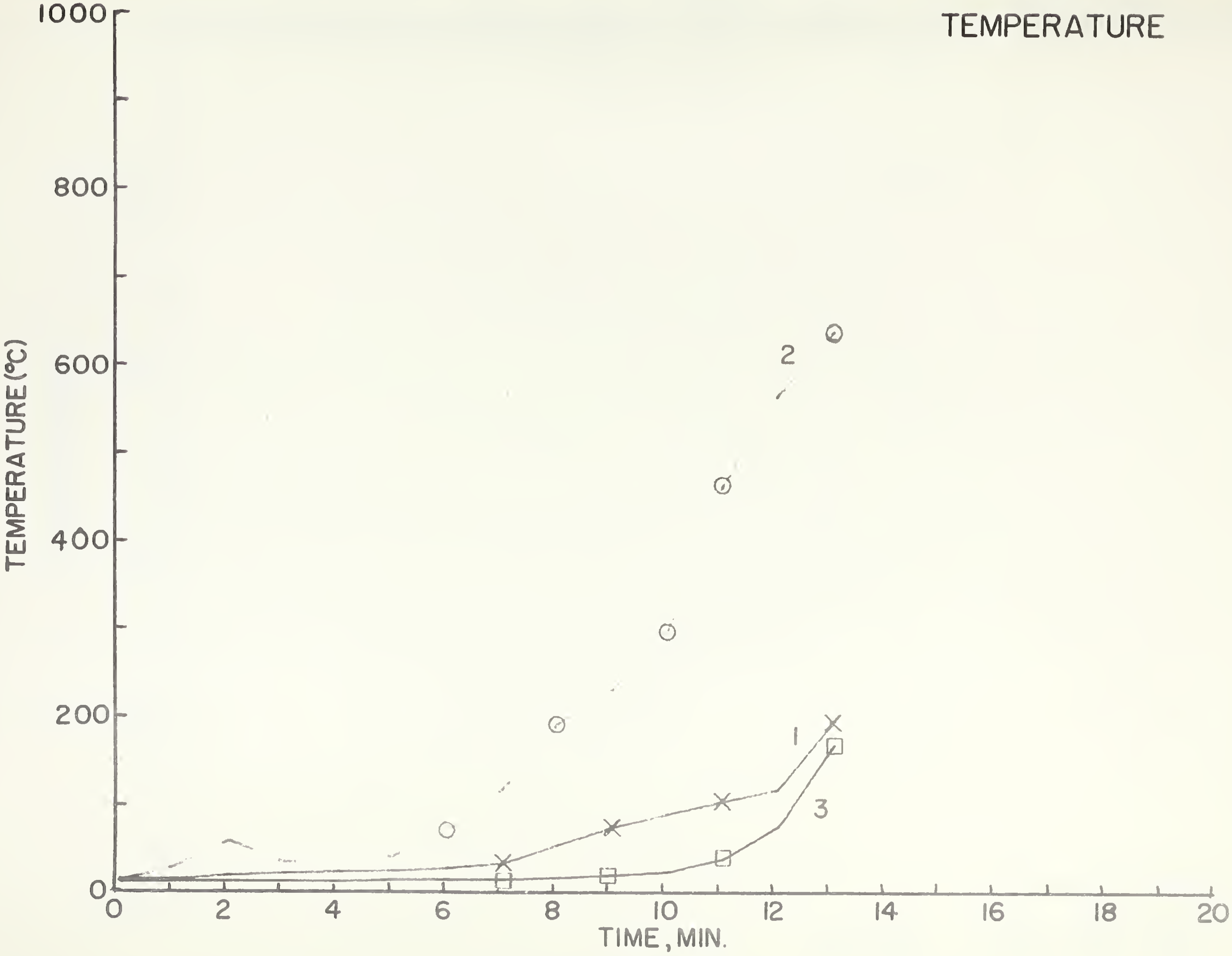


FIG. 50 TEST NO. 26
TEMPERATURE

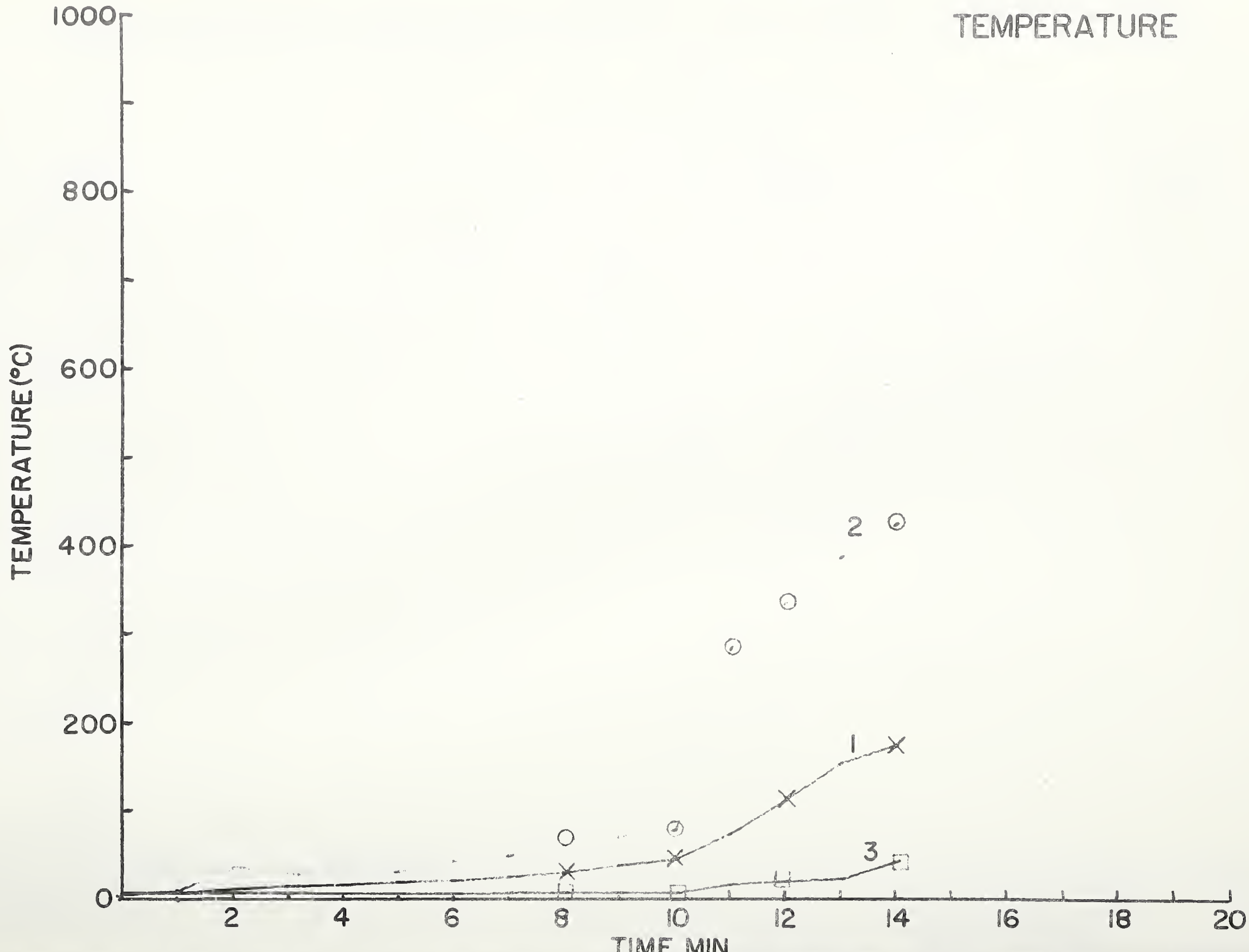


FIG. 51 TEST NO. 27

TEMPERATURE

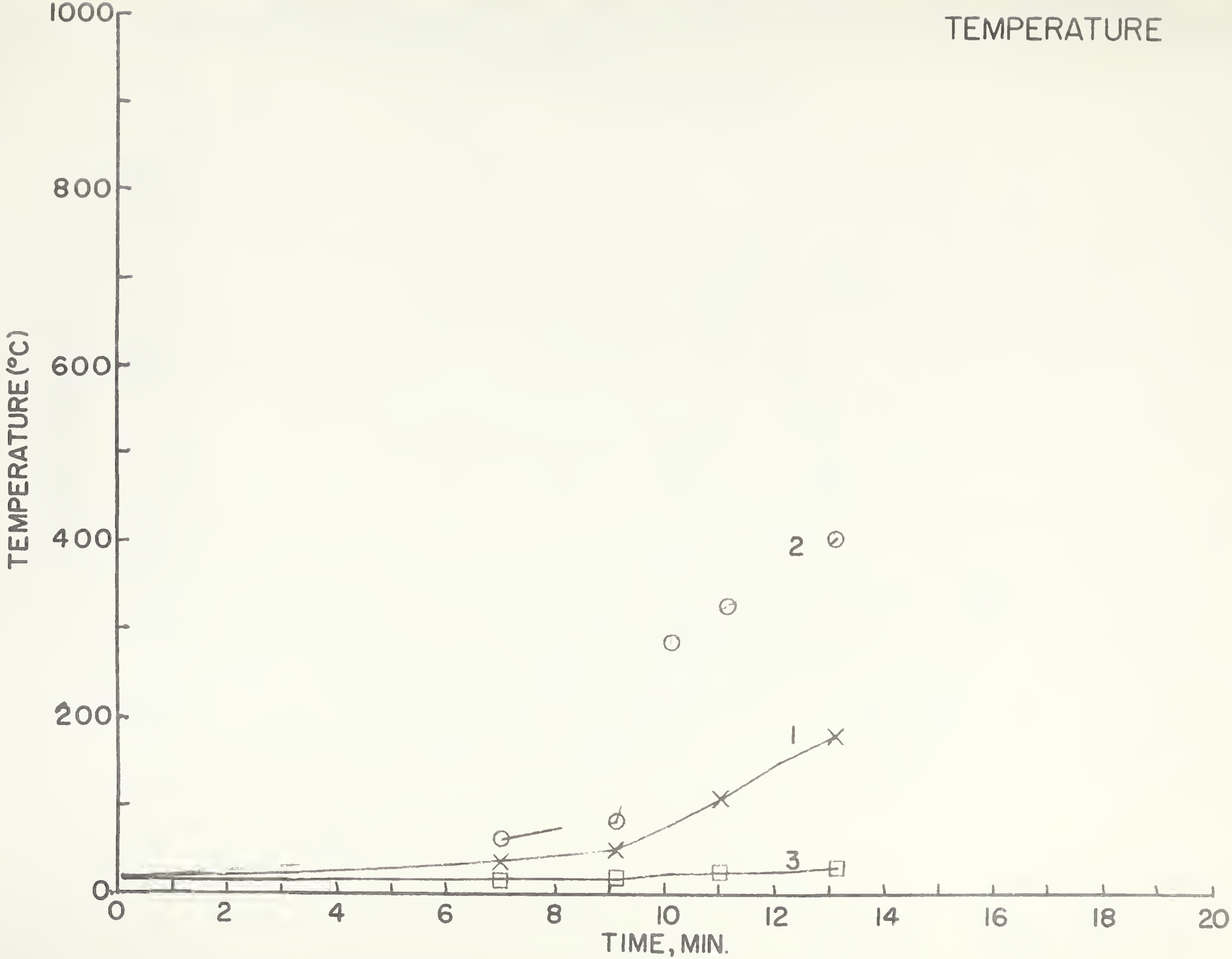


FIG. 52 TEST NO. 28
TEMPERATURE

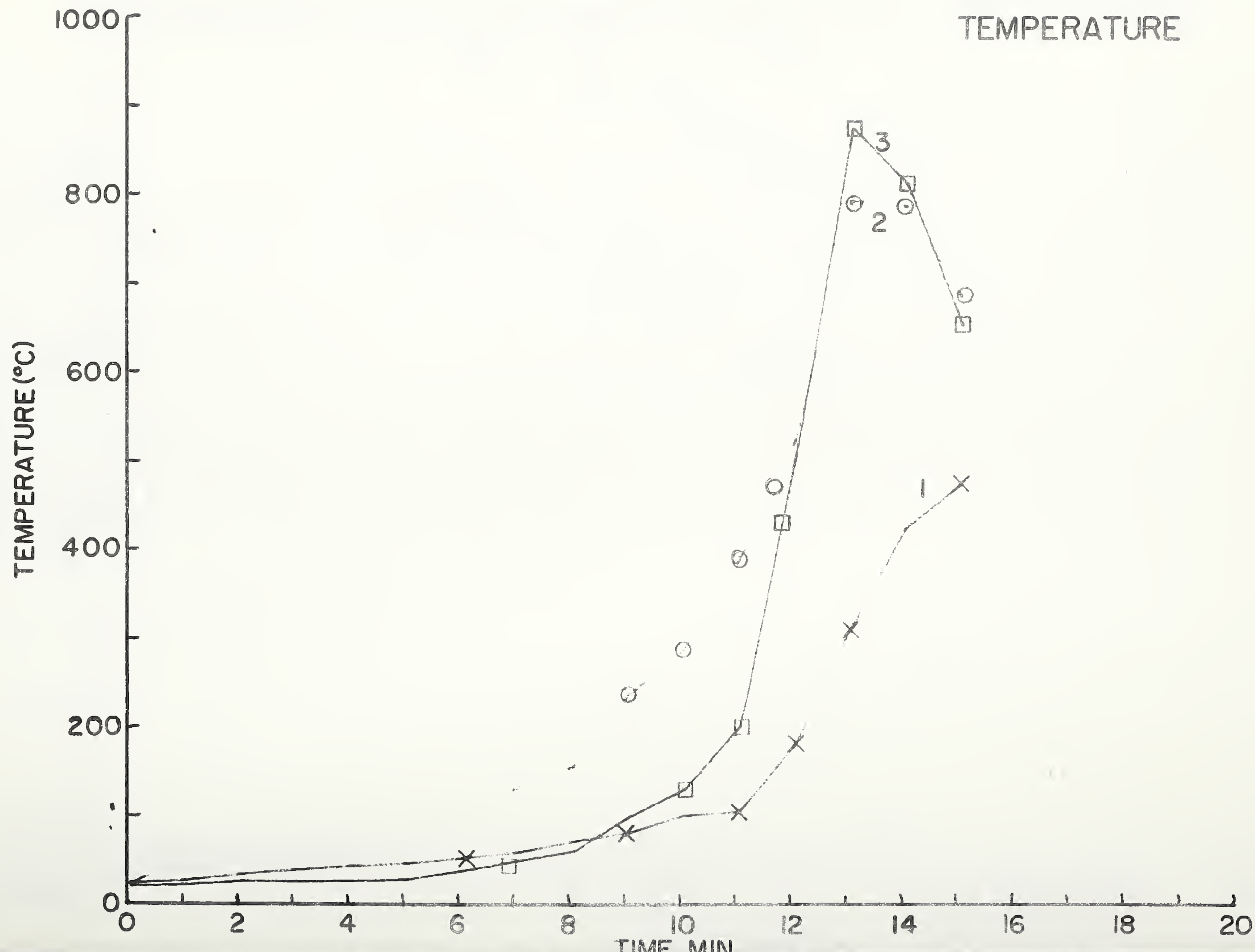


FIG. 53 TEST NO. 29

TEMPERATURE

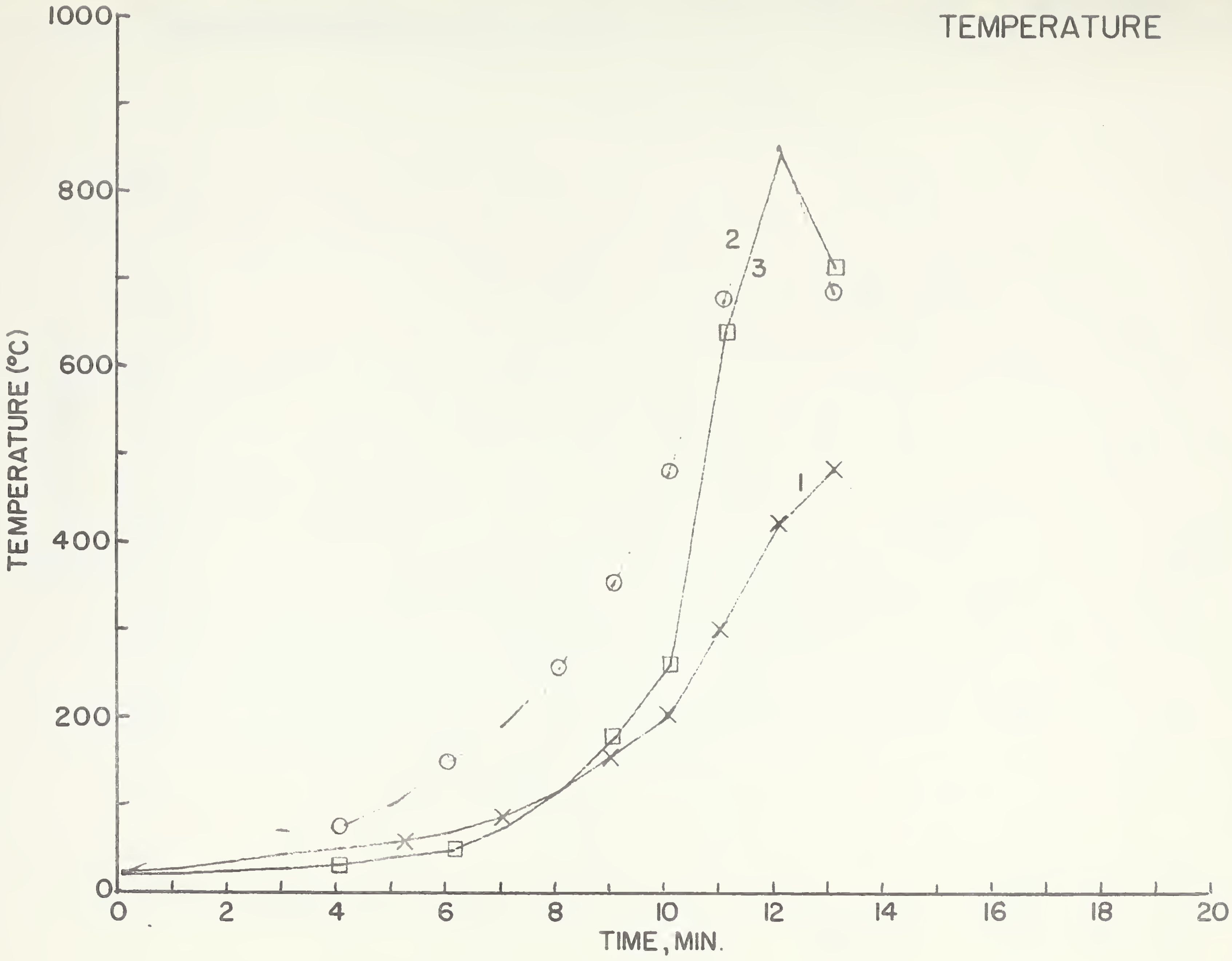


FIG. 54 TEST NO. 30 TEMPERATURE

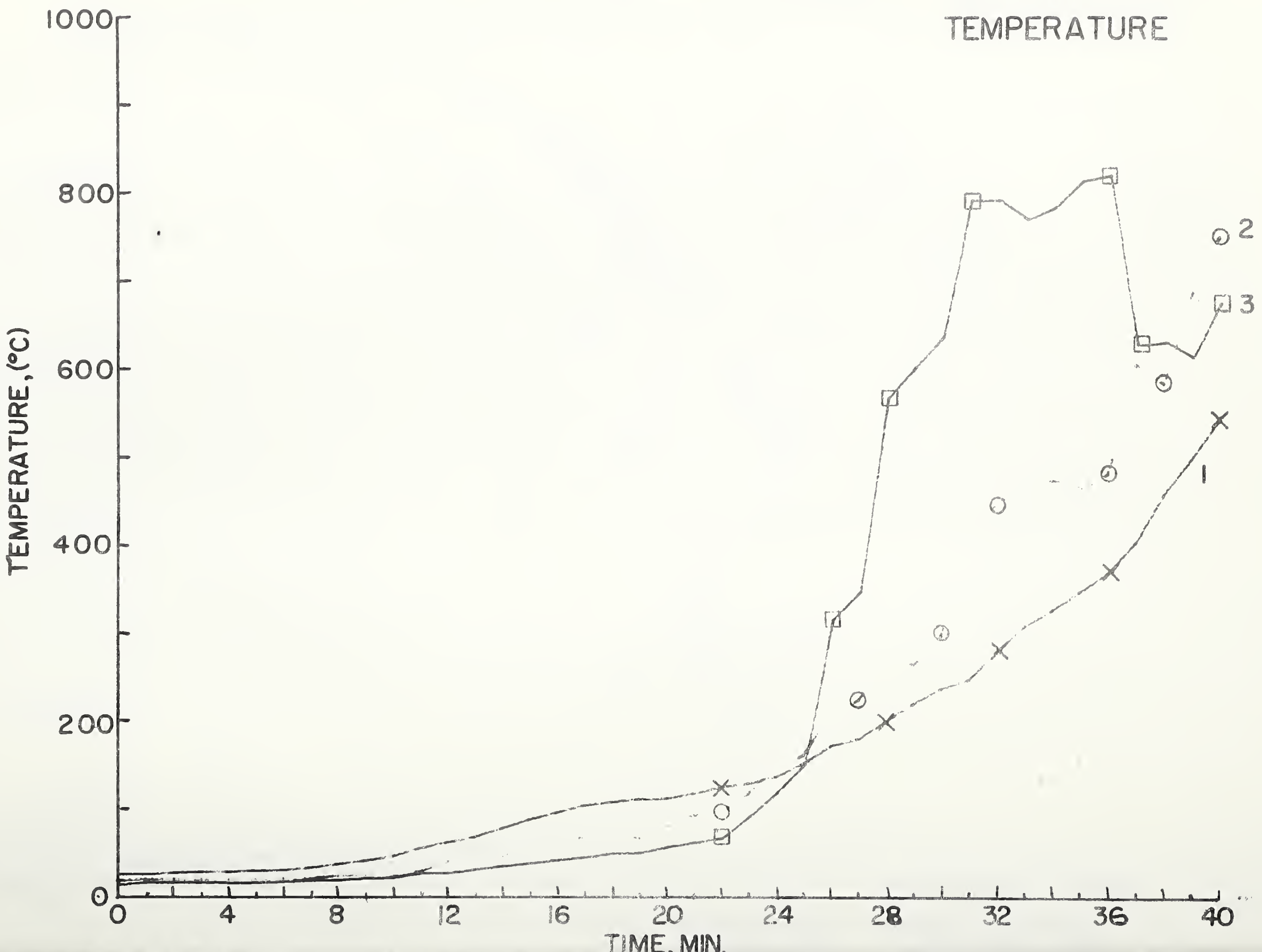


FIG.55 TEST NO. 31

TEMPERATURE

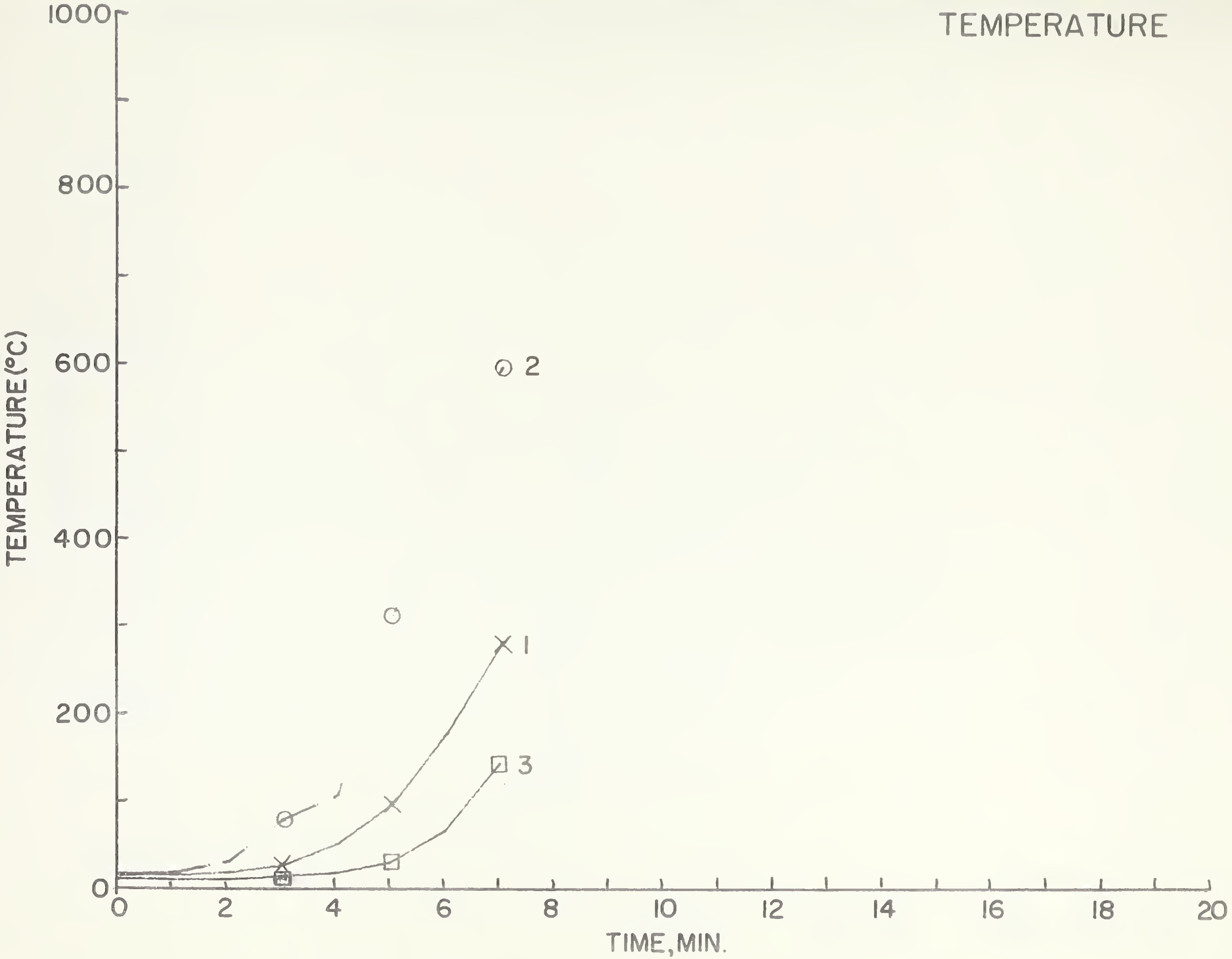


FIG. 56 TEST NO. 32
TEMPERATURE

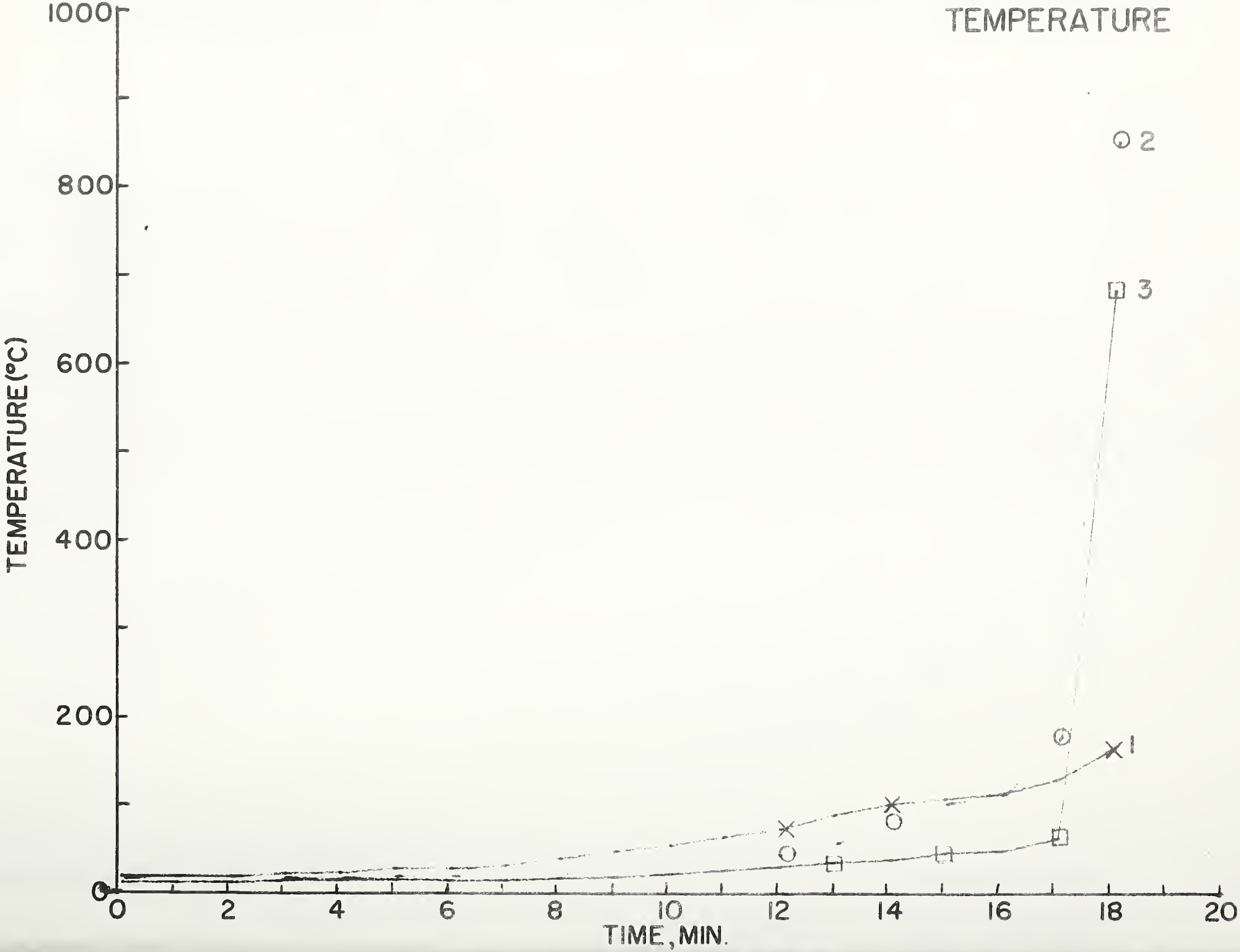


FIG. 57 TEST NO. 33

TEMPERATURE

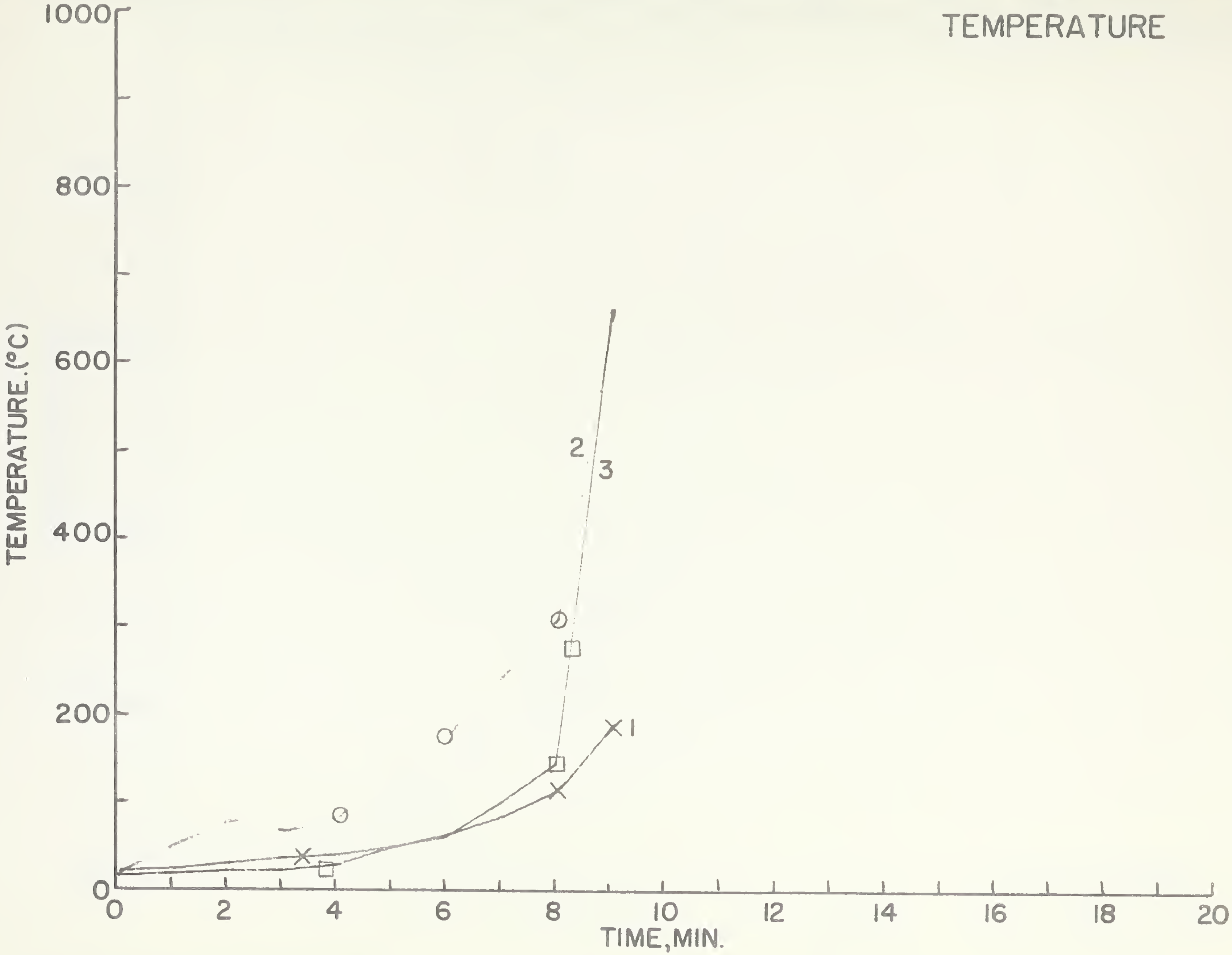


FIG. 58 TEST NO. 34

TEMPERATURE

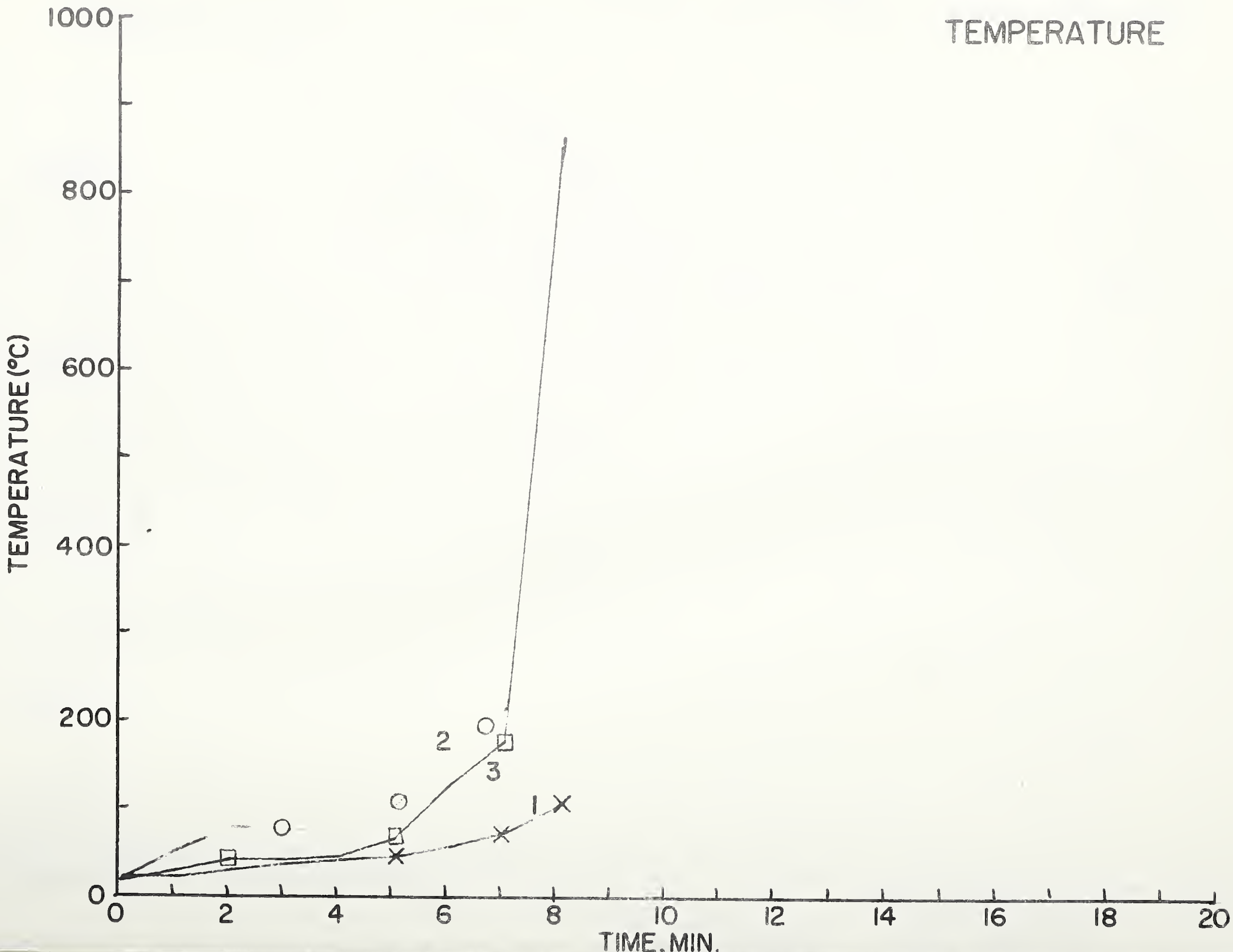


FIG. 59 TEST NO. 35

TEMPERATURE

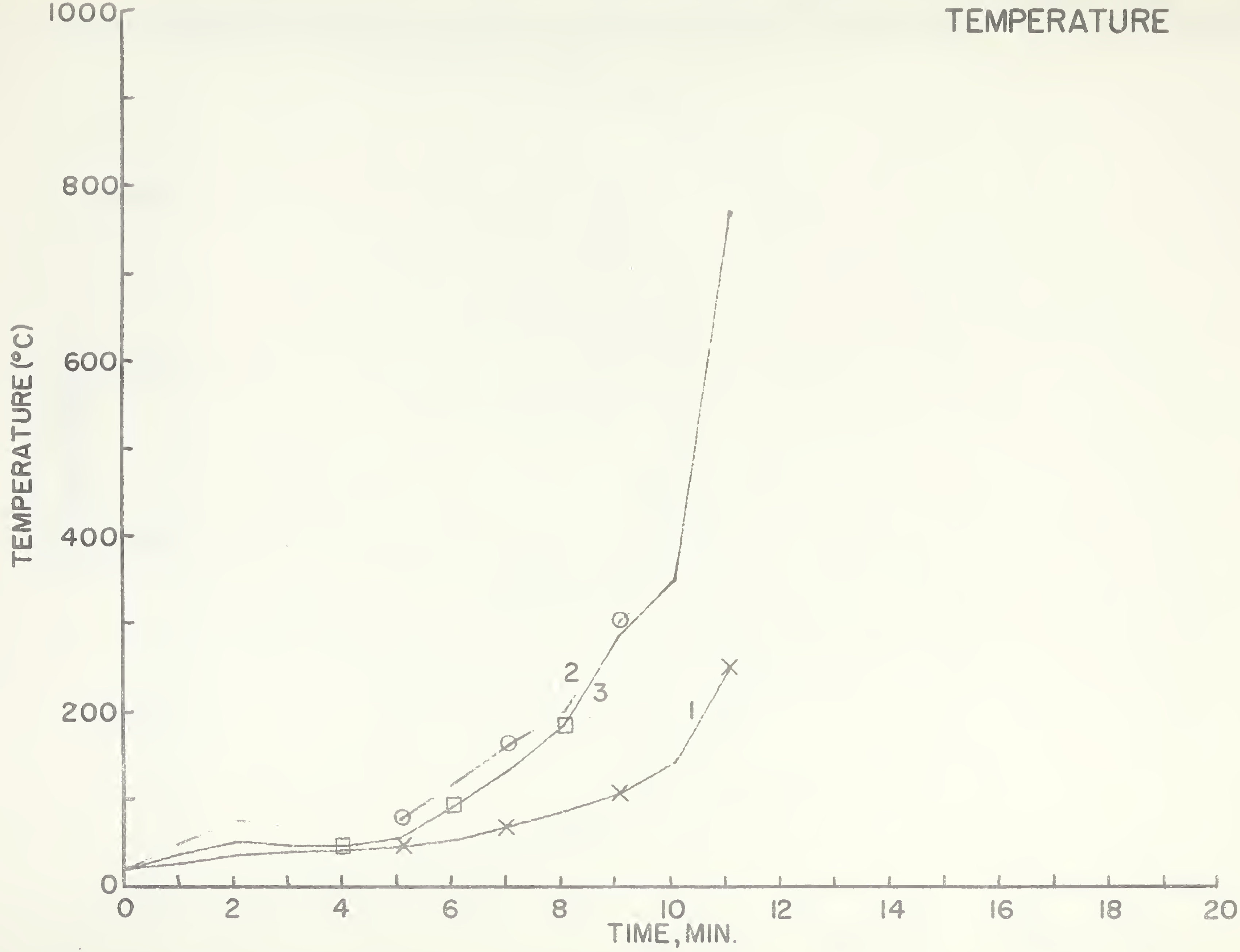


FIG. 60 TEST NO. 36 TEMPERATURE

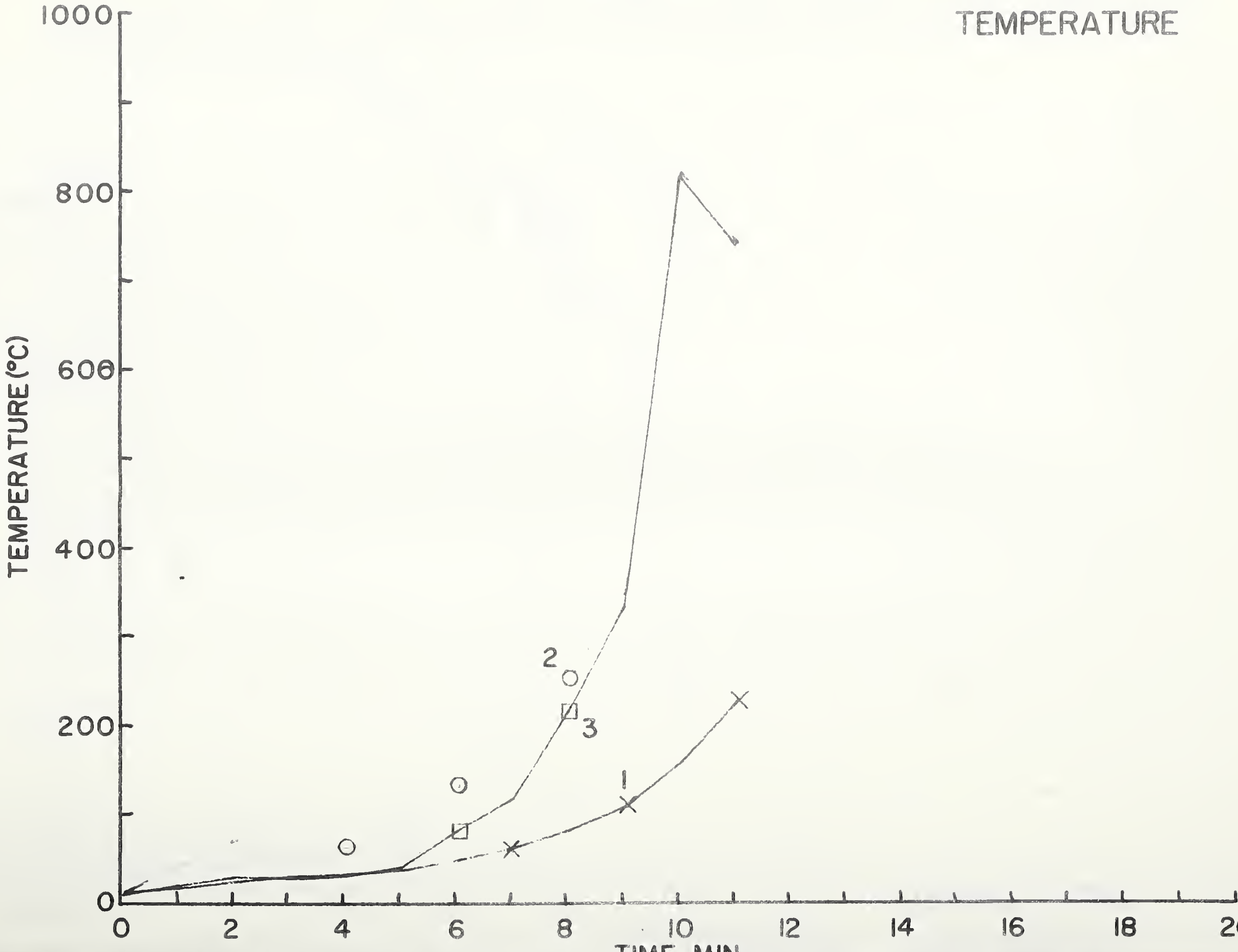


FIG. 61 TEST NO. 37

TEMPERATURE

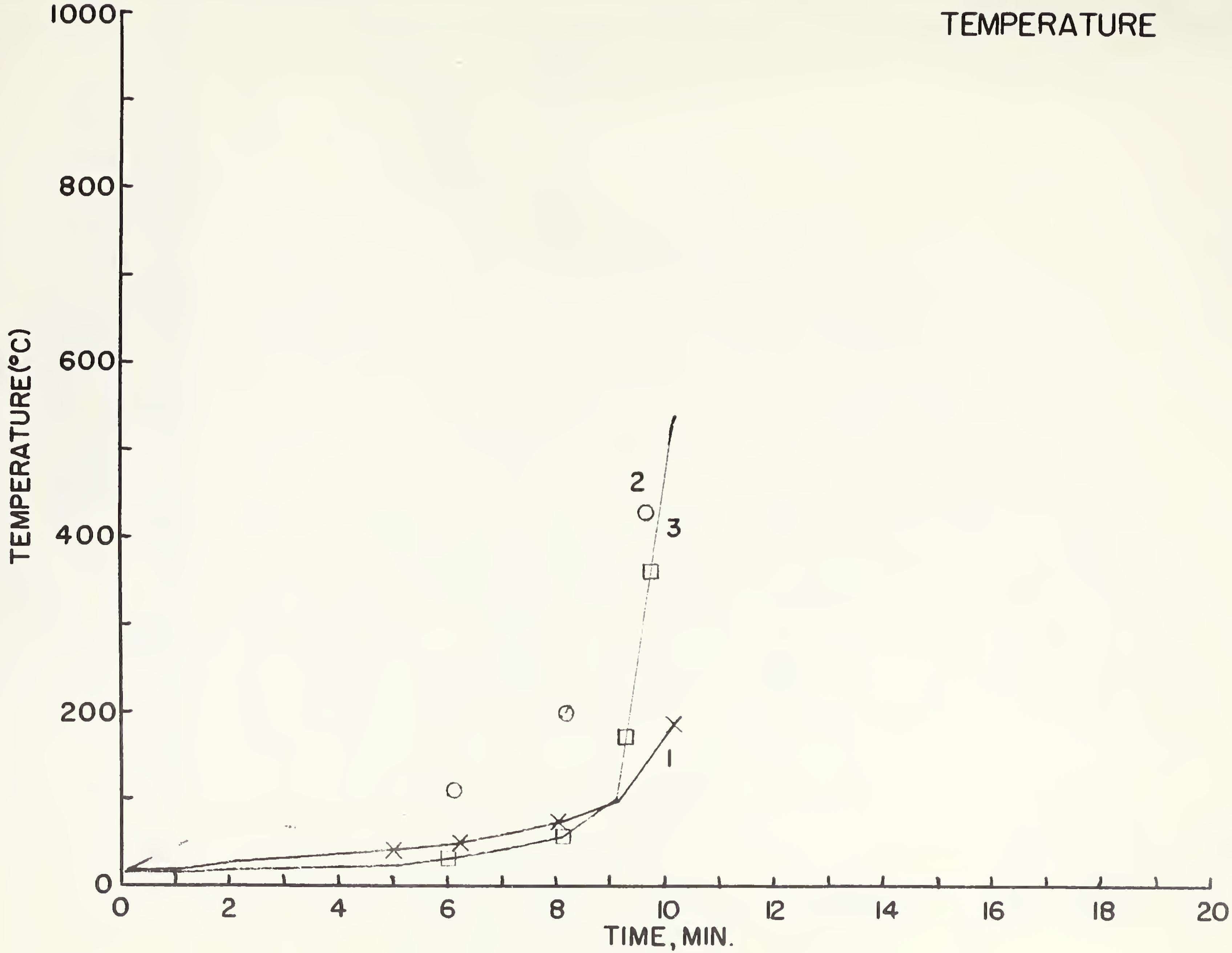


FIG. 62 TEST NO. 1
RADIATION INTENSITY

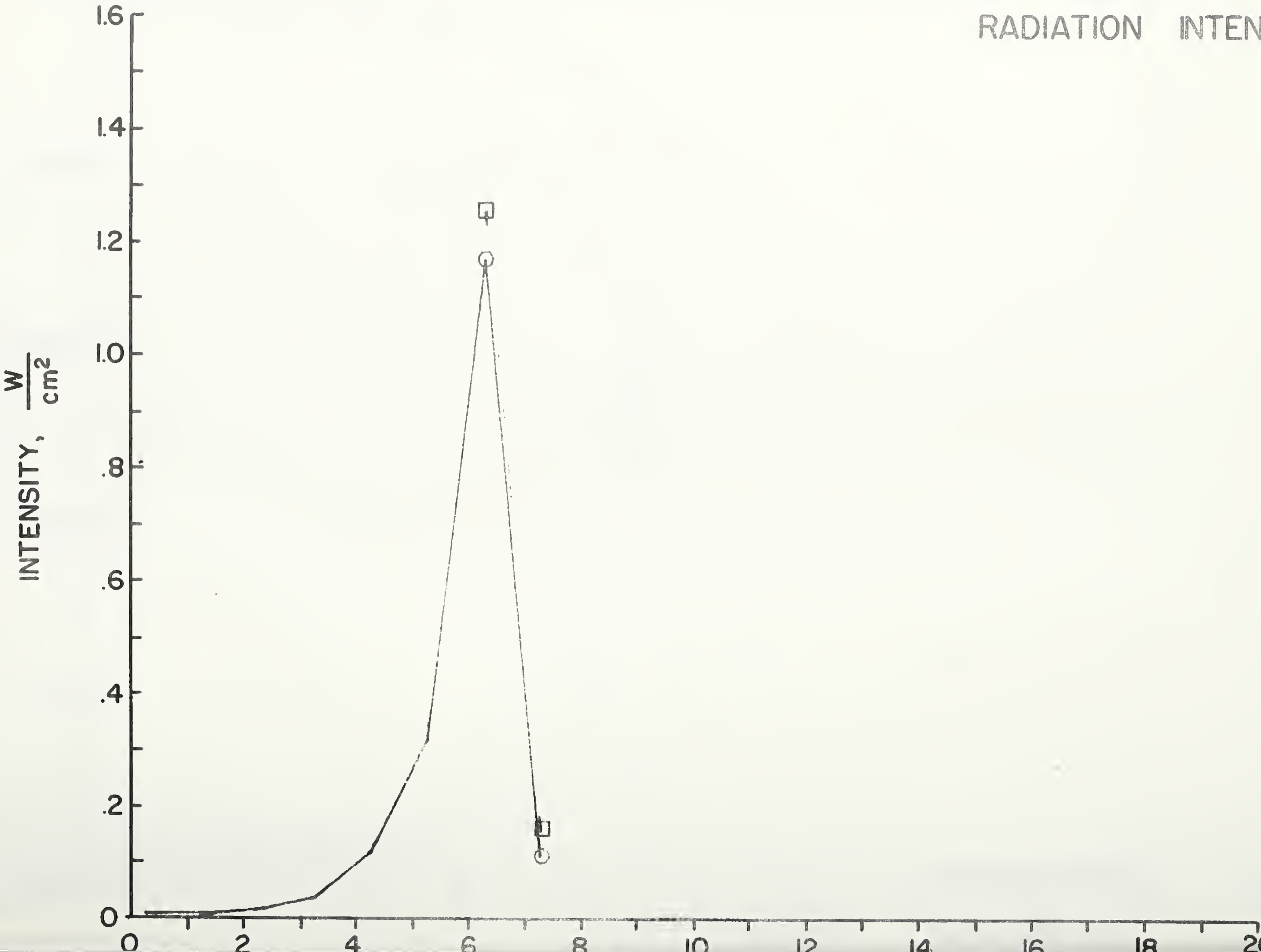


FIG. 63 TEST NO. 2

RADIATION INTENSITY

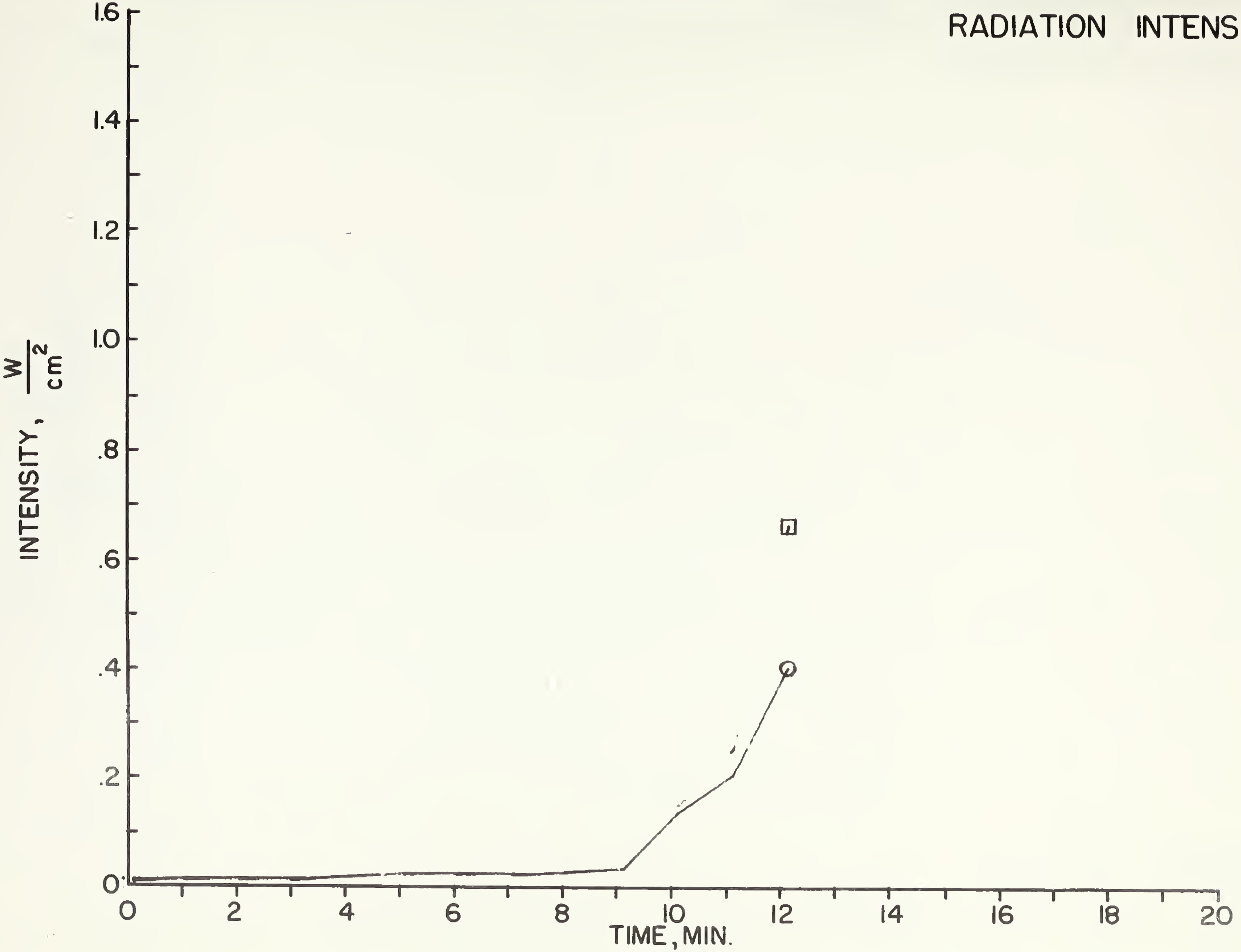


FIG. 64 TEST NO. 3

RADIATION INTENSITY

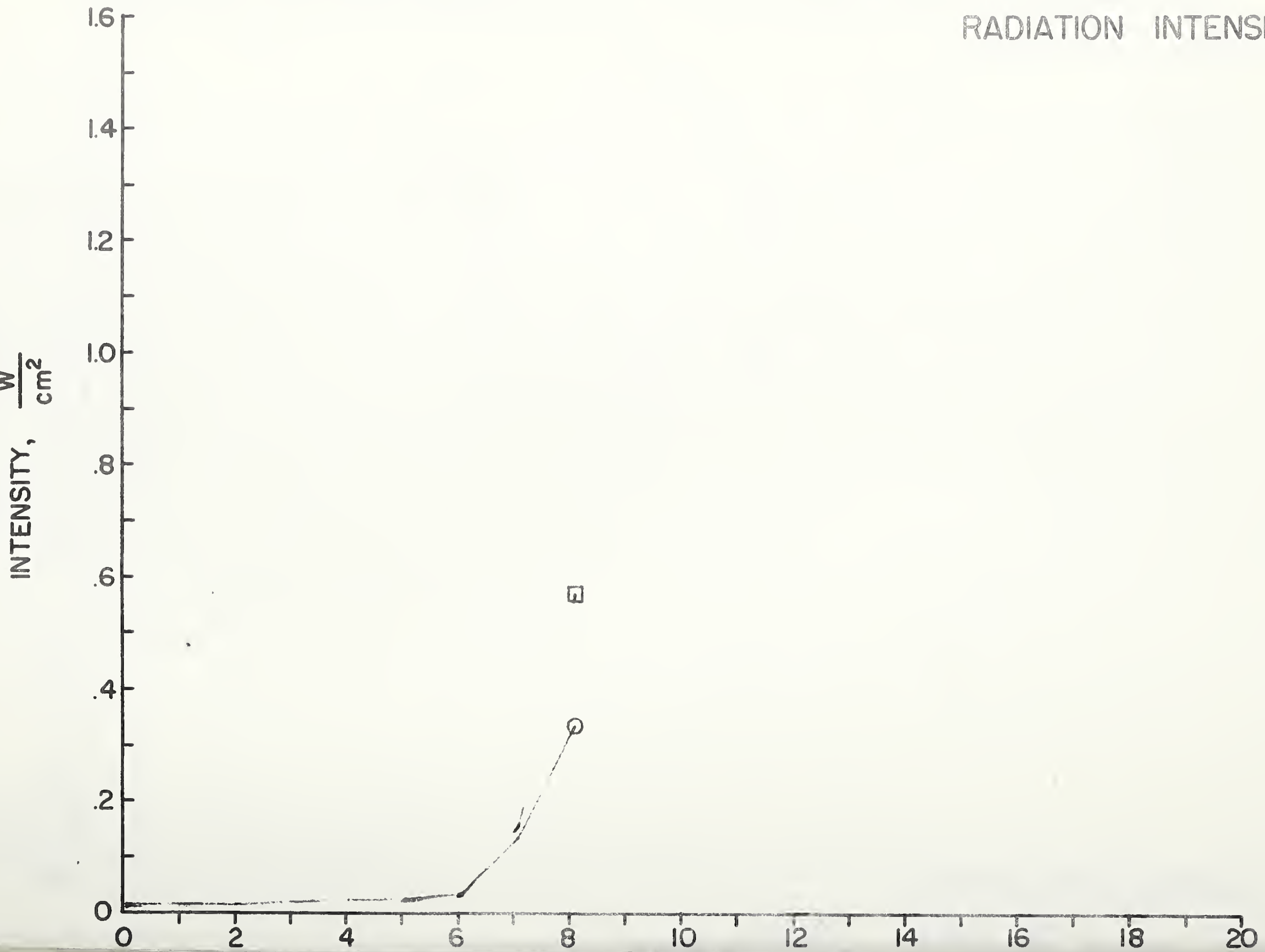
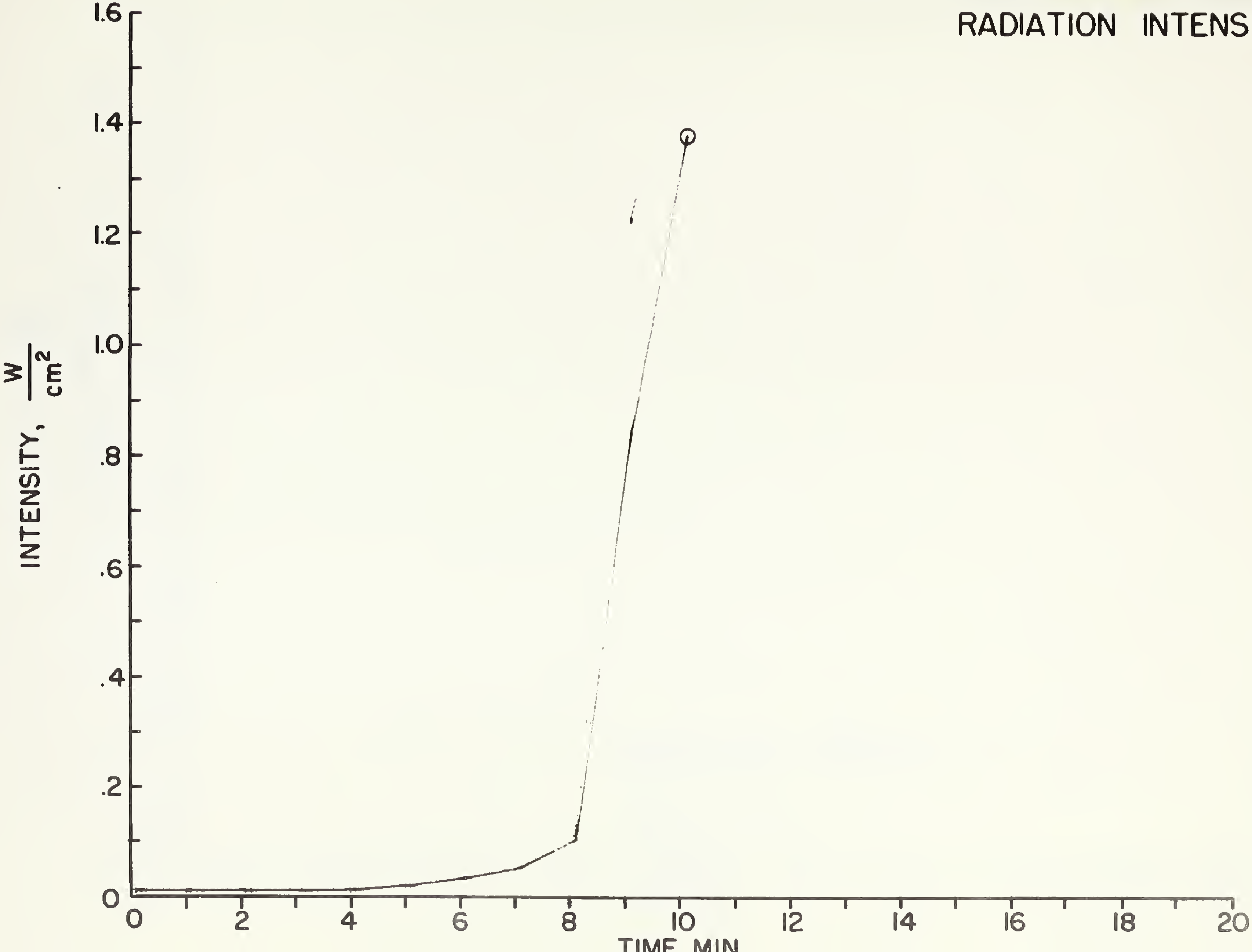


FIG. 65 TEST NO. 4
RADIATION INTENSITY



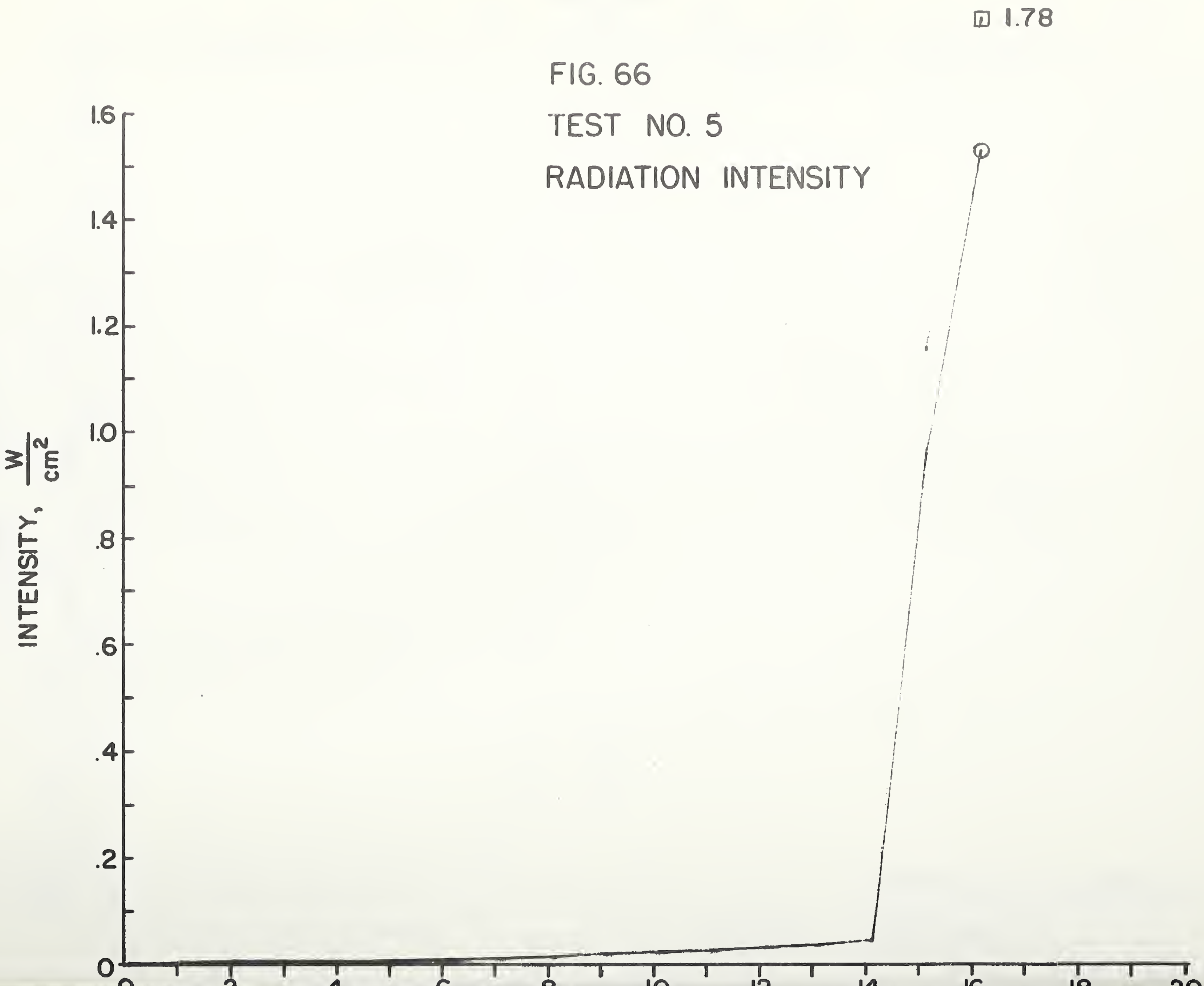


FIG. 66
TEST NO. 5
RADIATION INTENSITY

FIG. 67 TEST NO. 6

RADIATION INTENSITY

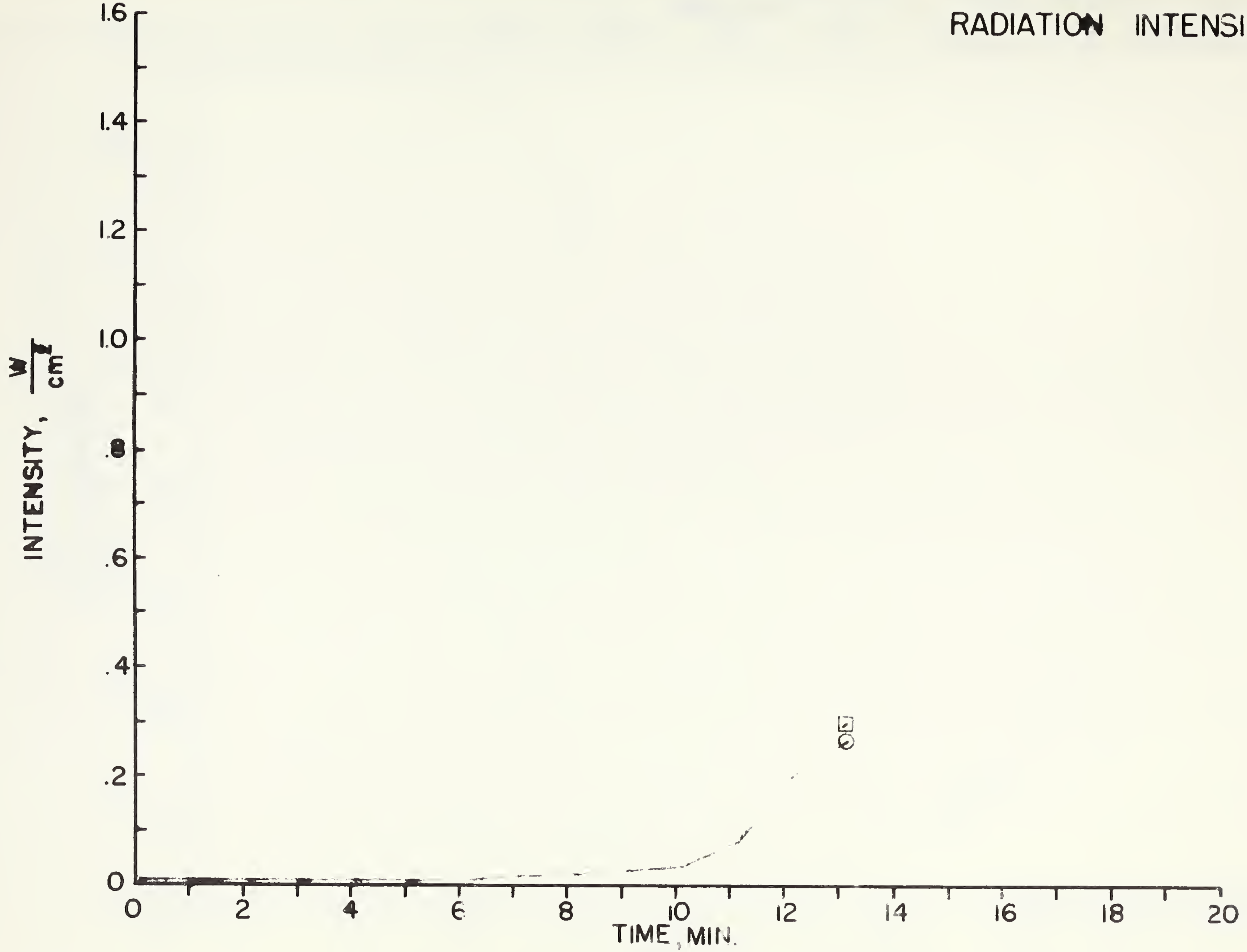


FIG. 68 TEST NO. 7

RADIATION INTENSITY

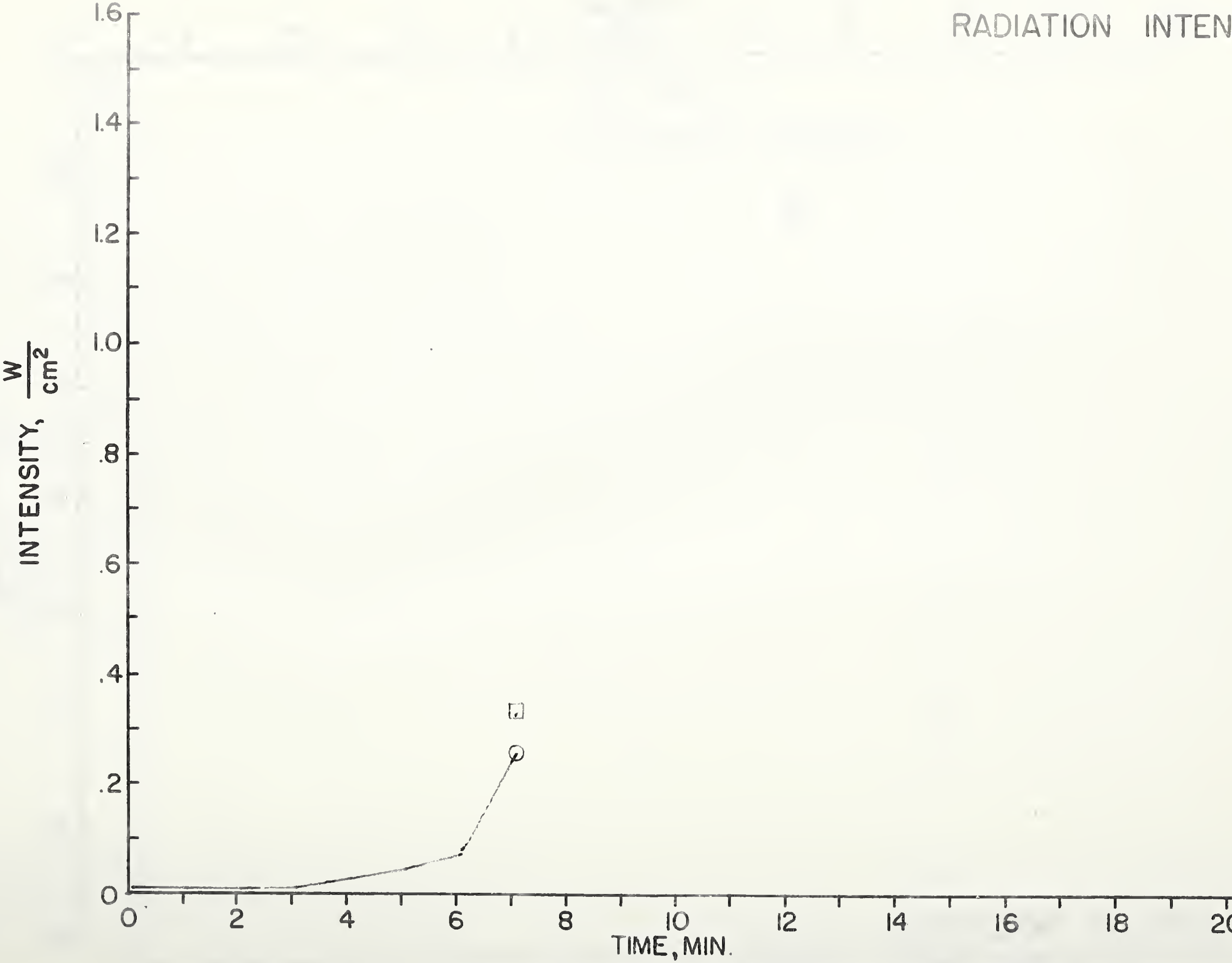


FIG. 69 TEST NO. 8

RADIATION INTENSITY

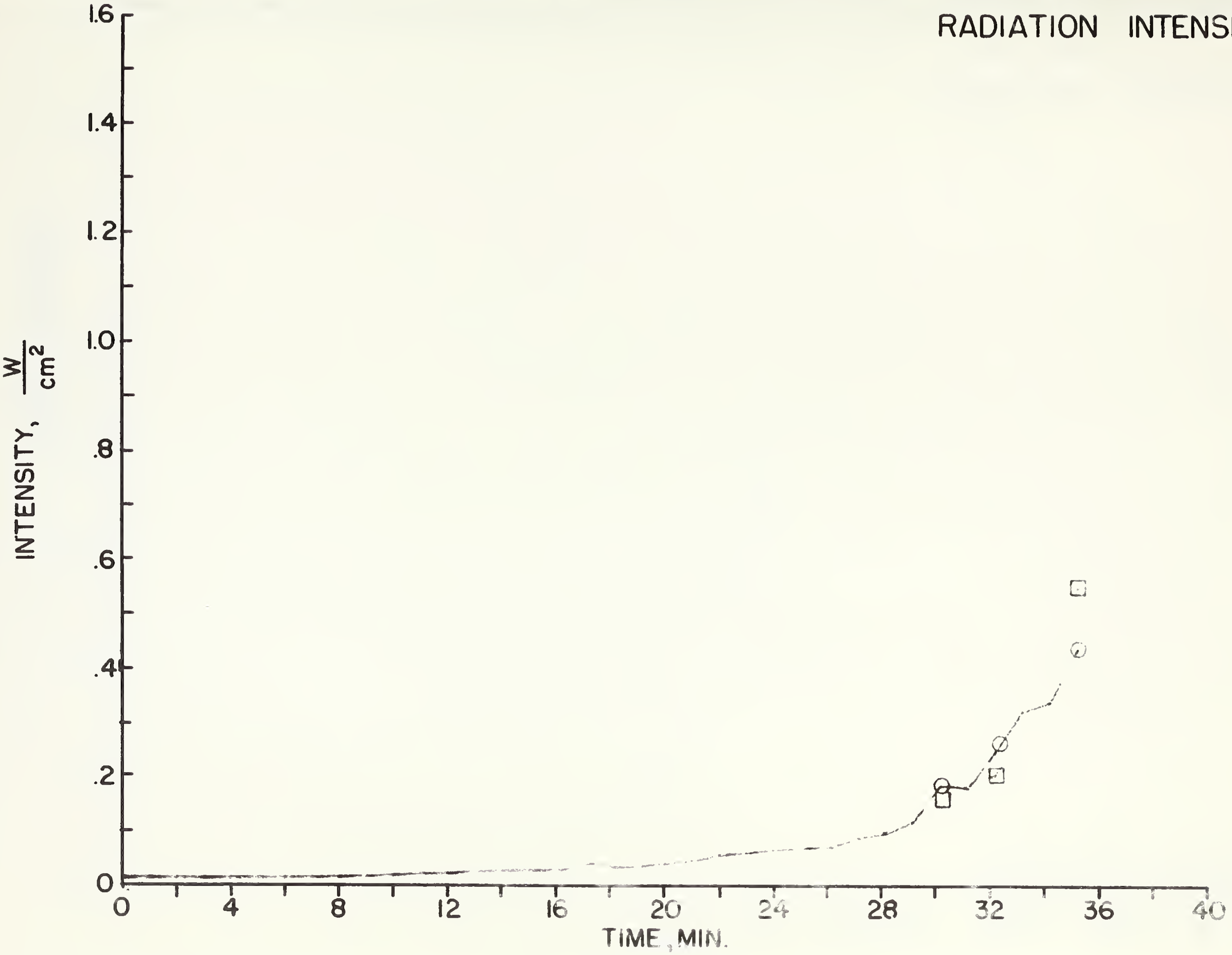
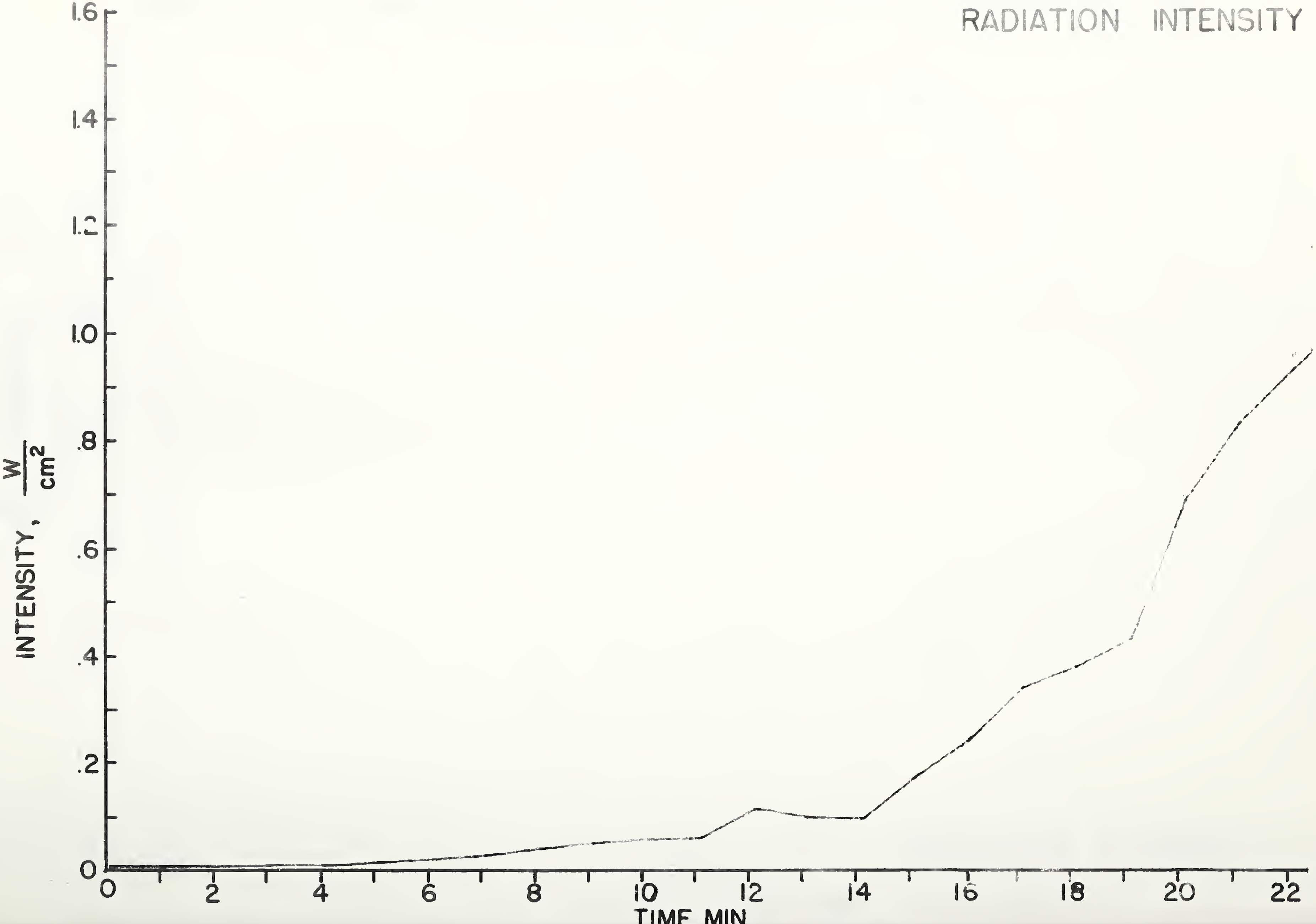


FIG. 70 TEST NO. 9
RADIATION INTENSITY



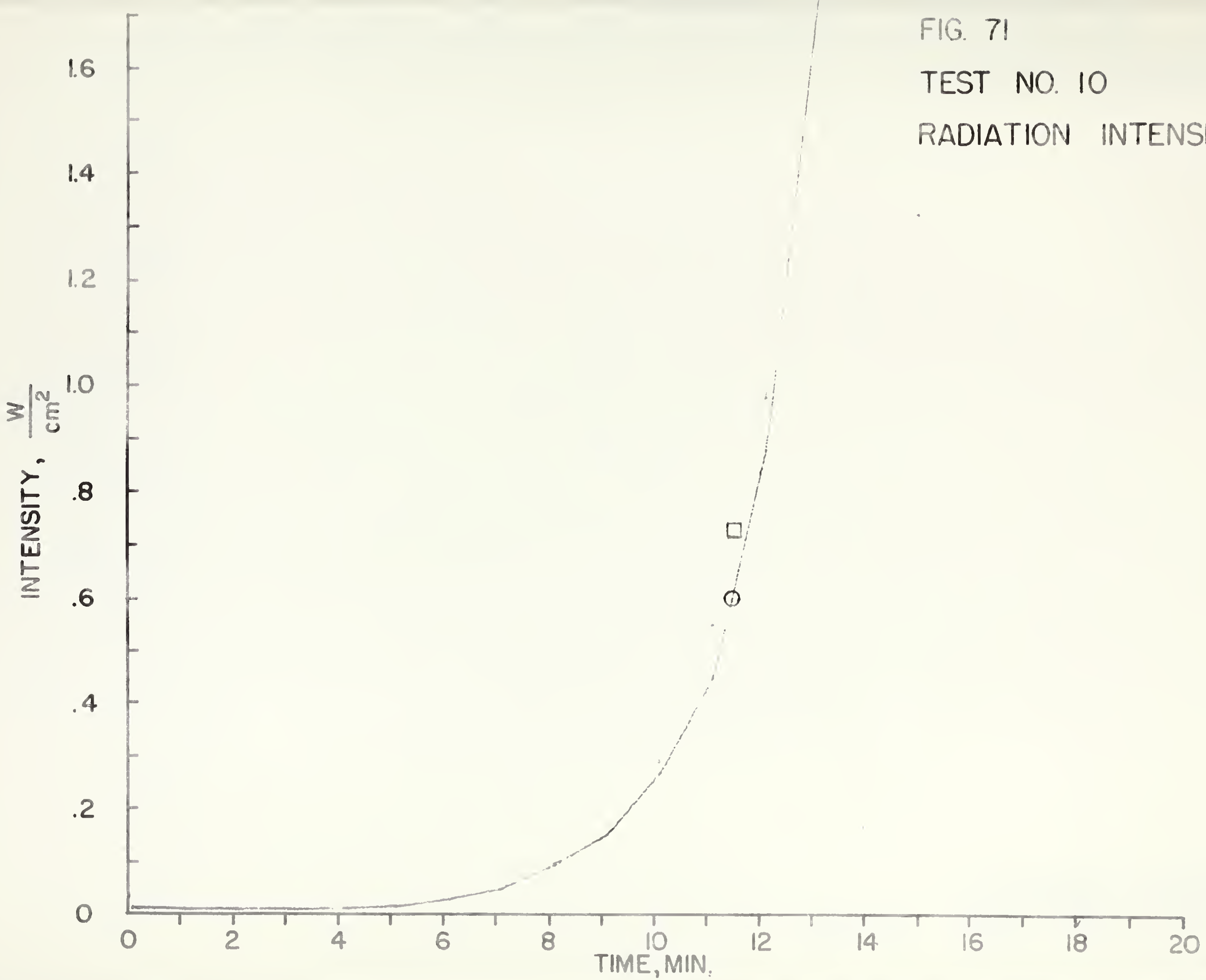


FIG. 71
TEST NO. 10
RADIATION INTENSITY

FIG. 72 TEST NO. 11

RADIATION INTENSITY

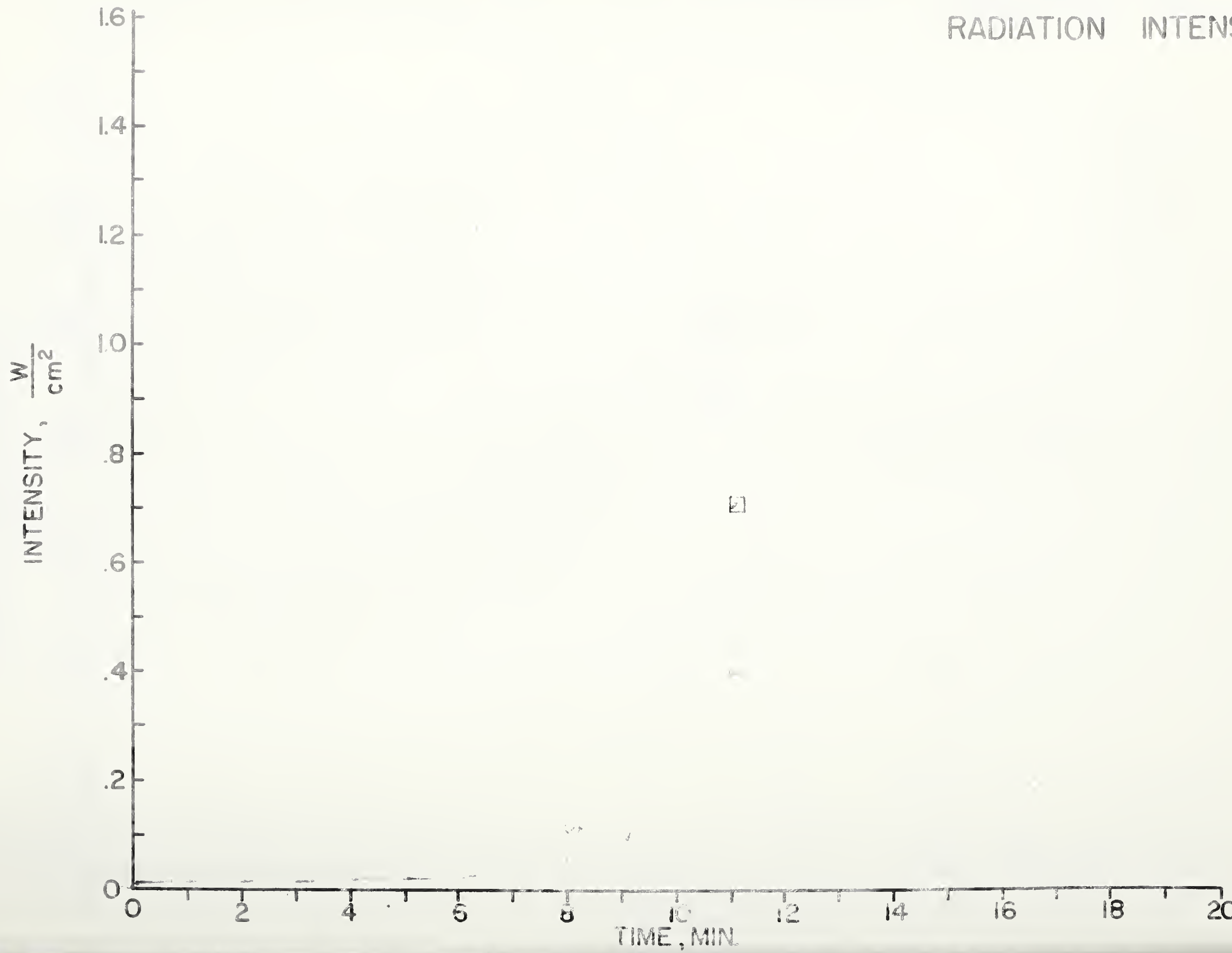


FIG. 73 TEST NO. 12

RADIATION INTENSITY

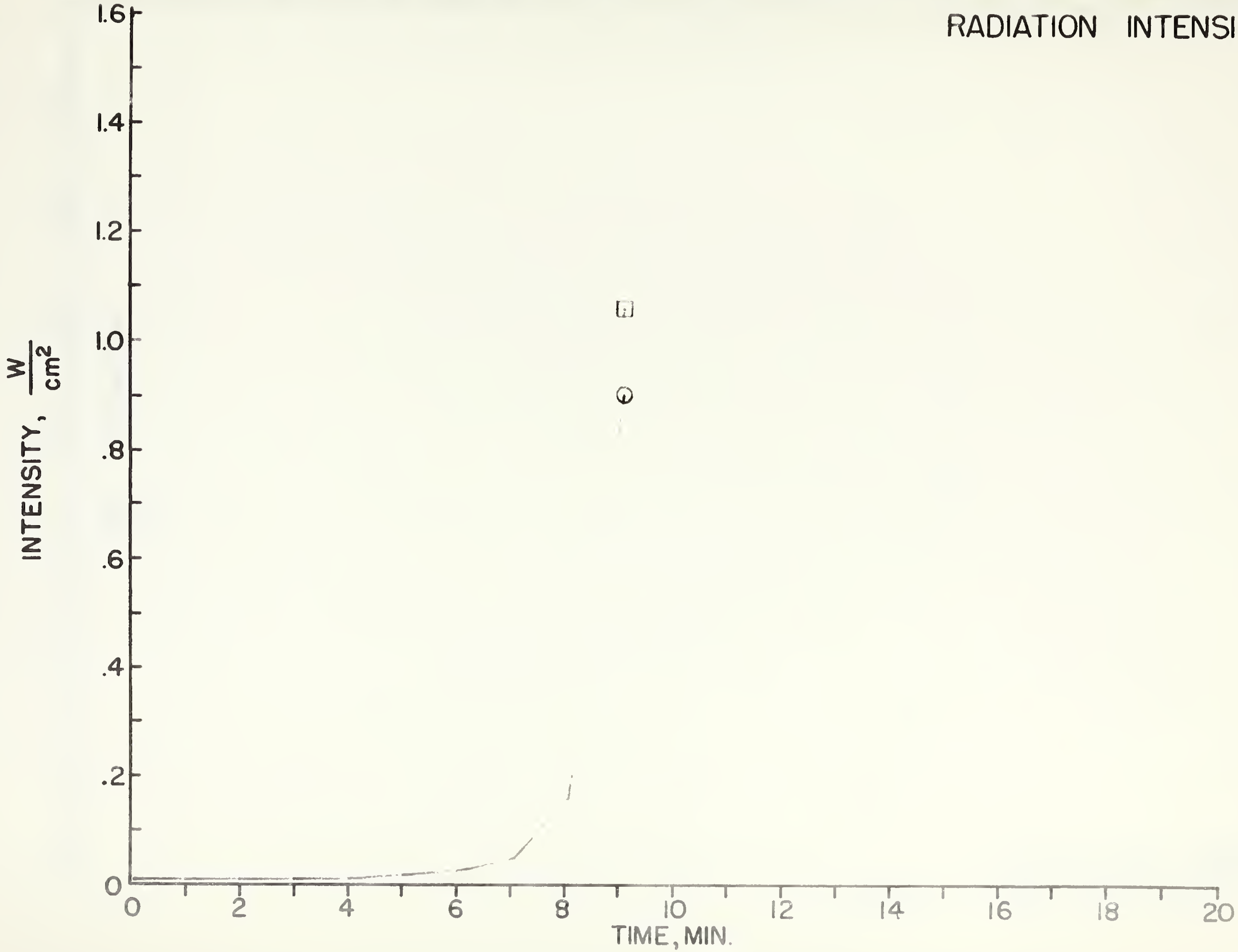


FIG. 74 TEST NO. 13
RADIATION INTENSITY

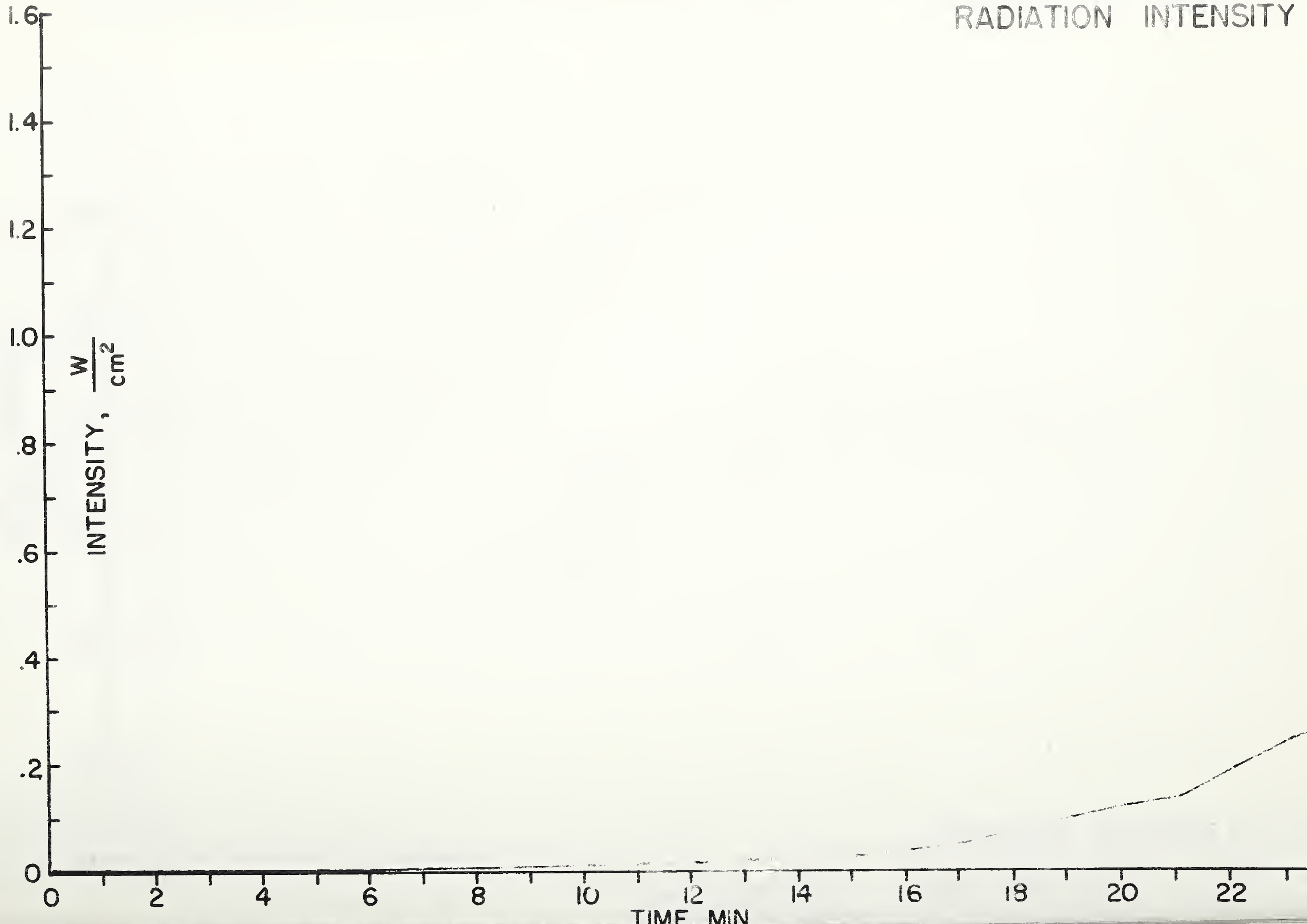


FIG. 75 TEST NO. 14

RADIATION INTENSITY

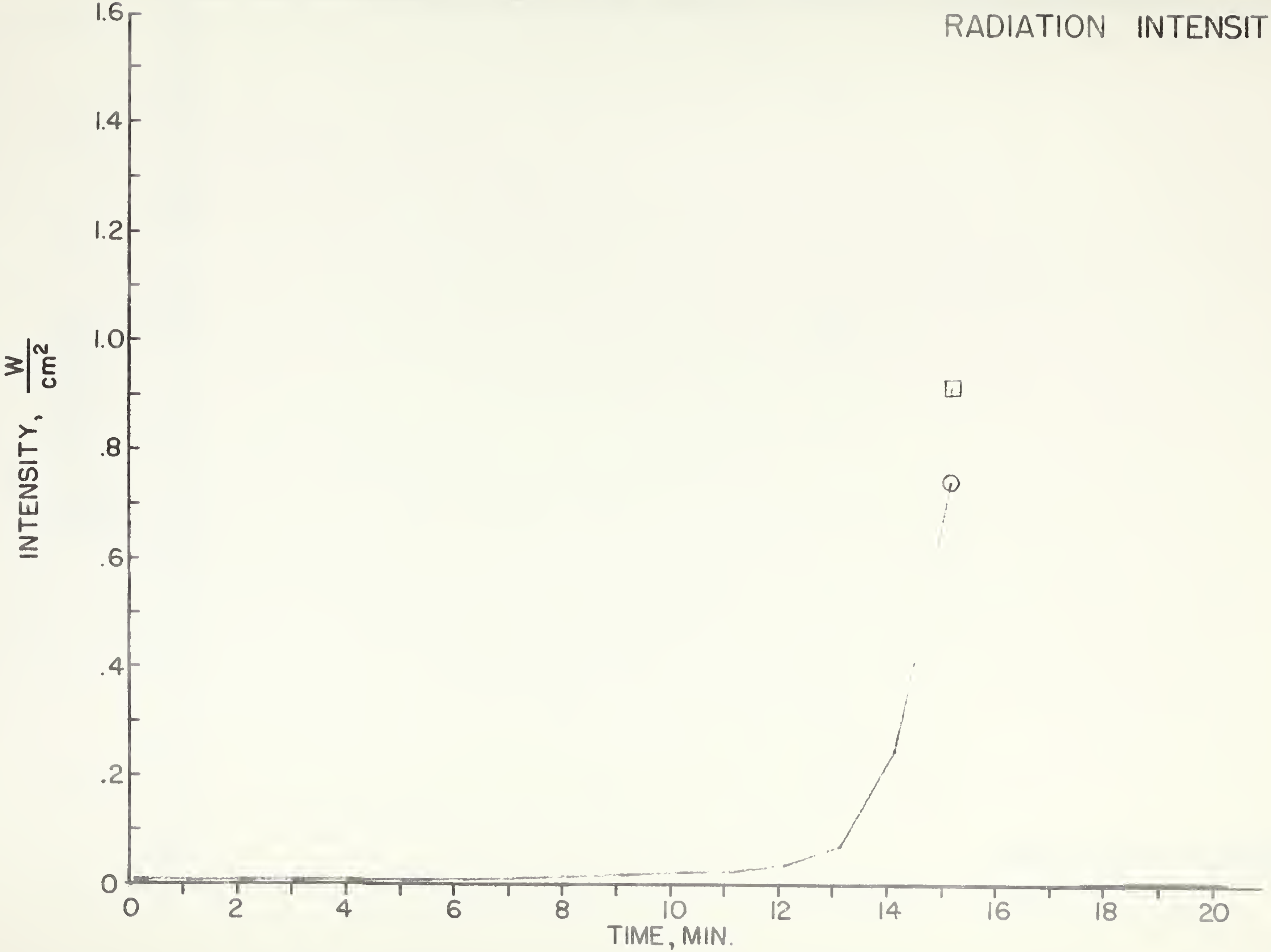


FIG. 76 TEST NO. 15

RADIATION INTENSITY

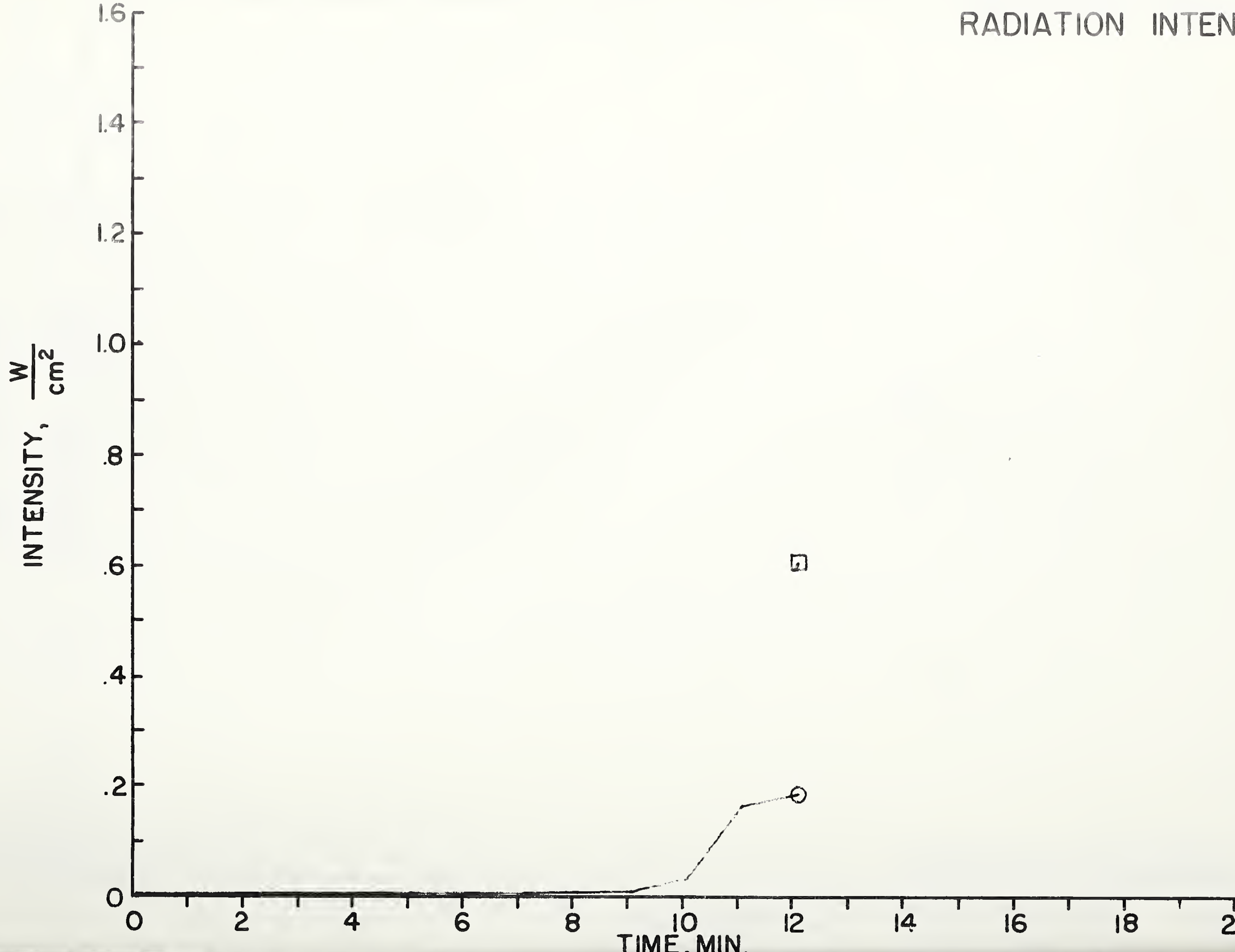


FIG. 77 TEST NO. 16

RADIATION INTENSITY

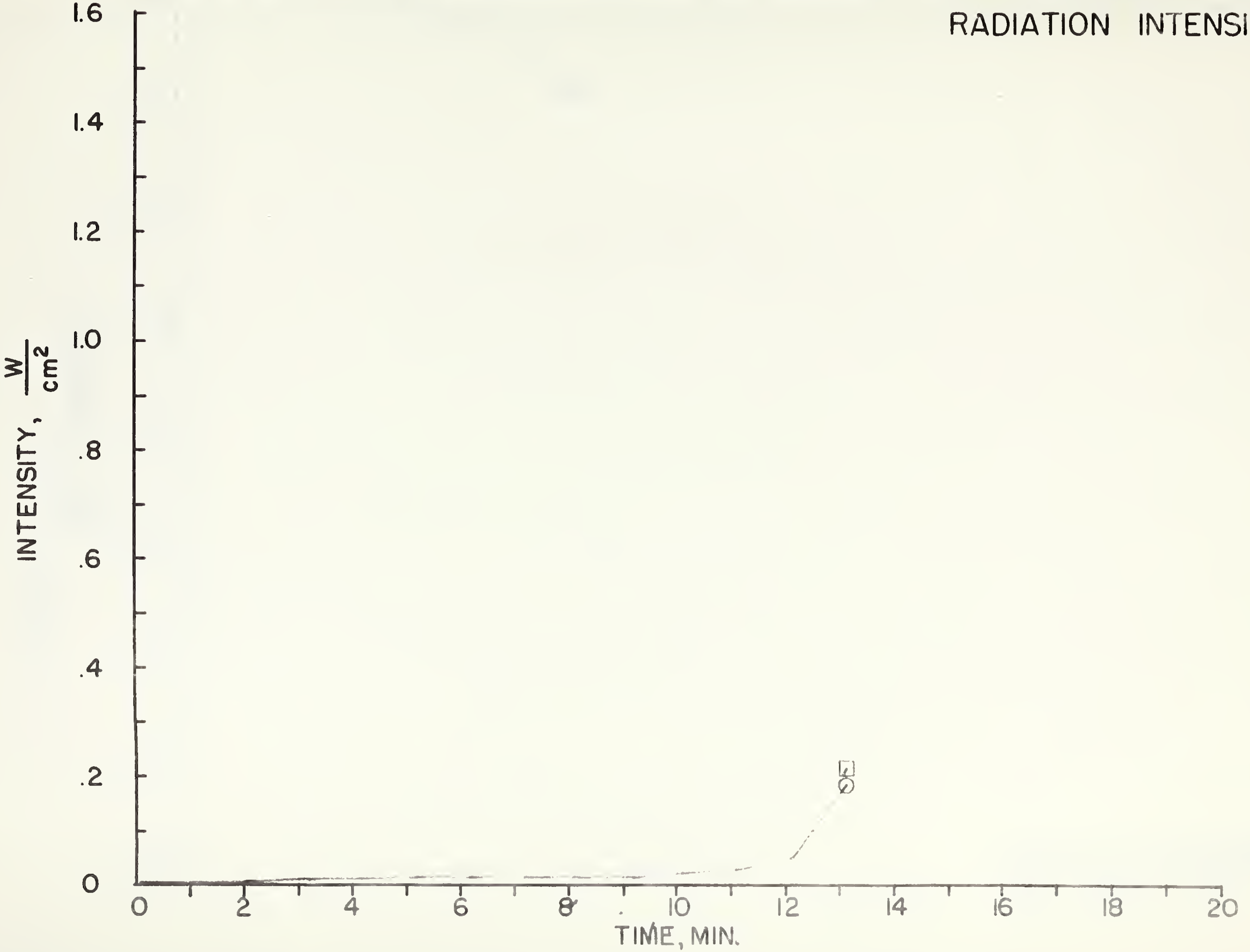


FIG. 78 TEST NO. 17
RADIATION INTENSITY

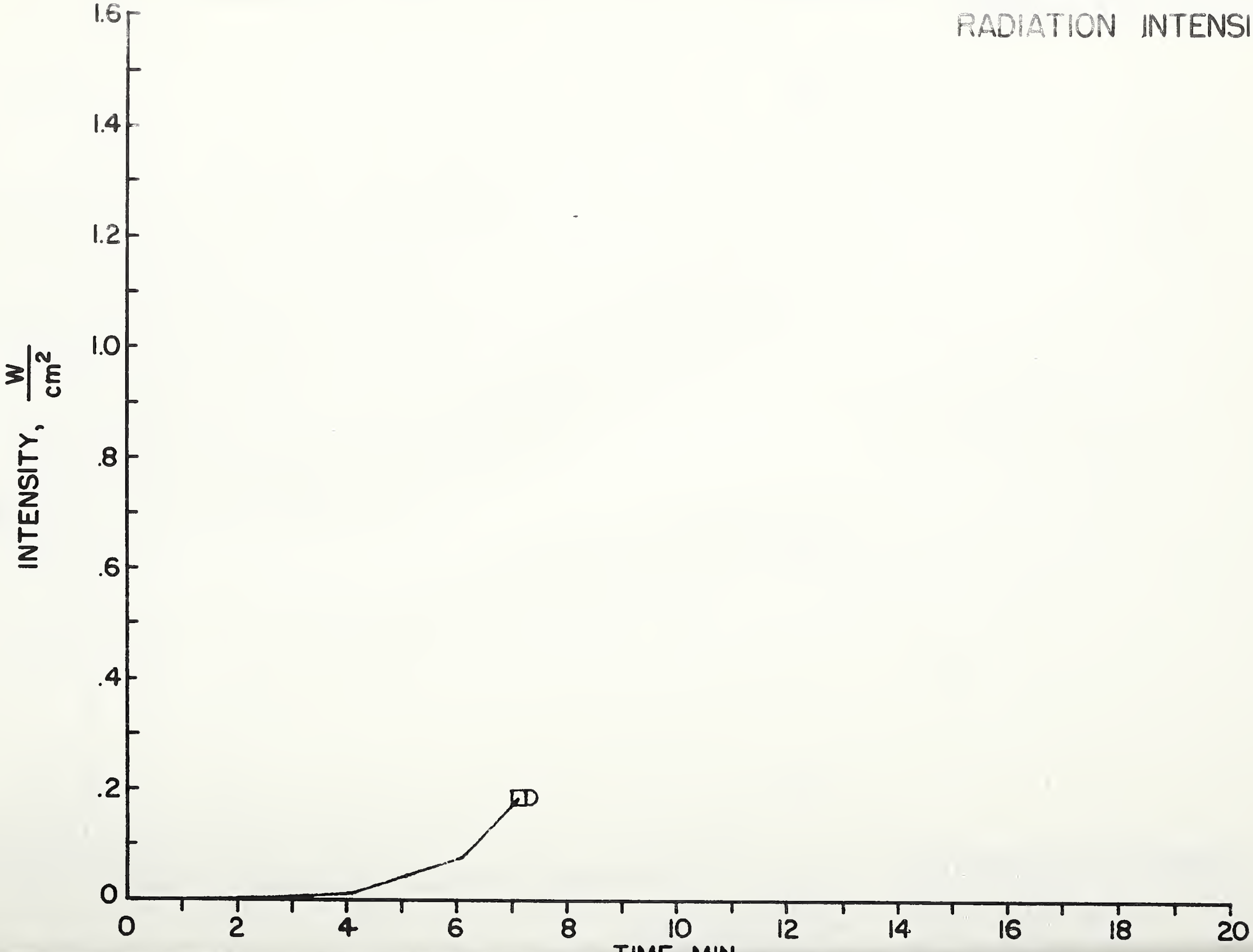


FIG. 79 TEST NO. 18

RADIATION INTENSITY

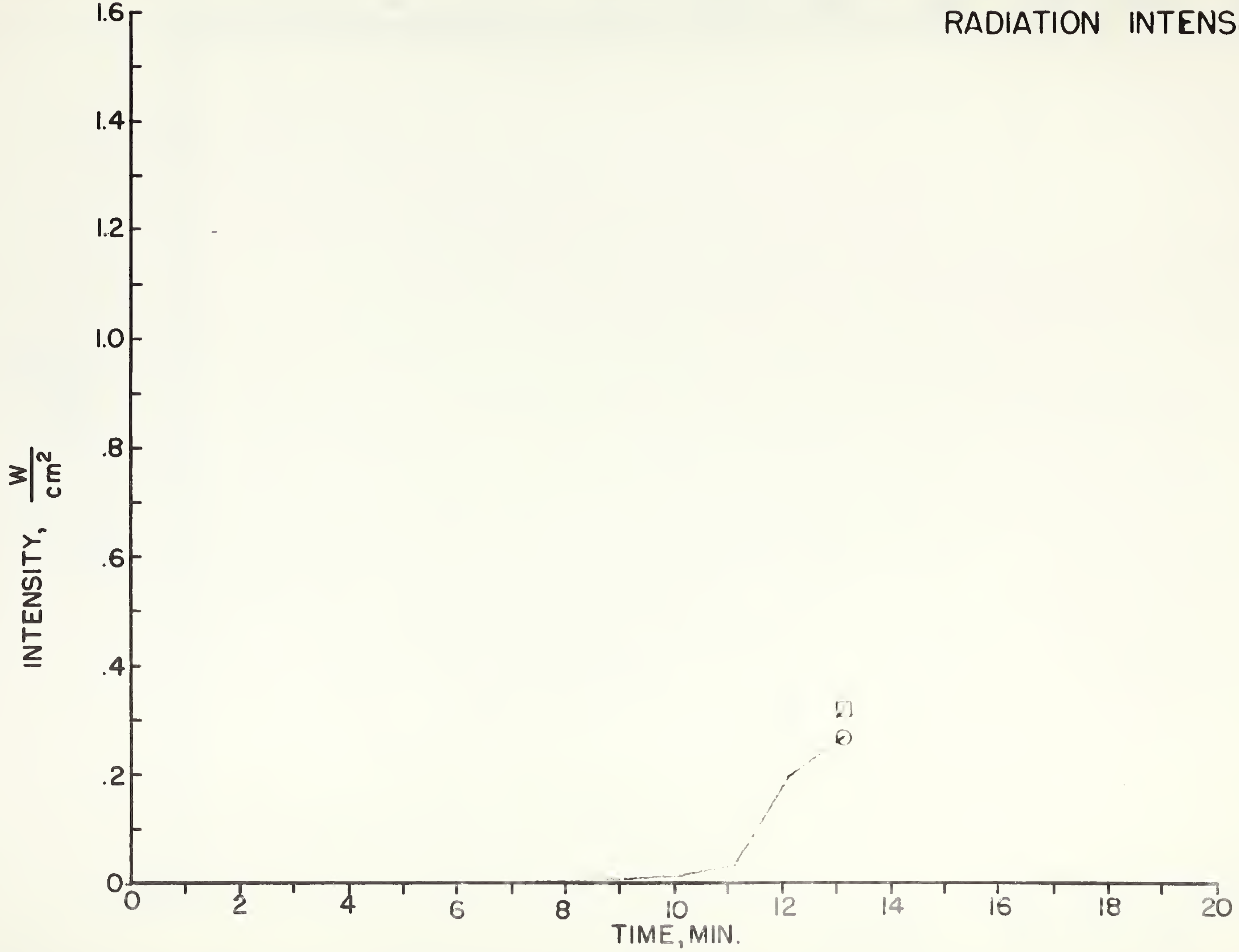


FIG. 80 TEST NO. 19
RADIATION INTENSITY

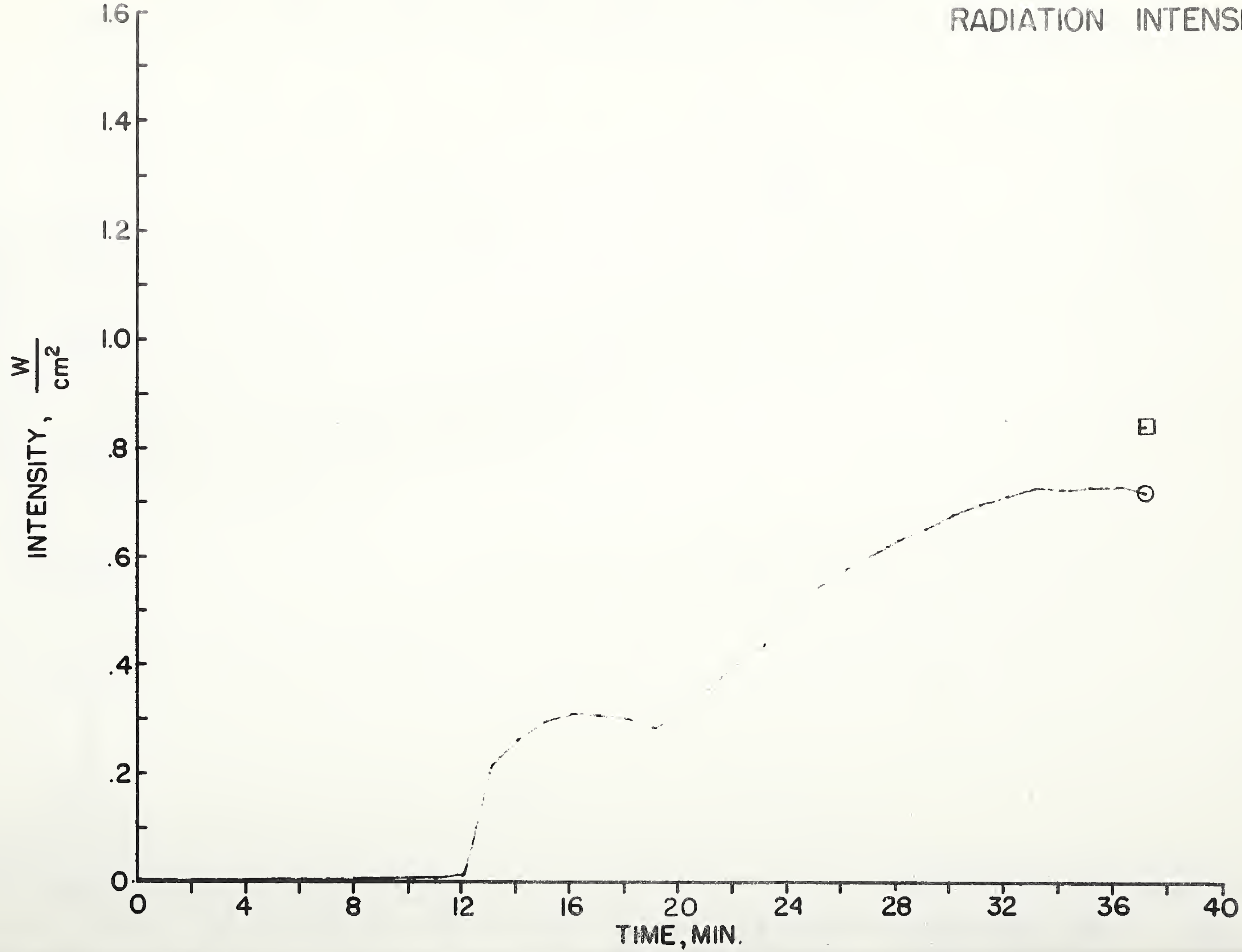


FIG. 81 TEST NO. 20

RADIATION INTENSITY

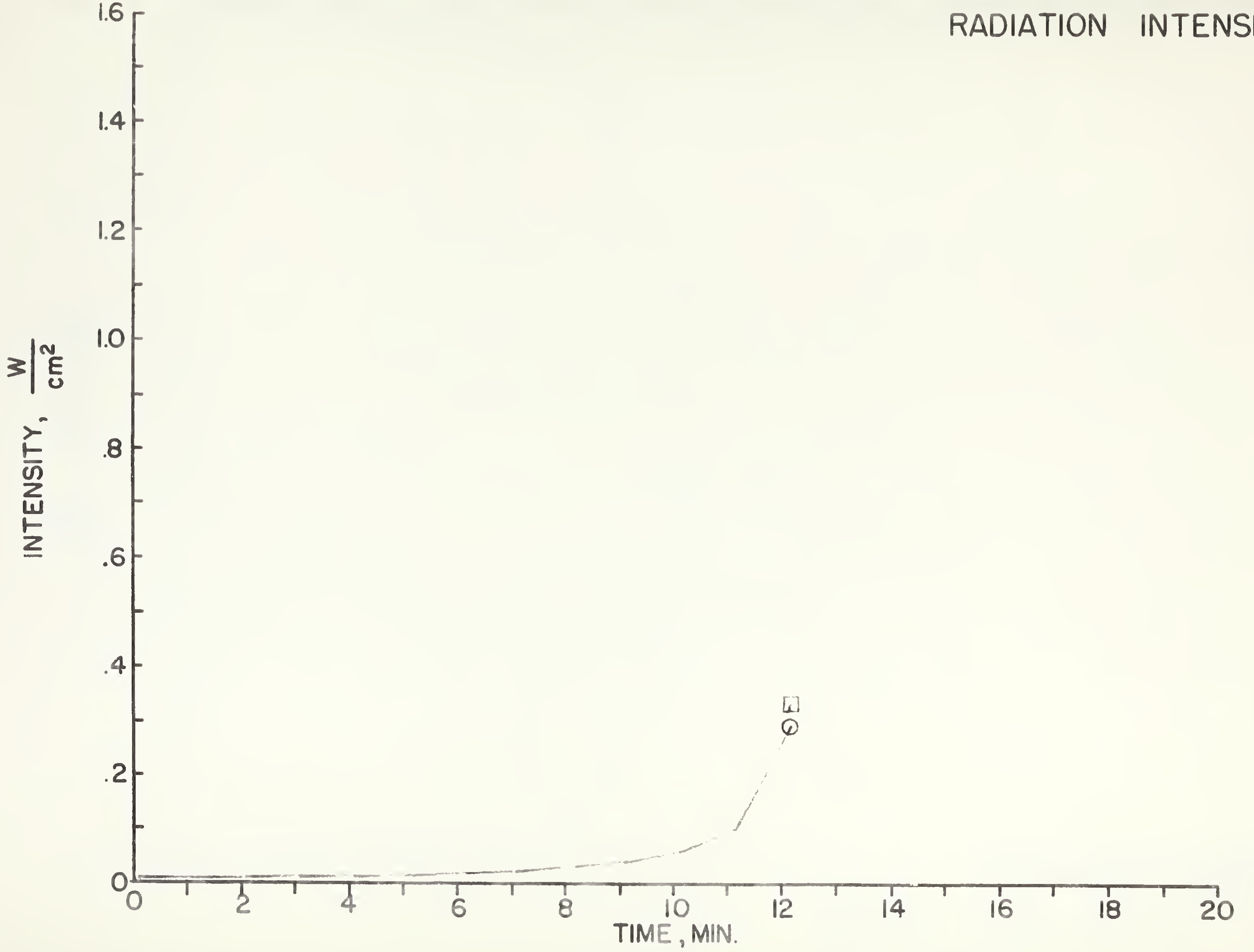


FIG. 82 TEST NO. 21

RADIATION INTENSITY

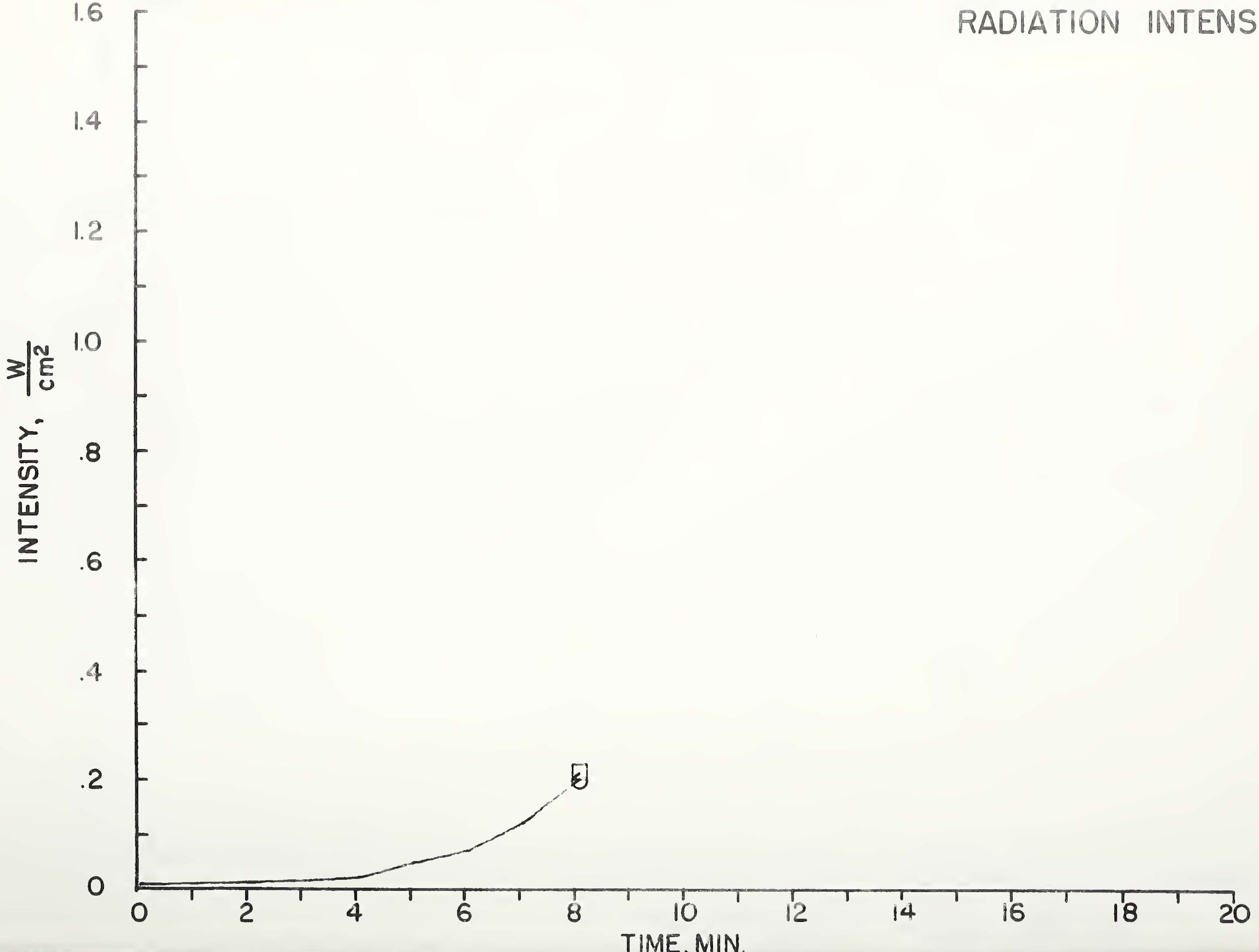


FIG. 83 TEST NO. 22

RADIATION INTENSITY

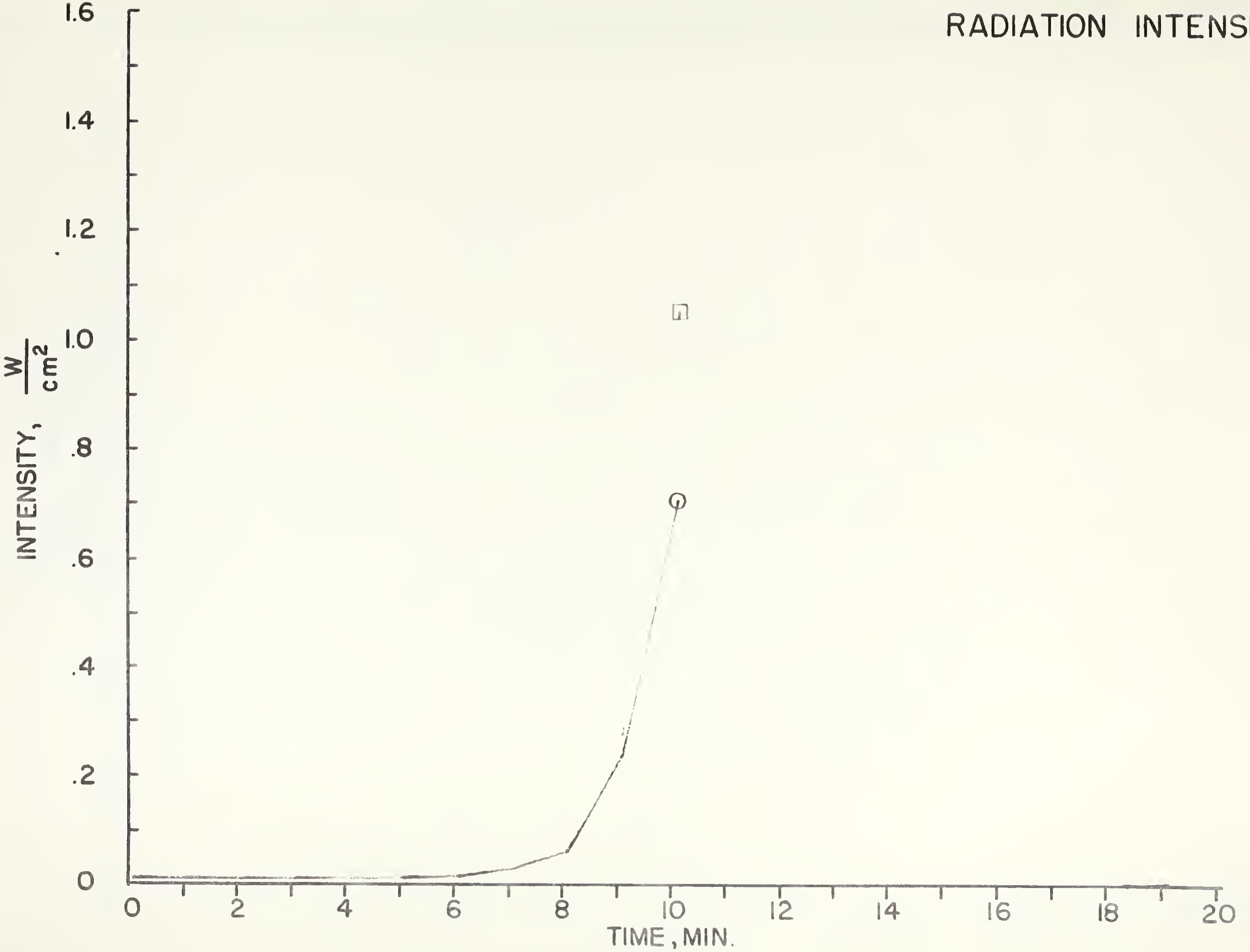


FIG. 84 TEST NO. 23
RADIATION INTENSITY

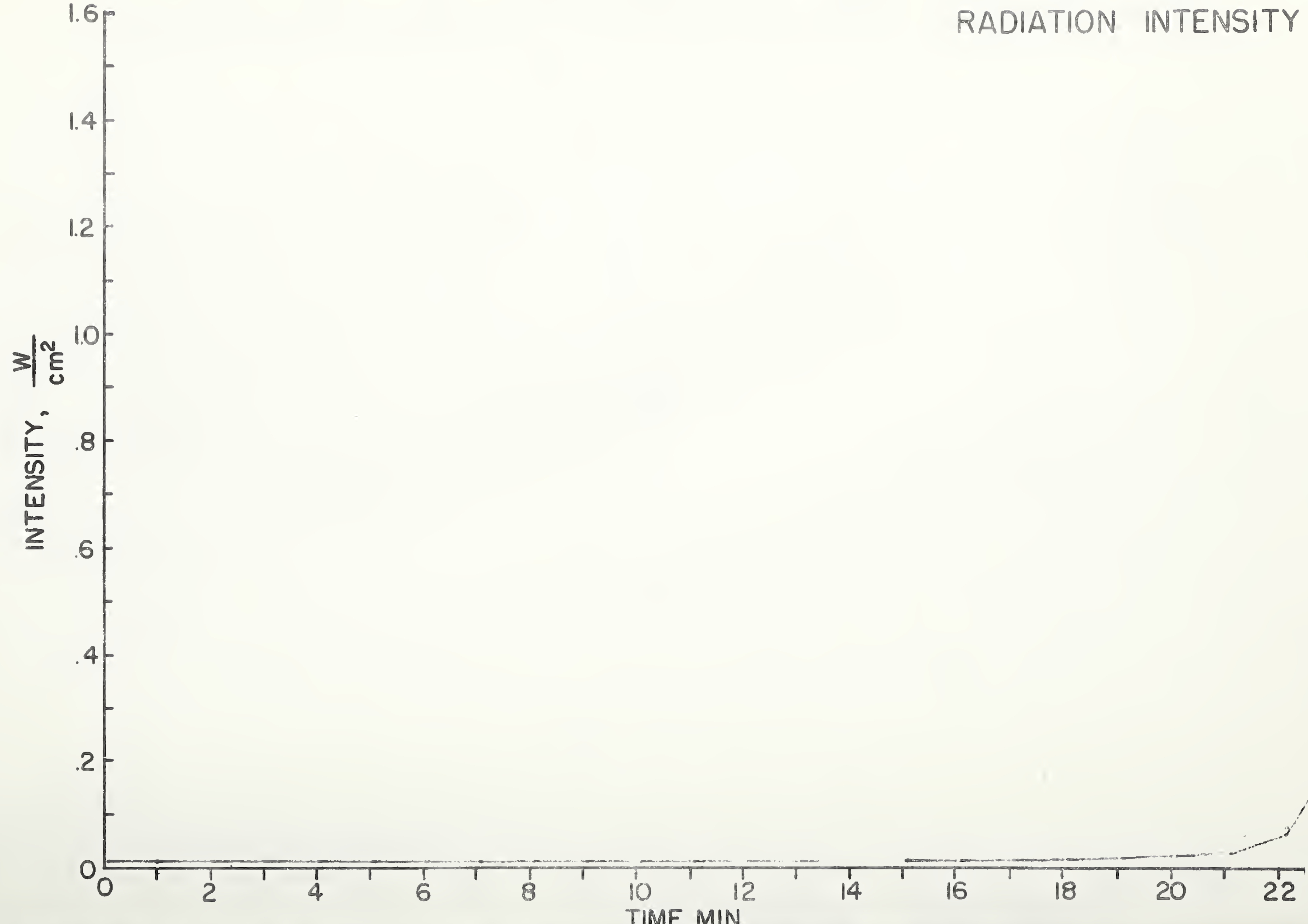


FIG. 85 TEST NO. 24

RADIATION INTENSITY

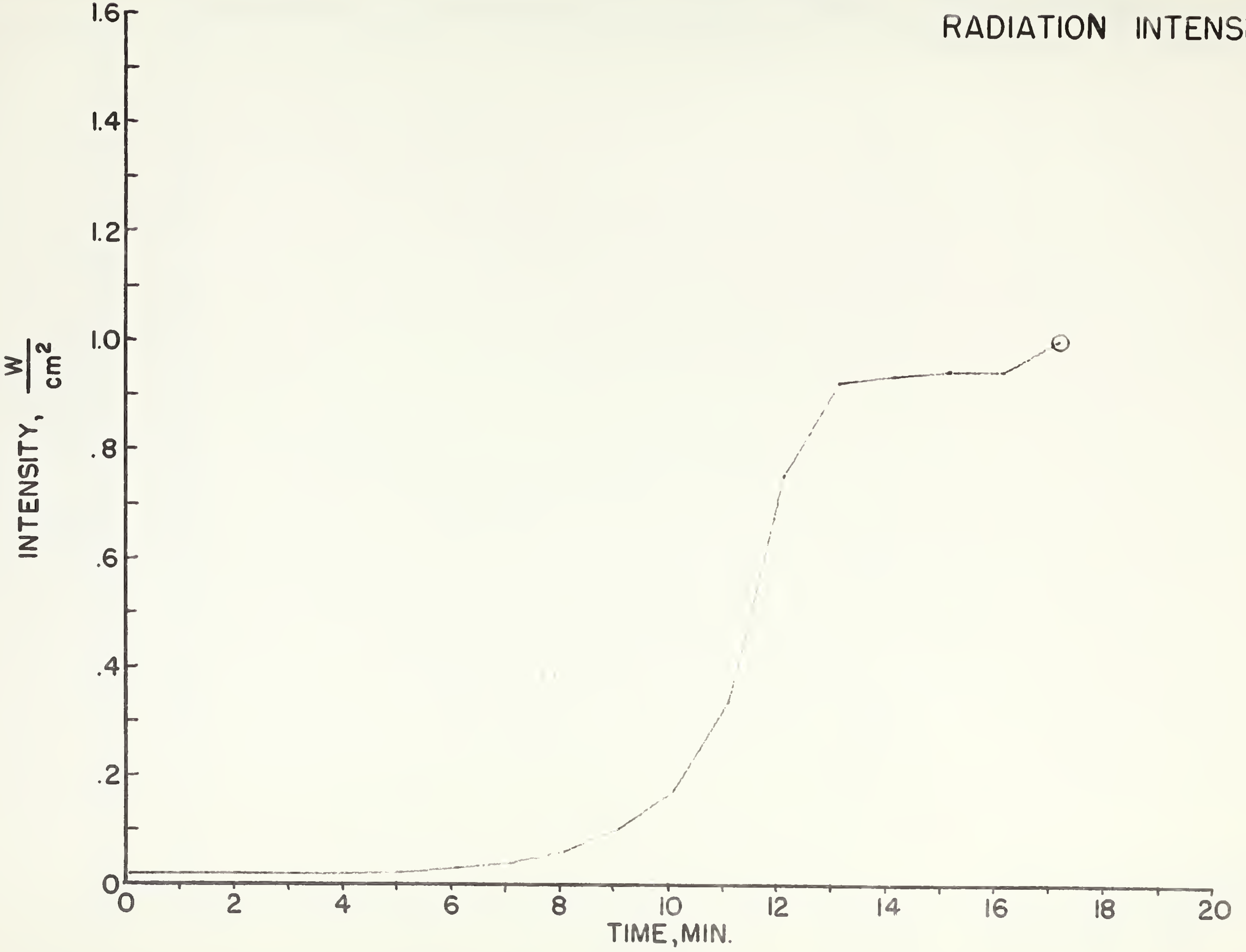


FIG. 86 TEST NO. 25

RADIATION INTENSITY

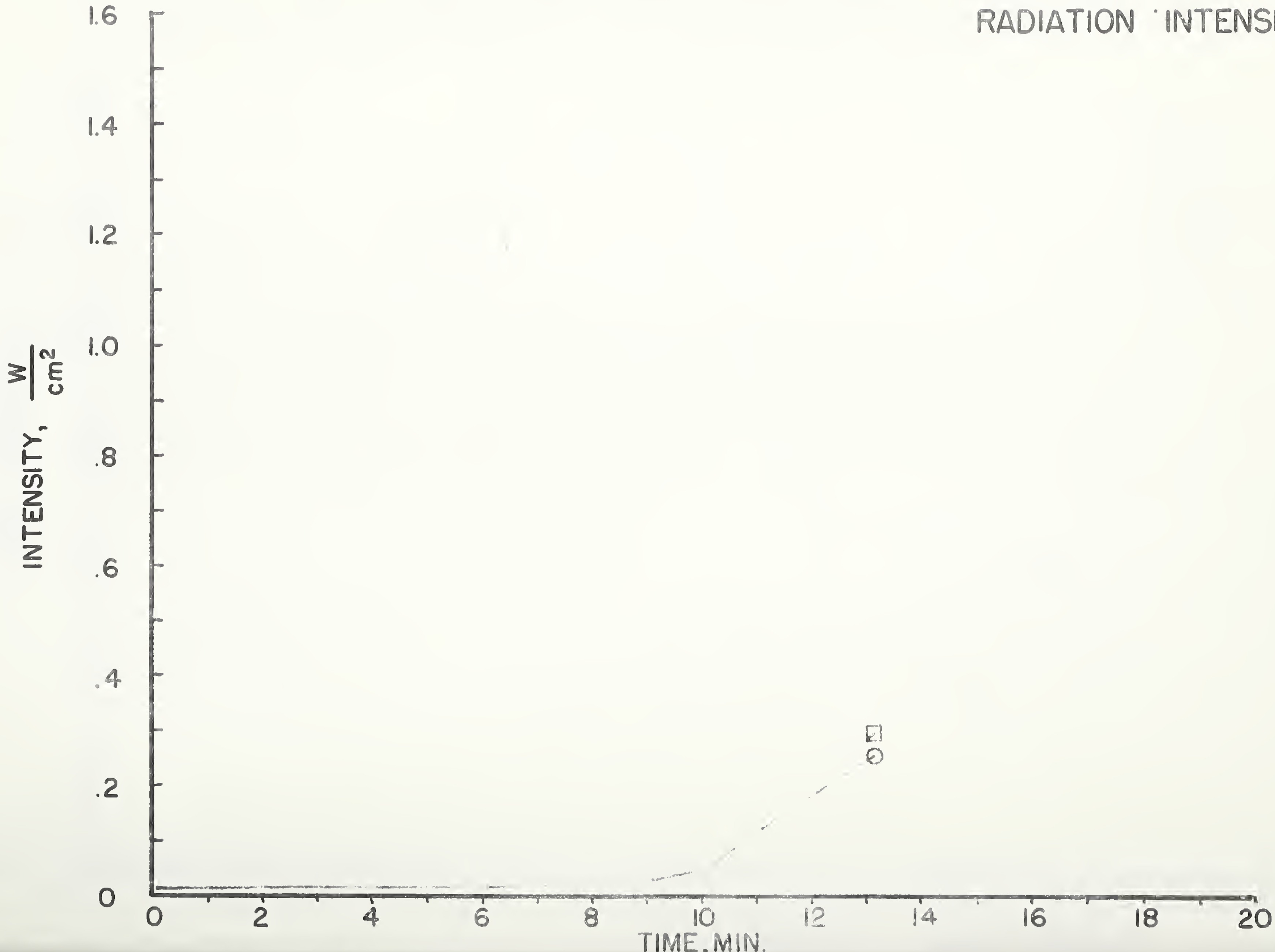


FIG.87 TEST NO. 26

RADIATION INTENSITY

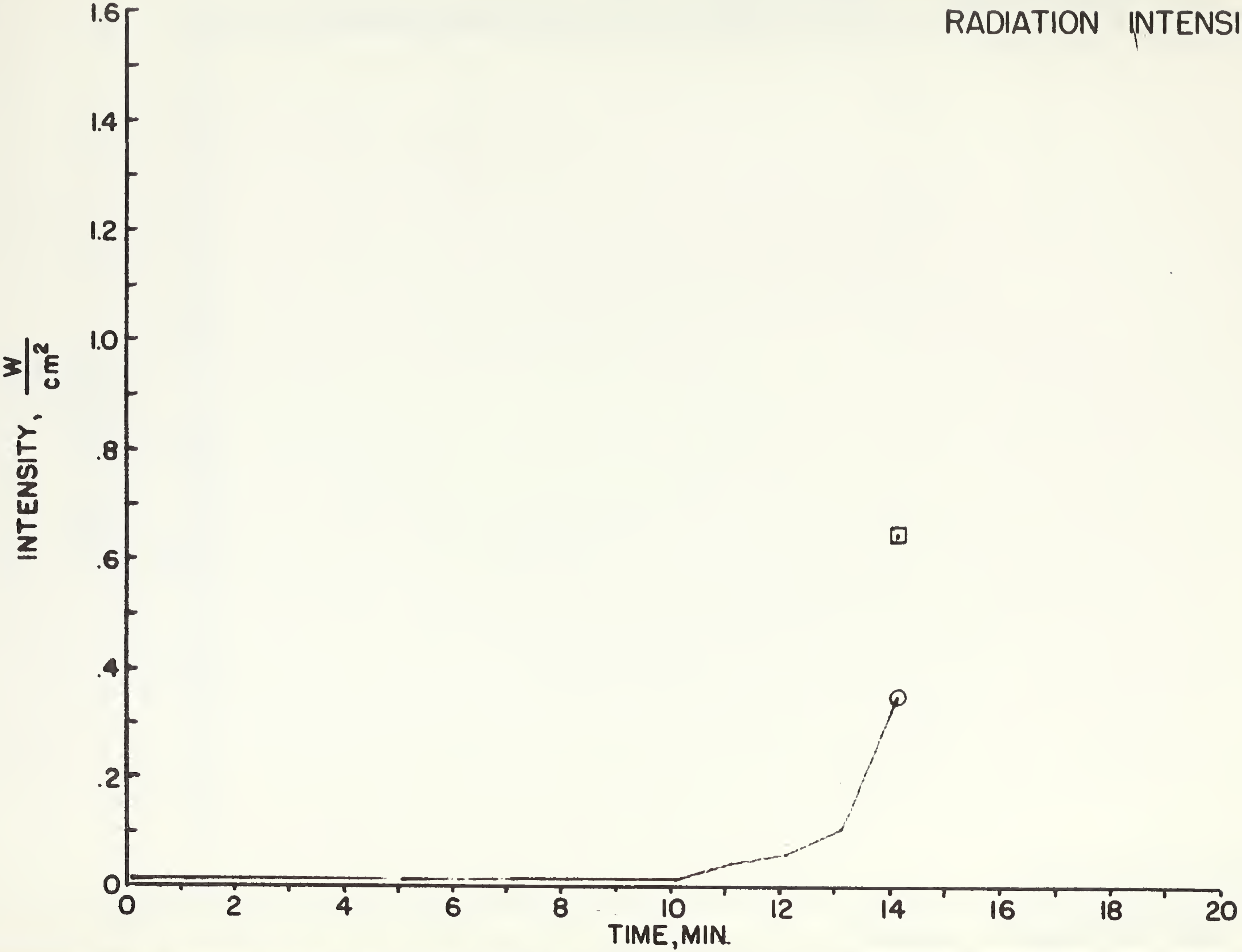


FIG. 88 TEST NO. 27
RADIATION INTENSITY

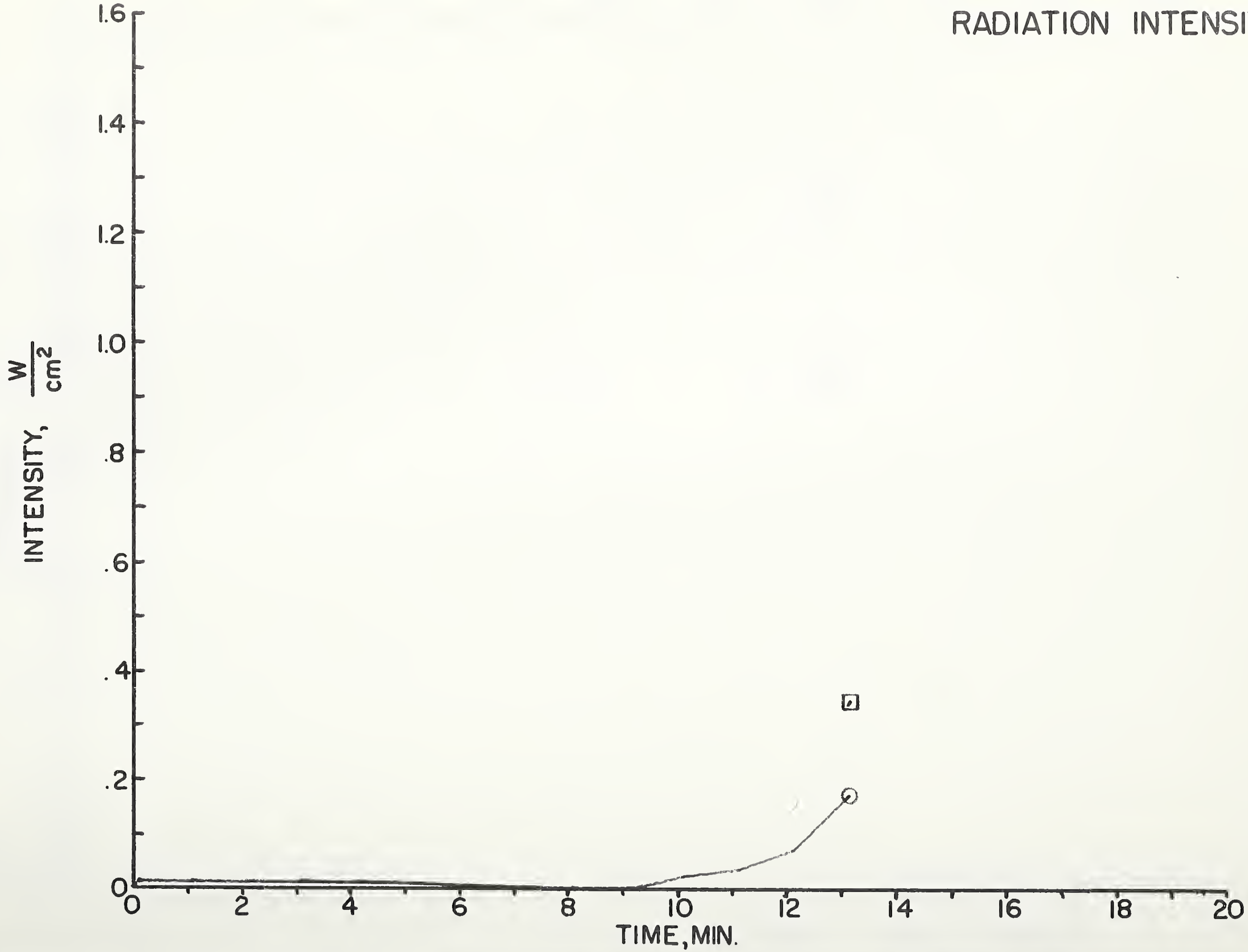


FIG. 89 TEST NO. 28

RADIATION INTENSITY

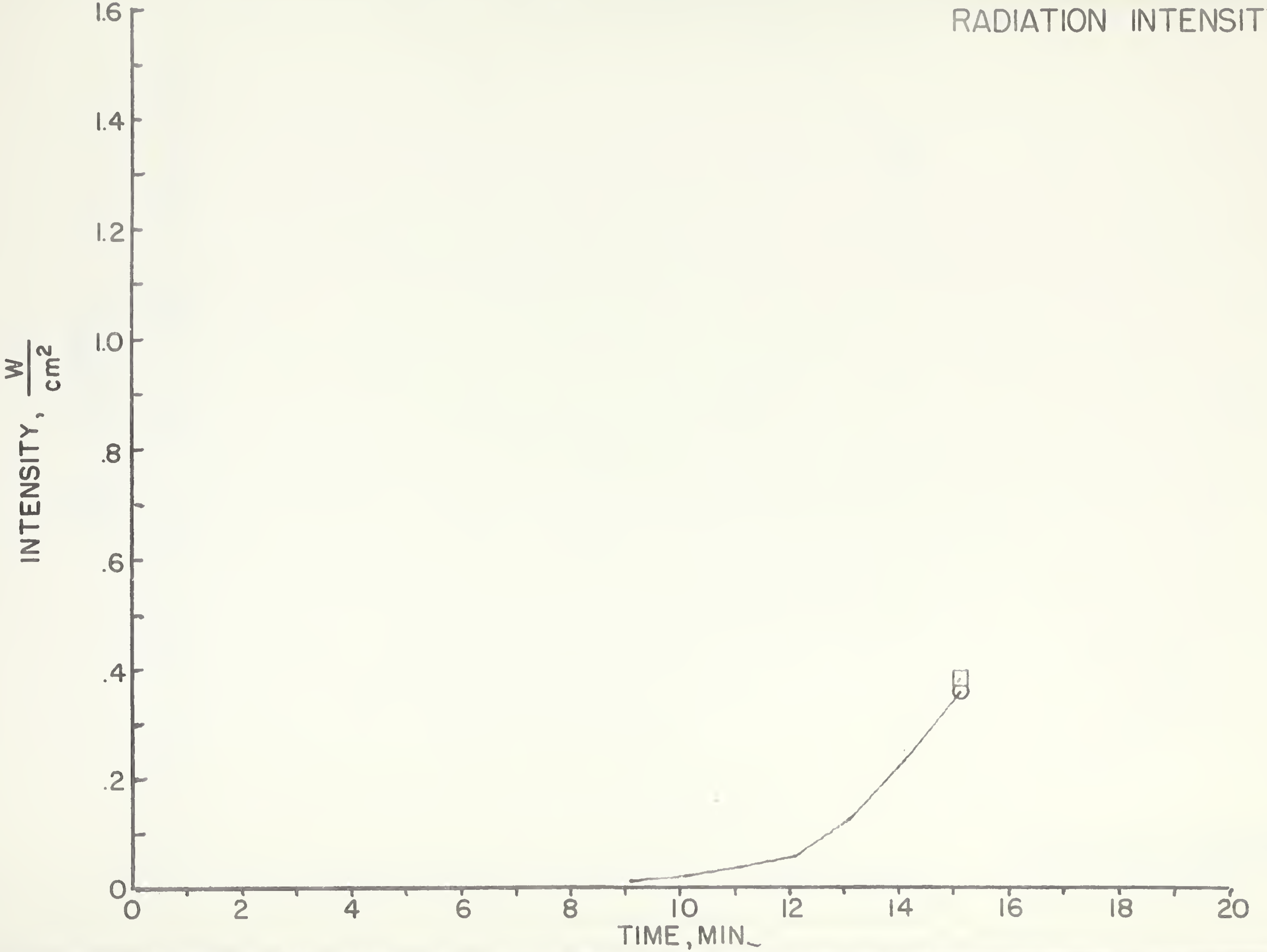


FIG. 90 TEST NO. 29
RADIATION INTENSITY

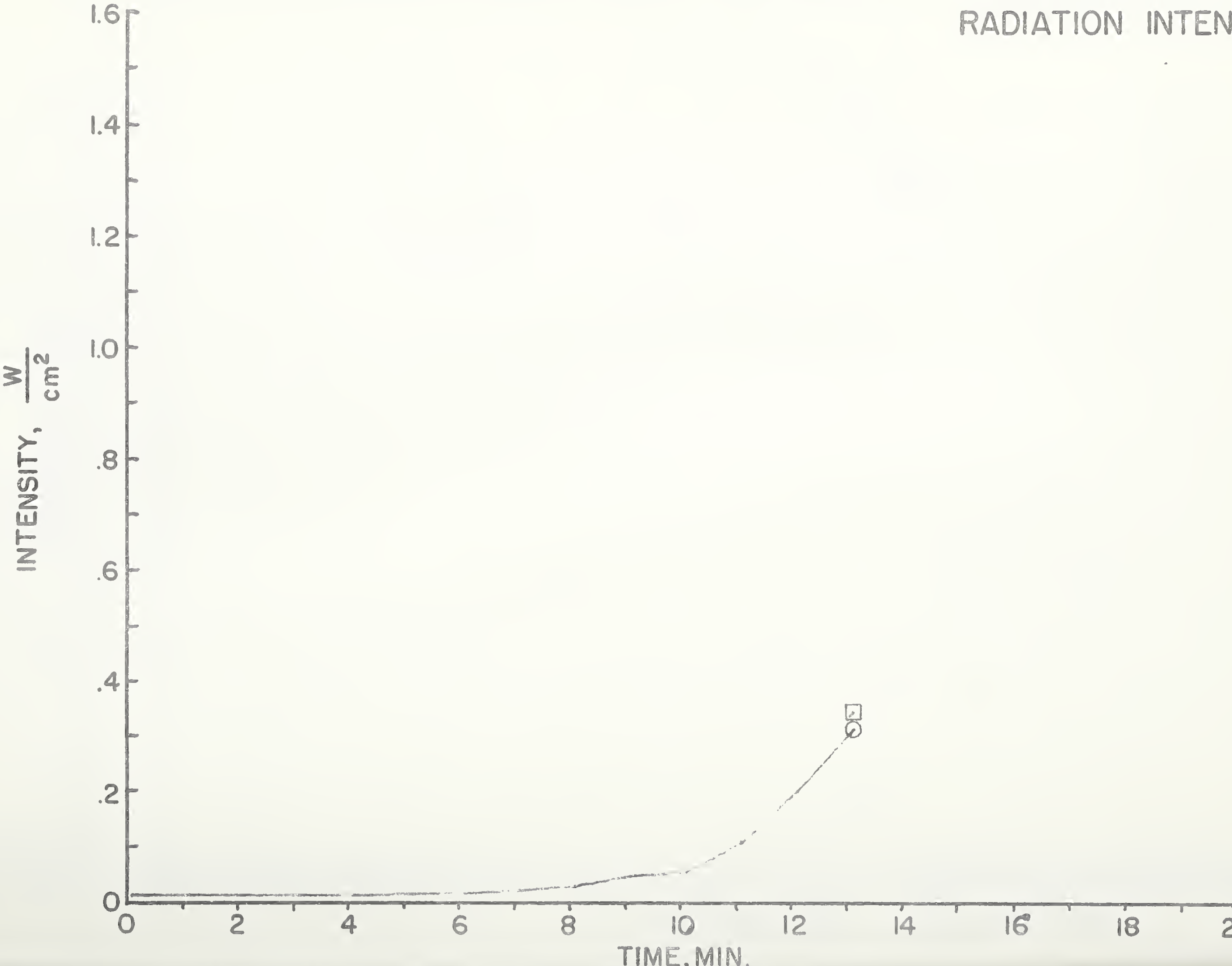


FIG. 91 TEST NO. 30

RADIATION INTENSITY

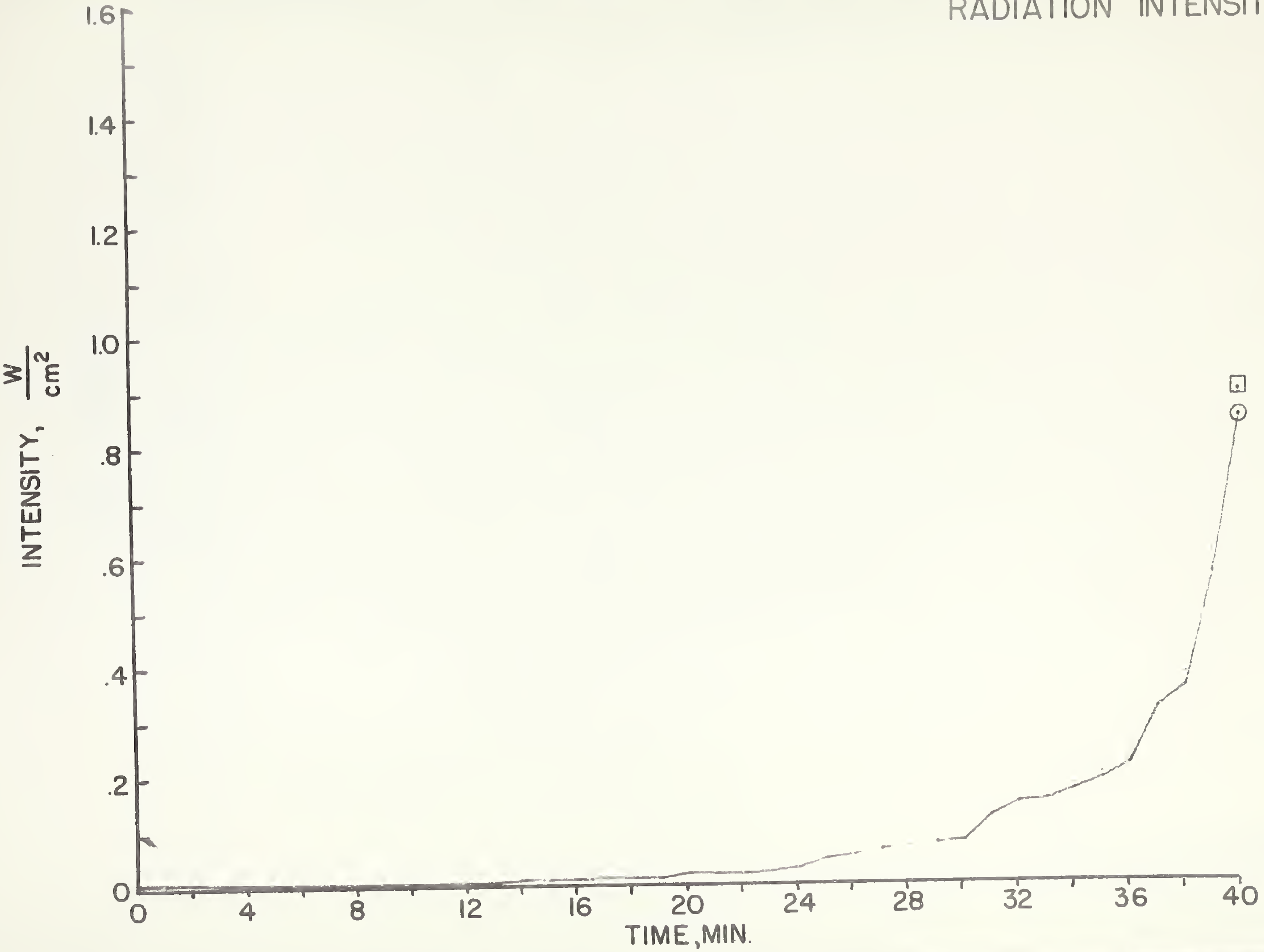


FIG. 92 TEST NO. 31
RADIATION INTENSITY

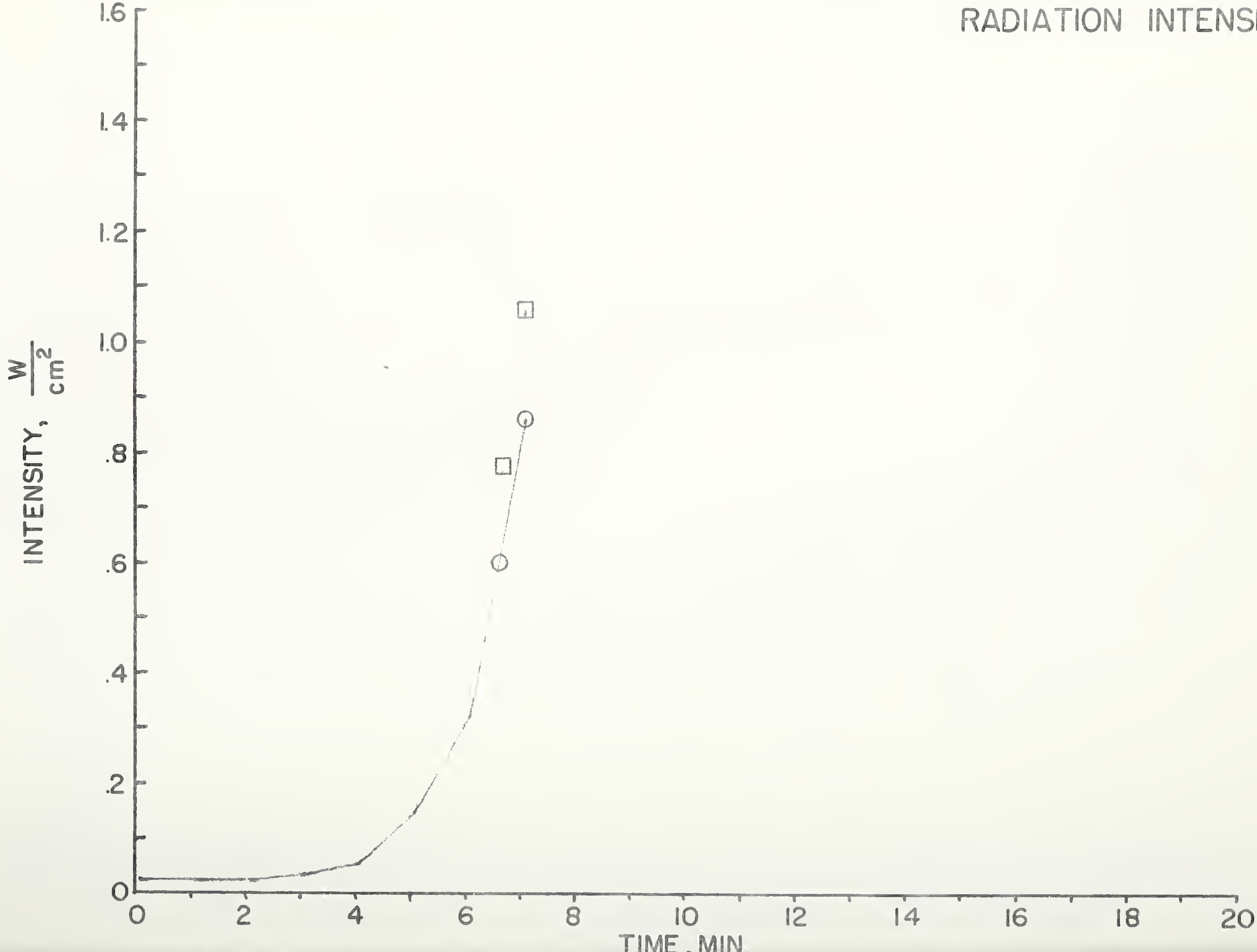


FIG. 93 TEST NO. 32

RADIATION INTENSITY

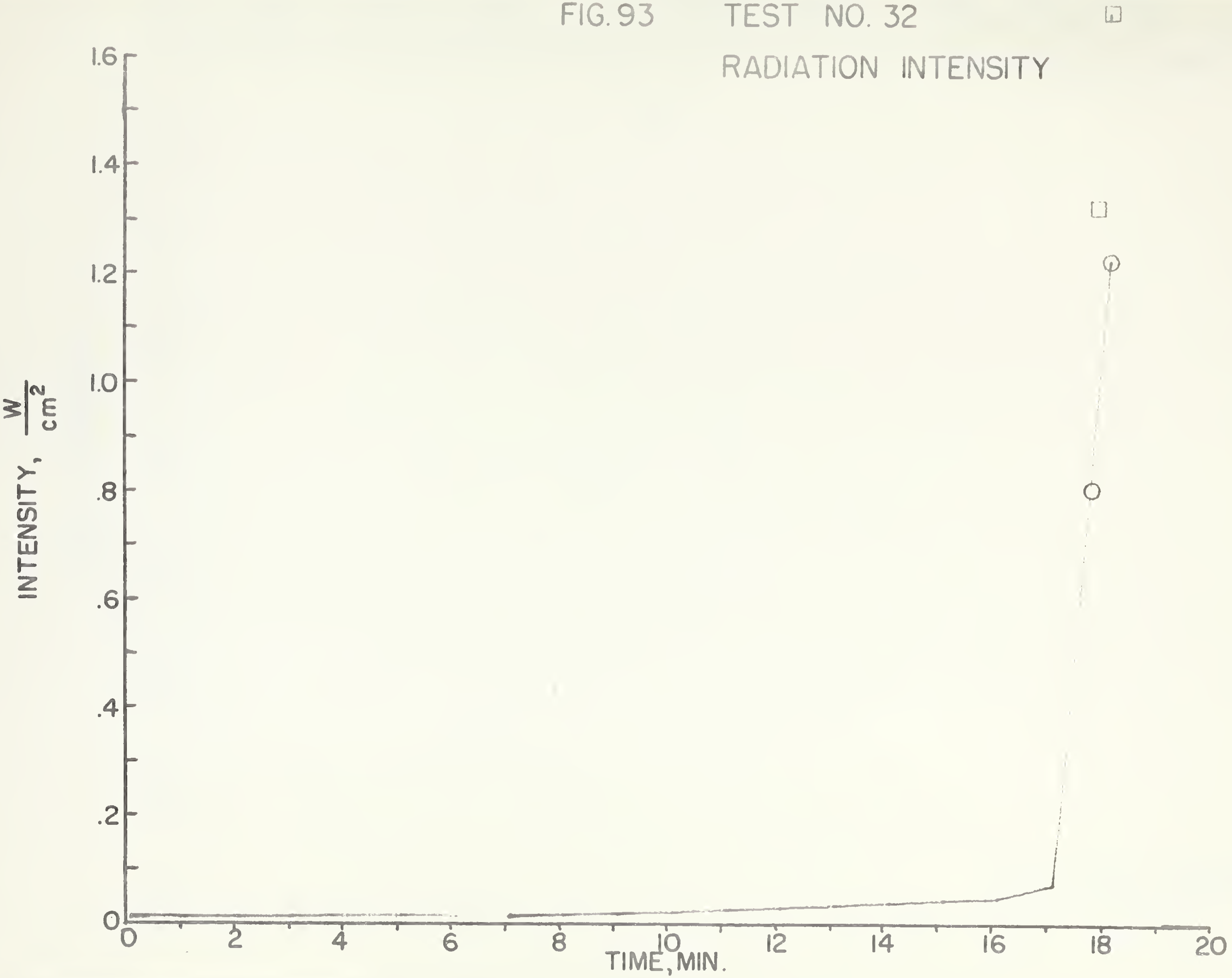


FIG. 94 TEST NO. 33

RADIATION INTENSITY

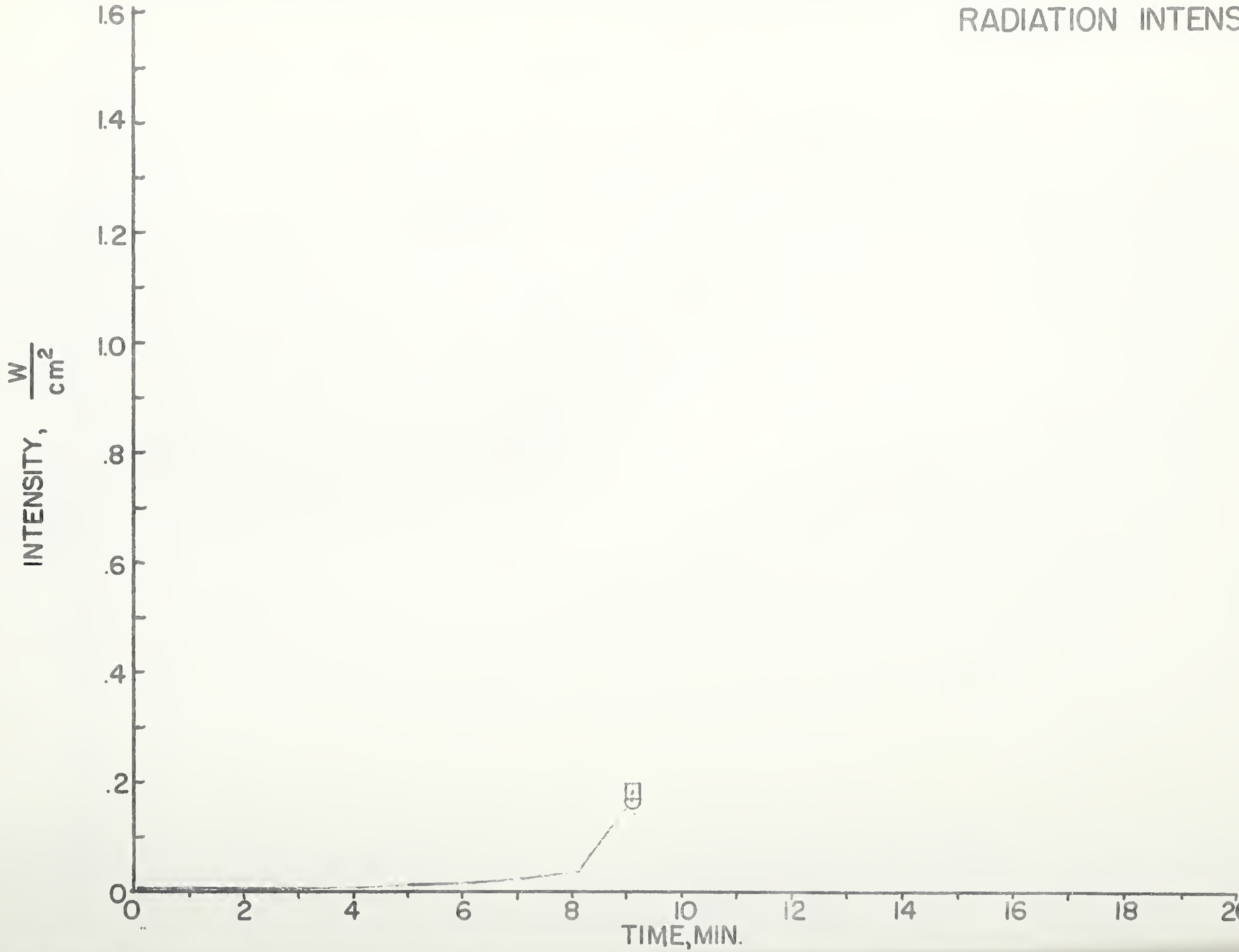
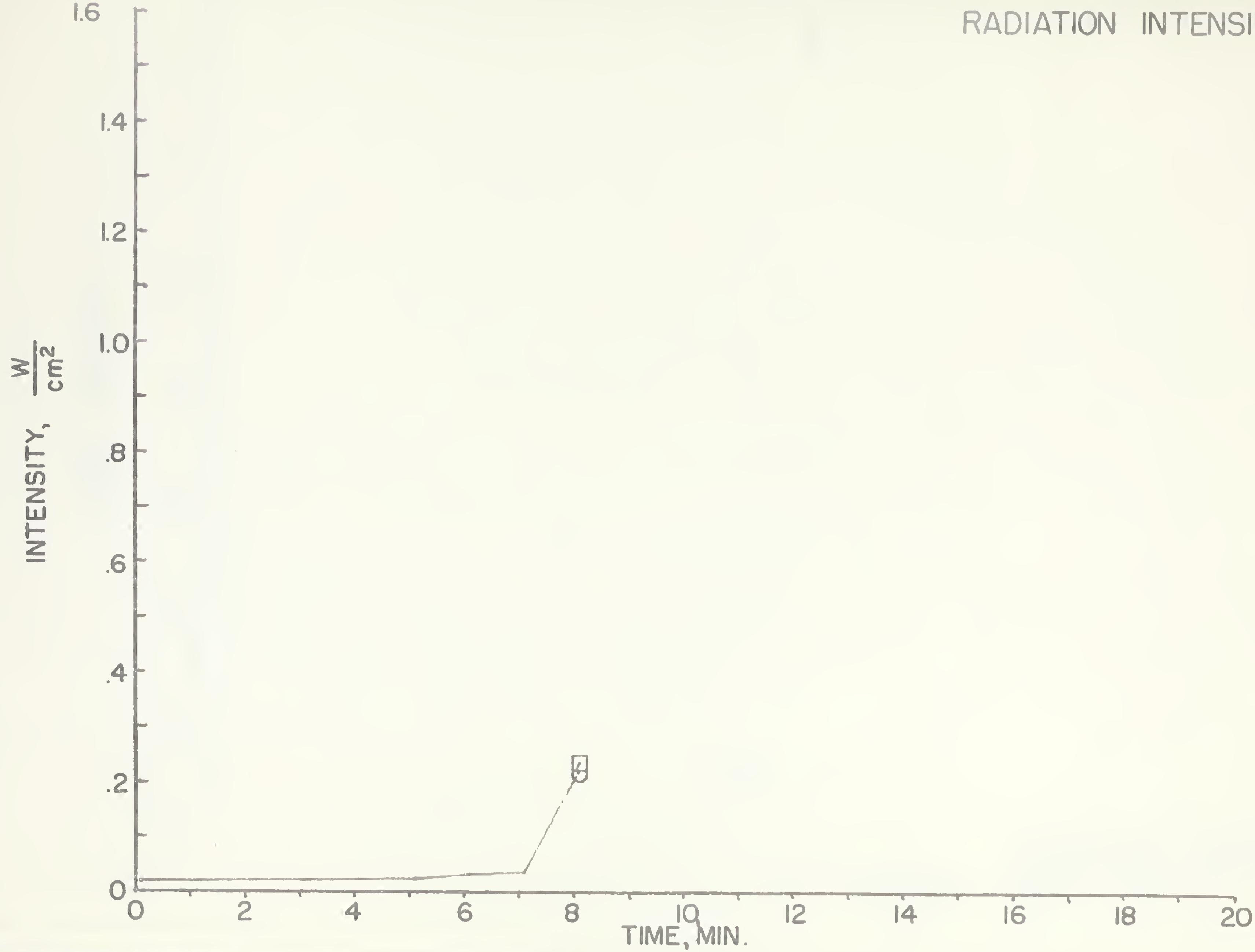


FIG. 95 TEST NO. 34

RADIATION INTENSITY



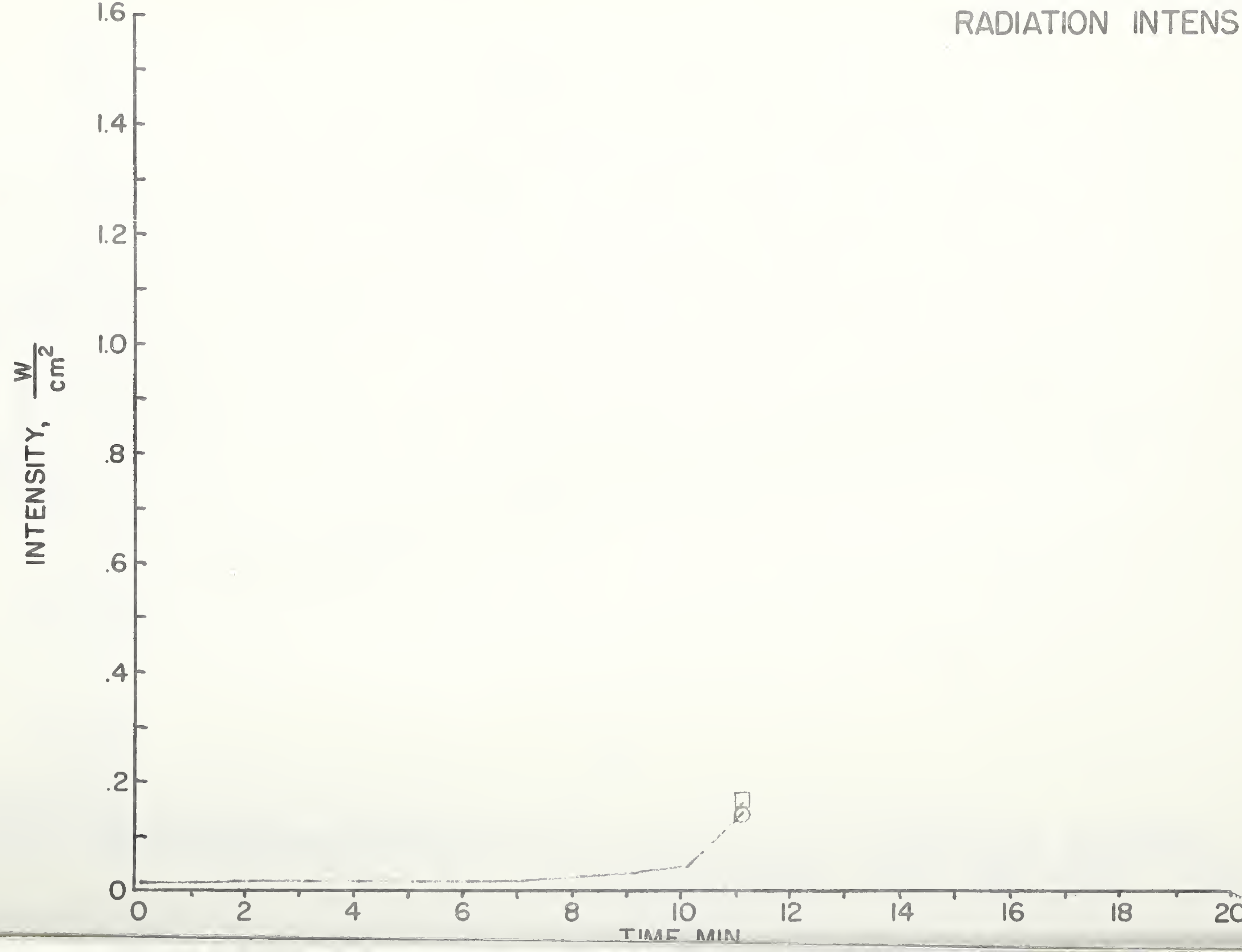
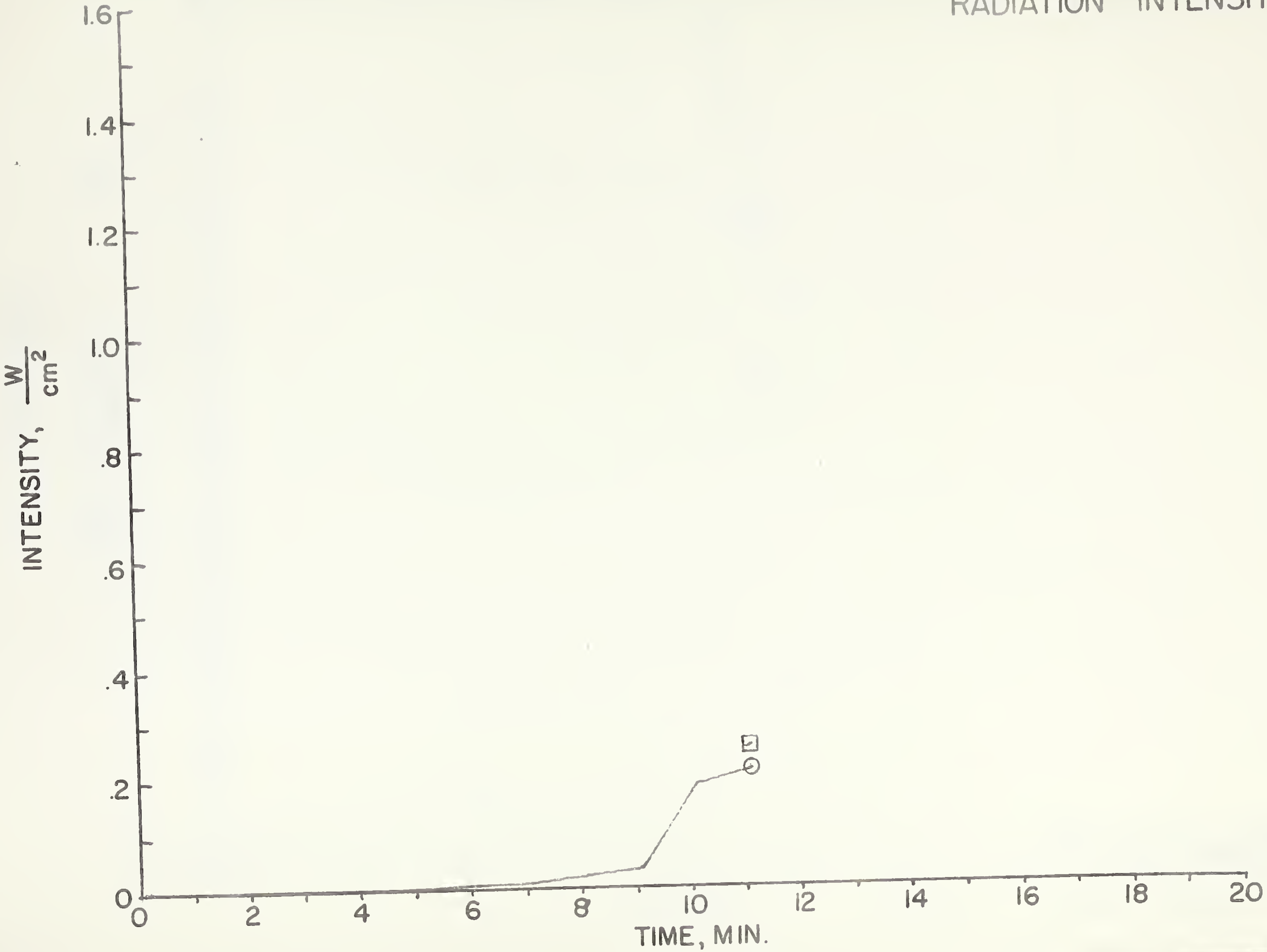


FIG. 96 TEST NO. 35
RADIATION INTENSITY

FIG. 97 TEST NO. 36

RADIATION INTENSITY



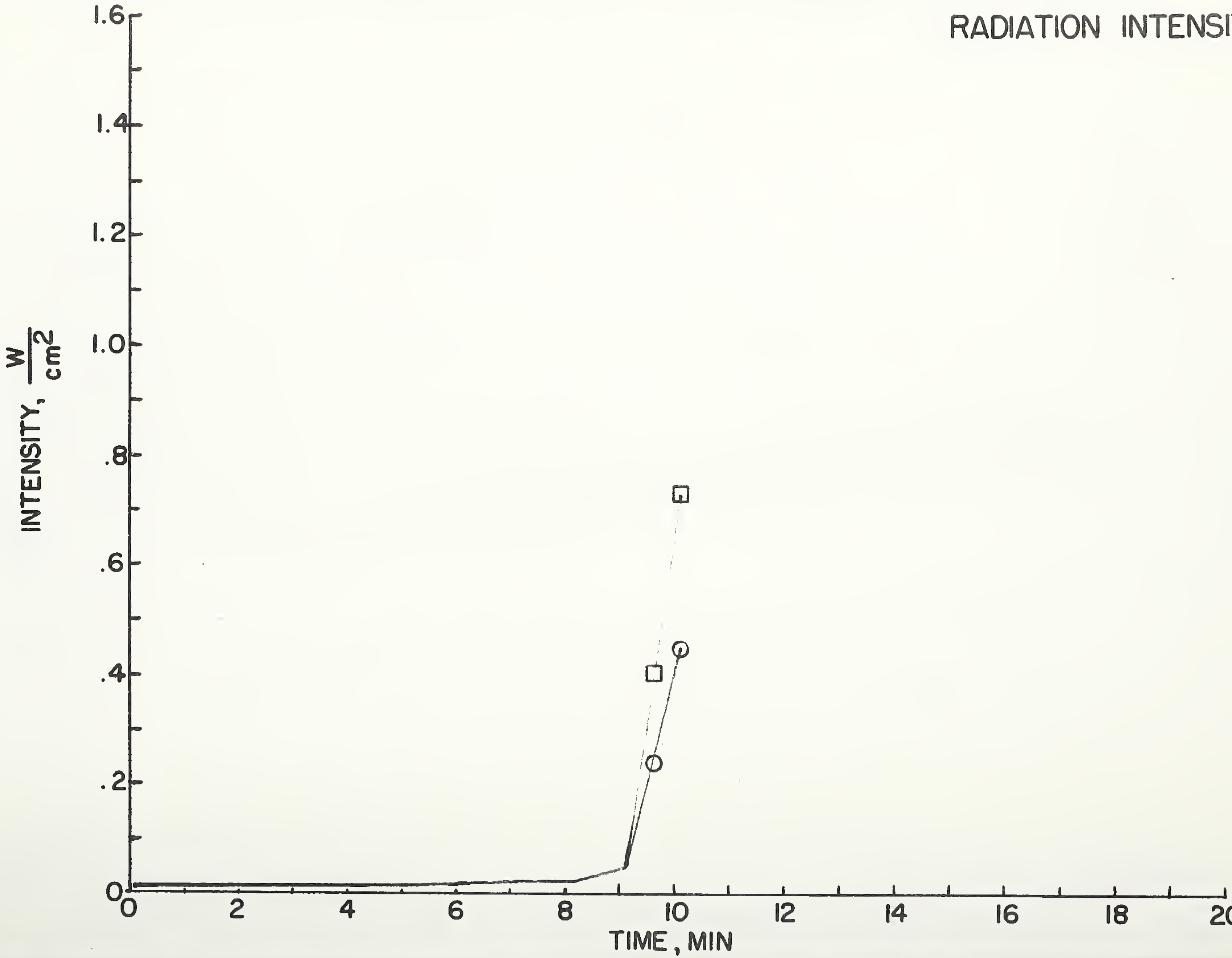


FIG. 98 TEST NO. 37
RADIATION INTENSITY

FIG. 99 TEST NO. 2

GAS CONCENTRATION

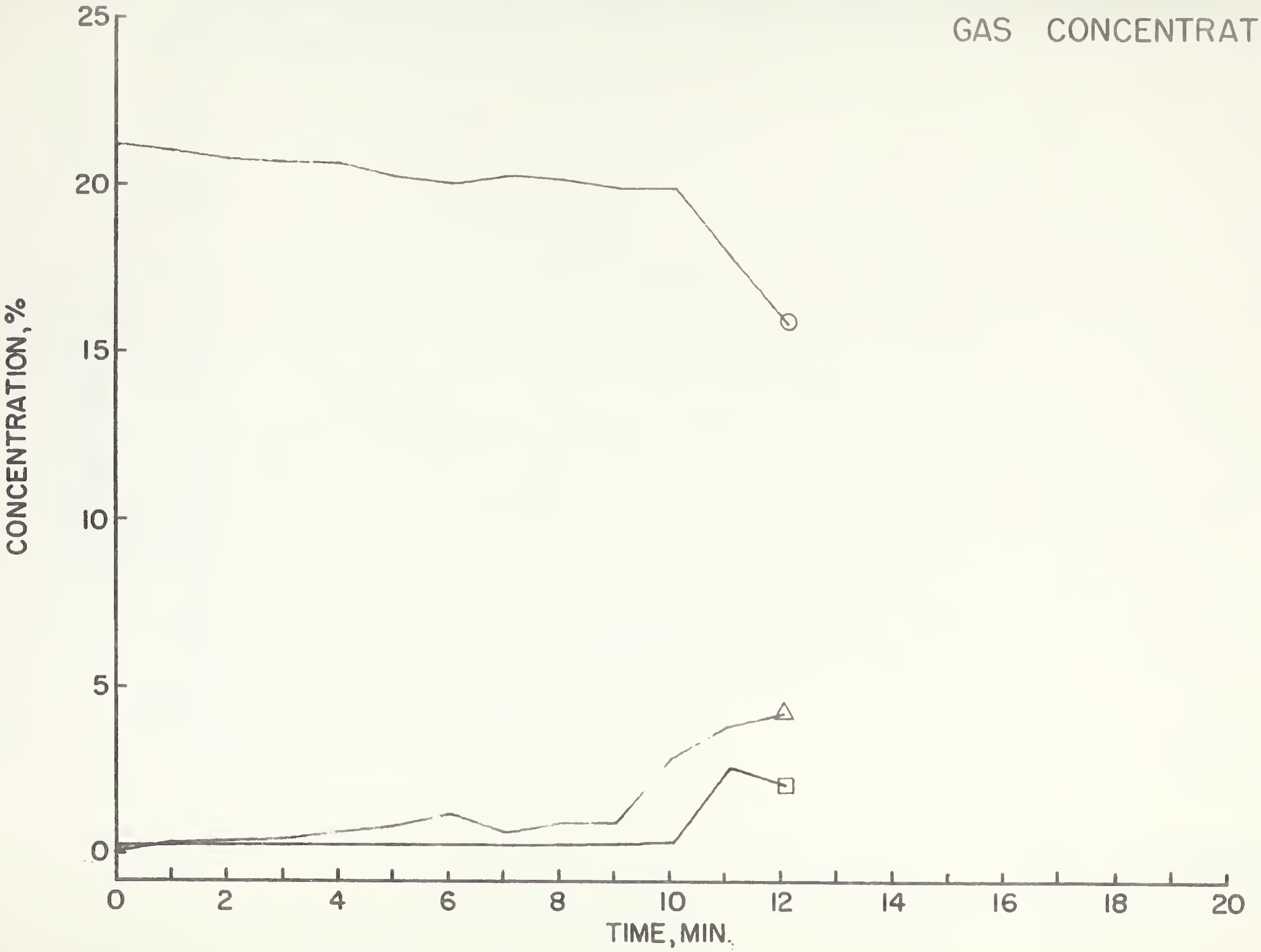


FIG. 100 TEST NO. 3

GAS CONCENTRATION

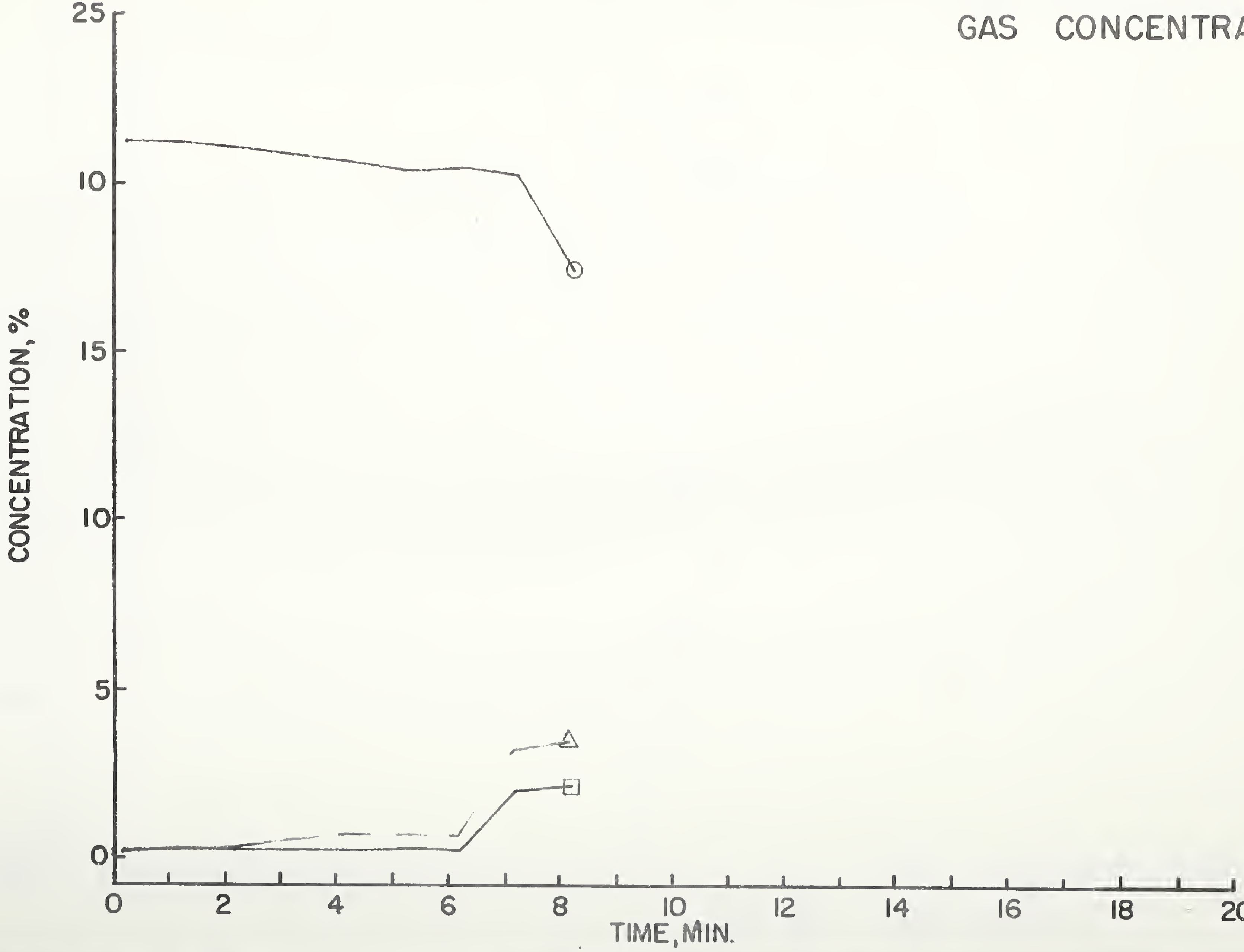


FIG. 101 TEST NO. 4

GAS CONCENTRATION

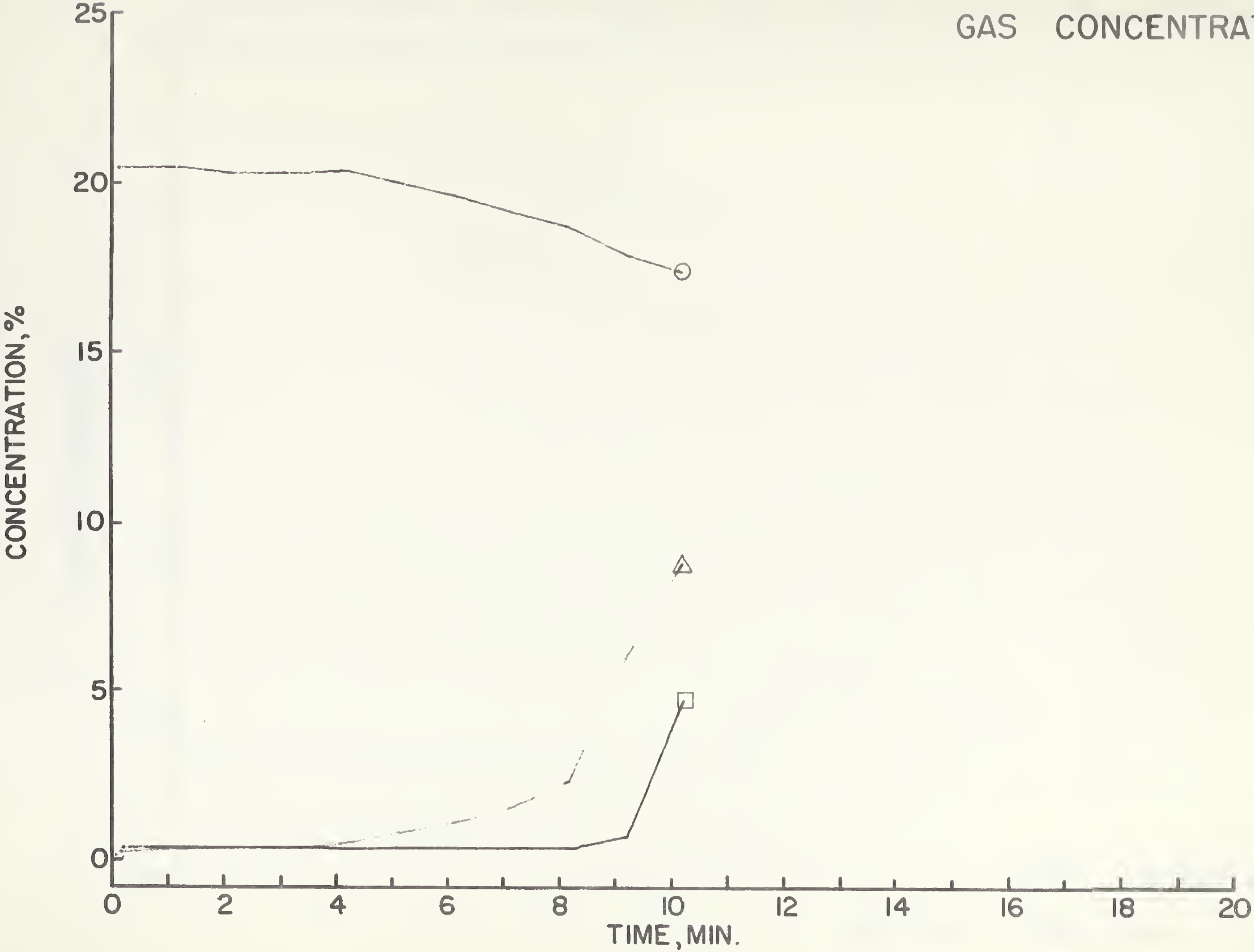


FIG. 102 TEST NO. 5

GAS CONCENTRATION

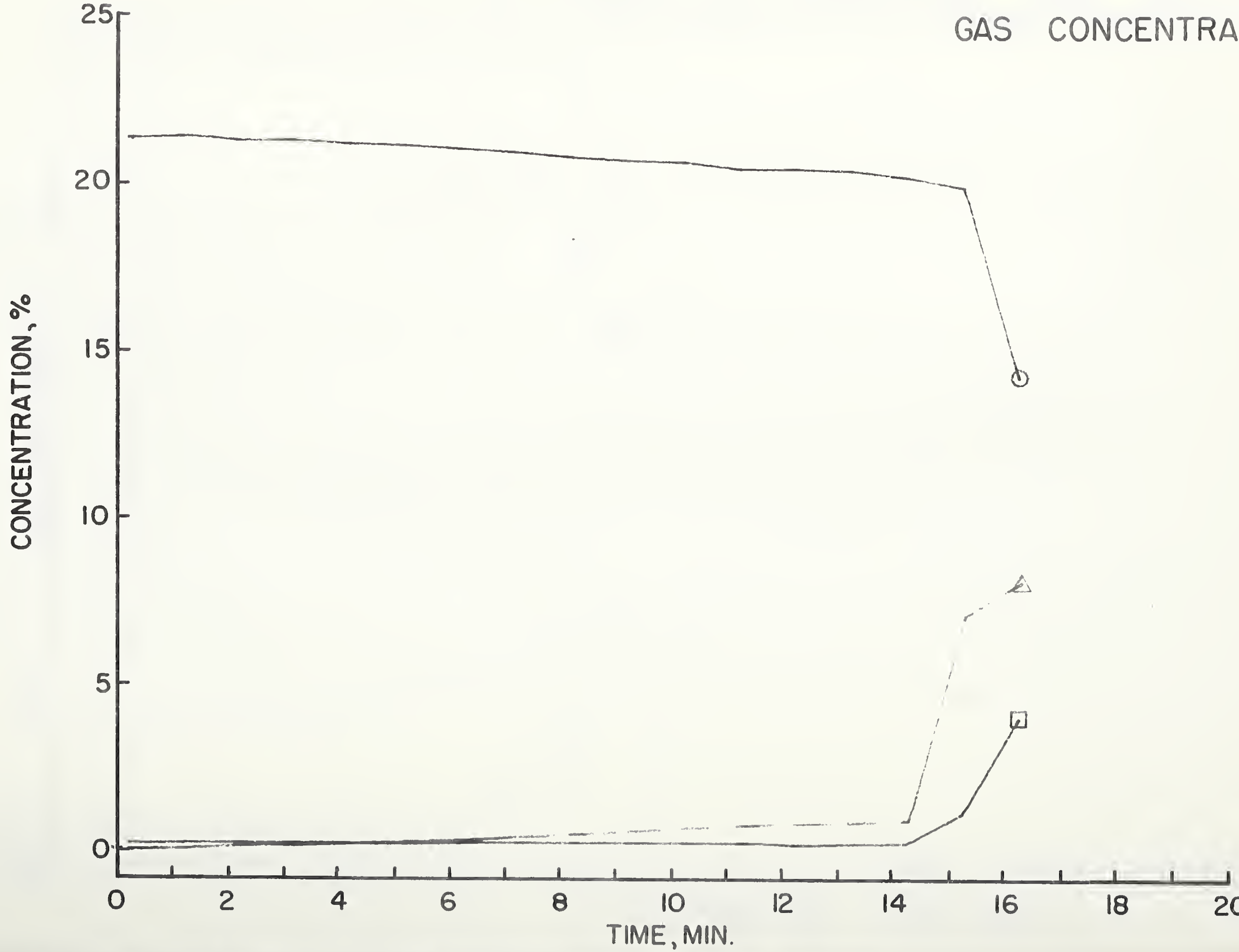


FIG. 103 TEST NO. 6

GAS CONCENTRATION

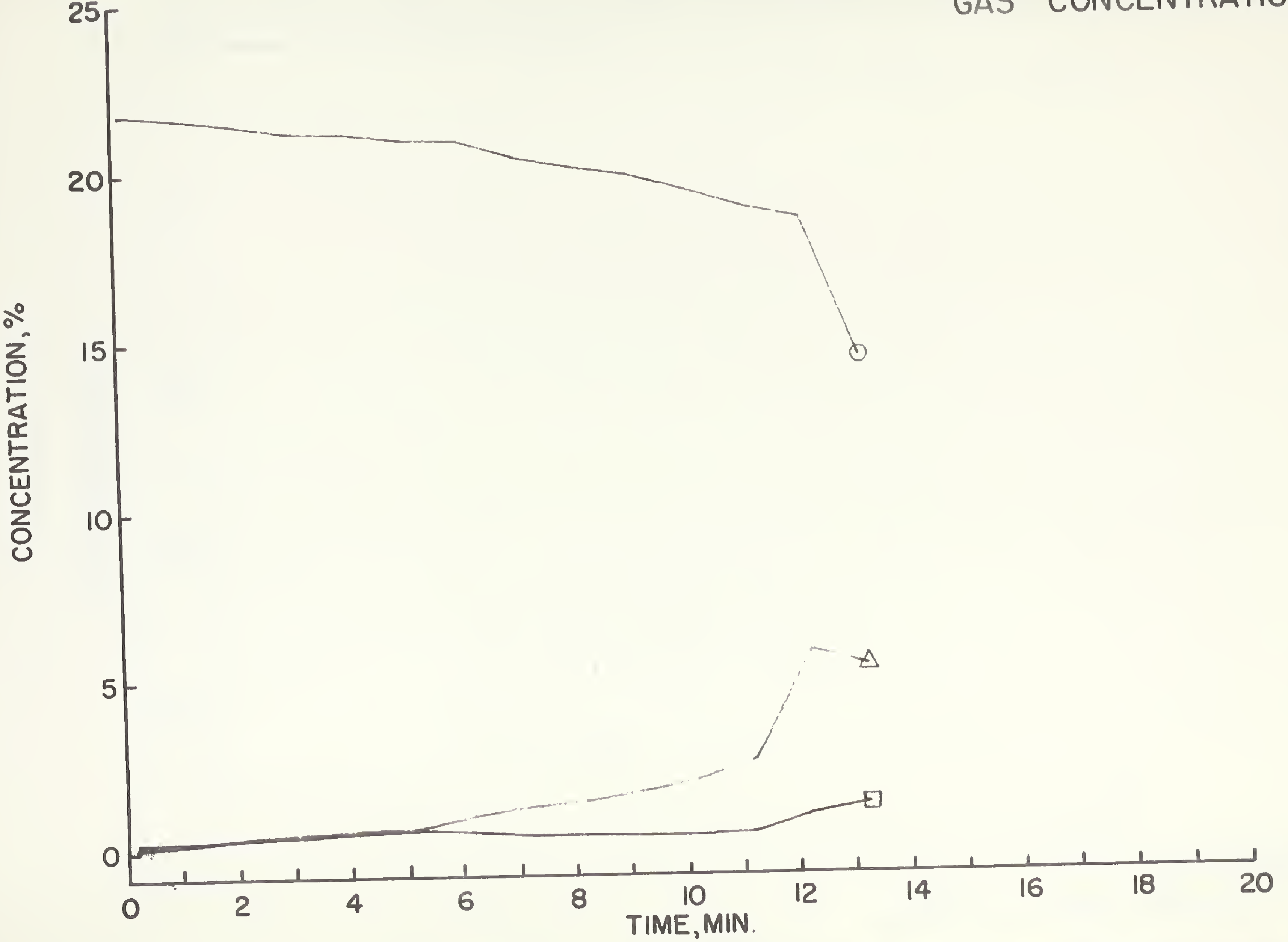


FIG. 104 TEST NO. 7
GAS CONCENTRATION

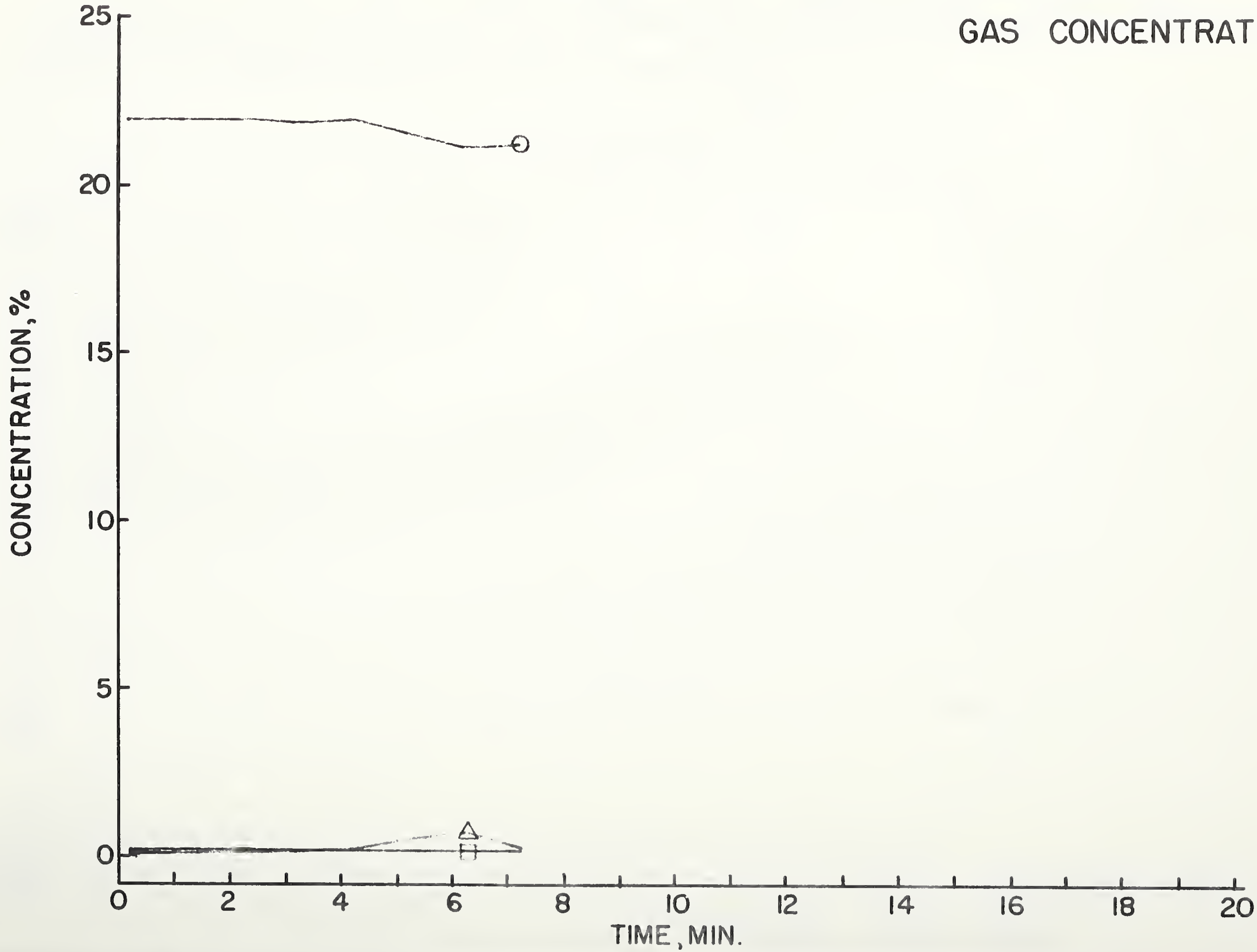


FIG. 105 TEST NO. 8
GAS CONCENTRATION

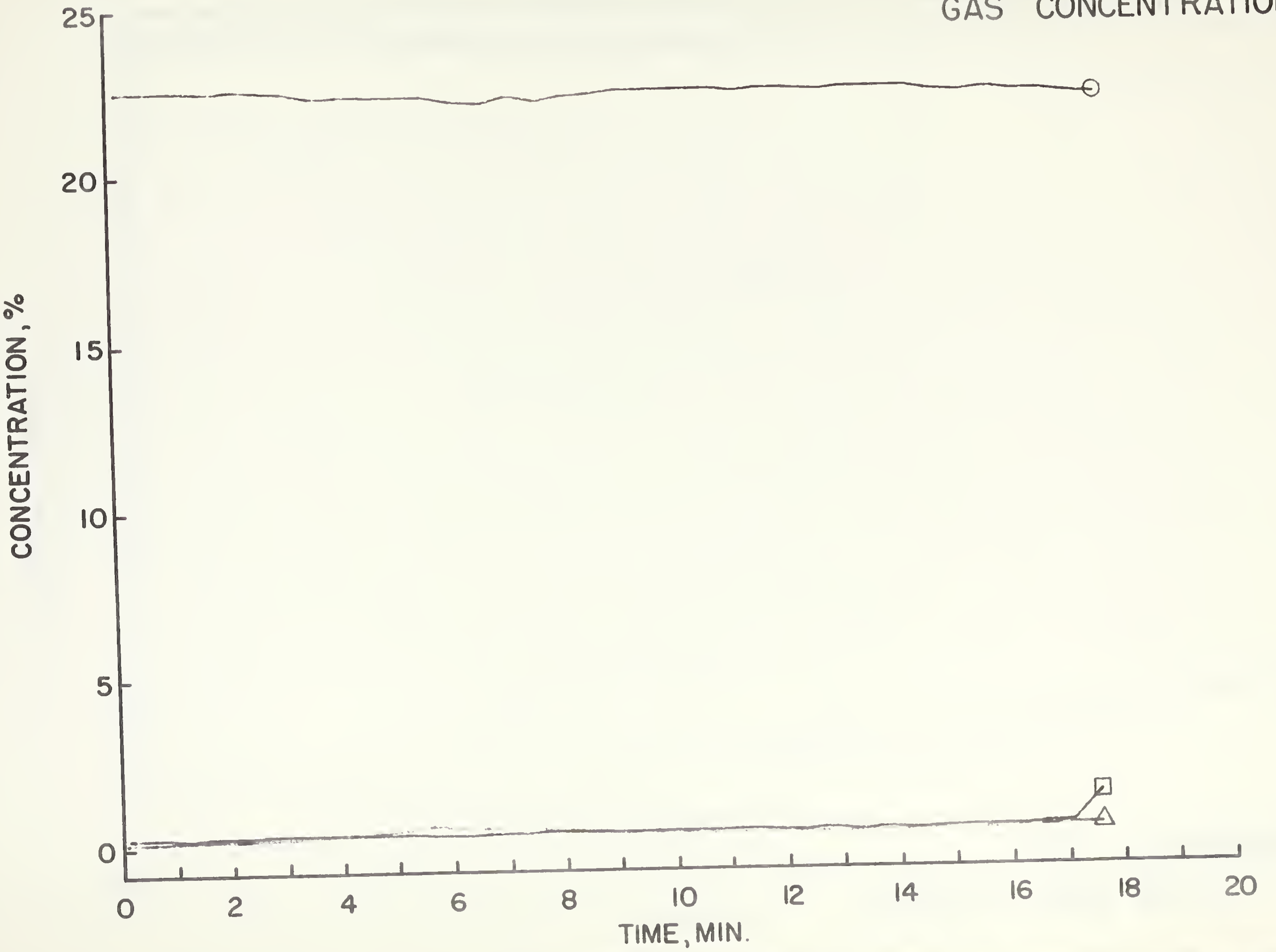


FIG. 106 TEST NO. 9
GAS CONCENTRATION

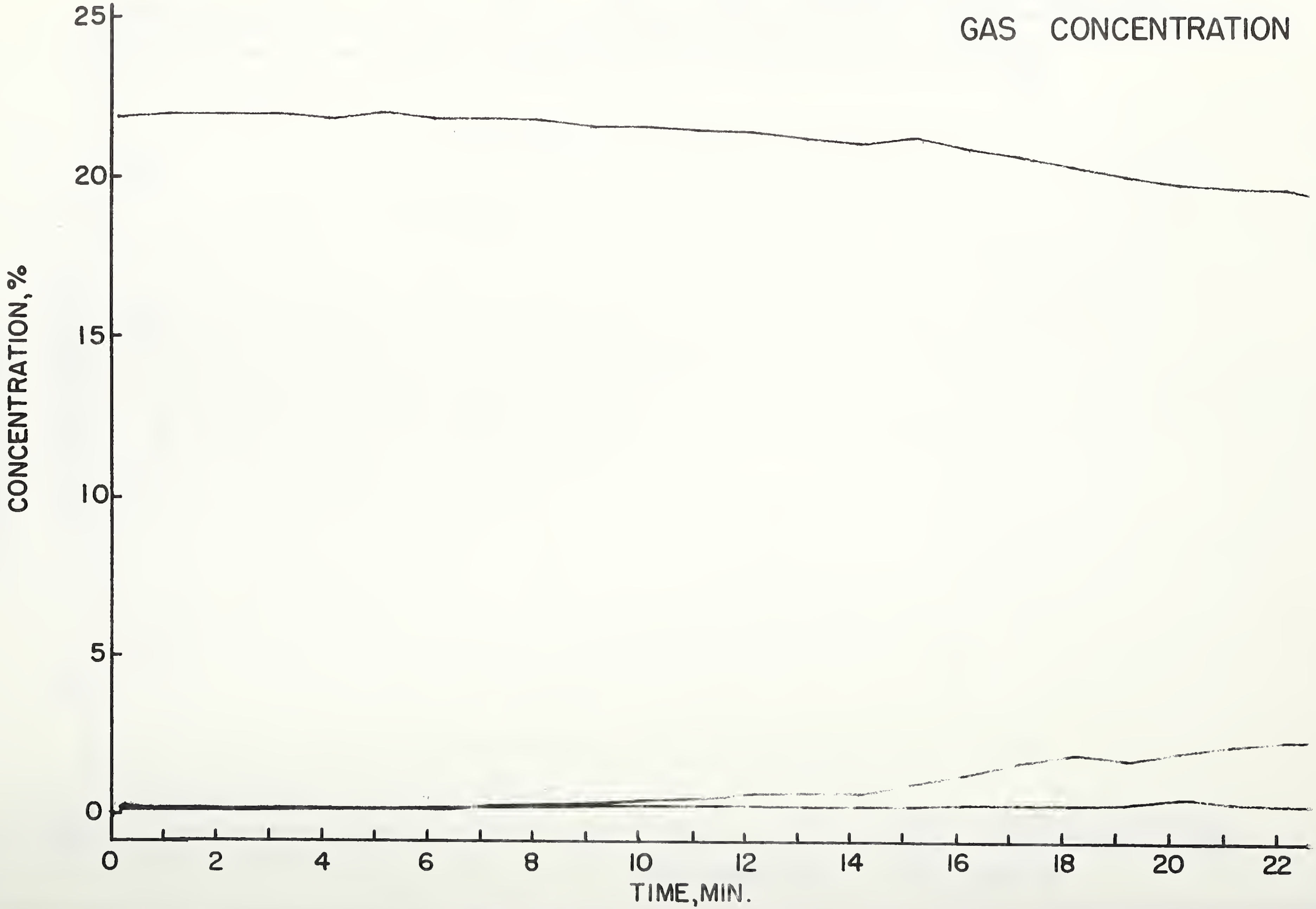


FIG. 107 TEST NO. 10

GAS CONCENTRATION

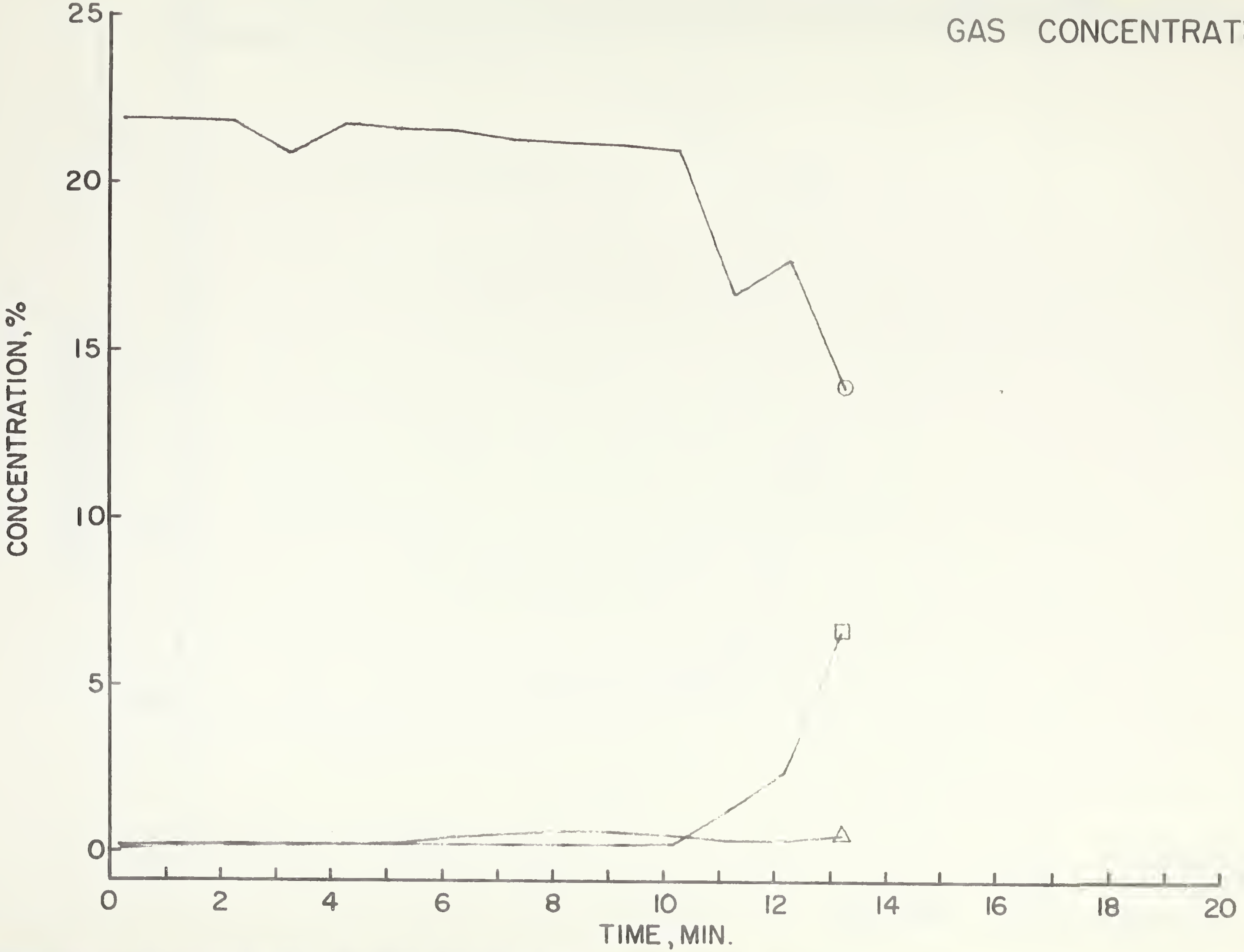


FIG. 108 TEST NO. 11
GAS CONCENTRATION

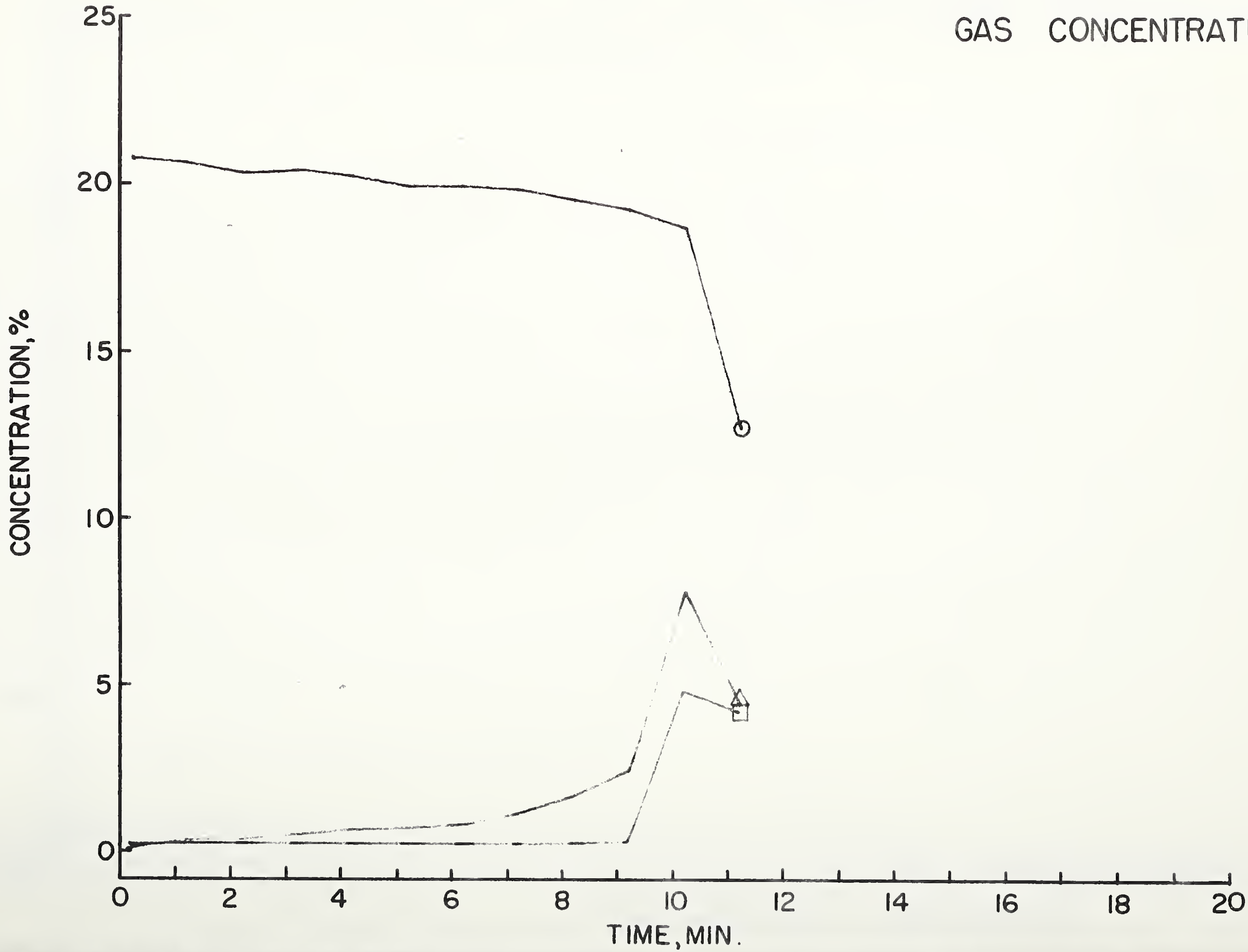


FIG. 109 TEST NO. 12

GAS CONCENTRATION

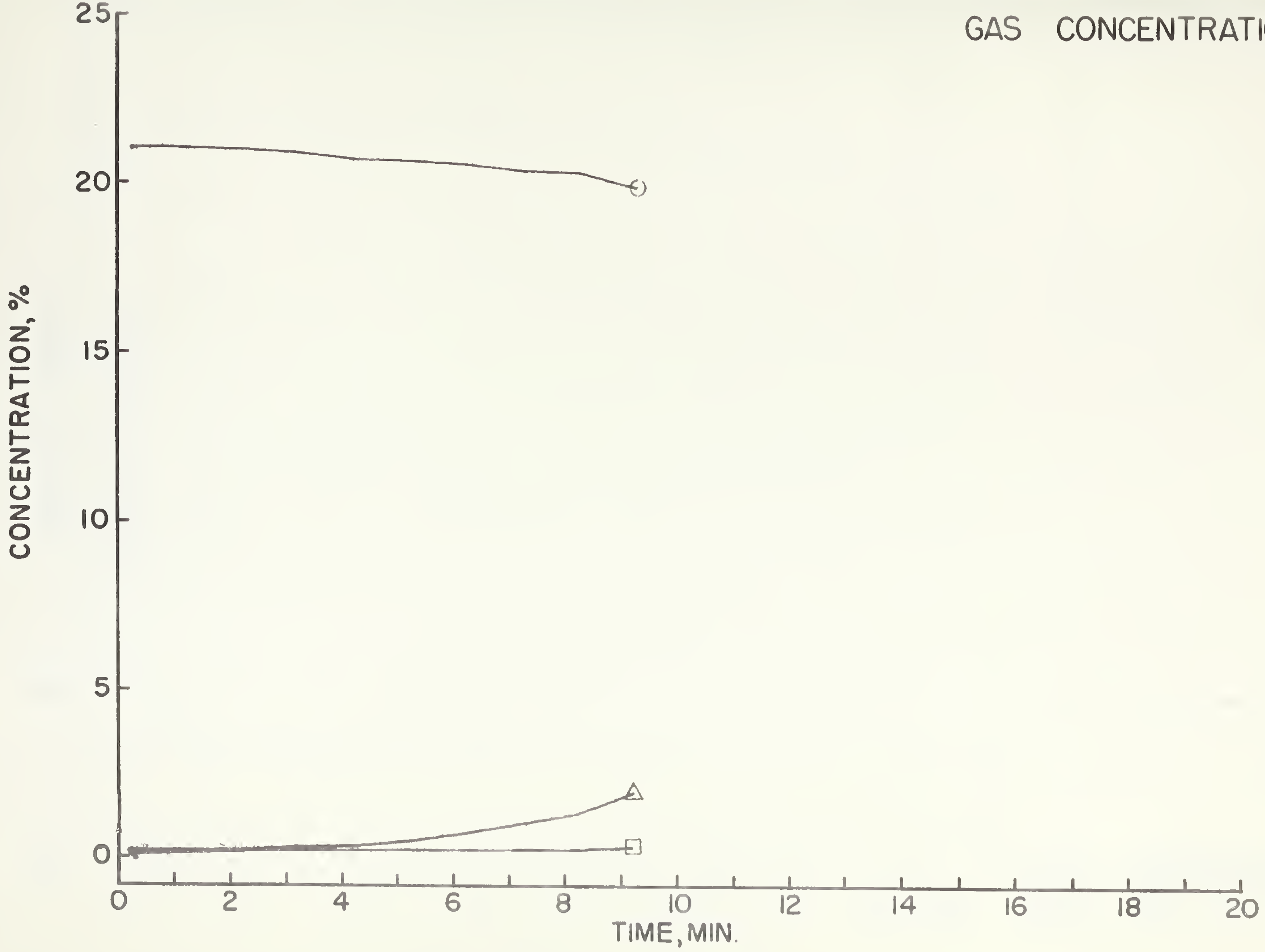


FIG. 110 TEST NO. 13

GAS CONCENTRATION

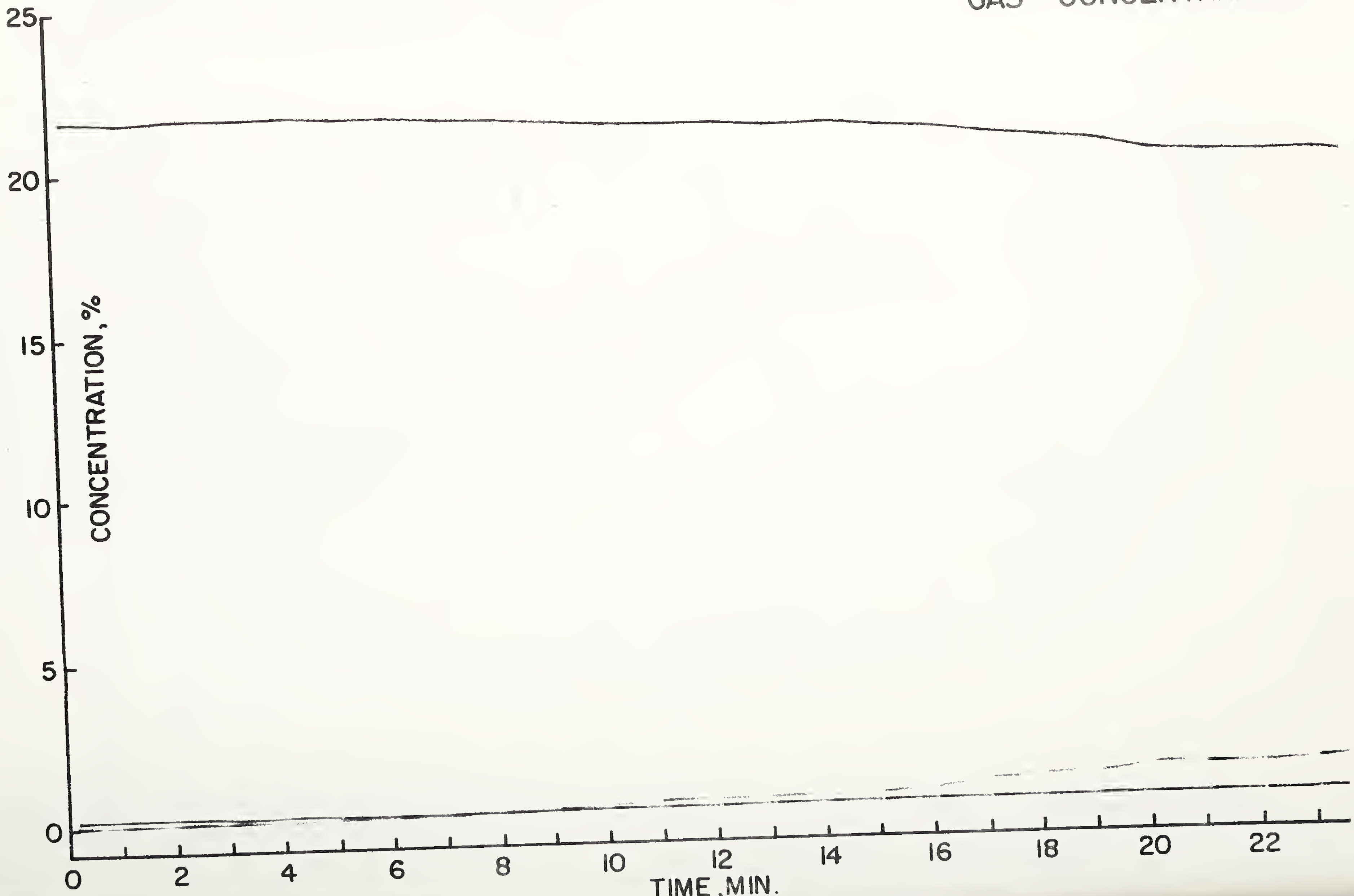


FIG. III TEST NO. 14

GAS CONCENTRATION

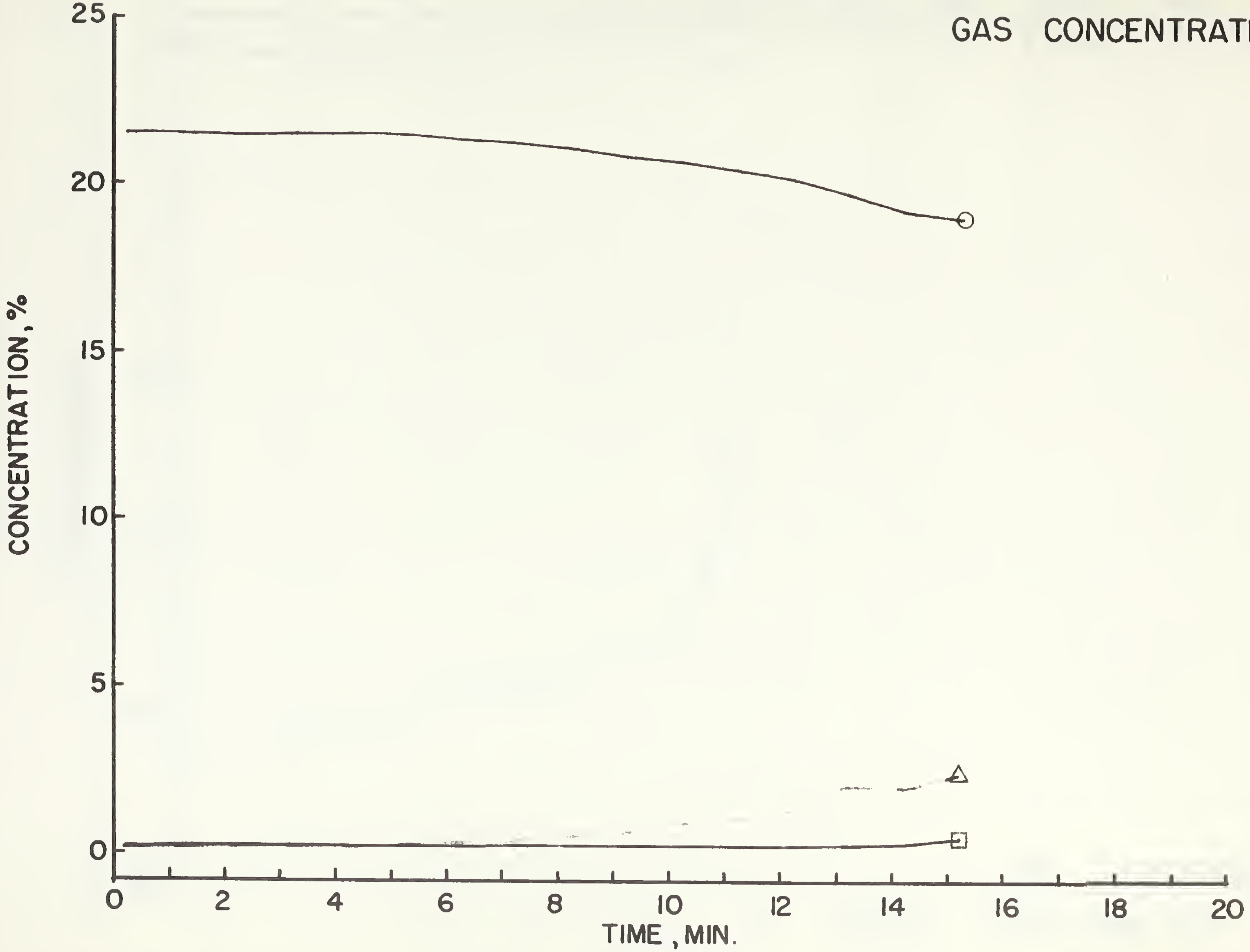


FIG. 112 TEST NO. 15

GAS CONCENTRATION

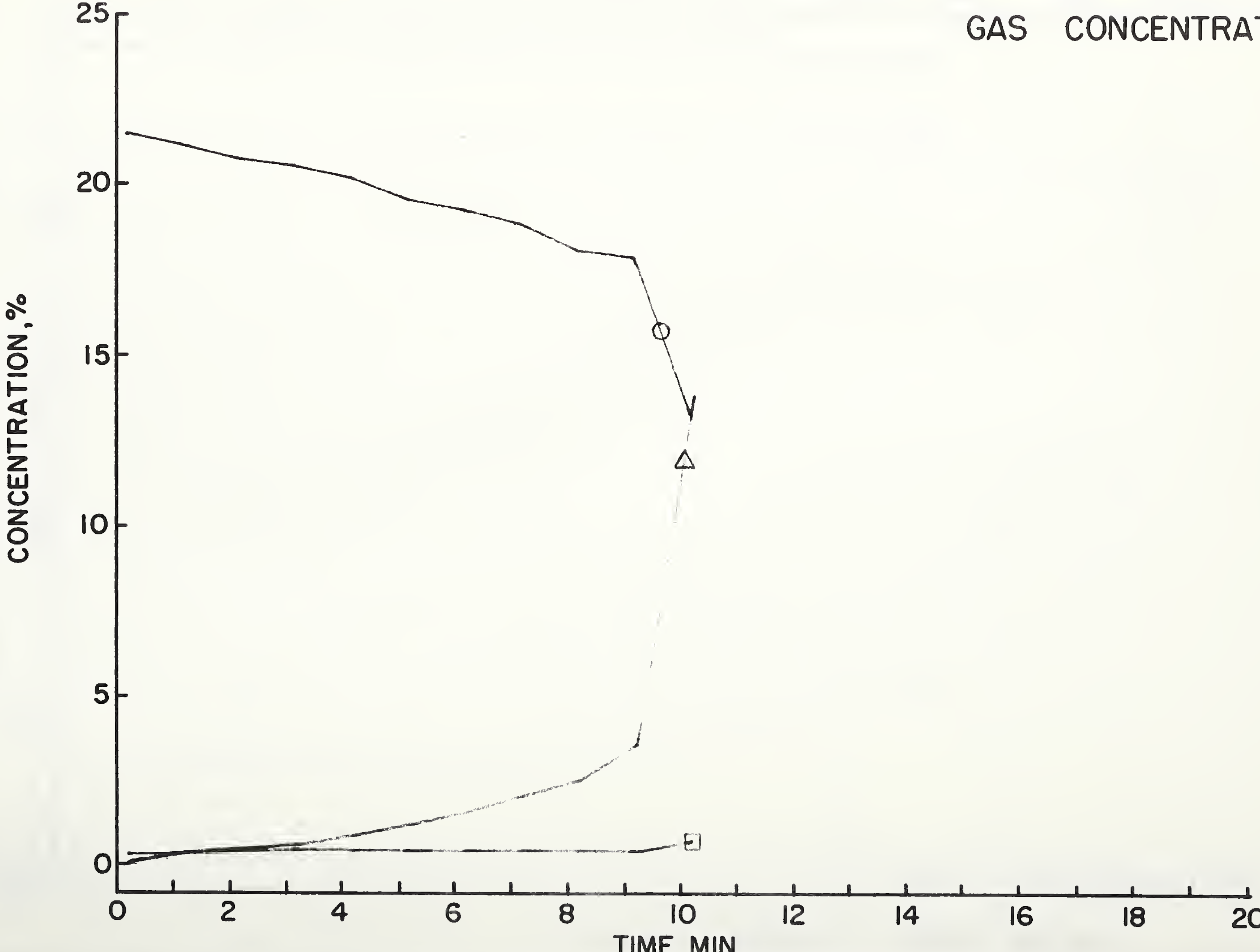


FIG. 113 TEST NO. 16

GAS CONCENTRATION

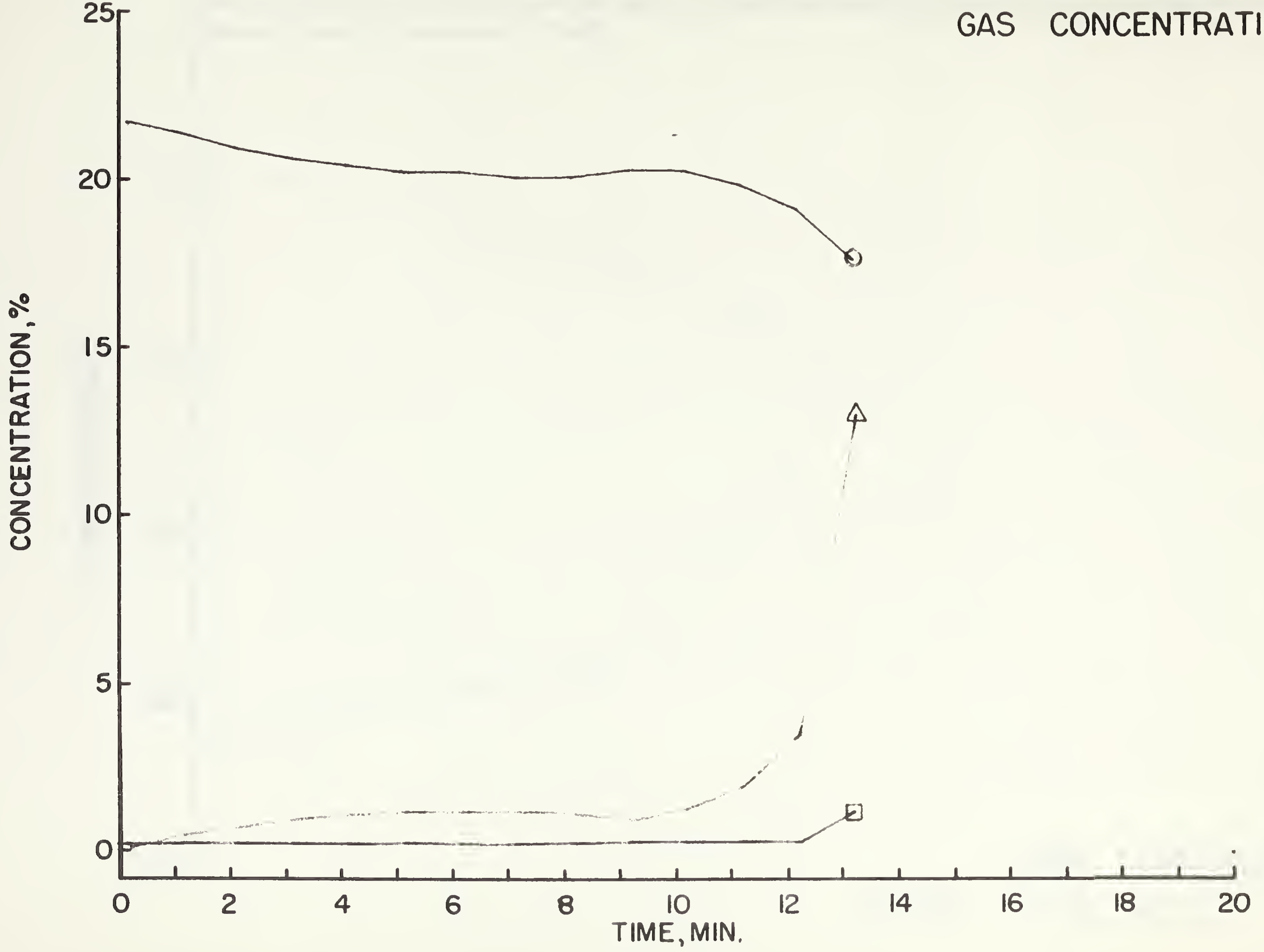


FIG. 114 TEST NO. 17

GAS CONCENTRATION

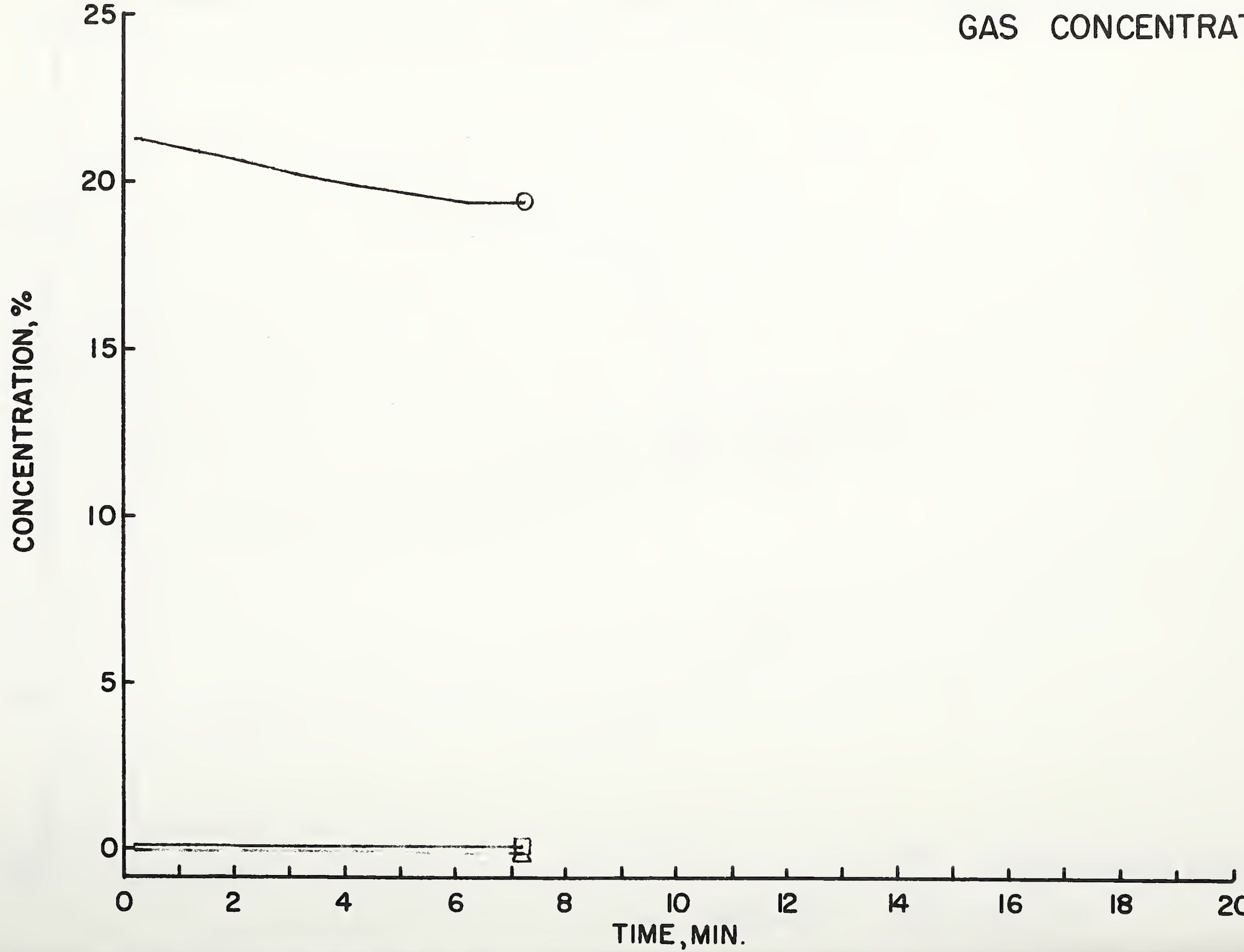


FIG. 115 TEST NO. 18

GAS CONCENTRATION

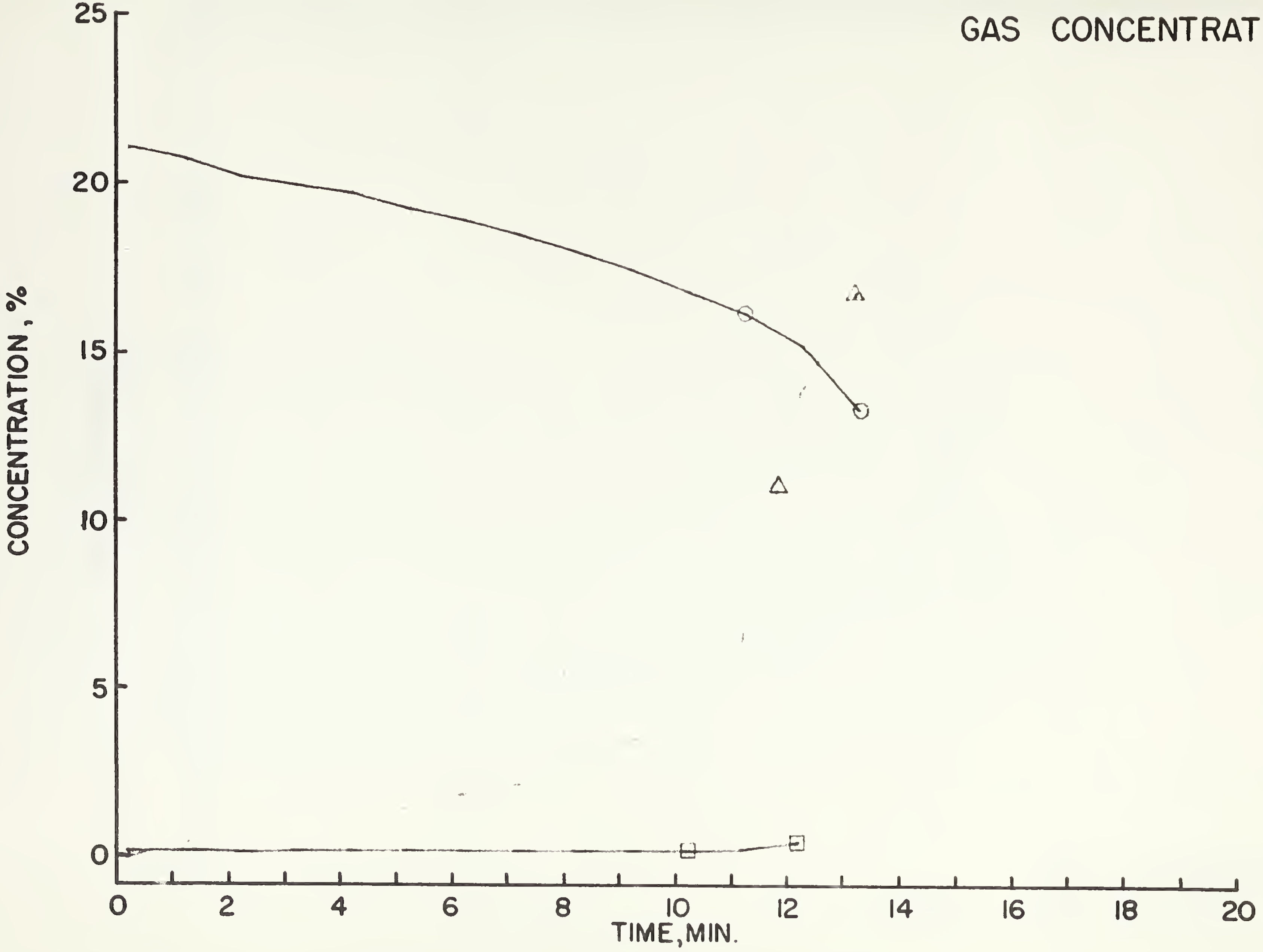


FIG. 116 TEST NO. 19

GAS CONCENTRATION

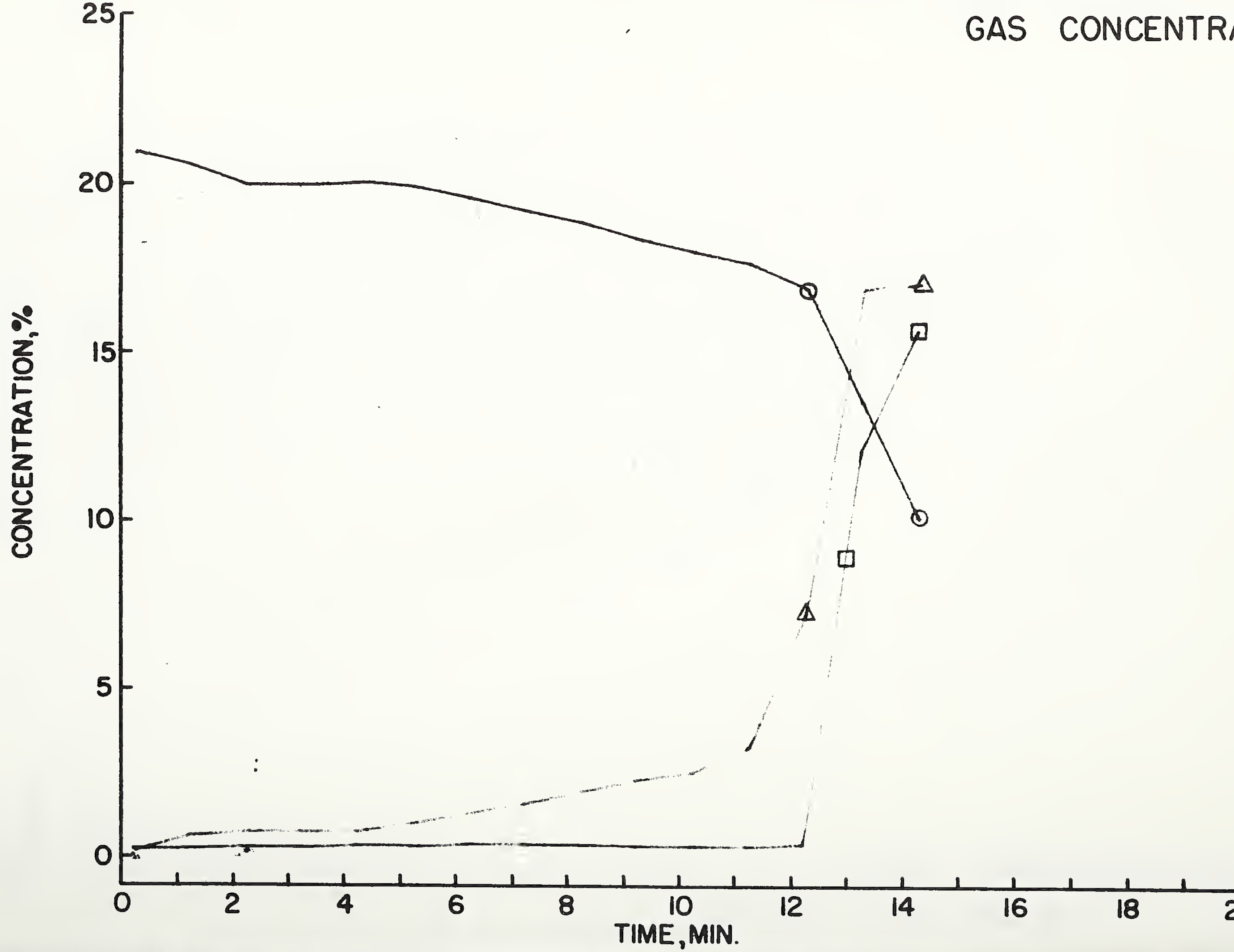


FIG. 117 TEST NO. 20

GAS CONCENTRATION

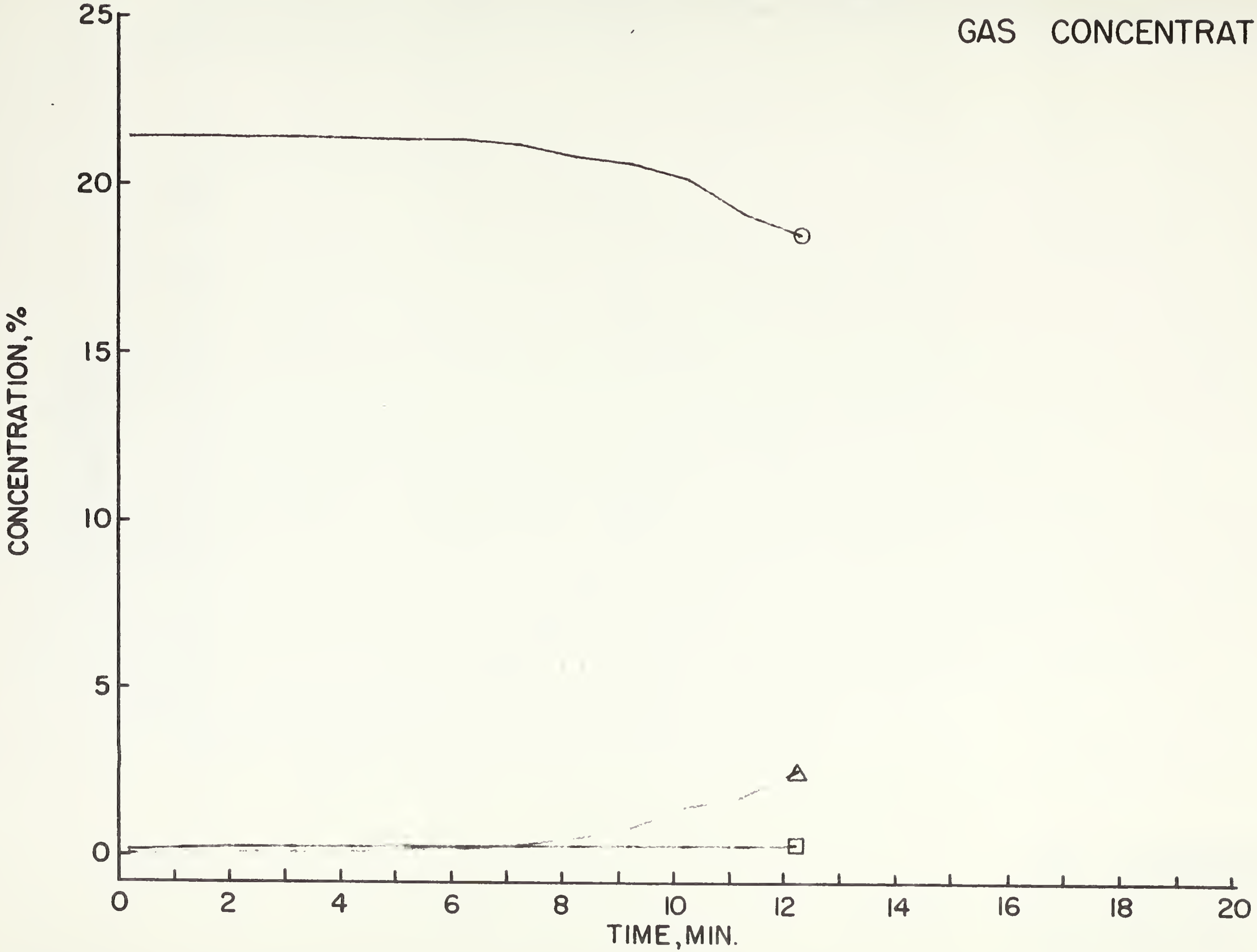


FIG. 118 TEST NO. 21

GAS CONCENTRATION

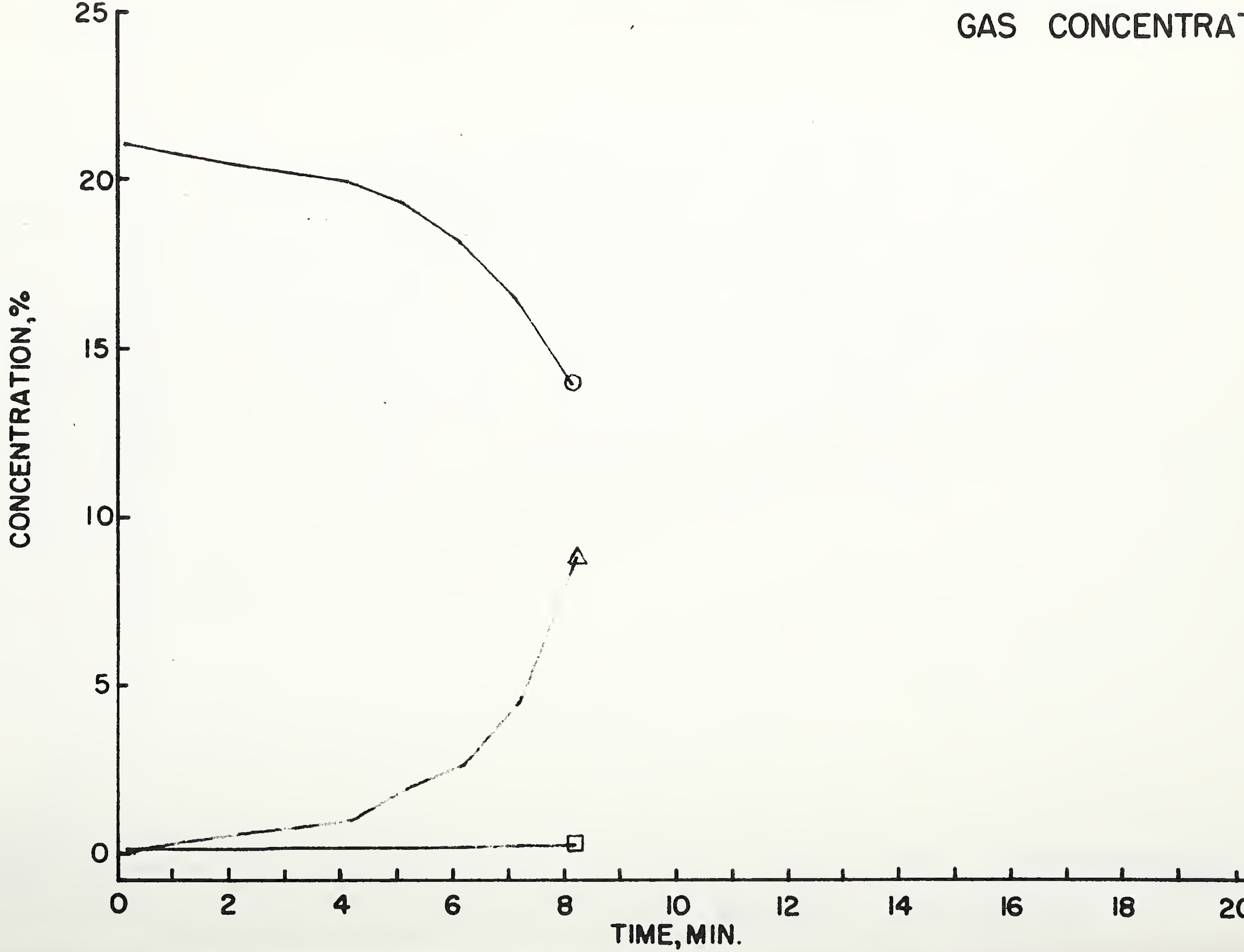


FIG. 119 TEST NO. 22

GAS CONCENTRATION

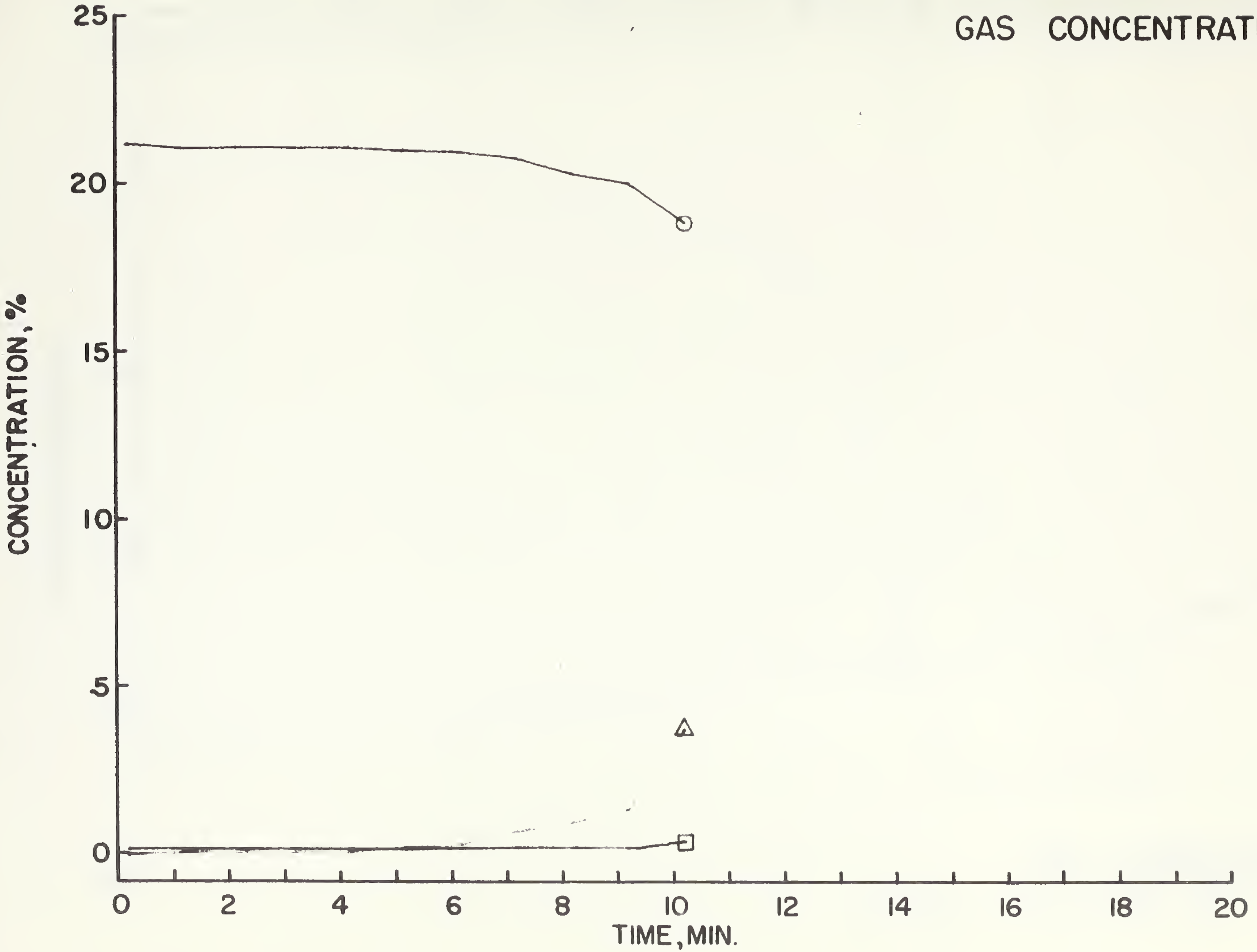


FIG. 120 TEST NO. 23

GAS CONCENTRATION

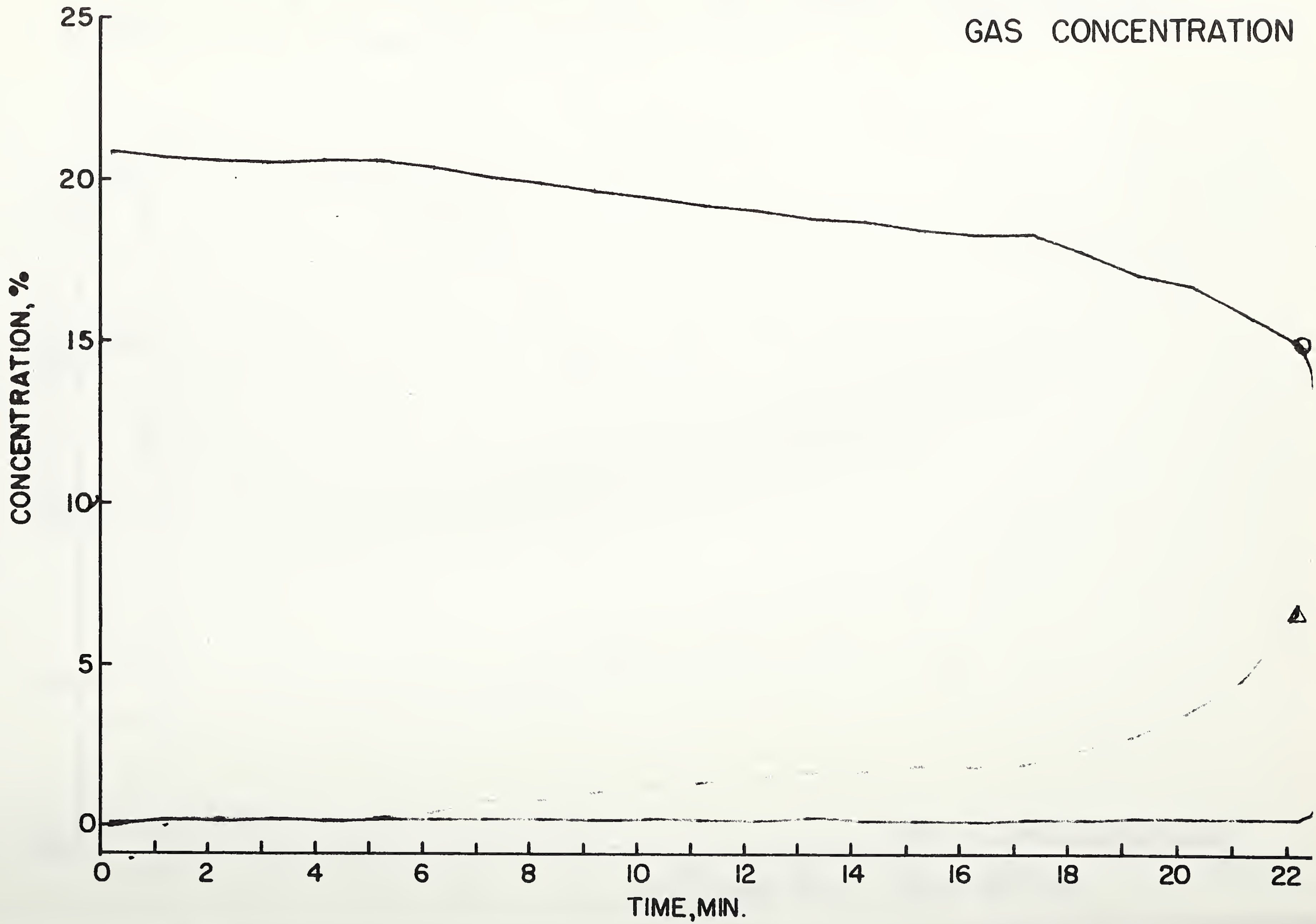


FIG. 121 TEST NO. 24

GAS CONCENTRATION

FIG. 122 TEST NO. 25
GAS CONCENTRATION

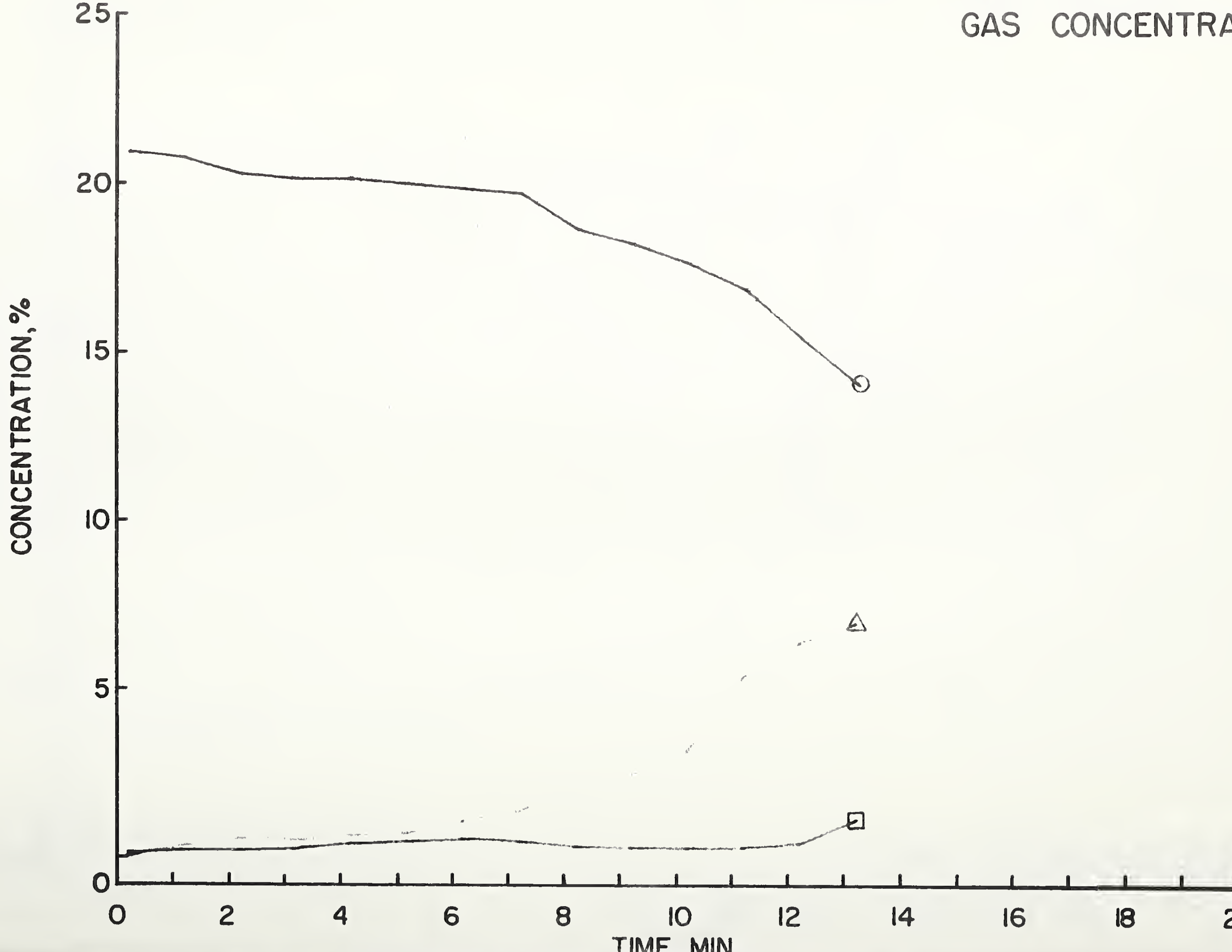


FIG. 123 TEST NO. 26

GAS CONCENTRATION

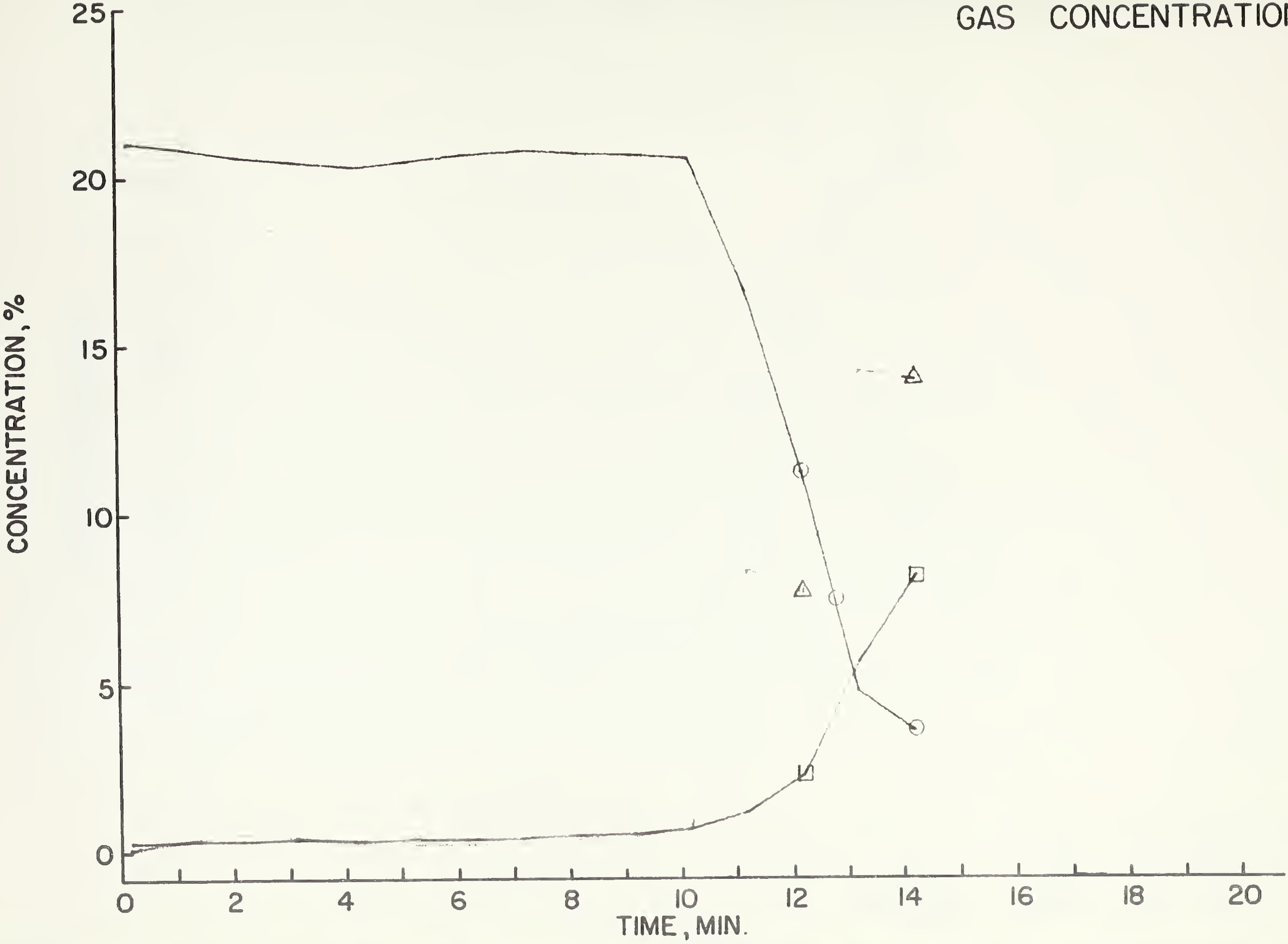


FIG. 124 TEST NO. 27
GAS CONCENTRATION

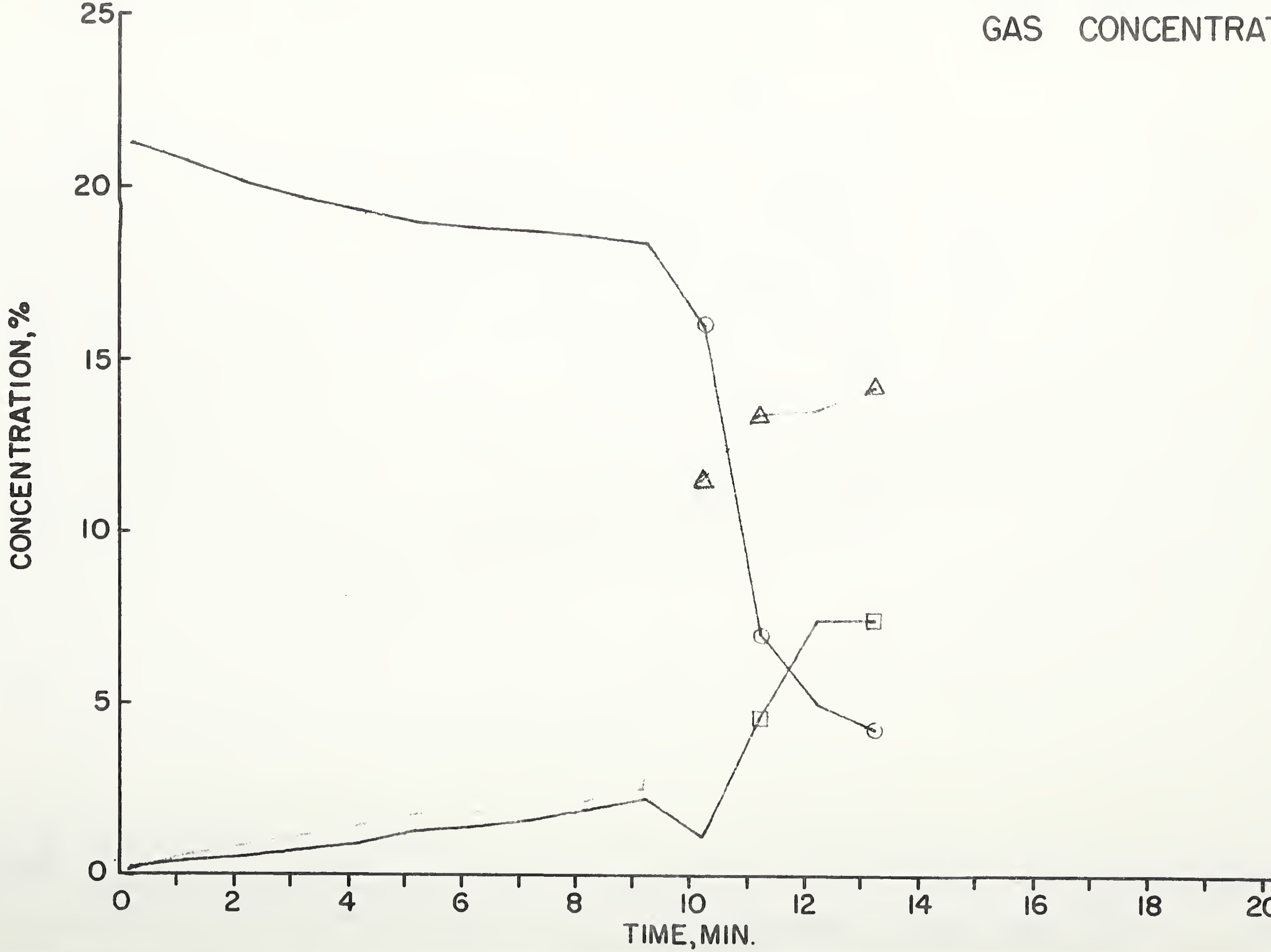


FIG. 125 TEST NO. 28

GAS CONCENTRATION

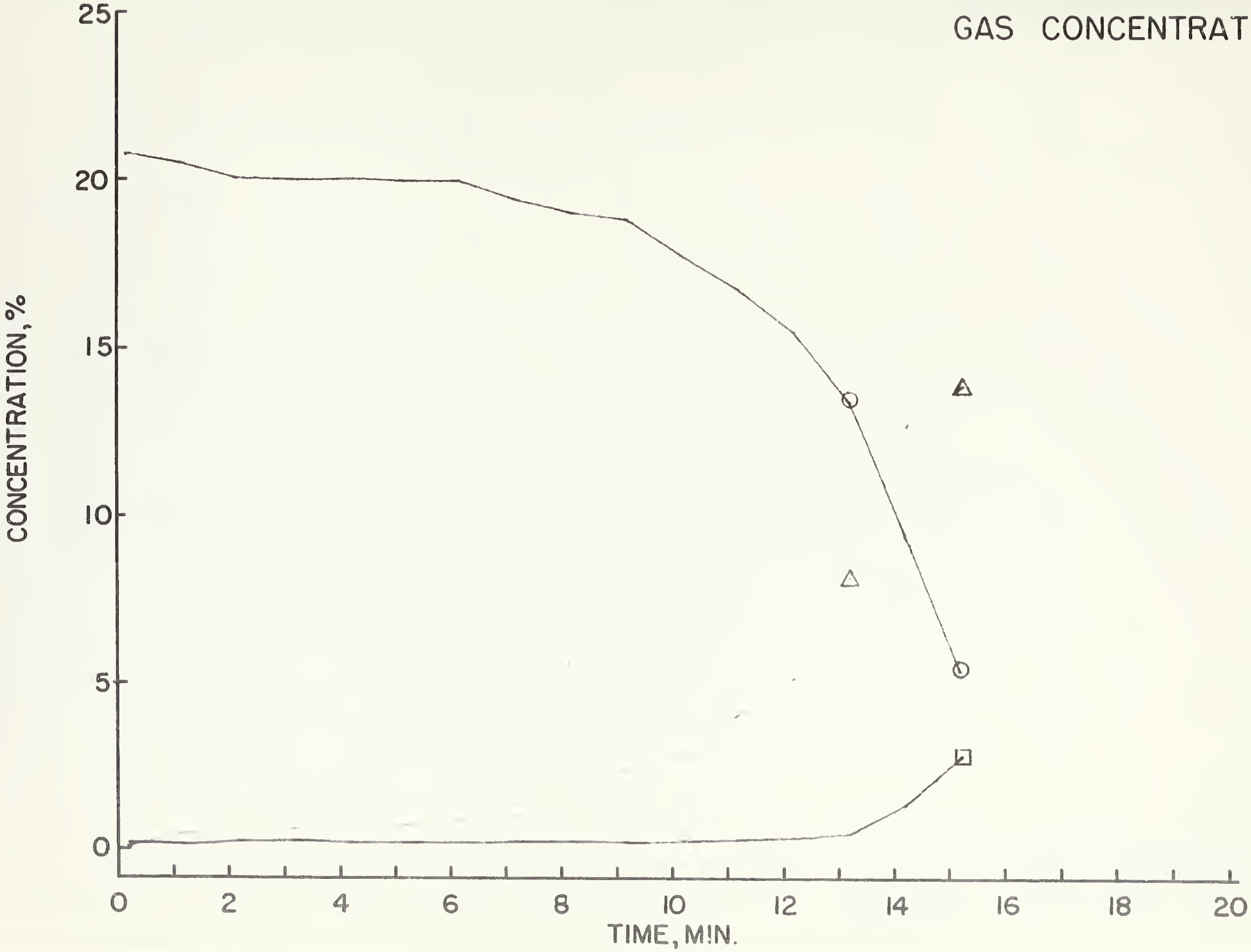


FIG. 126 TEST NO. 29
GAS CONCENTRATION

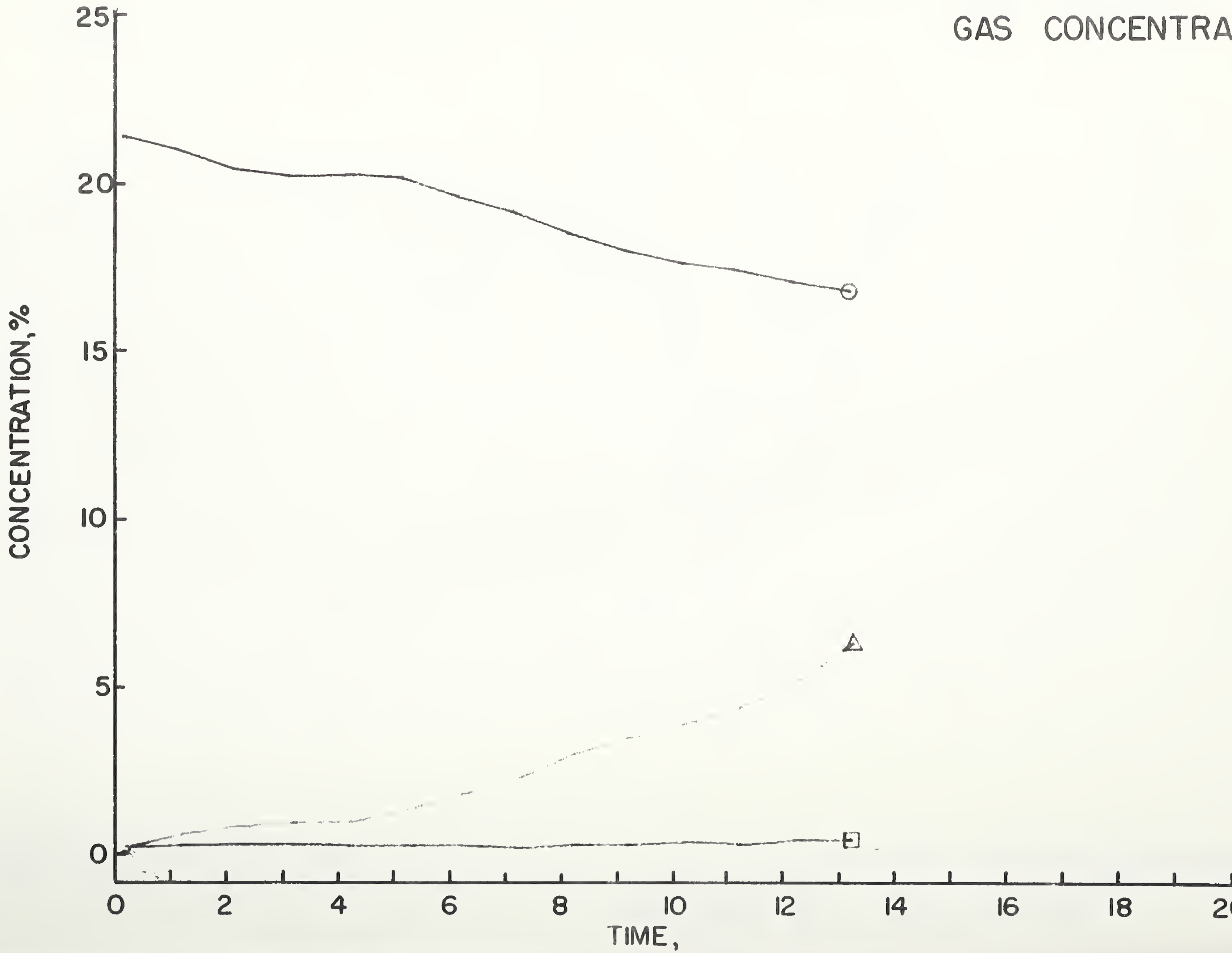


FIG. 127 TEST NO. 30

GAS CONCENTRATION

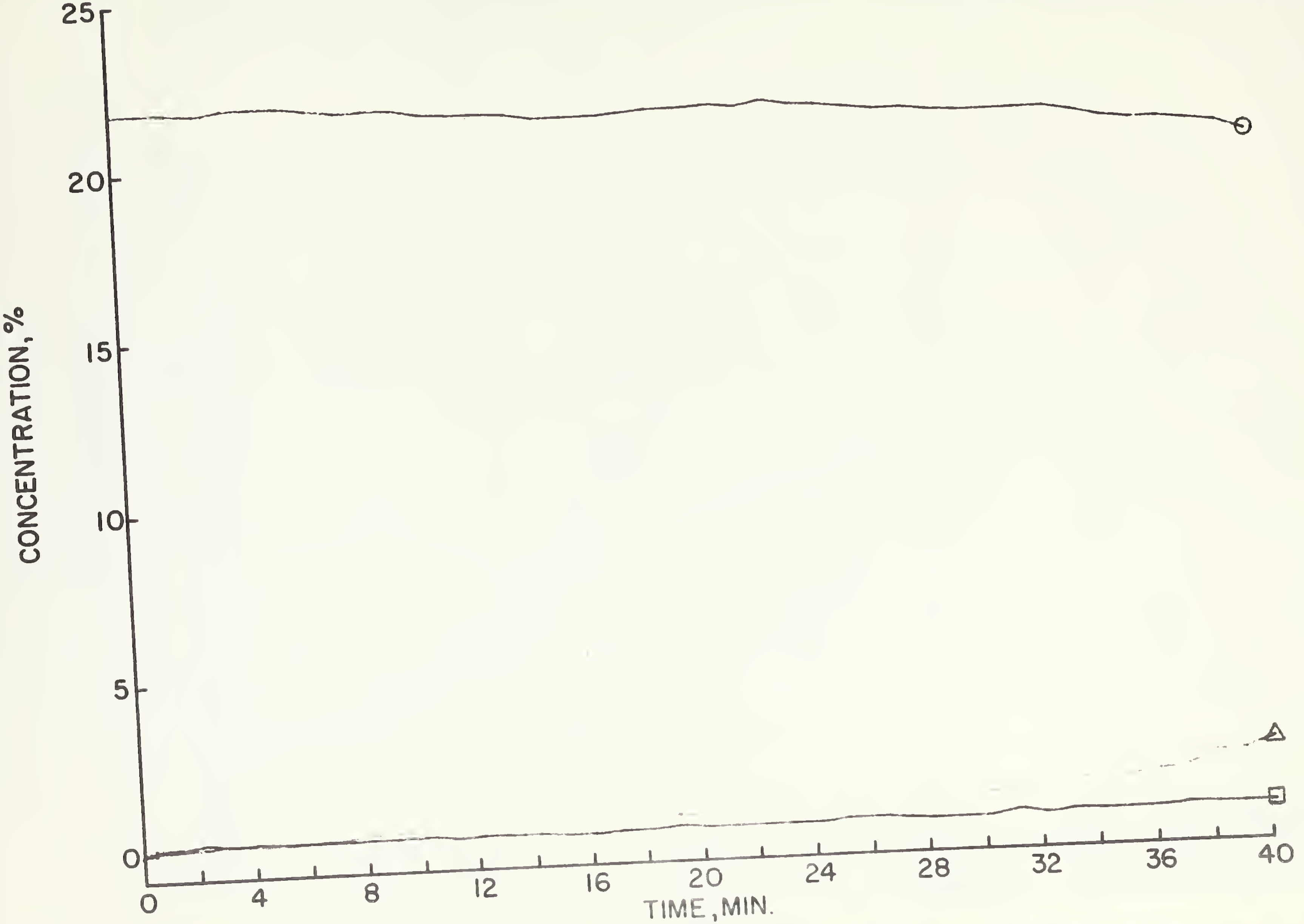


FIG. 128 TEST NO. 31

GAS CONCENTRATION

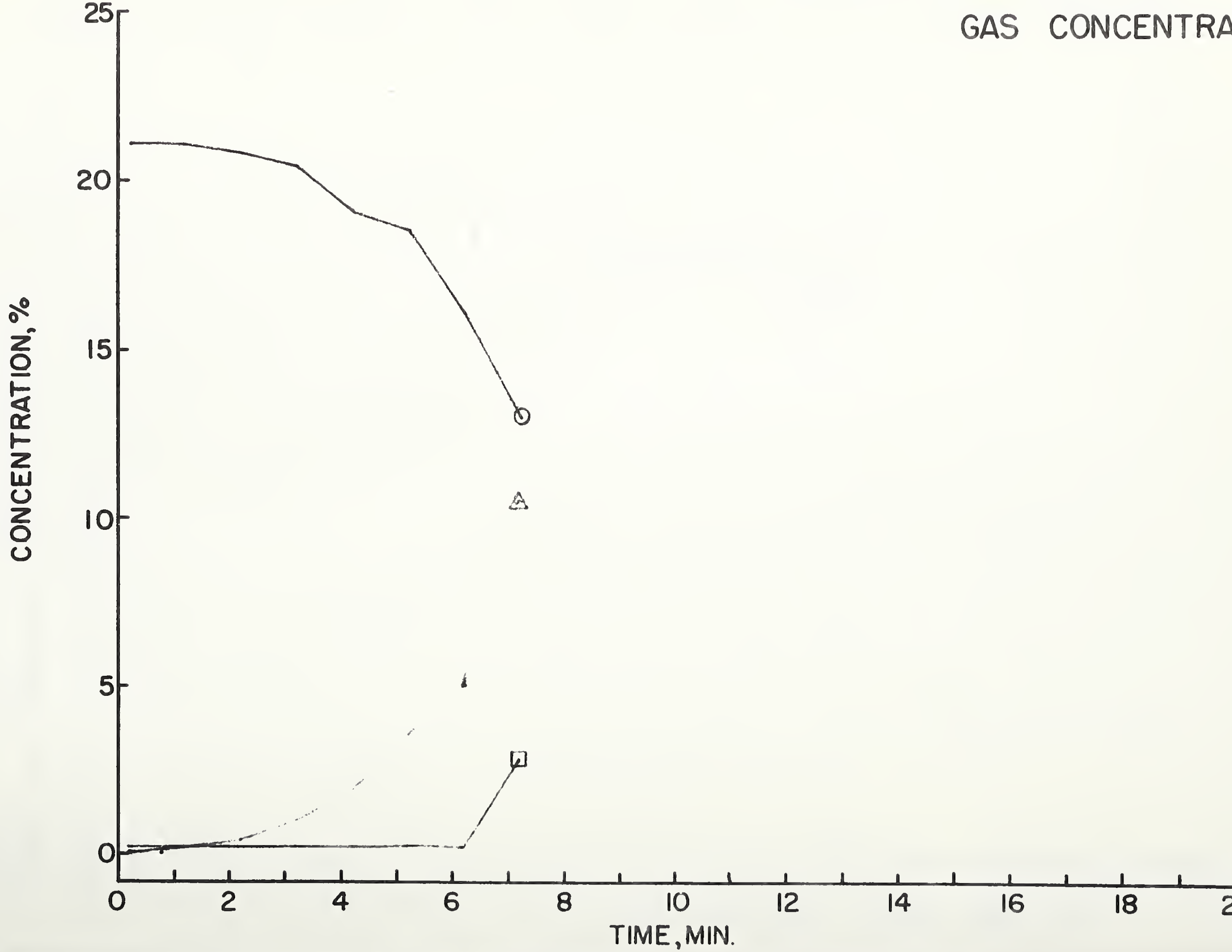


FIG. 129 TEST NO. 32

GAS CONCENTRATION

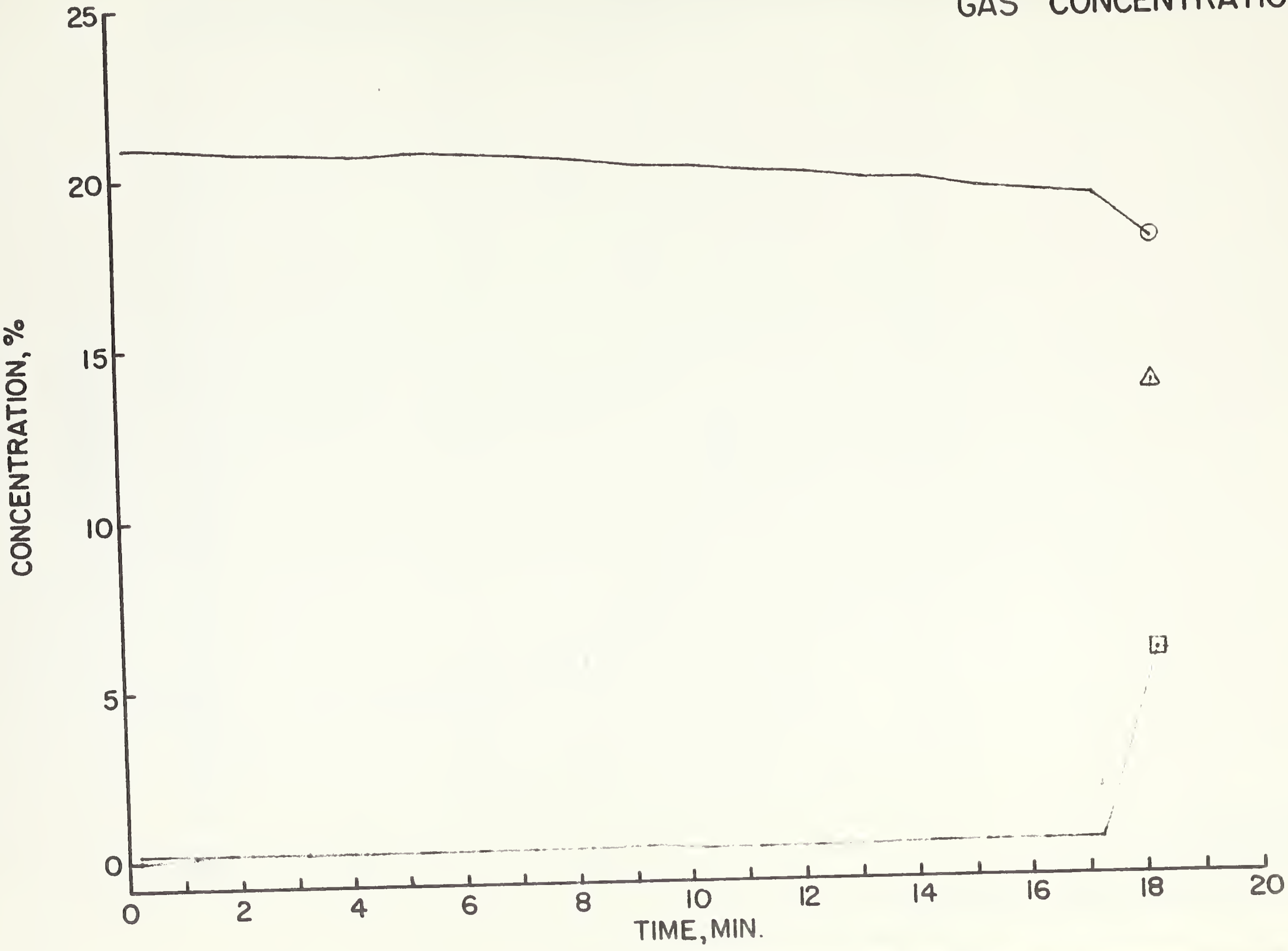


FIG. 130 TEST NO. 33

GAS CONCENTRATION

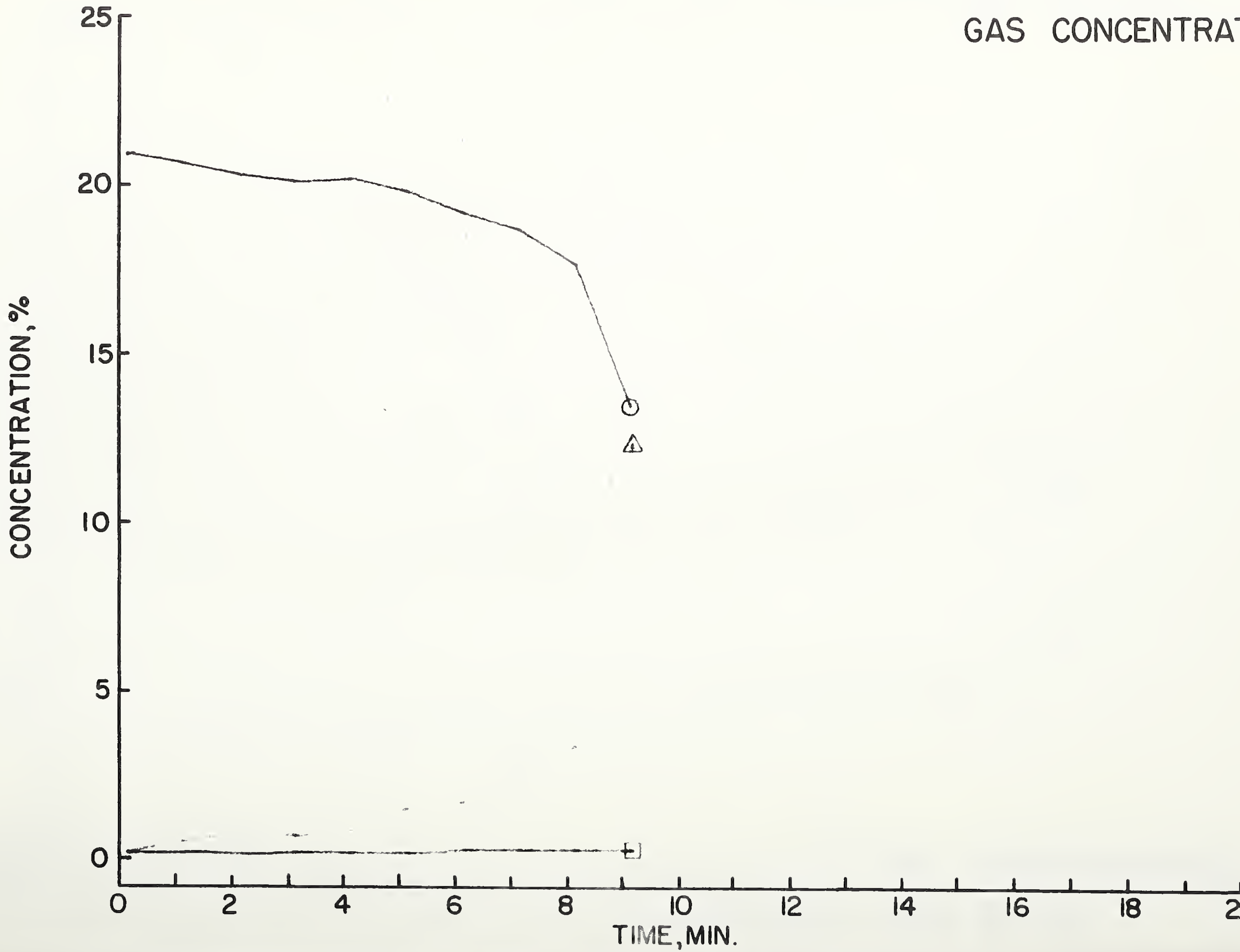


FIG. 131 TEST NO. 34

GAS CONCENTRATION

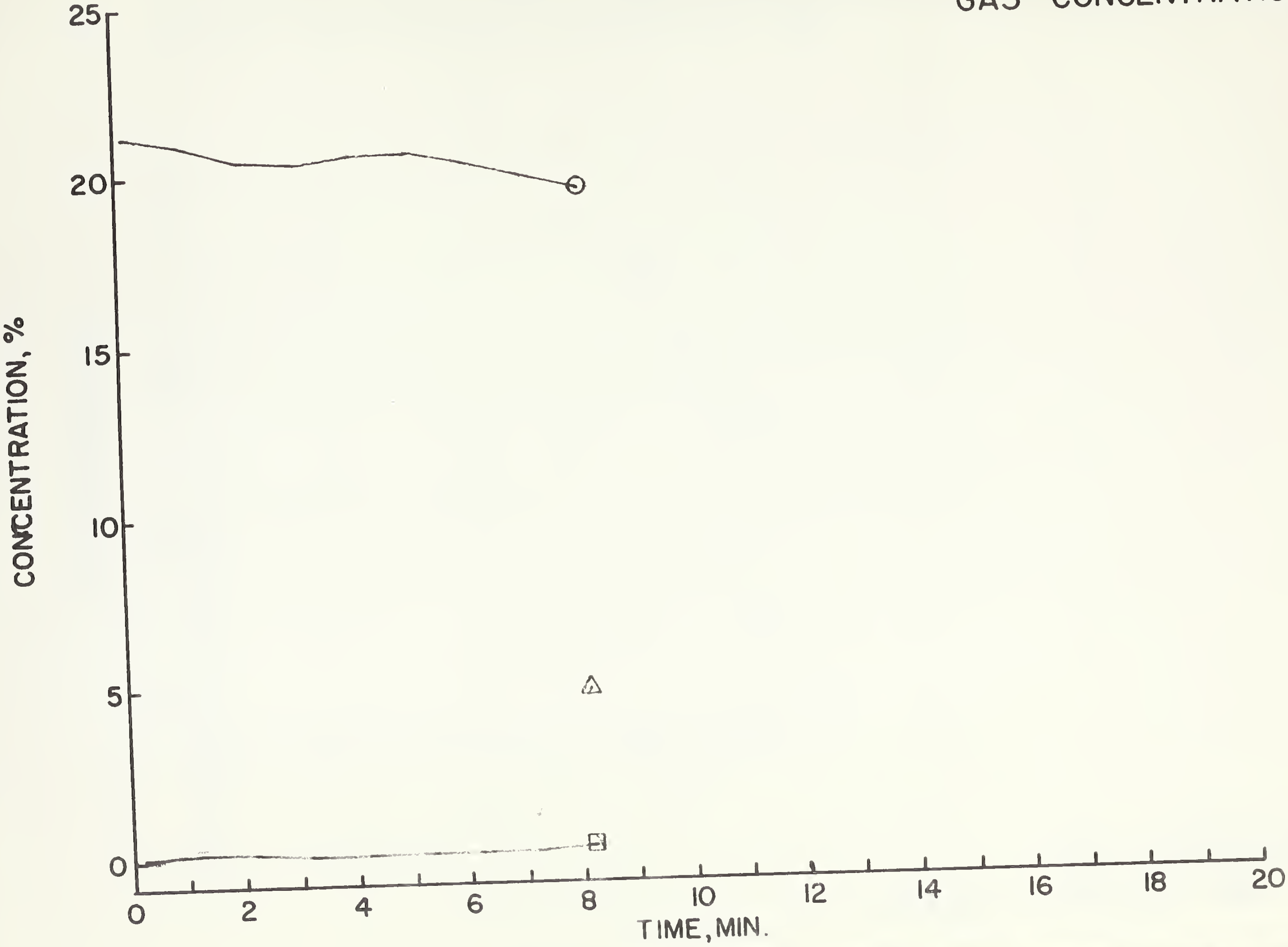


FIG. 132 TEST NO. 35

GAS CONCENTRATION

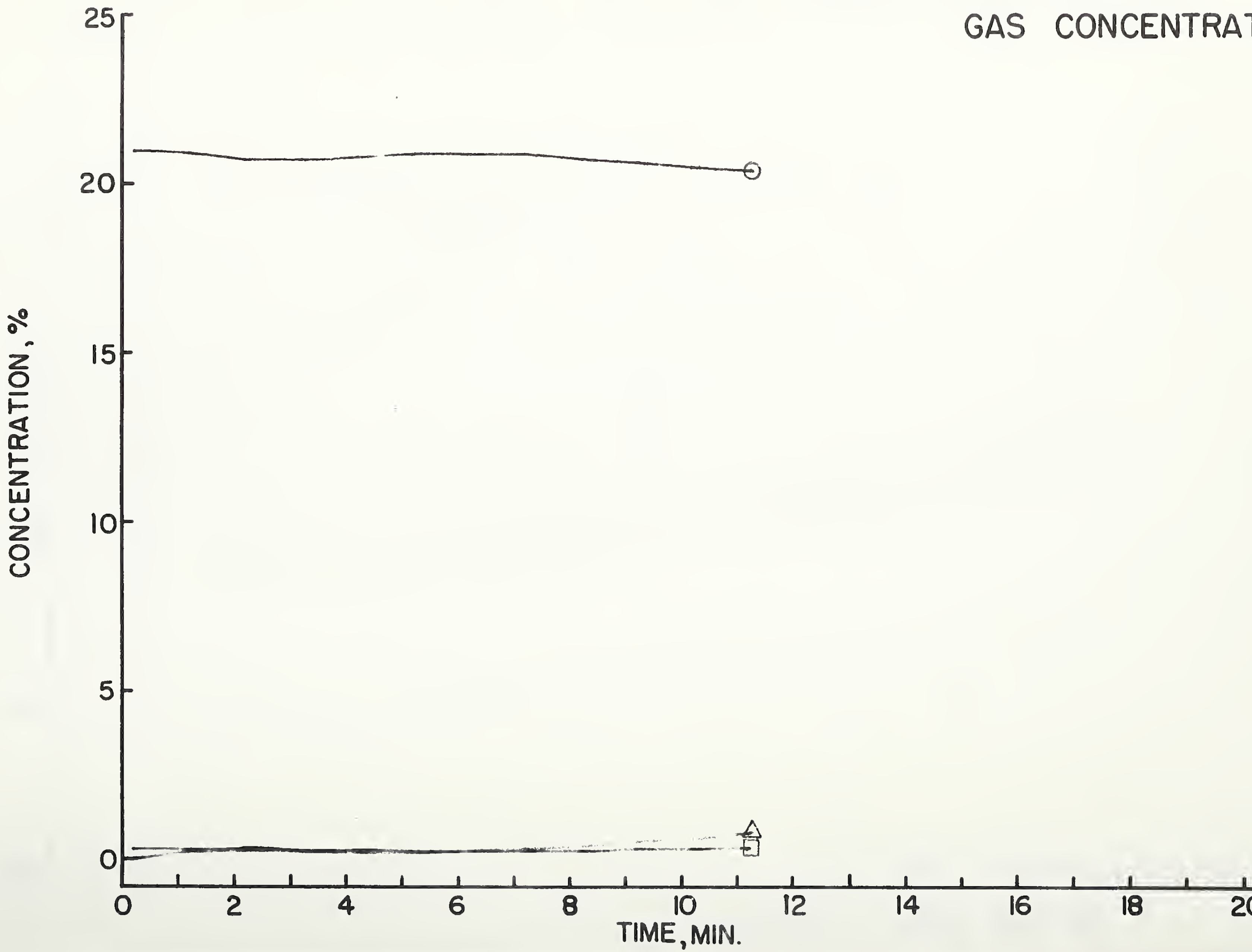


FIG. 133 TEST NO. 36

GAS CONCENTRATION

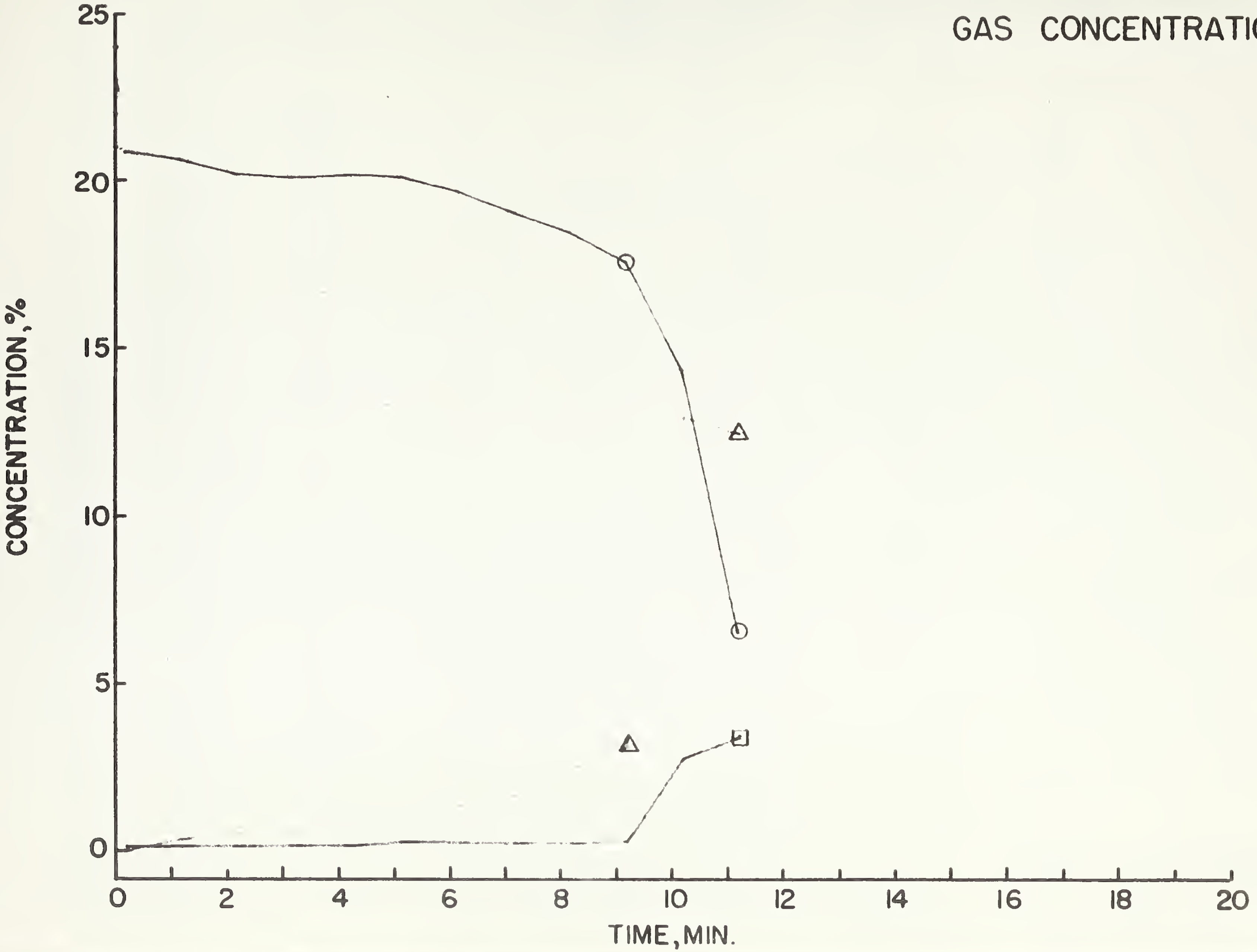


FIG. 134 TEST NO. 37

GAS CONCENTRATION

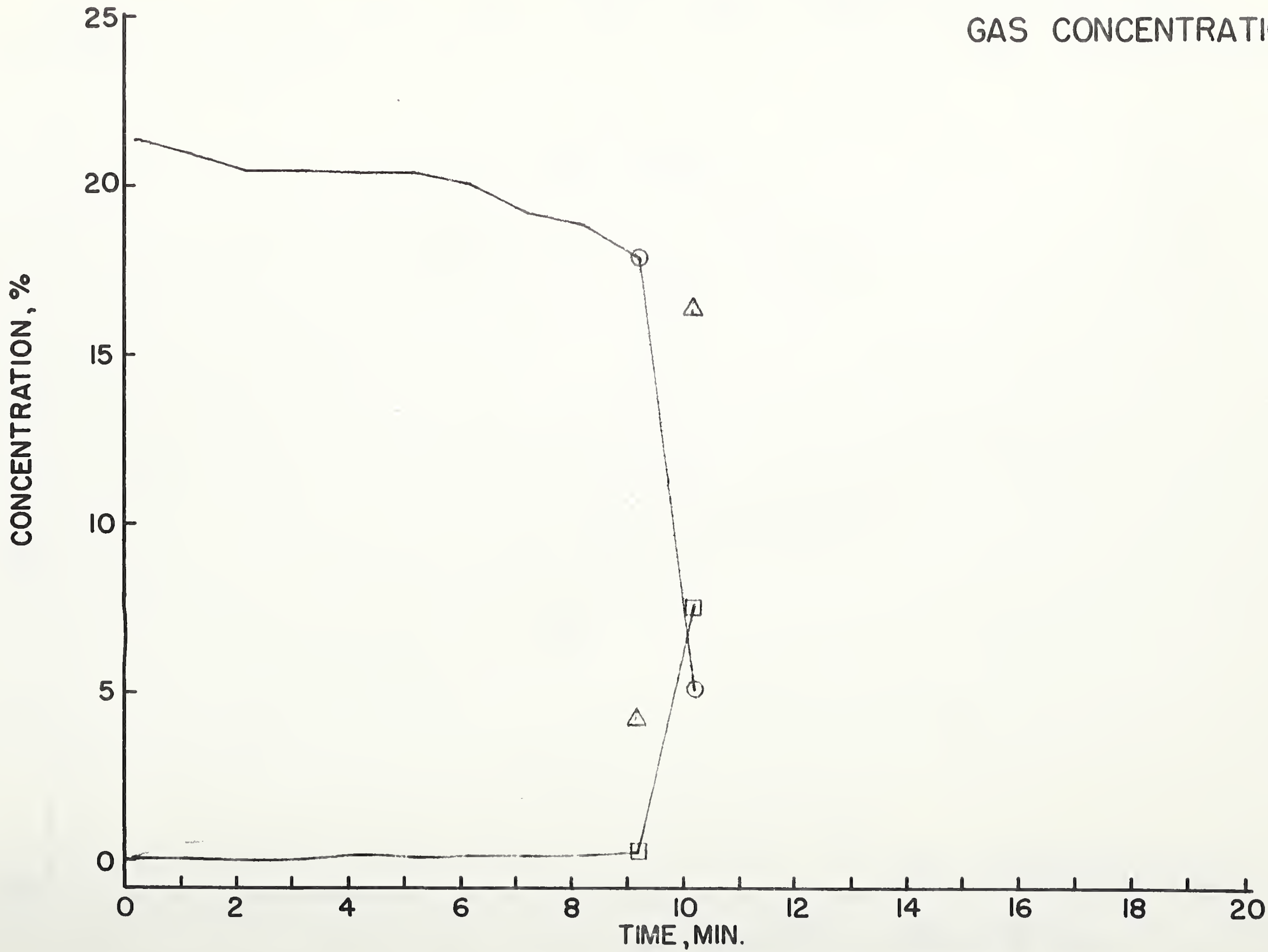


FIG. 135 EFFECT OF THERMAL INERTIA ($k\rho c$) OF COMPARTMENT LINING ON FINAL TRANSITION TIME (T_2)

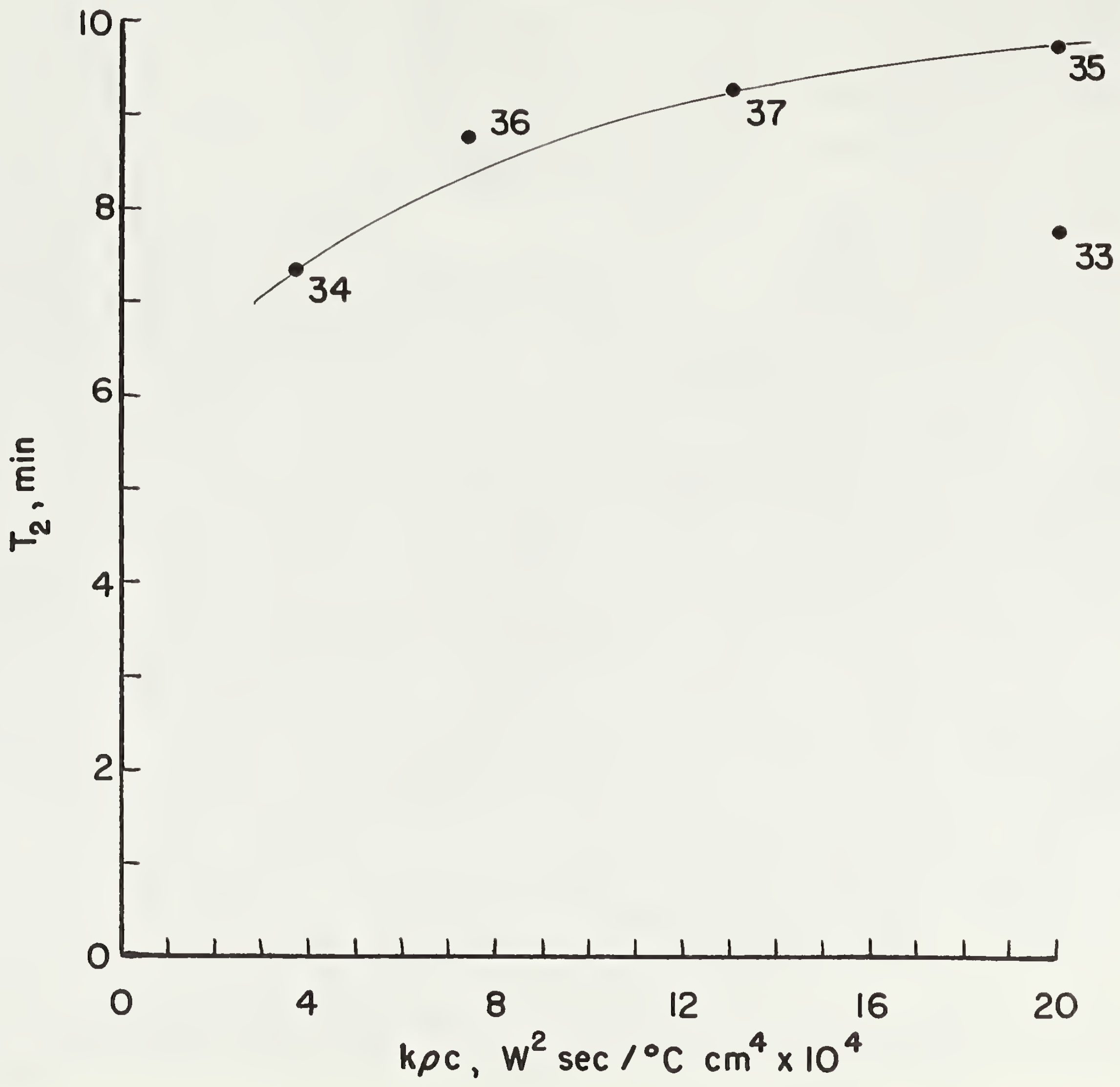


Figure 136 Test #4 121 shape
21 small cribs
6 cm spacing

Figure 137 Test #14 211 shape
1 continuous crib
2 cm spacing

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