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# Fire Spread on Exterior Walls Due to Flames Emerging from a Window in Close Proximity to a Reentrant Wall Corner

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Center for Building Technology
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Final Report

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NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

Table of Contents

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BY

B. C. Son and J. B. Fang

## Abstract

As a part of the research program concerning the recommended criteria for fire safety in Operation BREAKTHROUGH, two full scale fire tests were performed on a mockup of a reentrant corner, i.e., the interior corner formed at the intersection of the exterior walls of adjacent buildings, such as townhouses and garden apartments.

In each test, two wall specimens representing exterior walls were erected perpendicular to a wall containing a window opening into a fire room. One wall was located 1 foot east and the other one 5 feet west of the edges of the window. The objective of the reentrant corner fire test was to study the potential ignition and spread of fire from the room to an adjacent exterior combustible wall.

In the first test, charring on the east wall, but no surface ignition was observed during the test. The peak temperature measured did not exceed 350°C (660°F). In the second test, surface ignition occurred on the east wall 9 minutes after the wood crib, representing the combustible contents of the room, was ignited. No significant changes were observed on the west wall during either test.

The instantaneous heat flux incident on the east wall just prior to

ignition and the total heat energy absorbed were estimated to be on the order of 1.0 $W/cm^2$ and 175 $Joules/cm^2$ respectively.

Key Words: Exterior wall, fire spread, fire test, ignition, Operation BREAKTHROUGH, reentrant corner.

## 1.0 INTRODUCTION

In the Operation BREAKTHROUGH Program, for separate tenancy housing, a flame spread index of not more than 75 was imposed on materials for exterior, mutually perpendicular walls, one of which contains a window opening, the edge of which is less than 5 feet from the adjacent wall. Due to the lack of specific fire performance data for the reentrant wall corner situation the flame spread index was conservatively set at a value of 75 based on the indices of representative exterior construction materials. As a part of the research program to validate this recommended criteria for fire safety, two full scale fire tests were initially performed at the Fire Test Laboratories of the National Bureau of Standards, Washington, D.C., utilizing a representative exterior plywood facing material having a flame spread index of 103.

The objective of this reentrant wall corner fire testing was to study the potential ignition and spread of fire on exterior combustible walls due to flames emerging from a window opening in close proximity to an adjacent wall. In such an arrangement, the burning rate of the combustible contents, ventilation conditions, the size and configuration of the window, the distance from the window to the wall, the flammability of the exterior siding, and environmental conditions will effect the ease and extent of potential fire spread. The room fire, provided by the burning of wood cribs, was intended to provide realistic levels of radiation and convection on the exterior wall due to flames emerging from the window.

## 2.0 TEST ARRANGEMENT

For these tests, a framework was erected for mounting wall specimens at the required distance and orientation from a fire room containing a single window. This test arrangement was located within a large building which represented essentially draft free conditions. The fire room was 6 ft. wide by 10 ft. 5 in. long and 10 ft. high and had a window opening located 3 ft. above the floor on the south wall (see figures 1 and 2). The window opening was 38 in. high and 3 in. deep; its width was 24 in. for Test Number 1 and 32 in. for Test Number 2. The fire room had three 6 in. by 12 in. low level openings for the inlet of air supplied through a duct and a blower. The walls and ceiling of the fire room, or burn room, were lined with one layer of 5/8-in. thick Type X gypsum board sprayed with vermiculite plaster. The gypsum board on the ceiling was secured with 3/8-16 NC bolts, 1-1/2 in. long on 24 in. centers held with 3/8 in. expansion shells. Gypsum boards on the side walls were secured with the same bolts on 16 in. centers. The floor in Test Number 1 was concrete. Since the floor was damaged during Test Number 1, in Test Number 2 the floor was covered with fire sand and then fire bricks were placed evenly with a gap between each brick of 1/2-in. Exterior wall specimens were erected on each side of the window opening (24 in. x 38 in. in Test Number 1, 32 in. x 38 in. in Test Number 2) perpendicular to the south wall of the fire room. One wall was located 1 ft. east, and the other 5 ft. (in Test Number 1) and 4 ft. 4 in. (in Test Number 2) west, of the edges of the window. Each wall was 12 ft. long and

16 ft. high and composed of a single layer of 1/2 in. thick A-C grade exterior plywood in 4 x 8 ft. sheets over one layer of gypsum board backing. The plywood, selected as a representative exterior wall facing material, had a flame spread index of 103 as measured by ASTM E162.[1]

The burn room was loaded with wood cribs representing the fire load of combustible contents. Fifteen wood cribs, equally spaced, were placed on the floor in three rows along the north-south axis. Each wood crib was made of multiple layers of nominal 2-in. by 2-in. by 14-in. long kiln-dried wood sticks nailed into a lattice arrangement as shown in figure 1. For Test Number 1 the cribs were five layers high and weighed approximately 18 pounds each (4.4 pounds per square foot of fire load); while in Test Number 2 the cribs were seven layers high and weighed approximately 24 pounds each (6.3 pounds per square foot of fire load). The 4.4 and 6.3 pounds per square foot of fire load are considered representative of the combustibles in a typical residential room condition[2]. Liquid heptane in a sheet metal trough 90 in. long, 6 in. wide placed under each row of wood cribs was used to ignite the wood.

## 3.0 INSTRUMENTATION

Instrumentation consisted of 48 thermocouples, two radiometers and a radiation pyrometer. A total of 48 Chromel Alumel (Type K, No. 24 gage 0.020 in. diameter wire) thermocouples were installed as shown in figure 2.

Four ASTM* thermocouples mounted in protective 1/2 in. diameter wrought iron pipes were located in the burn room and 44 thermocouples were on the plywood surfaces, (32 on the east wall and 12 on the west wall). The radiometer (Location A in figure 2) was mounted flush with the west wall panel facing the east wall panel in order to measure the radiation from the east wall. It was 5 ft. away from the plane of the window and even with the top of the window. The radiation pyrometer (Location B in figure 2) was centered facing the window at its mid-height and at a distance of 10 ft. from the window.

The field of view for the particular lens of the pyrometer used at 10 ft. was 24 in. in diameter. In Test 2, an additional radiometer (Location C in figure 2) was mounted in the west wall 5 in. from the south wall of the fire room and at the same height as the top of the window. It was used to measure the radiation from the flame exiting from the window.

## 4.0 TEST RESULTS

### Test Number 1

The complete log of test observations is given in Appendix I. In Test Number 1 approximately 1540 cfm (cubic feet per minute) of air was supplied to the burn room starting at 1 min:30 sec after ignition. At

*The thermocouple was of the type used to measure the furnace temperature during a fire test in accordance with Standard Methods of Fire Tests of Building Construction and Materials (ASTM E119-70)[3].

approximately 5 min. of test time some flame emerged from the window and caused steaming and charring of the east wall plywood adjacent to the window. As the test progressed, the flame projection from the window became intermittent. No surface ignition was obtained on the plywood for either the east or west wall.

Figure 3 is a plot of temperature isotherms on the east wall after 5 minutes. Similar plots at 10, 16 and 20 minutes are shown in figures 4, 5, and 6. The peak temperatures measured did not exceed 350°C (660°F). Figures 7 and 8 are plots of temperature readings versus time of the nine thermocouples on the east wall and of the six thermocouples on the west wall, respectively.

The rate of burning of the wood cribs was estimated to be 14 pounds per minute. For a heat of combustion of 7500 Btu/pound, the rate of heat release was on the order of $1.0 \times 10^5$ Btu/minute. The burn room time-temperature curve compared to the standard curve specified in ASTM E119-70[3] is shown in Figure 9.

## Test Number 2

Since flame projection beyond the burn room through the window in Test Number 1 was less than anticipated, several changes were made in Test Number 2. The fire load was increased from 4.4 pounds per square foot to 6.3 pounds per square foot. The air supply to the burn room was 1300 cfm at the beginning of the test and increased to 1750 cfm at test time of 4 minutes. The burn room time-temperature curve compared to the standard curve is shown in figure 10.

In this test surface ignition occurred at 9 minutes on the east wall. The magnitude and progression of flaming is shown in the photograph (figure 11). Figures 12 and 13 are plots of temperature isotherms on the east wall at 5 and 10 minutes after initiation of the test. No significant changes were observed on the west wall during the test. Figures 14 and 15 are plots of temperature readings versus time of the nine thermocouples on the east wall and of the six thermocouples on the west wall, respectively.

The instantaneous heat flux absorbed by the east wall just prior to ignition and the total heat energy absorbed, were estimated to be on the order of 1.0 $W/cm^2$ and 175 $J/cm^2$ respectively. These values were calculated by a heat balance equation using an integral method[4] based on the assumption that the plywood wall could be represented as a semi-infinite slab with constant thermal properties, and by use of the experimental surface temperature data at the location where ignition occurred.

Figure 16 shows the temporal distributions of radiant flux and blackbody temperature levels measured at several locations and the average fire room temperature plotted for comparison. It can be seen that the blackbody temperature at the window opening and the projected flame were considerably higher than the average room temperature during the early stage of the fire test. This is due to the large thermal lag and to conduction loss to the cold walls through the iron pipes mounting the thermocouples in the fire room. As shown in Figure 16, the radiant flux, monitored continuously by the two radiometers mounted on the west wall, was mainly due to the flame emerging from the window opening and due to flaming of the east wall. The intensity measured at Location C was found to be 2.8 $W/cm^2$ at the peak fire condition.

## 5.0 DISCUSSION AND CONCLUSIONS

Comparing figure 9 and figure 10, in the early stage of the tests the fire room temperature in Test Number 2 is slightly lower than that in Test Number 1. This difference in fire room temperatures, during the early test stage, could have been created by variations in the wood crib stack height, changed geometric configuration, radiation absorption and initial heat release, etc.

Ignition of the exterior plywood panels located 1 ft. from the edge of the window in a reentrant corner did not occur due to the burning of a room fire load of 4.4 pounds per square foot of floor area. However, surface charring occurred and peak surface temperatures of 350°C (660°F) were measured. When the fire load was increased to 6.3 pounds per square foot, and air was continuously introduced into the burn room, surface ignition took place at 9 minutes on the plywood in the vicinity of the window opening.

The incident irradiance and the total amount of heat energy absorbed at the exposed surface of the east plywood wall prior to ignition were estimated to be approximately 1.0 $W/cm^2$ and 175 $J/cm^2$ respectively.

Since there was no ignition of the exterior plywood (flame spread index-103) on the west wall (4-1/2 to 5 feet from the opening) for either fire load and since there was ignition of the plywood on the east wall (1 foot from opening) for only the higher fire load it would appear that the choice of a limiting flame spread index of 75 for the exterior combustible wall surface material in a reentrant wall corner configuration was a sound technical judgment. However, to refine this index, additional testing and analysis involving variations in the window to wall separation distance and wall materials would be required.

The ultimate goal of continued testing would be to develop a model of the radiation and convective heat transfer from flames emerging from a window to a wall of specified surface flammability properties and to calculate the separation distances required to prevent ignition for any window and wall arrangement.

## APPENDIX A

### Log of Test Observations

<u>Test Number 1</u>

| Time min:sec | Observations |
|---|---|
| 0:00 | Start test. Ignition of heptane fuel. |
| 1:00 | Black smoke from the heptane fuel and wood cribs. The wood cribs ignited. |
| 1:30 | Flame is rising up inside the fire room. Air (1540 cfm) supplied to the fire room. |
| 2:00 | Flames starting to project from the fire room window. |
| 5:00 | Flame is shooting out at an angle of about 45° and the maximum length from the window is approximately 4 ft. |
| 5:30 | Charring and steaming observed on the east wall right above 0 line around No. 53 thermocouple. |
| 7:00 | Flame projecting out from the window is reduced. |

| | |
|---|---|
| 10:00 | A sudden large flame is shooting out of window. |
| 12:00 | The plywood surface is buckling near No. 53 thermocouple. |
| 16:00 | Most of the wood cribs have been consumed. No visual change has been observed on the west wall. Charring and sparking but no flaming ignition has been observed on the east wall surface. |
| | END OF TEST |

Test Number 2

| Time min:sec | Observations |
|---|---|
| 0:00 | Ignition of heptane fuel. The blower is turned on to supply 1300 cfm of air. |
| 3:00 | Wood cribs are burning severely. |
| 4:00 | The air supply is increased to 1750 $feet^3$/minute. |

| | |
|---|---|
| 5:00 | Flames start to project from the fire room window. |
| 5:30 | Charring is observed on the east wall around 2 foot line near thermocouple No. 47. |
| 7:00 | Smoke and sparking is observed at the same site. Flame from the window impinging on the east wall. |
| 9:00 | Surface ignition is occurring over a wide area of the east wall. |
| 9:30 | Fog spray is applied to extinguish the fire on the east wall to prevent further spread. |
| 10:00 | The east wall catches fire again. |
| 15:00 | Extinguishment and reignition have occurred several times. |
| 16:00 | Flaming inside the fire room diminishes. |

| | |
|---|---|
| 24:00 | The air blower is turned off. Most of the wood cribs has been consumed. No visual changes have been observed on the west wall. |

END OF TEST

APPENDIX B

REFERENCES


1. "Standard Method of Test for Surface Flammability of Materials Using a Radiant Heat Energy Source," American Society for Testing and Materials Designation E162-70, available at 1916 Race Street, Philadelphia, Pennsylvania 19103.

2. Fire-Resistance Classifications of Building Constructions, Building Materials and Structures Report BMS 92 and BMS 149, National Bureau of Standards, Washington, D.C.

3. "Standard Methods of Fire Tests of Building Construction and Materials," American Society of Testing and Materials Designation E119-70.

4. T. R. Goodman, "The Heat Balance Integral--Further Considerations and Refinements," ASME Journal of Heat Transfer, Vol. 83, pp 83-86, (1961).

## APPENDIX C

### SI Conversion Units

In view of present accepted practice in this country in this technological area, common US units of measurement have been used throughout this paper. In recognition of the position of the United States as a signatory to the General Conference on Weights and Measurements which gave official status to the metric SI system of units in 1960, we assist readers interested in making use of the coherent system of SI units by giving conversion factors applicable to US units used in this paper.

Length

1 in = 0.0254 meter

1 ft = 0.3048 meter

Mass

1 lb = 0.45 kilogram

Stress

1 psf = 47.88 newton/meter$^2$

1 psi = 0.332 newton/meter$^2$

1 plf = 13.49 newton/meter

Temperature

Temperature in °F = 9/5 (temperature in °C) + 32°F

Energy

1 BTU = 252 cal = 1055 Joule

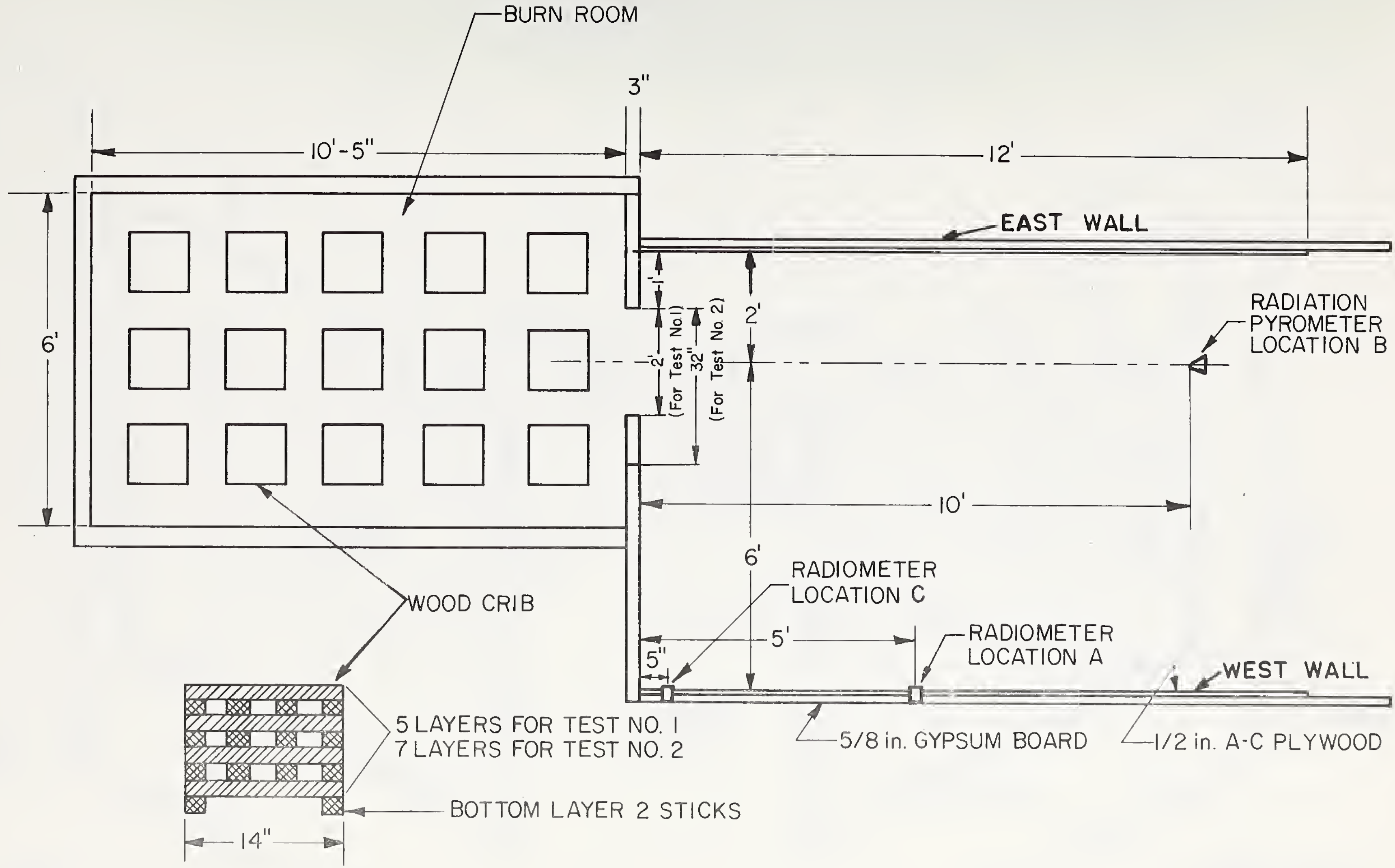


Figure 1. Plan view of the specimen and fire room configuration.

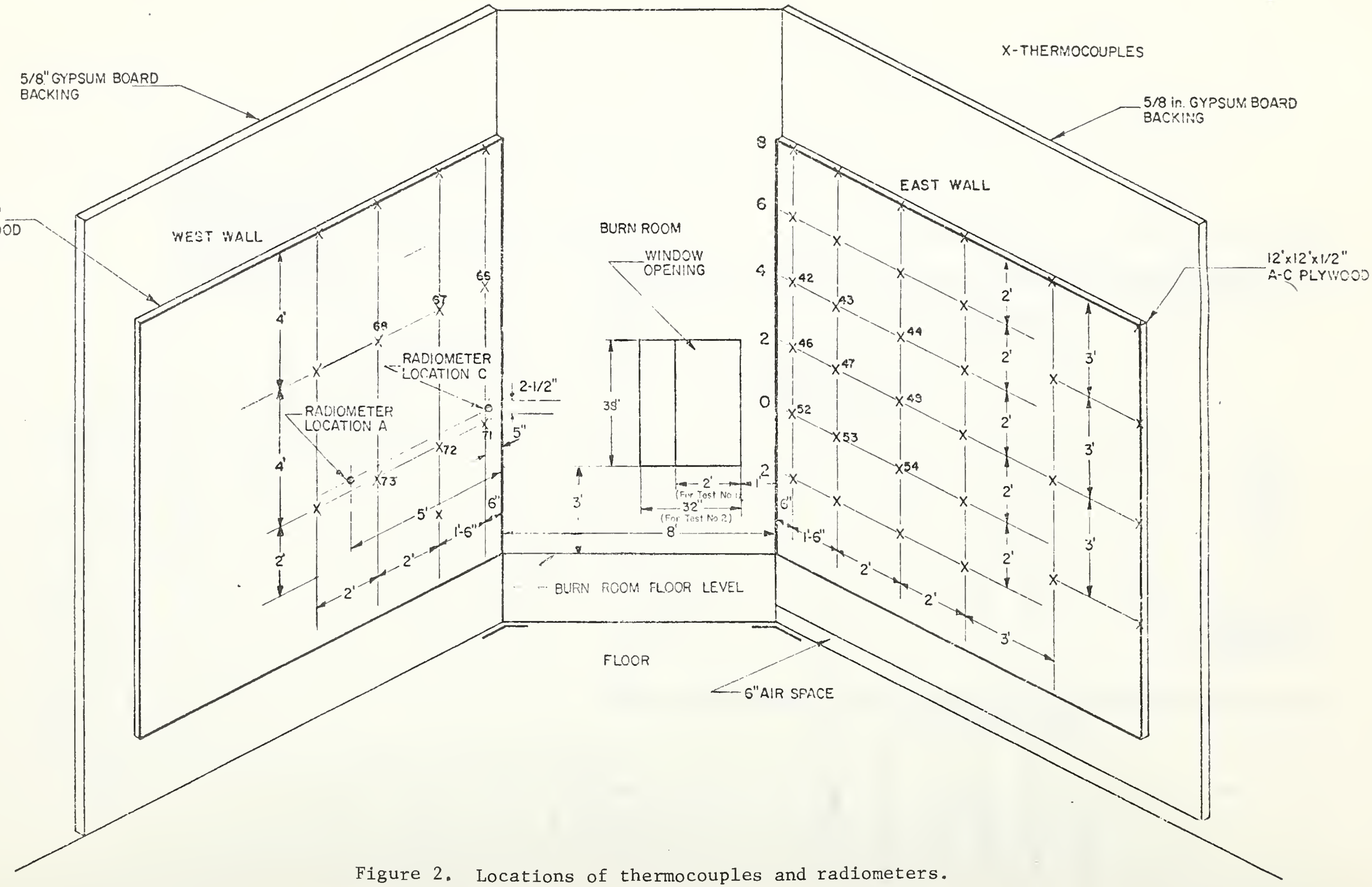


Figure 2. Locations of thermocouples and radiometers.

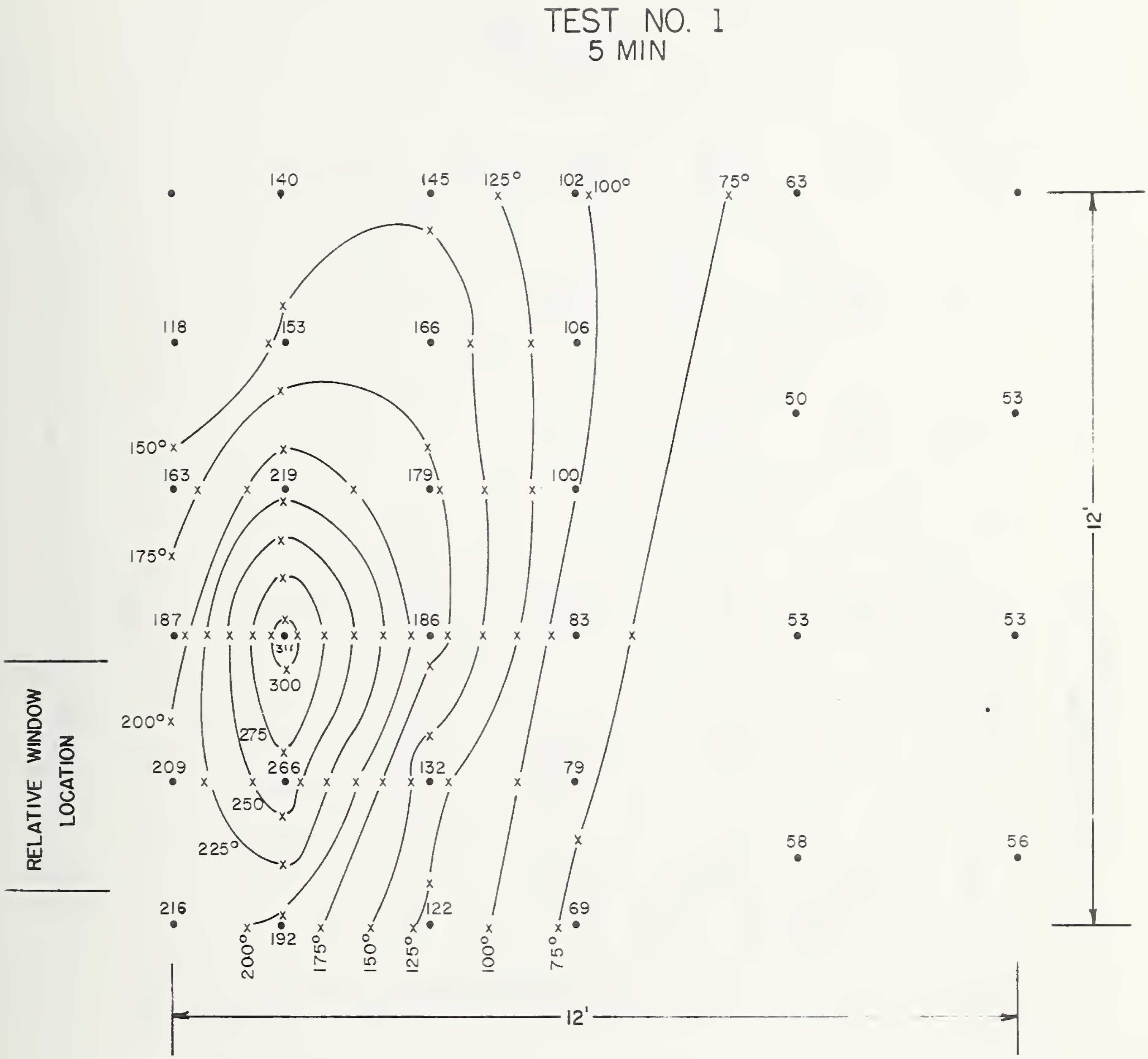


Figure 3. Temperature Isotherms (Deg C) on the East Wall at 5 minutes test number 1.

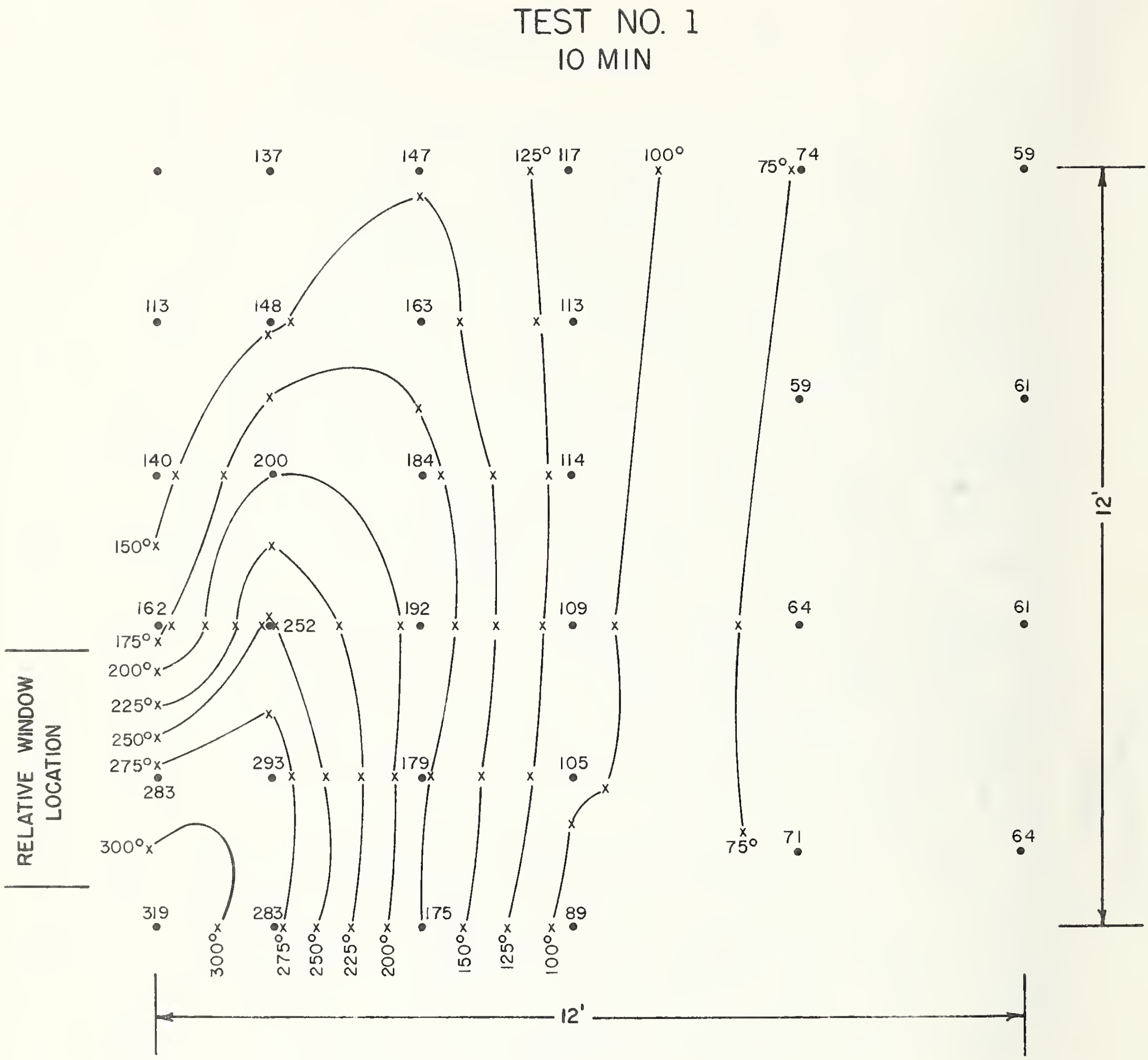


Figure 4. Temperature Isotherms (Deg C) on the East Wall at 10 Minutes, test number 1.

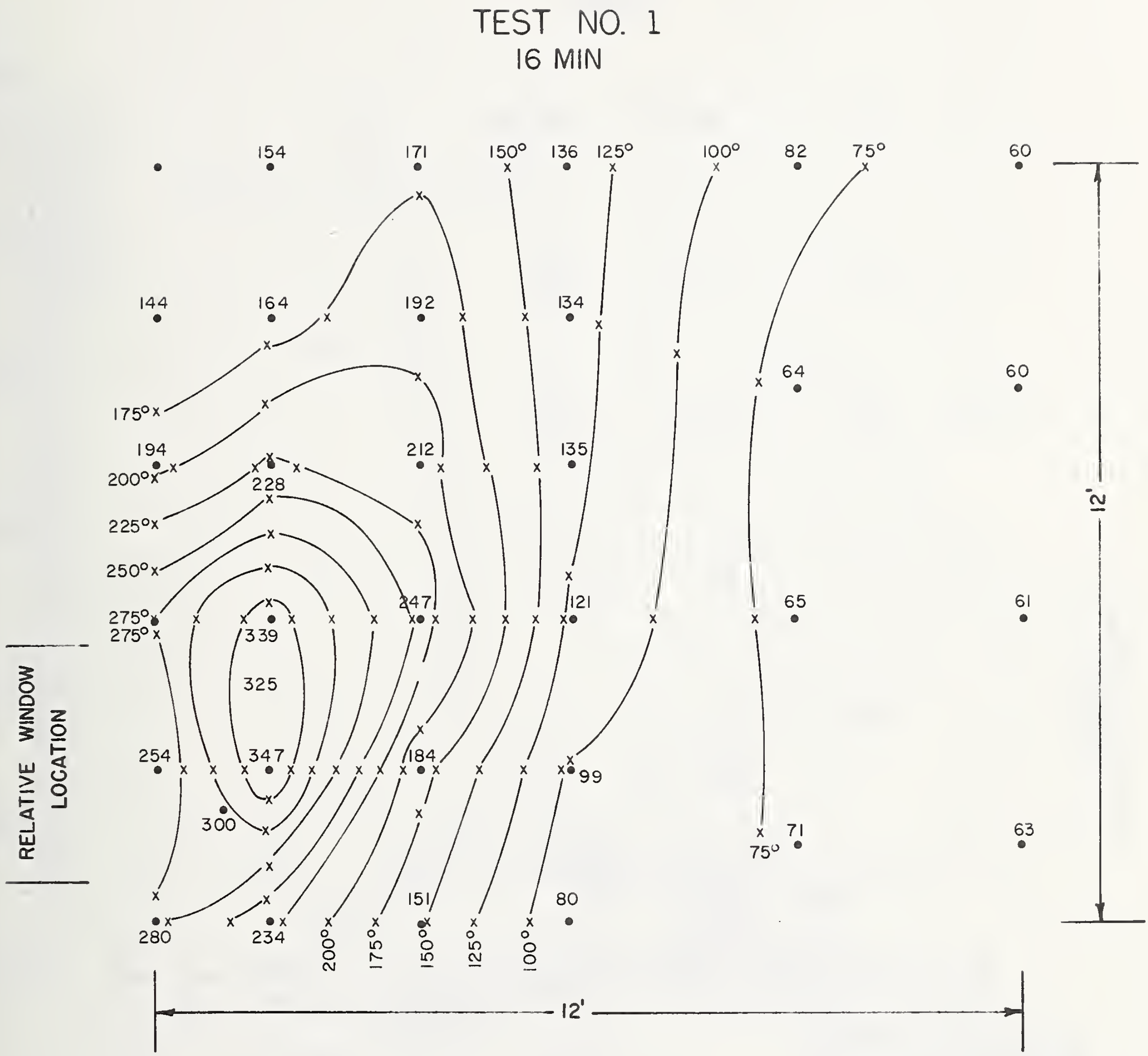


Figure 5. Temperature Isotherms (Deg C) on the East Wall at 16 minutes, test number 1.

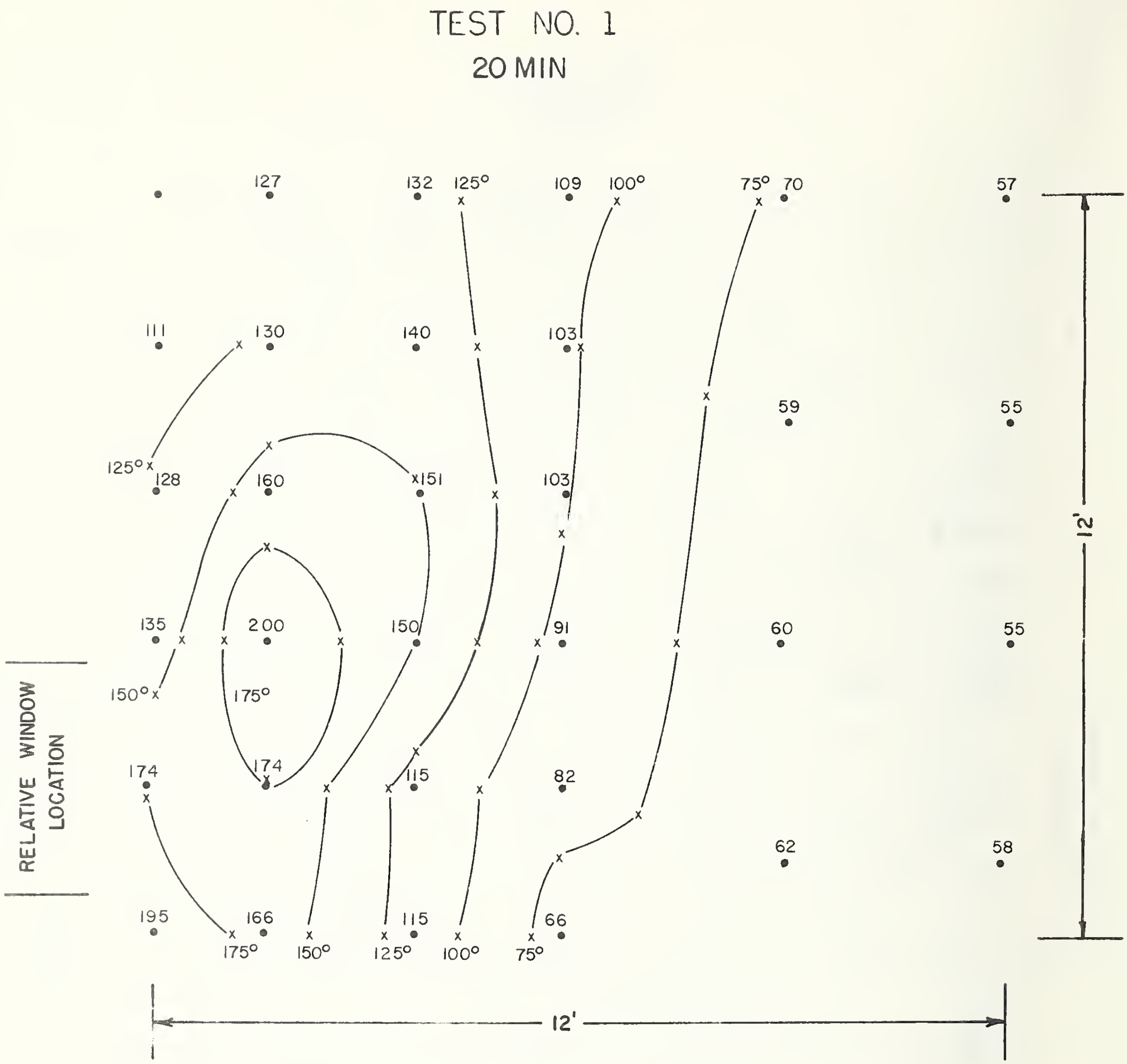


Figure 6. Temperature Isotherms (Deg C) on the East Wall at 20 minutes, test number 1.

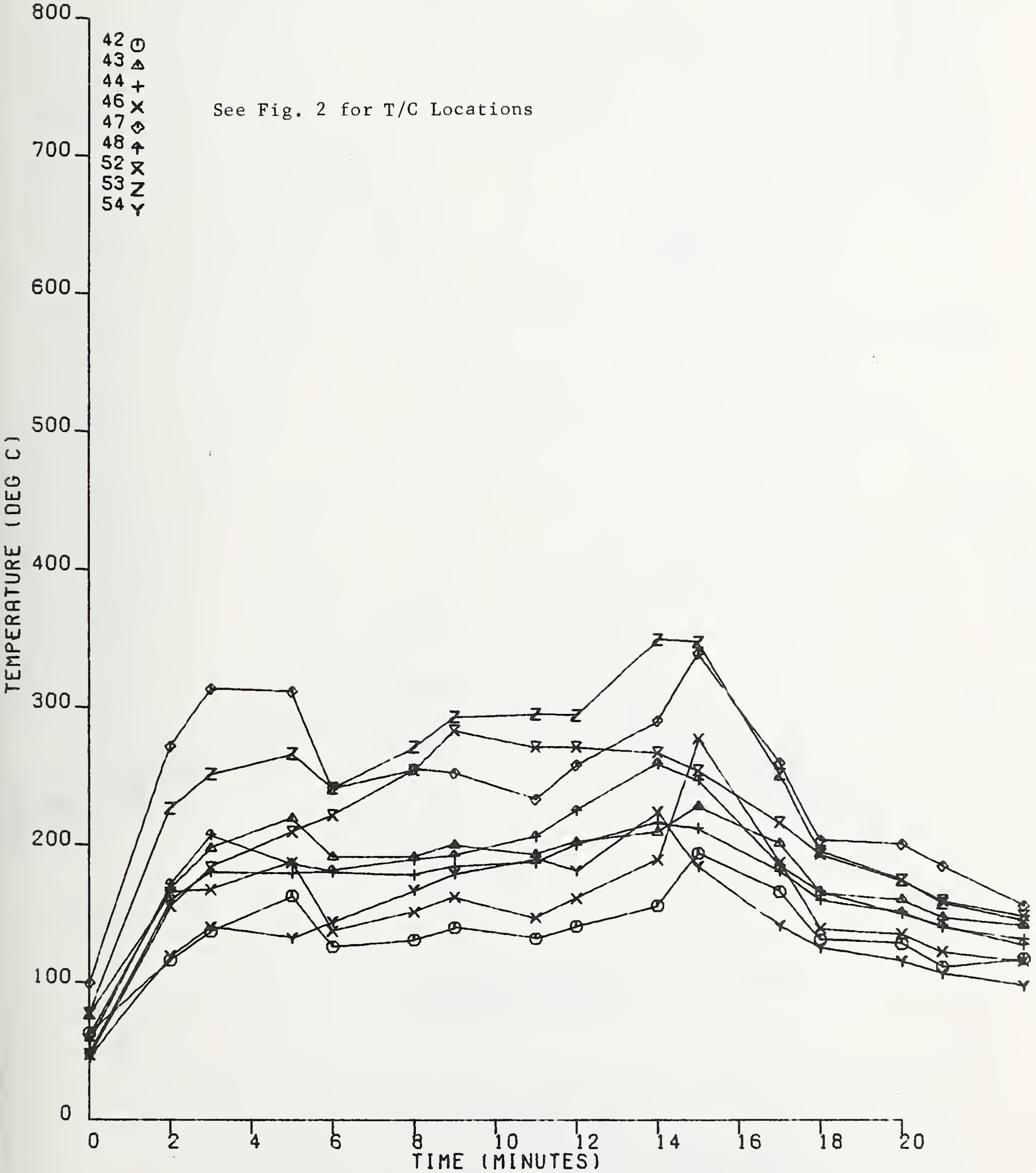


Figure 7. 9 Thermocouple Temperatures on East Wall adjacent to window, (test number 1).

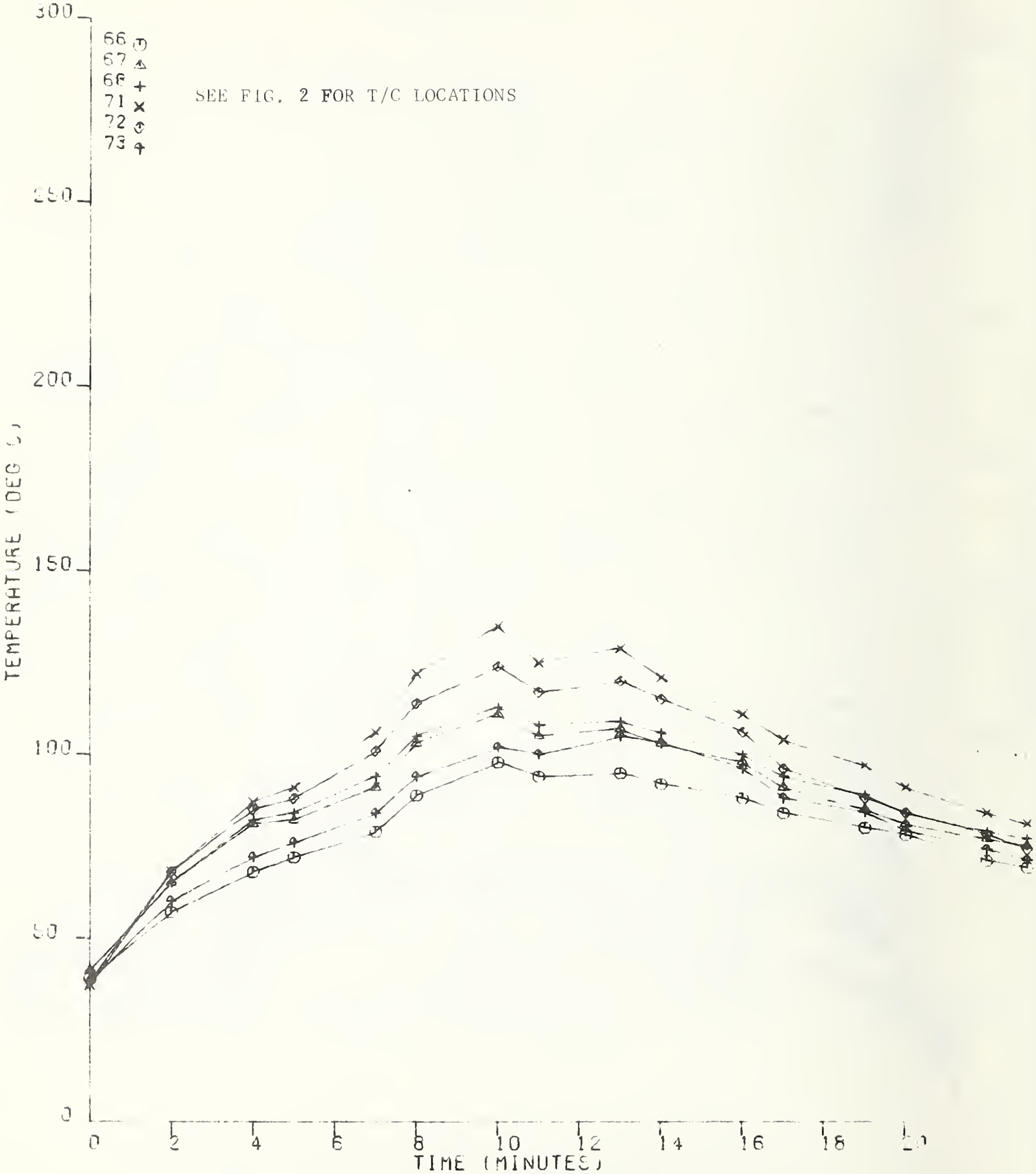


Figure 8. 6 THERMOCOUPLE TEMPERATURES ON WEST WALL ADJACENT TO WINDOW (test number 1).

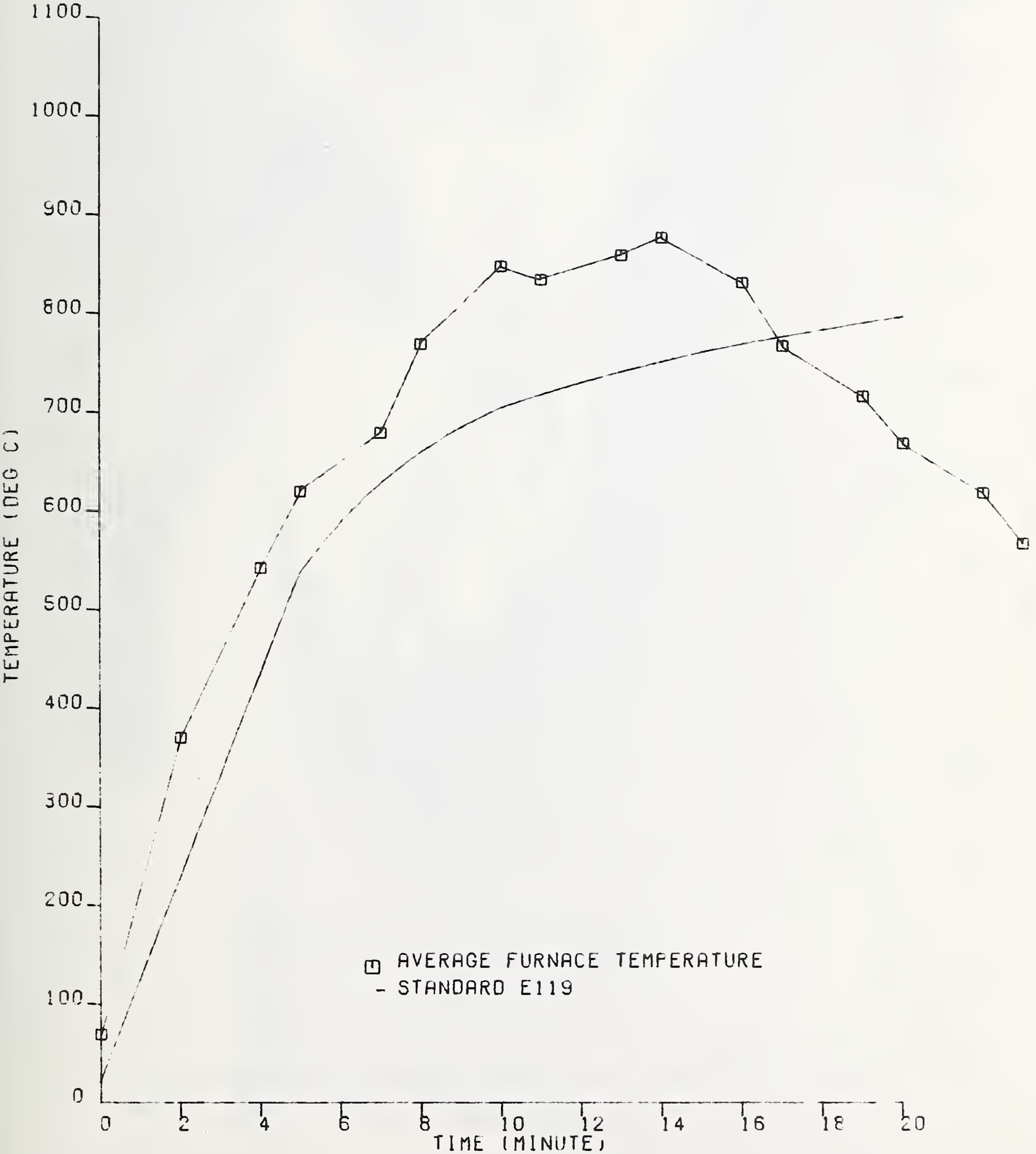


FIGURE 9. AVERAGE FIRE ROOM TEMPERATURE FOR TEST NO. 1(4.4 psf FIRE LOAD) COMPARED WITH STANDARD E 119.

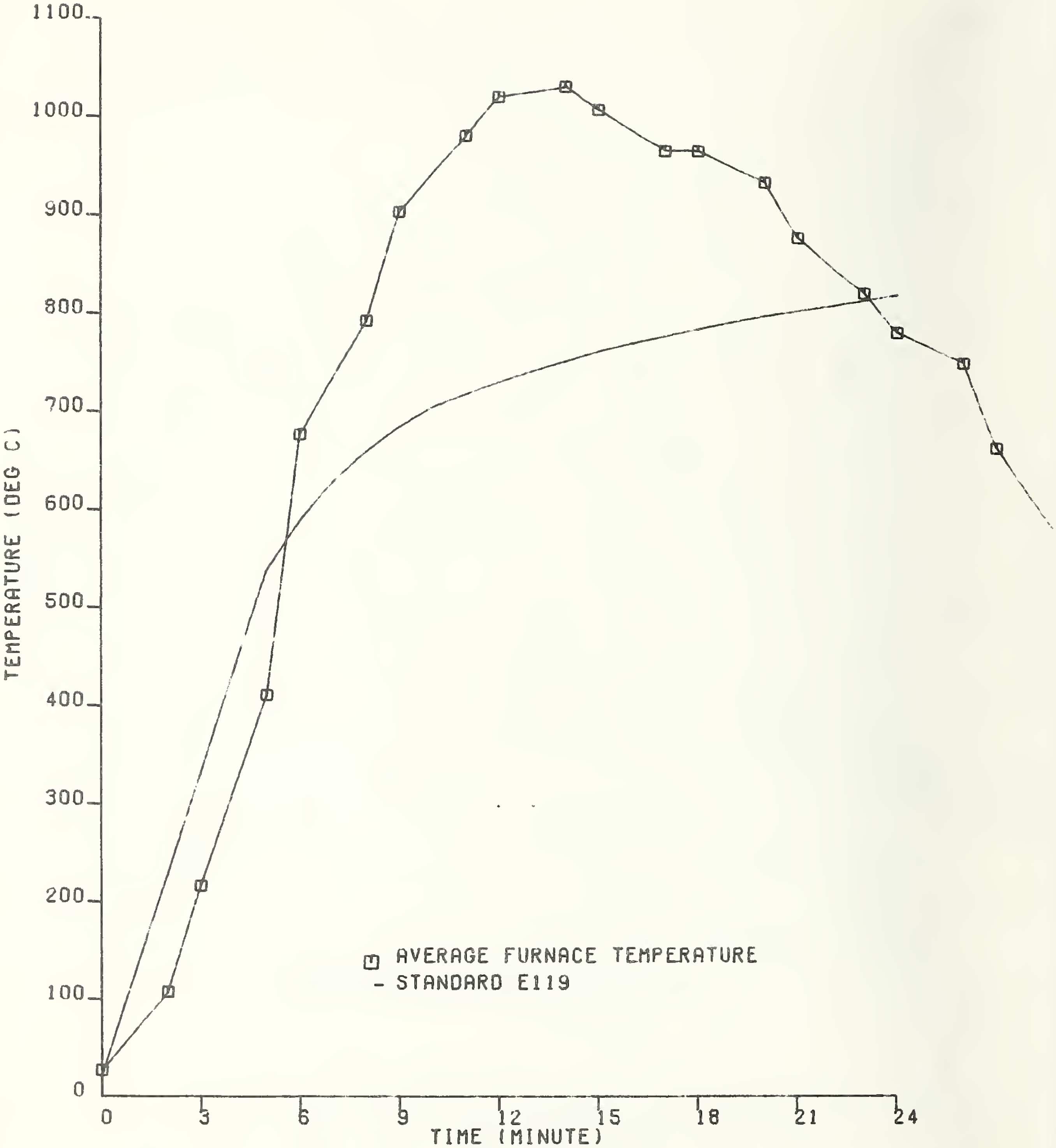


FIGURE 10. AVERAGE FIRE ROOM TRMPERATURE FOR TEST NO.2(6.3 psf FIRE LOAD) COMPARED WITH STANDARD E 119.

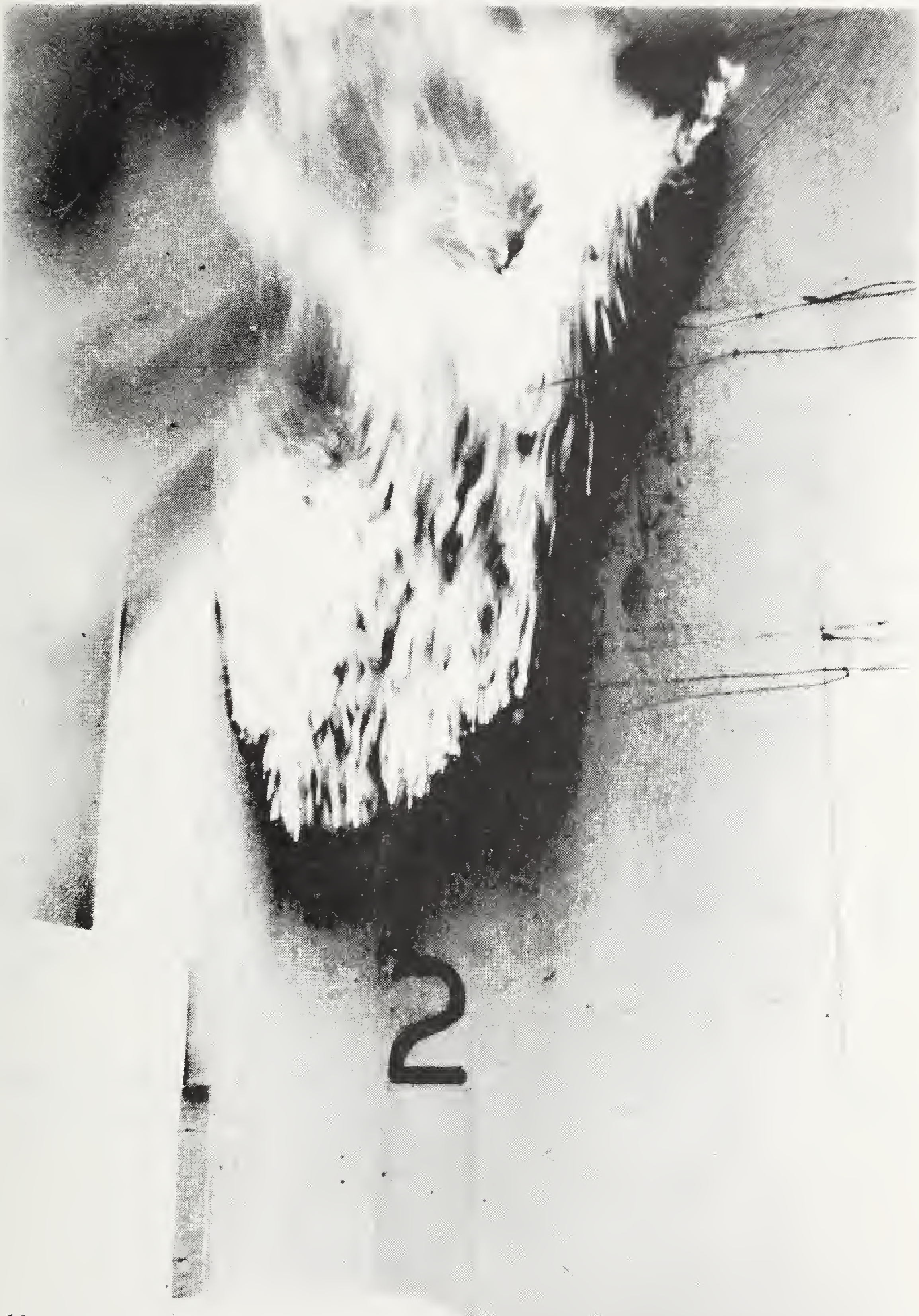


Figure 11. The plywood exterior wall ignited by flames emerging from a window opening 9 min. after start of test number 2.

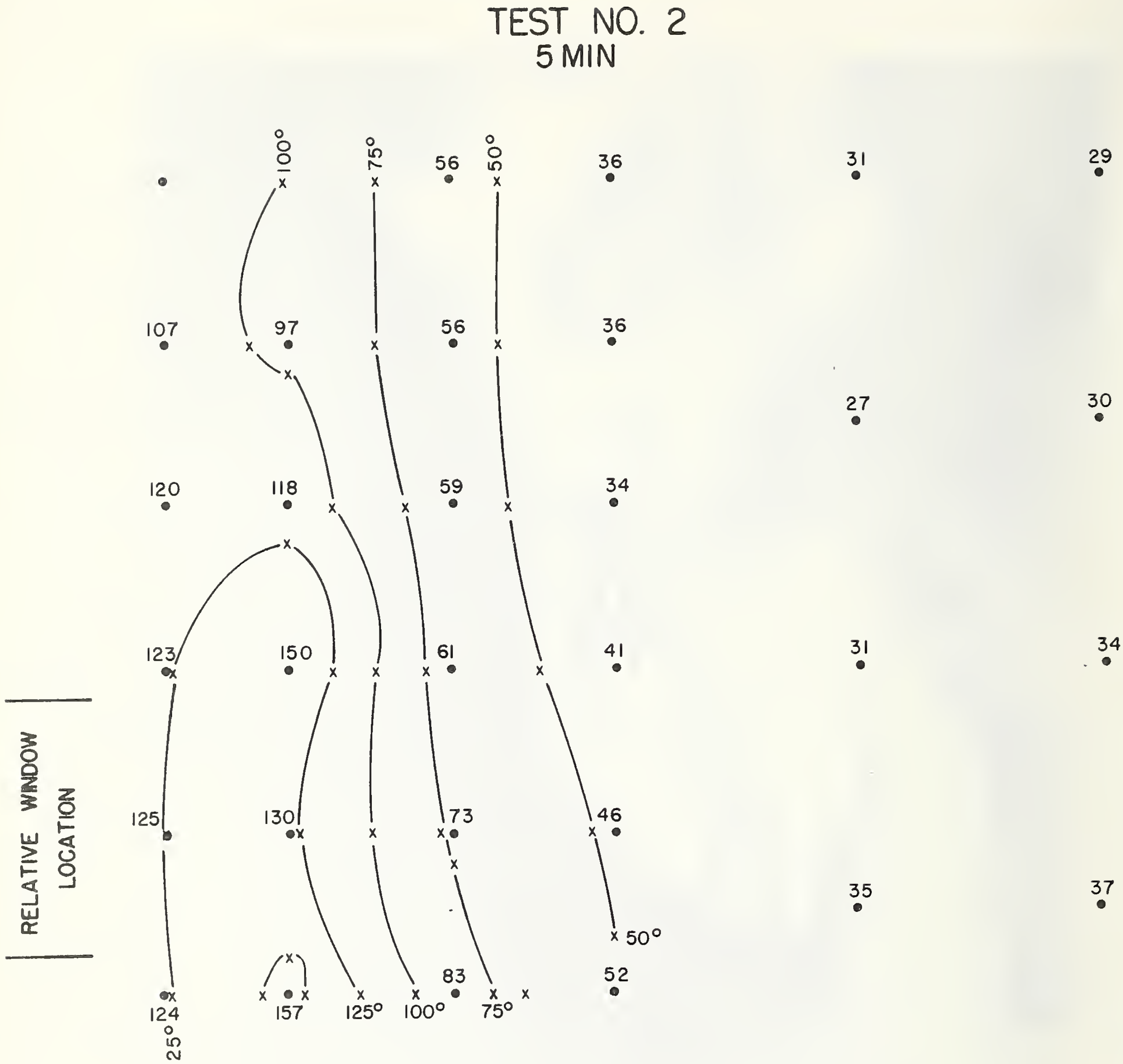


Figure 12. Temperature Isotherms (Deg C) on the east wall at 5 minutes, test number 2.

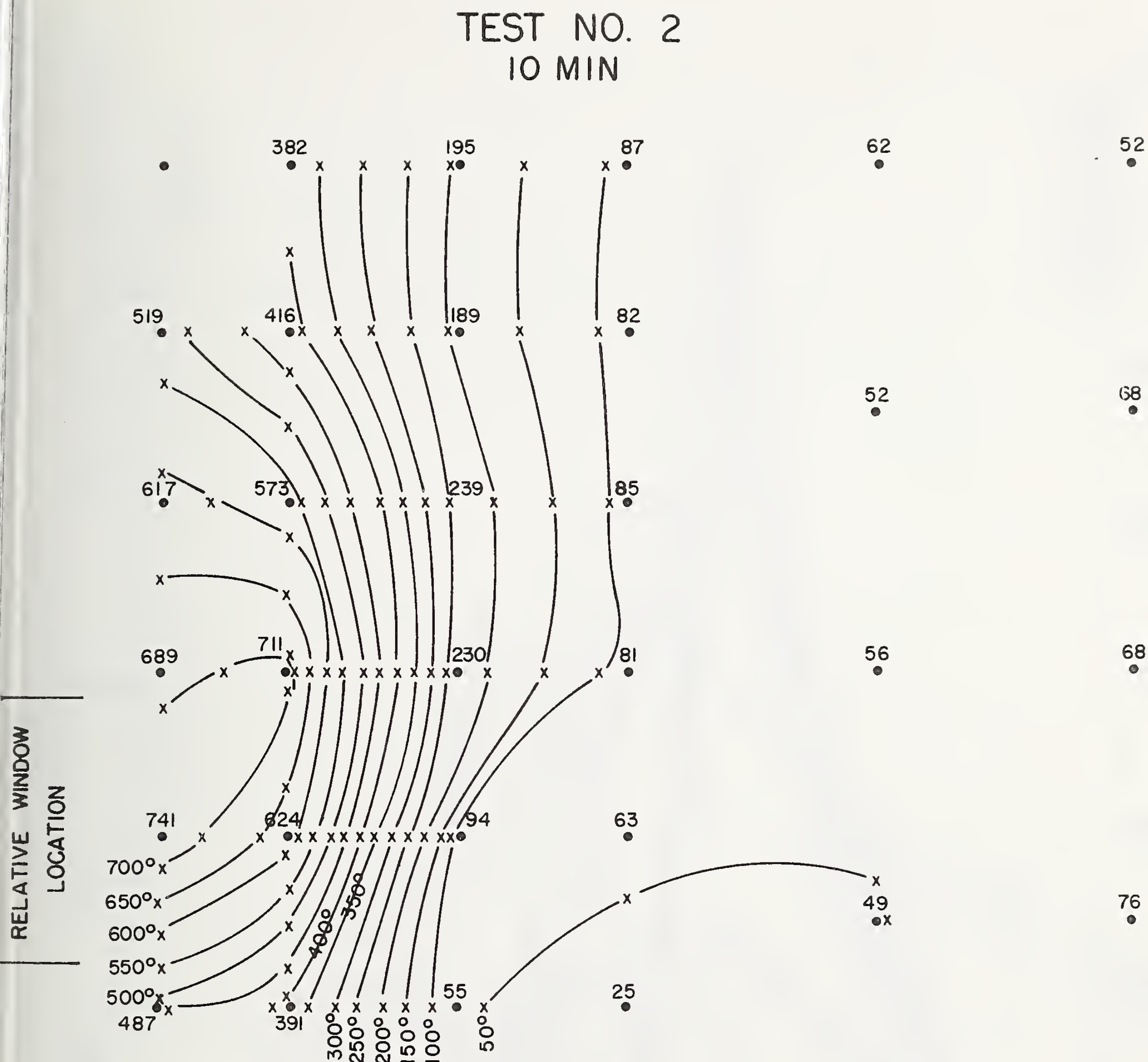


Figure 13. Temperature Isotherms (Deg C) on the east wall at 10 minutes, test number 2.

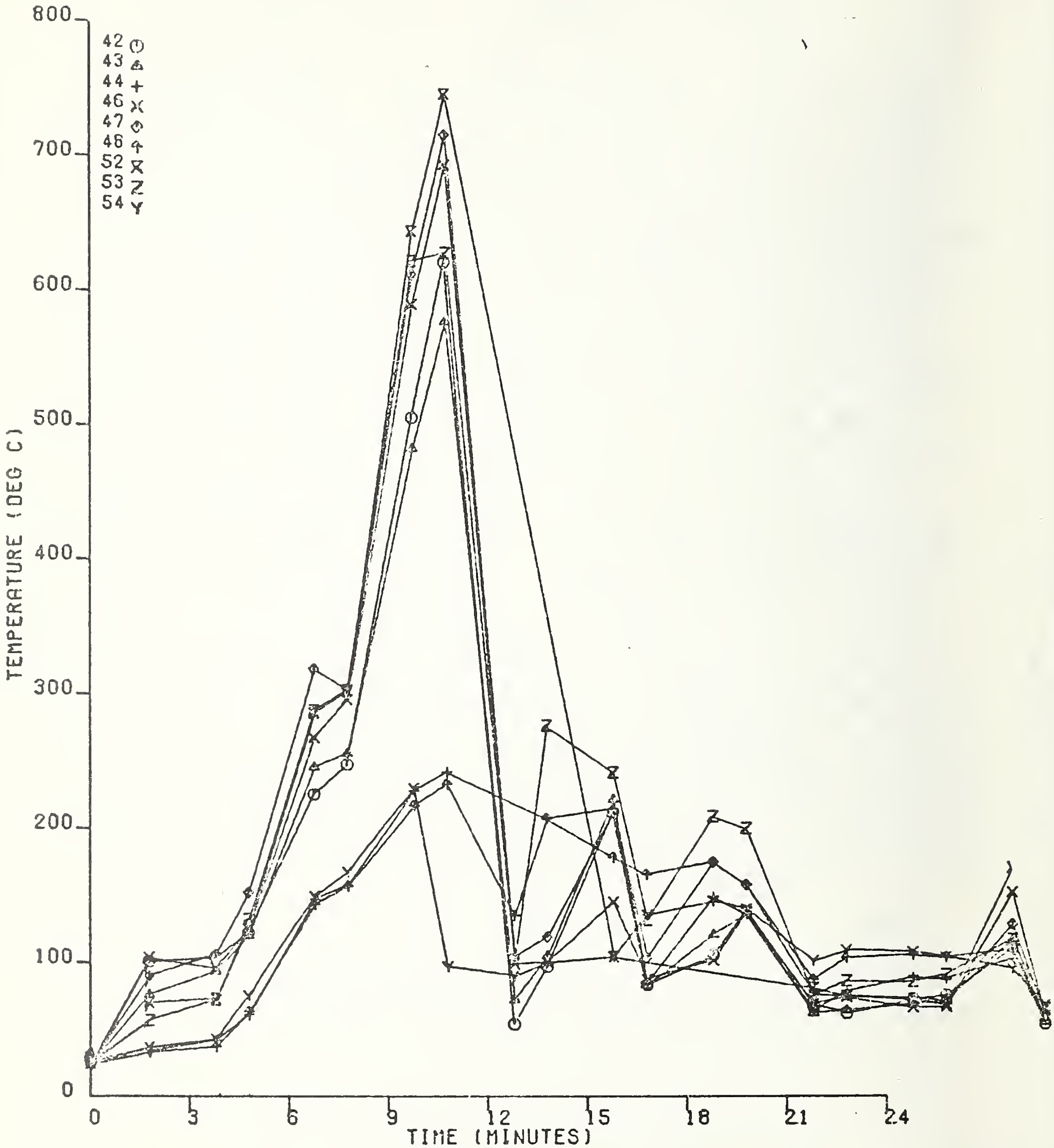


FIGURE 14. 9 THERMOCOUPLE TEMPERATURES ON EAST WALL ADJACENT TO WINDOW (test number 2).

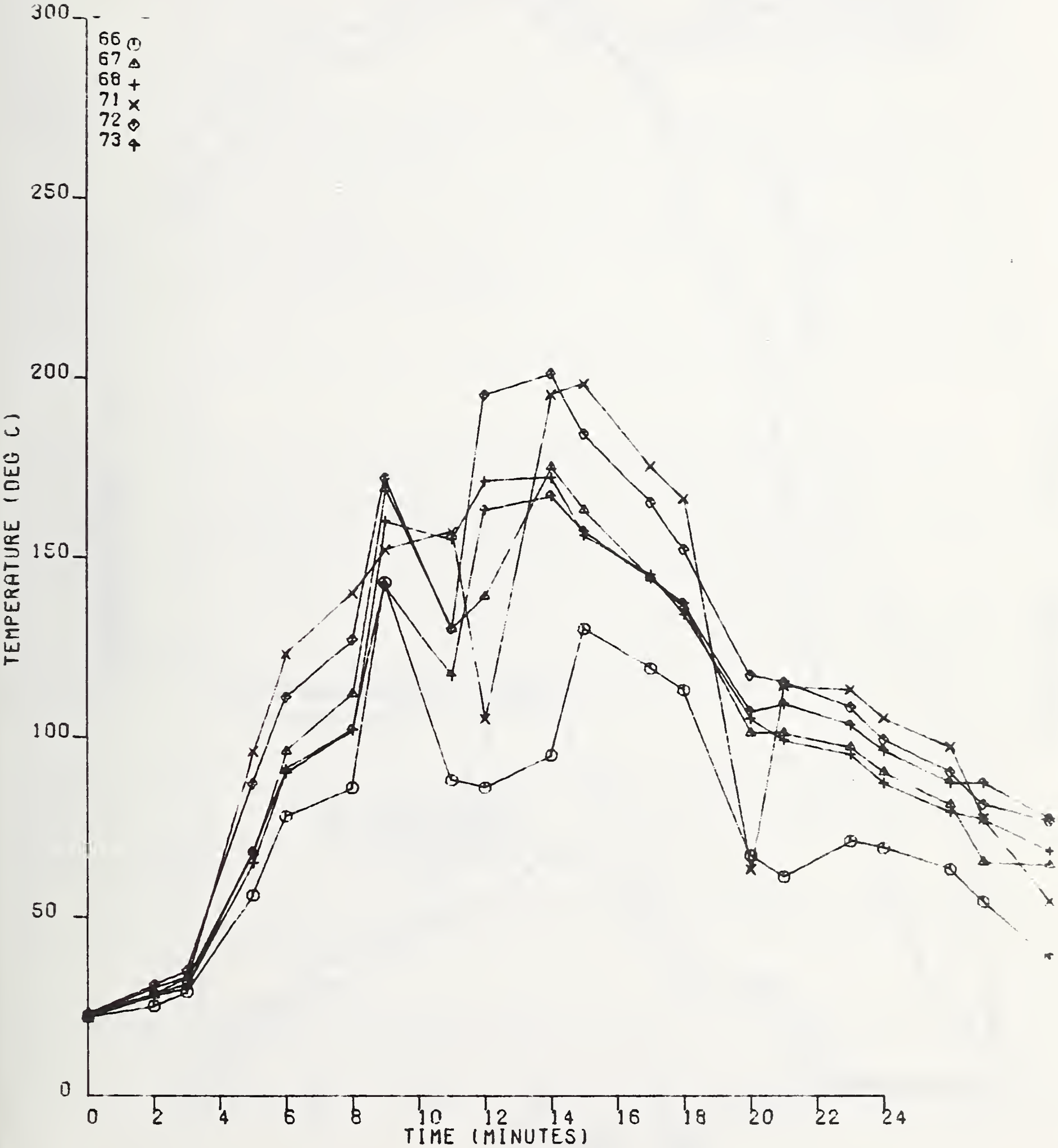


FIGURE 15. 6 THERMOCOUPLE TEMPERATURES ON WEST WALL ADJACENT TO WINDOW (test number 2).

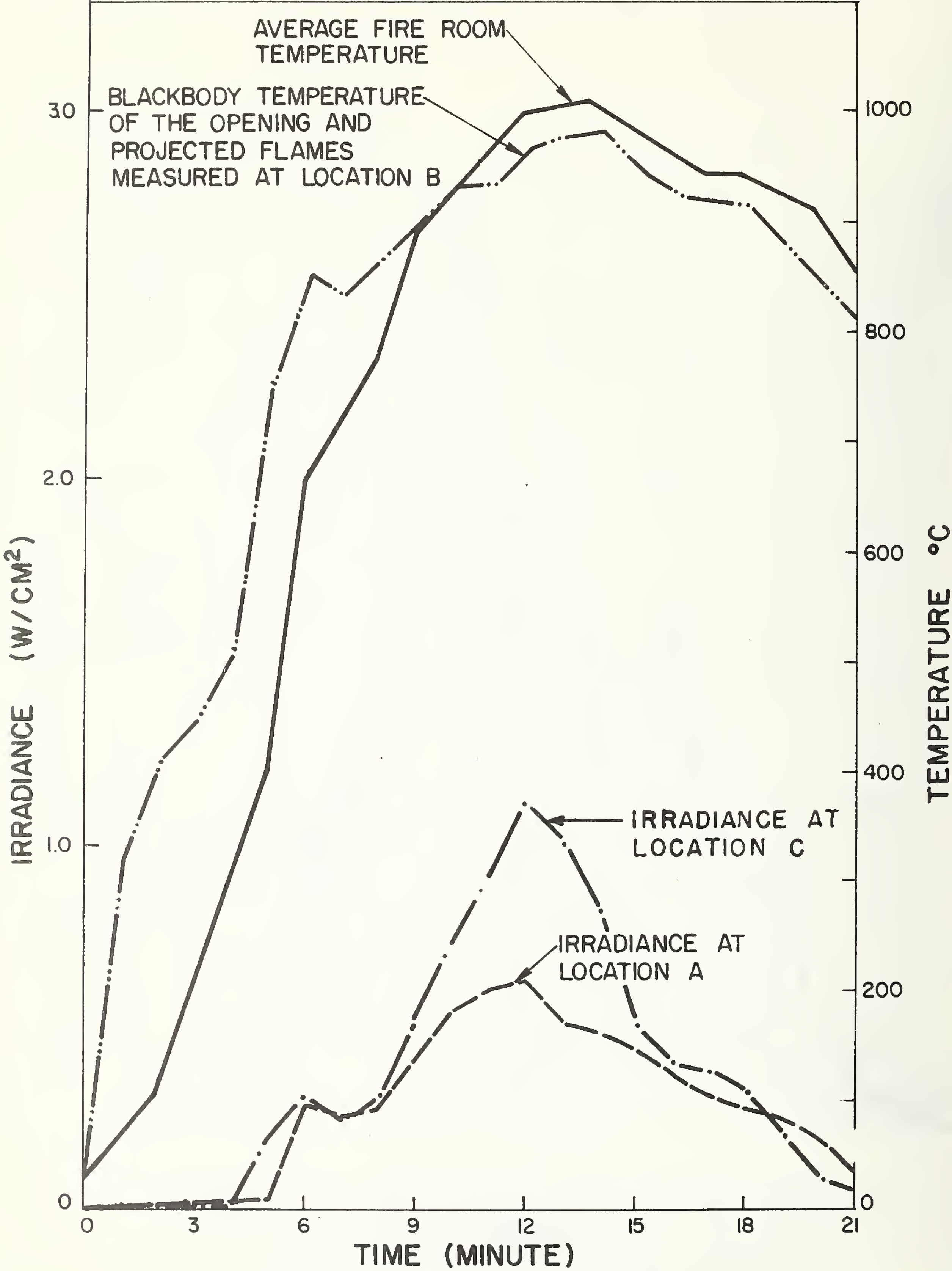


FIGURE 16. TEMPORAL DISTRIBUTION OF RADIATIVE FLUXES MEASURED AT SEVERAL LOCATIONS AND BLACKBODY TEMPERATURE OF THE WINDOW AND THE PROJECTED FLAMES FOR TEST 2.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)


As a part of the research program concerning the recommended criteria for fire safety in Operation BREAKTHROUGH, two full scale fire tests were performed on a mockup of a reentrant corner, i.e., the interior corner formed at the intersection of the exterior walls of adjacent buildings, such as townhouses and garden apartments.

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17. KEY WORDS (Alphabetical order, separated by semicolons)
exterior wall; fire spread; fire test; ignition; Operation BREAKTHROUGH; reentrant corner

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