# NATIONAL BUREAU OF STANDARDS REPORT

9026

DWELLING UNIT BURNOUT TESTS

in

PRATT INSTITUTE TEST BUILDING

by

D. Gross

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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D. Gross

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TABLE OF CONTENTS

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## ABSTRACT

Results are reported of three burnout tests in an experimental test building, using a wood crib fuel load of 6 $lb/ft^2$ and a structural design load of 40 $lb/ft^2$. Measurements were made of temperature, radiation, smoke, gas composition, and deflection. A discussion of the fire performance of materials and methods of construction, and conclusions with regard to specific fire-protective objectives are presented.

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## 1. Introduction

A temporary test building was erected by the Research Department of the School of Architecture of Pratt Institute as part of its work under a Low Income Housing Demonstration grant from the U. S. Housing and Home Finance Agency. The purpose of the Pratt Institute study was to demonstrate (in an actual building to be erected subsequently) that significant reductions can be achieved in the cost of high-rise housing by the use of new materials and advanced methods of construction.

The project requires the establishment of technical standards to be used in place of any previously-established design criteria or building code requirements.

The purpose of the test building was to develop technical information needed for the evaluation of the various materials and methods of construction which are being considered for use in the demonstration building. Information on the fire-protective features of the construction was to be obtained by means of full-scale burnout tests in the test building. The Fire Research Section, National Bureau of Standards, undertook the responsibility for the planning and conduct of the burnout tests, and this report summarizes the results of the tests.

## 2. Objectives

With respect to fire protection, the primary aims of Pratt Institute were the protection of the occupants and the prevention of fire spread to other apartments and buildings. The protection of the building itself or of property within it was not a primary aim.

In the test building, structural and planning features were incorporated with the aim of accomplishing the following specific objectives:

1. Confinement of fire and smoke within the dwelling unit or other space in which the fire starts.

2. Protection of the building structure against failure to carry load.

3. Use of minimum quantities of combustible construction materials.

To the extent possible, the burnout tests were designed to obtain information on the degree to which these objectives could be accomplished.

Pratt Institute established additional fire resistance requirements [1], conformance to which was outside the scope of the burnout tests. The following tentative requirements, based on performance during a standard fire endurance test [2], were established:

| | Requirement | |
|---|---|---|
| Component | Fire Endurance [2] | Noncombustible [3] |
| Structural - columns, bearing walls, girders, floor slabs, beams | Thermal 1/2 hr.<br>Structural 1 hr | |
| Exterior non-bearing walls | | Noncombustible, if 30 ft or more from another building |
| Partitions between adjacent dwelling units;<br>Partitions between dwelling units and public or service areas | Thermal 1/2 hr | |
| Partitions within dwelling unit;<br>Closet shelving and kitchen cabinets | | Noncombustible |
| Tenant storage area | Thermal 1 hr | |

## 3. Description of Test Building

The test building consisted of two two-story wings connected by a wood platform and stairs, see Fig. 1. One wing was of steel frame construction with exposed exterior columns and dry floor construction; the other was of precast concrete, bearing wall construction. Each wing contained three rooms per story: two rooms, each about the size of a small bedroom, and the third representing a room of an adjacent apartment. The latter room contained a half-bath and an entrance to an outside balcony. The steel wing was approximately 12 by 34 feet in outside dimensions (balcony not included) with floor area per room ranging from 114 to 134 square feet; the concrete wing was approximately 14 by 32 feet outside with floor area per room ranging from 100 to 123 square feet. Ceiling height was 8 feet. Three types of curtain wall construction, two types of party walls, two types of floating floor construction, and innovations in plumbing and heating were incorporated in the test building. Additional details are supplied elsewhere [4].

Erection of the steel wing was done in May, the concrete wing in June, with the entire interior finishing completed by mid-July. Following acoustical tests of sound transmission through walls and floors in early August, burnout tests were conducted in the steel wing on August 24th, and in the concrete wing on September 1 and November 3, 1965.

## 4. Test Plan

Fig. 2 is a plan view of the test building showing the arrangement of instrumentation for the first two burnout tests. The third test was similarly, but less completely, instrumented. During each test, a photographic record and visual observations were made and measurements were also made of temperature, radiation, smoke, gas composition and deflection. However, because of staff and budgetary limitations, and the fact that the test site was located 200 miles from the laboratory, certain measurements were limited in scope, while others, e.g., ventilation effects, were not considered feasible.

A fire load of 6 pounds per square foot of floor area was placed in rooms 1-6 of the steel wing and rooms 1-3 and 2-3 of the concrete wing for the respective tests and consisted of nominal 2 by 4 in. dry Douglas fir lumber nailed into lattice-type cribs, see Fig. 3. The cribs were supported 16 inches above the floor and ignition was by means of a flammable liquid (6 or 10 quarts of normal heptane) placed in pans beneath the wood cribs. The initial window openings - 11 in. wide by 60 in. high for room 1-6, and 14 in. wide by 50 in. high for rooms 1-3 and 2-3, were chosen to limit the maximum burning rate and to extend the burning period, but no effort was made to prevent glass breakage and fallout due to the effects of fire. All other doors and windows were closed during test. No combustible material was placed in the adjoining rooms.

For Tests 1 and 2, the three second-floor rooms (except bathroom) were loaded to the 40 psf design load using concrete block set on end. For Test 3, the 20-ft long roof slab above the fire test apartment was similarly loaded.

Photographic coverage included 16 mm color movies from several locations, 16 mm color time-lapse movies from a fixed location and 35 mm color transparencies.

Temperature measurements were made using thermocouples placed in the test room, on or near structural elements and on "unexposed" wall and floor surfaces of the adjacent rooms. The location of thermocouples is shown in Figs. 4 and 5, and listed in Table 1. Except for air thermocouples, all thermocouples were of No. 24 B&S gage chromel and alumel wires, the welded beads of which were mechanically fastened into pre-drilled holes in steel or concrete, or were placed under asbestos pads on "unexposed" surfaces. Four metal-sheathed, ceramic-insulated No. 18 B&S gage chromel-alumel thermocouples with fast response times were used to measure air temperature in the fire room in all tests. In Test No. 3, two No. 18 B&S gage chromel and alumel wire thermocouples mounted within porcelain insulators in steel pipes (ASTM-type) were added for comparison purposes.

Radiometers were placed as shown in Fig. 2 with the objective of measuring irradiance levels and permitting estimates to be made of distances at which the spread of fire by radiation might occur through doors, windows, and between buildings. Irradiance levels were measured with a wide-angle disc radiometer with a mica window [5] and with a wide-angle thermopile radiometer with an Irtran window. A commercial, narrow-angle radiation pyrometer was used to measure the blackbody temperature of the flaming interior of the fire room.

Meters for measuring the attenuation of light due to smoke accumulation were placed in rooms adjacent to or above the fire room, see Fig. 2. The light source, consisting of a 30-watt lamp, and the light detector, a type 1P39 vacuum phototube and battery, were assembled in a single box placed on the floor. Using a mirror flush-mounted on the ceiling, a double vertical light path was obtained, extending from 1 ft above the floor to the ceiling. This reduced errors in total smoke measurement due to stratification effects. The optical system of the meter was designed to exclude, as much as possible, all light not originating from the 30-watt lamp source. As noted later, this was only partially achieved.

Measurements were made of toxic combustion products in rooms adjacent to the fire room by means of direct reading colorimetric gas detecting tubes [6]. Using a manually-operated hand pump, a sample of the gas to be analyzed was drawn through the previously sealed detector tube where a chemical reaction occurred and gas concentration was indicated by the pre-calibrated length of stain. A separate tube was used to indicate the volumetric concentration of each particular component of interest. Measurements were made of CO, $CO_2$, HCl and HCN at selected locations indicated in Fig. 2.

Measurements were made of the deflection of the floor (or roof) above the fire room, both at the center of the room and near the partition at the approximate mid-span of the floor system. In tests 1 and 2, invar wires were fastened to the surface of the finished floor above and passed upwards around pulleys mounted on the unloaded, relatively cool ceiling directly above the measuring points. The wires were then passed horizontally near the ceiling through a hole in the exterior wall to pulleys mounted entirely free of the building under test. Each wire passed downward and terminated with a weight to maintain wire tension. An indicating marker on each wire was used to follow deflection changes on a graduated scale mounted behind the wire. In Test 3, a wooden boom, unsupported by the test building, was installed in order to mount the pulleys above the measuring points. A few measurements were also made of the lateral movement of exterior wall panels. In Test 1, the invar wire was fastened to the interior face of the light-aggregate concrete panel and passed to (and through) the opposite wall just above the finished surface of the second floor. In Test 3, the invar wire was fastened to the aluminum-faced, polystyrene core sandwich panel exterior face. In Test 2, lateral movements of the north (concrete) wall and the concrete floor slab were made using dial gages. An invar wire was also fastened to the concrete party wall at the second floor level to indicate longitudinal expansion of the 20-ft floor slab.

## 5. Test Results

### 5.1 Test Log

The following is a log of visual test observations and measurements as well as post-test investigation notes compiled for each test:

Test No. 1--Room 1-6, Steel Wing, August 24, 1965

| Time (min) | Brief Summary Observations |
|---|---|
| 0 | Test started at 11:22 a.m. Weather: Clear; Temperature: 74 °F; RH.: 56%. Wind 7 mph, Direction: 30° (NE) |
| 5 | Heavy smoke in Room 1-5. |
| 15 | Windows in fire room fell out. Flashover. |
| 16 | Part of east partition wall fell into fire. |
| (22-23 | Wallboard ceiling fell off; joists and beams exposed) |
| 25 | Part of west partition wall fell into fire. |
| 35 | Fuel supply essentially consumed. |

| Time (min) | Detailed Test Observations |
|---|---|
| 1:30 | Heavy smoke |
| 2:30 - 3:30 | Cracking of window glass and fallout of vinyl stripping. |
| 5:00 | One sq ft section of window glass fell out; smoke filling room 1-5 through door separations. |
| 9:00 | Heavy white smoke, Room 1-5. |
| 10:00 | Window glass bowing out at top. |
| 13:30 | Floor tile burning. |
| 14:45 | Window glass fell out; first flames out of window. |
| 15:15 | Flashover |
| 15:45 | Part of east partition wall fell into fire |
| 16:00 | Exterior door badly charred upper half; bowed in 1/2 in. |
| 16:15 | Paint ignites on outside of exterior door. |
| 16:45 | Flaming from exterior wall panel above window. |
| 17:00 | Flames reach top of second floor window. |
| 19:00 | East partition wall burning; flames reach radiometer. |
| 20:30 | Clock stopped; paint burning on exterior column |
| 20:45 | Second floor window pane out. |
| 22:00 | Clock and stake on fire. |
| (22:00 - 23:00 | Gypsum board ceiling fell) |
| 25:00 | Part of west partition wall fell into fire; heavy smoke from second floor window. |
| 28:00 | Flames dying down. |
| 29:00 | More active flaming |
| 30:00 | Flames dying down; stucco on steel curtain wall panel flaming; panels deforming. |

| Time (min) | Detailed Test Observations (cont'd) |
|---|---|
| 33:00 | No further flaming out of window. |
| 34:00 | Remainder of second floor window pane fell out. |
| 35:00 | Interior of steel curtain wall bare of gypsum board and insulation. |
| 39:00 - 53:00 | Sections of east and west partitions fell. |

## Post-Test Observations

1. Steel Curtain Wall Panels - Buckling and distortion to roof level. Exterior stucco surface had ignited and burned on a portion of panels. Poured gypsum firestop fairly effective except where pierced by electrical conduit. A few localized areas where fire propagated in the insulation of second-floor wall. No insulation or gypsum board remained on wall of fire room after fire test.

2. Light Aggregate Concrete Panels - Severe outward bowing. 1 - to 2-in. separation from floor system provided access for smoke and fire to upper floor. No access where panel butted up against exterior column. Polystyrene aggregate burned out. Very little structural strength remaining.

3. Interior Door - Passage of flame above door frame into Room 1-5. Floor tile blistered.

4. Joists - Maximum permanent deflection approximately 6 in. on both joists along centerline of Room 1-6. Web rods near walls badly buckled. No apparent break in welds between joist and girder.

5. Spandrel Beam (North) - Sag (less than 1 in.), distortion and warping.

6. Girder (East) - No excessive distortion. Fire stop above girder generally effective except where interrupted for structural members and electrical conduit.

7. Exterior Column - Temporary distortion and bowing, approximately 1/2 in. over length.

8. Gypsum Board-Glass Fiber Composite Wall - Very little of the gypsum board panels on the fire-exposed layer of the walls remained after fire test. Holes for electrical conduit (BX conduit), radiant heaters and thermostats permitted the passage of smoke into adjoining rooms on the first floor. No smoke penetration through second floor partitions. Asphalt-impregnated paper flamed and produced heavy black smoke.

9. Floor - considerable burnout of asphalt tile floor.

10. Window - Upper two-thirds of aluminum window frame melted.

Test No. 2, Room 1-3, Concrete Wing, September 1, 1965

| Time (min) | Brief Summary Observations |
|---|---|
| 0 | Test started at 11:23 a.m. Weather: Partly cloudy; Temperature: 74 °F; RH.: 69%. Wind 14 mph, Direction: 180-200° (S). (Newark Airport Weather Report). |
| 7 | Section of upper right glass pane (1/2 $ft^2$) fell out. |
| 8 | Smoke at ceiling, Room 1-4. |
| 9 | Single crib only burning. |
| 30 | Upper two-thirds of right window pane fell out. |
| 41 | Window blown out by explosive concrete spalling; heavy black smoke; fire building up. |
| 44 | Flashover; flames out of window. |
| 41-70 | Intermittent violent spalling. |
| 40-80 | Development and enlargement of cracks in concrete walls, particularly at joints; water weeping from concrete walls; smoke and steam through cracks. |
| 70 | Decreased flaming; heavy smoke upstairs, Room 2-3. |

Detailed Test Observations

| | |
|---|---|
| 0:30 | Dark smoke, becoming light at 2 minutes. |
| 6:00 | Window glass cracking; heptane flames from two pans only. |
| 7:00 | Section of upper right glass pane (1/2 $ft^2$ area) fell out. |
| 8:10 | Smoke at ceiling, Room 1-4. |
| 9:00 | Single crib only burning; upper edge of glass pane leaning out approximately 2 in. |
| 14:00 | Heavy white smoke in Room 1-4. |

| Time (min) | Detailed Observations (cont'd) |
| --- | --- |
| 20:00-26:00 | Bulging of aluminum sandwich panel, approximately 1- to 1-1/2 in. in some places. |
| 26:00 | Exterior door bowing about 1/4 in. |
| 29:30 | Increase in smoke from fire room, upper two-thirds of right windowpane fell out. |
| 31:30 | Concrete spalled off back wall. |
| 35:15 | East wall of fire room bowed in. |
| 41:00 | Window blown out by explosive concrete spalling; heavy black smoke; fire building up. |
| 44:00 | Flashover; flames out of window. |
| 47:00 | Gypsum board layer on east wall of fire room down. |
| 41:00-70 | Intermittent violent spalling from south and west walls. |
| 58:00 | Joint crack on exterior (North) wall about 1/4 in.; reinforcing bars in west wall exposed. |
| 60:00 | Water dripping down wall, Room 1-1; separation at wall of Room 1-2, approximately 1/4 to 1/2 in. |
| 67:30 | Insulation in east wall exposed through large opening. |
| 72:00 | Smoke heavy in Rooms 1-4 and 2-3. |
| 73:00 | Handle and upper portion of exterior door charred badly. |
| 75:00 | Flames receding; water weeping down exterior (north) wall. |
| 86:00 | Joint crack on exterior (north) wall ranges in width from 7/32 in. (base) to 7/16 in. (top of bldg.). |
| 88:00 | Smoke (steam)in Room 1-1 increasing from ceiling down. |

## Post-Test Observations

Room 1-3 --(Fire room) Severe spalling of concrete on north and especially west walls, with many reinforcing bars exposed. Maximum spall depth, up to 2 in. Aluminum sandwich panels intact except for hole in inner ply at upper corner of window; polystyrene insulation burned out; aluminum straps distorted severely. No spalling of hollow-core concrete floor slabs forming ceiling, but gridwork pattern of cracks over entire ceiling with severe cracks (1/16 in.) at SW corner. Cracks at ceiling joints, 1/6 in. to 1/8 in. Gypsum board cover for steel angle still in place for approximately 6 ft. East wall--outer ply of gypsum board 2/3 down, glass fiber insulation exposed. Large crack (1-1/2 in.) between this and aluminum sandwich panel. Door frame warped; door bowed out slightly; wall above and around door badly blackened.

Room 1-1 --East wall--floor to ceiling separation (1/8 in.) at concrete wall joint; separation from aluminum door frame, 1/8 in.; widespread hairline cracks over entire surface and water stain damage due to extensive condensation and runoff. No damage to south, north or west walls.

Room 1-2 --No damage.

Room 1-4 --Cracks in hollow-core concrete floor slabs forming ceiling. Fire damage along upper 3 ft. of intersection of composite wall and alumimum sandwich panel (1-1/2 in. separation). The composite wall caved in toward Room 1-3, maximum 5 in. Fire penetration damage between wall and door frame limited to upper 2 ft; door and frame reasonably undistorted. Scorch marks on upper 8 in. of closet facing composite wall. No apparent damage to basemold (along 4 walls) or vinyl molding around closet. Extensive and general smoke and water sweat marks.

Room 2-1 --Floor to ceiling separation in East wall (party wall) joint, and corresponding roof slab joint. Maximum separation about 5/16 in. closing up to about 3/16 in. when cool. Additional hairline cracks at corner joints between prefabricated gypsum board partition wall and concrete wall and roof slabs. Steam penetration through hairline cracks.

Room 2-2 --Hairline cracks at ceiling joints; separation 1/16 in. upper half of joint at poured concrete wall filler unit. No damage due to fire, smoke or water (from concrete sweating).

Room 2-3 --North wall -- separation of floor both horizontally and vertically approximately 3/8 in.; slight evidence of smoke penetration under basemold; floor to ceiling crack in gypsum board. East wall (gypsum board partition) intact. West wall -- floor to ceiling cracks (3/16 in. max) at wall panel joint; hairline cracks and water (concrete sweating) damage up to 2 ft above floor. South wall (aluminum sandwich panel) -- separation from floor approximately 1/8 in. vertically and horizontally; fire and smoke penetration between panel and basemold at two locations above floor, SW corner of room.

Room 2-4 --Separation of partition from roof panels, 5/16 in. max provides clear access to Room 2-3. Maximum separation at floor 3/16 in. vertically in SW corner; 1/8 in. norizontally NW corner. Separations of closet and of gypsum board (east wall) from roof slabs. Cracks along all hollow-core concrete roof slab joints. No fire, smoke or water vapor damage.

Exterior --North side -- major floor to roof cracks (1/8 in. max after cooling) along vertical mortar joint east of exterior door. Slight hairline cracks at other vertical joints further east. Foundation (concrete block) cracks at NE and NW corners. Shear crack at floor level of poured concrete filler unit (near exterior door) with 3/16 in. horizontal displacement. South side -- separation (1/4 in.) of aluminum sandwich from concrete wall. Cracks and separation of concrete balcony units, both floors. East and west sides -- hairline cracks in vertical mortar joints only.

Test No. 3 Room 2-3, Concrete Wing, November 3, 1965

| Time (min) | Brief Summary Observations |
|---|---|
| 0 | Test started at 9:55 a.m. Weather: Clear; Temperature: 46 °F; RH.: 68%; Wind: 11 mph, Direction 220° (SW). |
| 3 | Section of window glass (1-1/2 $ft^2$) fell out. |
| 4 | Section of window glass (1/2 $ft^2$ fell out. |
| 10 | Bowing of aluminum sandwich panel and aluminum window frame. |
| 20 | Drops of boiling plastic expelled. |
| 28 | Remainder of window glass fell out. |
| 31 | Concrete spalling. |
| 33 | Sandwich panel fell out; room completely involved in flames. |
| 45 | Fuel supply exhausted. |
| 45 - 150 | Progressive smoldering and occasional flaming in sandwich panel of east room |

| Time (min) | Detailed Test Observations |
|---|---|
| 3:10 | 1-1/2 sq ft section of window glass fell out. |
| 4:00 | Another 1/2 sq ft section of window glass fell out; strong flaming observed in west and center cribs. |
| 7:00 | Left aluminum sandwich panel warped at upper right corner. |
| 9:50 | Window frame and aluminum sandwich panel bowed out at top approximately 1 in. |
| 10:30 | Entire center portion of left aluminum sandwich panel bowed out. |
| 19:10 | Flames bathing entire rear wall. |
| 20:30 | Smoking drops of boiling plastic expelled from top of window frame. |
| 24.00 | Cracks developing in east (gypsum board partition) wall; flames reach window. |
| 28:10 | Remainder of window glass fell out. |
| 28:30 | Thick flames fill upper half of room. |
| 30:15 | Aluminum window frame melting and falling out. |
| 31 - 32 | Concrete spalling. |
| 32:50 | Aluminum sandwich panel fell out; entire side open; complete flame involvement. |
| 33:20 | Heavy spalling. |
| 44:30 | Collapse of last crib; occasional flames and smoke from aluminum sandwish panel of east room. |
| 47:00 | Flaming in partition near door to east room |
| 50:00 | Very few flames visible in fire room. |
| 58:00 | Smoke issuing from bathroom vent to roof. |
| 59:00 | Asphalt dripping from floor ledge. |
| 60 to 150 | Slow smoldering and occasional flaming with smoke and charring progressing in aluminum sandwich panel of east room. |

## Post Test Observations

Room 2-3 --(Fire room) Concrete spalling on north and west wall, but no reinforcing steel exposed; maximum depth 1-1/2 in. Gypsum board cover over steel angle still in place although sagging in spots. Slight asphalt dripping from roof through ceiling slab joint. Gypsum board partition wall erect, but practically unsupported. Opening along vertical joint of concrete wall; several other small cracks and separations. Separation between interior door frame and north concrete wall.

Room 2-4 --Blisters on interior door except for lower 4 in. Scorch marks (from ceiling to mid-height) on wall adjacent to door. Several holes through aluminum sandwich panel; polystyrene core burned out except for sections above and on east side of window frame. Maximum separation of aluminum sandwich panel approximately 1-1/4 in. at southwest corner of room. Separations at hollow-core concrete roof panel joints not appreciably greater than from Test No. 2.

### 5.2. Moisture

The relative humidity in fire rooms 1-6 (Test 1) and 1-3 (Test 2) averaged 65% during the 7-day period prior to test.

The moisture content of the wood comprising the cribs was 10 to 12%, as measured with a prong-type electical resistance moisture meter.

Measurements were made of the relative humidity of air in cavities within the second floor hollow-core concrete floor slabs and of the load-bearing partition wall one week prior to Test 2 with the following results:

| | |
|---|---|
| Hollow-core floor slab, in web between cores, | 73% rh |
| Hollow-core floor slab, near grout joint, | 82% rh |
| Solid partition | 84% rh |

Direct moisture content measurements of the concrete by extracting cores were attempted but did not prove successful.

## 5.3. Temperatures

### Test No. 1

Selected temperatures recorded during Test No. 1 are shown in Fig. 6. Air temperatures in the fire room rose steadily until shortly after 15 minutes when flashover occurred, causing a further sharp increase. Temperatures remained near 1000 °C (1832 °F) from 18 to 32 minutes and then dropped off. The maximum individual temperature reading was 1167 °C (2133 °F). The furnace time-temperature curve prescribed in the standard laboratory fire test [2] is included for comparison. In any comparison, however, it should be borne in mind that the latter test prescribes slow-response thermocouples (mounted in heavy protective iron pipes) compared to the faster response thermocouples actually used.

Also shown in Fig. 6 are average or representative temperature curves for the 12-in. beam, the 10-in. girder, the lower chord of the joist, and the exterior unprotected column at a height of 8 ft above the room floor. Temperatures on the interior structural members were rapidly elevated from about 100 °C (212 °F) to about 800 °C (1472 °F) when the gypsum board ceiling rapidly and completely dropped at about 22-1/2 minutes. Temperature measurements were made on the inner and outer flanges of the exterior column at heights of 5, 8, 11 and 14 feet above the floor of the fire room. The temperature was highest at the 8-ft height and lowest at the 15-ft height. The outer flange was generally, but not always, hotter than the inner flange. A maximum temperature of 520 °C (968 °F) at 30 minutes was recorded on the outer flange at a height of 8 ft. Temperatures in excess of 440 °C (825 °F) and extending approximately 4 ft on the outer flange, 5 ft on the inner flange and 3 ft on the web were recorded. Some portions were exposed to this temperature for 15 minutes.

The temperature on the exterior face of the light-aggregate concrete panel under an asbestos pad reached a maximum of 176 °F at 90 minutes. The temperature at the center of the "unexposed" surface of the composite party wall adjoining Room 1-5 attained a maximum of 238 °F at 105 minutes. A temperature rise of 250 degrees F was reached on the connecting steel door at approximately 10 minutes, and after flashover, the temperature on the back surface of the door was practically the same as that in the fire room. The air in Room 1-5 reached a temperature of 150 °F at 26 minutes and a maximum temperature of 235 °F at 41 minutes. The temperature at the center of the "unexposed" composite wall surface of the adjoining apartment (Room 1-8) reached 156 °F at 2-1/2 hours and was still rising slowly. The air temperature in the adjoining apartment reached a maximum of 108 °F after 31 minutes. The temperature on the finished floor (under thermocouple pads) of the room above the fire rose slowly to a maximum temperature of 170 °F at 85 minutes.

Test No. 2

The failure of all five cribs comprising the fire load to ignite simultaneously prevented the rapid and uniform buildup in temperature in the fire room. As shown in Fig. 7, the temperature measured by the NE thermocouple, situated above the burning crib, was considerably above the average of the three other thermocouples until after 41 minutes when complete window dropout and intense burning occurred. Because of the cooling effect of the southerly wind and fire room temperatures only slightly above the melting point of aluminum (660 °C , 1220 °F), the aluminum sandwich panel remained in place. The temperature on the exterior face of the aluminum sandwich panel under an asbestos pad reached a maximum of 410 °C (770 °F) at 55 minutes.

The temperature in the second floor slab above the fire at the level of the lower reinforcing wires is shown by a typical curve in Fig. 7. The maximum temperatures at six locations varied from 350 °C to 380 °C (635 to 716 °F) and occurred at approximately 80 minutes. At two other locations, moisture evaporation endotherms limited the temperature to 100 °C (212 °F) for extended periods and the maximum temperatures reached were 127 ° and 185 °C (260 and 365 °F).

A typical curve of temperature on the steel supporting angles is also shown in Fig. 7. At these east and west wall-ceiling joints, the migration (presumably through the hollow cores) and subsequent condensation of moisture, tended to hold the temperature at the steam point (100 °C) for extended periods. The maximum temperatures recorded on the steel angles ranged from 138 ° to 172 °C (280 to 341 °F) at about 100 minutes. In the grout joint along the north wall, a temperature of about 230 °C (446 °F) was measured during the period of 70 to 140 minutes.

The temperature at the center of the "unexposed" surface of the gypsum board partition between rooms reached a maximum of 206 °F at 120 minutes. A temperature rise of 250 degrees F was reached on the connecting steel door at approximately 15 minutes. The air in the adjoining Room 1-4 reached a temperature of 150 °F at 42 minutes, and a maximum temperature of 205 °F at 72 minutes. The temperature of the "unexposed" surface of the concrete partition to the adjoining apartment reached a maximum of 176 °F after 170 minutes. The air temperature in the adjoining apartment did not exceed 90 °F. The temperature on the finished floor (under thermocouple pads) of Room 2-3, above the fire, rose slowly and had reached 150 °F when measurements were discontinued after 5-1/2 hours.

Test No. 3.

Air temperatures measured in the fire room were intermediate to those measured in Tests Nos.1 and 2, and slightly below the standard fire curve until 35 minutes. As shown in Fig. 8, room air temperature dropped rapidly when the aluminum sandwich panel wall fell out.

A comparison between the temperature recorded by a fast-response thermocouple and an ASTM-type thermocouple is also shown. The thermocouple within the heavy steel pipe was in close proximity to a fast-response thermocouple whose temperature was in good agreement with the overall average. It is evident that, during a rapid buildup of temperature, a fast-response thermocouple may indicate temperatures one to two hundred degrees C higher than those indicated by the ASTM E-119-type thermocouple.

The temperature on the exterior face of the aluminum sandwich panel rose steadily to 450 °C (842 °F) at 30 minutes and then rapidly to a peak reading of 750 °C (1382 °F) immediately prior to panel fallout at 33 minutes.

Due to the rapid temperature drop in the fire room after 35 minutes, the temperature in the roof slab at the level of the lower reinforcing wires was significantly lower than in Test 2, reaching a maximum of 225 °C (437 °F) at 75 minutes.

The temperature rise at the center of the "unexposed" surface of the gypsum board partition came within a few degrees of the ASTM prescribed limit for an average temperature rise for failure of 250 degrees °F (139 degrees °C) at about 75 minutes. This limit was reached on the connecting steel door at approximately 7-1/2 minutes, and after 38 minutes, the door provided very little resistance to the flow of heat from the fire room. The air in the adjoining room reached a temperature of 150 °F at 31 minutes, a temperature of 194 °F at 49 minutes and a maximum temperature of 230 °F at 101 minutes.

The temperature at the center of the "unexposed" surface of the concrete partition to the adjoining apartment reached a maximum of 156 °F at 90 minutes. The air temperature in the adjoining apartment did not exceed 90 °F.

In Table 2, a summary is presented of appropriate values of temperature, temperature rise and time for the three tests.

### 5.4. Radiation

Two types of radiation instruments were placed at a selected distance from the fire room window: a wide-angle thermopile radiometer to measure the irradiance level (often called radiation intensity), and a narrow-angle radiation pyrometer to measure the blackbody temperature of a portion of the flames within the room.

Blackbody temperatures between 800 °C (1472 °F) and 1000 °C (1832 °F) and averaging approximately 900 °C (1652 °F), were recorded in Test No. 1 during the time period 15 to 35 minutes. This blackbody temperature corresponds to an actual (thermocouple) temperature of approximately 1000 °C (1832 °F) during the same interval, and indicates a flame emissivity of about 0.7. In Test No. 3, a maximum blackbody temperature of 920 °C (1688 °F) was recorded during the relatively brief period of peak flaming.

Blackbody temperature and irradiance level measurements during active flaming were not obtained for Test No. 2.

To permit a comparison of irradiance levels between tests to be made, the maximum irradiance values were divided by the configuration factor F, normally used in radiant energy calculations based on the window openings only, in the manner suggested in reference [7]. These hypothetical window radiation intensity values, as well as those based on blackbody temperatures, are listed in Table 3. Radiation levels at other points may be predicted by multiplying the hypothetical window radiation intensities by the configuration factor appropriate for the window area and point in question.

For Test No. 1, the hypotherical window radiation intensity was approximately 23 $w/cm^2$ compared to an intensity of 10.7 $w/cm^2$ corresponding to the measured blackbody temperature. This means that radiation from flames above and surrounding the window in Test No. 1 contributed as much as that directly from the window opening. For Test No. 3, the hypothetical window radiation intensity was 11 $w/cm^2$ just prior to fallout of the aluminum sandwich partition.

Also listed in the table are maximum irradiance values for points close to the window above the fire room and at a distance of three feet from the exterior door. The irradiance level at the exterior door was appreciably higher in Test No. 1 due to flaming of the surface coatings on the door and adjacent wall. The irradiance level in the room above the fire in Test No. 1 may have been high enough (2.5 $w/cm^2$) to cause ignition of drapes or other furnishings through the closed window.

### 5.5. Smoke

The attenuation of light due to smoke (and water vapor) accumulation was measured in terms of percent of initial light transmission (T). Readings were converted to optical density per foot, 1/L ($\log_{10}$ 100/T), where L, the optical path length was two times the smoke meter-to-ceiling height, approximately 14 feet. No corrections were made for possible slight drift in the phototube circuits, for the moisture or soot deposits on the lenses and mirrors, or for the scattering of daylight by the smoke. The results are plotted in Figs. 9, 10, and 11.

These results represent the accumulated or total smoke concentration in the various rooms adjacent to the fire room as measured over a vertical path, and are essentially independent of smoke stratification effects. In a typical fire situation, smoke stratification could alter the time period prior to the onset of impaired visibility. Decreasing values following a maximum may be due to smoke settling or agglomeration, loss through openings, etc., but in the case of Tests Nos. 2 and 3, was principally due to the condensation of the moisture vapor portion of the "smoke" aerosol.

### 5.6. Toxic Combustion Products

In Test No. 1, positive indications were obtained for CO and HCN, but not for $CO_2$ or HCℓ. In Test No. 2, several measurements for HCℓ also proved negative. In Test No. 3, observations were limited to CO, $CO_2$ and HCN and were taken only in Rooms 2-3 and 2-4. The maximum measured gas concentrations and the corresponding times for all tests are given in Table 4. Readings taken in the fire room (Room 2-3) in Test No. 3, although listed for information, are questionable because of: (a) excessive water vapor condensation in the sampling tube, and (b) temperatures in excess of the recommended operating range.

Because of the limited number of spot readings taken, the lack of positive readings should not be taken as proof of the absence of the component.

### 5.7. Deflection

Test No. 1.

Vertical and lateral deflection measurements are shown in Fig. 12. Rapid deflection of the floor at the center of the room followed shortly after the ceiling dropped and all structural members became directly exposed to fire. The maximum deflection observed was 7.4 in., with a permanent sag of about six in. after cooling. At the mid-span of the joists, the maximum deflection observed was 2-1/4 inches.

The exterior light aggregate concrete panel at the measurement location had deflected (bowed out) 0.5 in. at 41 min when the wire fastening came loose. After the test, it was noted that the panels had bowed out a maximum of about two inches.

Test No. 2

Vertical and lateral deflection measurements are shown in Fig. 13. The maximum deflection was 0.95 in. at the center of the room and 0.60 in. at the center of the span, both reached at 65 minutes.

The outward movement of the concrete north wall reached a maximum of 0.064 in. at 30 min, and then slowly receded. At 85 min, when readings were discontinued, the net movement with respect to the original position was 0.065 in. inward.

Expansion of the 20-ft floor slab (east-west), measured by means of an invar wire, occurred gradually and reached a maximum of 0.44 in. at 70 minutes. A complementary measurement using dial gages on the east and west exterior walls (total span 32 ft) gave an overall extension of 0.49 in. maximum at 80 min with a drop-off to 0.34 in. after nearly five hours. The maximum east-west expansion at the first floor level was 0.08 in.

Meaningful dial gage extension measurements on the exterior aluminum sandwich panel were not possible due to frequent flexures inward and outward, following burnout of the stabilizing polystyrene core. Visual observation of 1-1/2 in. extensions were noted during test.

Test No. 3

Maximum deflections of the roof slab were 1.3 and 1.2 in., at the center of the room and at mid-span, respectively. These occurred at 40 minutes. After 2-1/2 hours, when readings were discontinued, the slab had already recovered about 1/2 in. of this deflection.

The aluminum sandwich panel bowed in 1/2 in. within 2 min, and then reversed, bowing outward gradually and continuously to a reading of 2-3/4 in. at 30 minutes.

## 6. Discussion

Because of time and monetary limitations, field burnout tests are performed under a very restricted number of possible conditions. Such tests are neither standardized nor completely controllable, and considerable variations in time-temperature exposure may be encountered. It is clear that the area of ventilation openings (windows, cracks, etc.), the direction and magnitude of winds, and the type and orientation of the combustible load are of vital importance. These results apply only to the specific test conditions established.

### 6.1. Fire Intensity

For comparison purposes, the average fire room air thermocouple temperatures are plotted in Fig. 14 for all three tests. The differences may be attributed to: (a) wind and ventilation effects, including the vagaries associated with the fallout of window glass and the development of other wall openings, and (b) differences in thermal, physical and combustible properties of the room surfaces.

Comparing the two concrete wing tests, the cooling effect of the strong southerly wind in Test No. 2 prevented simultaneous ignition of all cribs and the pattern of fire development was appreciably slower than that of Test No. 3. Although the wind in Test No. 3 was also southerly and somewhat unfavorable to rapid fire development, complete flame involvement with subsequent fallout of the aluminum-faced polystyrene core sandwich panel occurred.

In Test No. 1, wind did not appear to affect fire development significantly. The flashover which occurred at 15 minutes is not unusual for rapidly developing fires in rooms with suitable ventilation and a fire load of 6 psf. Flashover has been noted in previous burnout tests, including some with mock furnishings of less than 4 psf [8]. However, the involvement of the asphalt-impregnated paper and glass fiber composite wall structure may have been a contributing factor to the severity of the fire which developed. It is estimated that the asphalt tile floor, burnout of which was extensive, could have provided the equivalent of 2 psf of combustible load.

It is probable that collapse of the gypsum board ceiling was a direct result of the simultaneous thermal expansion of steel supporting members and the contraction of the gypsum board due to calcination, shortly after flashover.*

There is some evidence that concrete structures, especially when uninsulated and relatively moist (as for example, the ceiling and party wall slabs in Rooms 1-3 and 2-3), may have a moderating effect on the temperature built up during fires. For example, the additional heat required to vaporize and raise the temperature of 1 lb. of water

*Such rapid and complete dropout of the gypsum board ceiling was not observed during a recently performed ASTM E-119 test on a floor-ceiling assembly of similar construction.

to 750 °C (1382 °F) is 1700 Btu. If 10 percent of the moisture content (assumed to be 10% by weight) in the two directly exposed concrete members were vaporized and heated to fire temperature, this would represent over 4 percent of the heat supplied by the fire load. Although the temperatures in both concrete wing tests were considerably below those in the steel wing test, no definite conclusions on this point appear justified. The use of heat flow transducers to measure the heat absorption of walls would be desirable in future tests.

Fire severity is a measure of the intensity and duration of a fire, and is commonly expressed in terms of the equivalent exposure time in the standard fire endurance test. Based upon a limited number of burnout tests performed in "fireproof structures" with various combustible contents [9], an approximate relationship between combustible load (lb per $ft^2$ of floor area) and fire severity (hr) was formulated [10]. On this basis, a fire severity of 1/2 hr was related to 5 psf of (wood and paper) combustibles. The latter reference also summarized measurements of the combustible contents of representative types of occupancies and buildings about 1940. From a total of 13 apartments and residences which comprised the survey, it was found that the movable-property combustible contents of an entire apartment or residence averaged over all areas (including basement, bathroom, bedroom, kitchen, living room, etc.) was 3.4 psf (range 2.4 to 4.9 psf). The average values for bedrooms, closets included, was 5.0 psf (range 2.5 to 7.3 psf), and for living rooms 3.9 psf (range 1.4 to 6.8 psf). It was on the basis of these considerations that the sponsor suggested and we concurred in the selection of a fuel load corresponding to 6 $lb/ft^2$ floor area.

The total heat released by the complete burnout of six $lb/ft^2$ of nominal 2-by 4-in. lumber arranged in lattice-type cribs is no greater than that from the complete burnout of six $lb/ft^2$ of wooden furniture arranged in a conventional manner. However, since the rate of fire growth in a "typical" furniture fire could vary widely depending upon its type, and upon the orientation of furniture with respect to sources of ignition, the use of closely-stacked cribs and simultaneous ignition was considered preferable and more readily reproduced. This arrangement produced a fire of considerable severity. For evaluating the fire safety of a structure by a single test demonstration, such a burnout test is not considered unreasonable or unrealistic.

## 6.2. Smoke

Measurements were made for the purpose of estimating the extent of smoke buildup which could seriously obstruct human vision during a building fire. From past experience with accidental fires, and in controlled burnout tests [7, 11], decrease in visibility is often considered to represent a major life hazard to occupants.

A criterion sometimes used is based on the assumption that when the "visibility" (or visual range) of a handlamp-illuminated sign drops to 4 feet, a room is smoke-logged to a degree that would seriously impede the escape of occupants [12]. It was inferred that this limit was reached when the light transmitted over a 4-ft path was reduced to 0.25% of the value in the absence of smoke, or an optical density of 0.65 per ft. Williams-Leir [13] has experimentally verified this threshold level and determined that it corresponded to the ability to distinguish a 10-watt lamp in a smoke-filled room at a distance of 11 feet. It should be borne in mind, however, that these values are based on detection by trained observers who were seeking an illuminated object or lamp in a known location. To allow for 98 percent probability of an average observer detecting a contrast in light in any (unknown) direction, and for the complex effects of hysteria, eye irritation, etc., under fire conditions, a combined "field factor" and "safety factor" of 10 may be applied to the optical density. That this is a more practical value may perhaps be gaged by the results of tests conducted by the Los Angeles Fire Department in 1962 [14]. In those tests, observers in a test room without breathing apparatus left when the smoke "became irritating with apprehension about personal safety," and that time corresponded to an average optical density of only 0.01 per foot as measured horizontally at a 5-ft level. Similarly, observers with self-contained breathing apparatus left when obscuration by smoke became untenable, and that corresponded to an average optical density of 0.04 per foot.

For a limiting optical density of 0.065 per foot, comparative critical times are summarized in Table 5. The similarity in time periods for the three measurement locations may be noted. As expected, smoke penetration to the adjacent room (through openings around the closed connecting door) became critical in 2 to 7 minutes.

It was determined, subsequent to completion of the tests, that the smoke meters probably were not completely free from the effects of smoke-scattered daylight entering through the windows. (This is generally minimized by proper collimation of the light beam source and the use of appropriate apertures in the smoke meter). Laboratory evaluation of the meters following the test series revealed that the smoke density test readings were lower than they should be, approximately 10 percent low at the limiting optical density. However, the effect upon the times listed in Table 5 are estimated to be relatively minor.

### 6.3. Toxic Combustion Products

The following "tolerable limit" values, taken or inferred from literature references, may serve as a guide in evaluating the measured concentrations of toxic combustion products.

| | Concentration | | | |
|---|---|---|---|---|
| Gas | Tolerable for Several Minutes | Tolerable 30-60 min | Critical 2-3 hours | MAC[a] |
| CO | 12800 ppm[b] | 1500 ppm[b] | | 100 ppm |
| $CO_2$ | 10-15% | 5% | | 0.5% |
| HCN | 100-150 ppm | 50 ppm | 30 ppm | 10 ppm |

It can be seen from the measured values in Table 4, that critical concentrations of CO, HCN and sometimes $CO_2$ were experienced in the room adjacent to the fire room. In Test No. 1, where an appreciable separation between the floor and wall panel occurred, a critical concentration of CO was measured in the room above the fire room. No measurements in the critical concentration ranges of these gases were obtained in the adjacent apartment of the steel or concrete wing.

### 6.4. Structural Effects

There was no evidence of rupture or other sudden structural failure of the floor and roof assemblies tested. Nevertheless, since excessive deflection of a structural member under the combined effects of load and fire exposure is of critical importance, a careful evaluation of deflection is necessary.

[a] Maximum average atmospheric concentration for 8-hr exposure without injury to health, as adopted by the American Conference of Governmental Industrial Hygienists, 1962.

[b] Depends upon degree of physical exertion

Deflection limits for fire-exposed assemblies in buildings have not as yet been established. However, vertical deflection criteria in terms of general design features have been proposed for defining load failure of beams, floors and roof constructions during fire tests [15]. Based on a survey of laboratory fire endurance tests on representative constructions (considered to have failed to sustain the applied load during test), the requirement was proposed that both a maximum deflection $D > L^2/800d$, and a maximum hourly rate deflection $R > L^2/150d$ be exceeded as an indication of load failure.

Whereas, in a laboratory fire test, the entire span length L is loaded and fire-exposed, in these tests only one-half the span was exposed to fire. Taking L = 10 ft and d (the depth of the joist) = 1 ft, load failure was arbitrarily considered to have occurred in Test No. 1 at 26 minutes. It should be noted, however, that the structure continued to support the 40 psf design load without collapse throughout the test.

Bowing of the unprotected steel column adjacent to the fire window of about 1/2 in. occurred in Test No. 1 according to visual estimate. This bowing may have resulted from thermal expansion of the 10-in. girder, and was recovered on cooling. However, it should be noted that the column was stressed to only a small fraction of its design load. Temperatures in excess of 825 °F and extending approximately 4 feet on the outer flange, 5 feet on the inner flange and 3 feet on the web were recorded. Some areas were exposed to this temperature for 15 minutes. The maximum temperature recorded was 968 °F. In light of these temperatures, it seems appropriate that serious consideration should be given to the use of fire-protective covering and/or maintaining greater spacing between columns and window openings, in order to provide a margin of increased safety for such structural elements.

Prior to test, concern was expressed regarding the possible spalling of concrete if fire-tested while moist. Such spalling did actually occur, and in Test No. 2, was sufficient to expose a considerable number of reinforcing bars. It is anticipated that with adequate curing and an approach to its equilibrium moisture content, the tendency of concrete members to spall under fire exposure should decrease.

## 7. Summary

The importance of full-scale burnout tests in providing valuable supplementary fire performance data was demonstrated in a series of three burnout tests in an experimental test building. These burnout tests permitted study of the fire effects on floor-wall joints, smoke penetration through doors and openings, and other complex interactions not generally feasible in conventional laboratory fire tests.

With regard to the specific objectives established by Pratt Institute for fire protection, the following results and comments were noted:

1. In both constructions, a small amount of flaming penetrated to the room above the fire room primarily through the development of separations between the floor assembly and the curtain walls. Some fire and smoke also penetrated through wall openings provided for electrical outlets. Fire penetrated gradually to the adjacent apartment in Test No. 1 through progressive smoldering of the composite party wall. Direct heat transmission through either the concrete slab floor or the joist and gypsum plank floor was not excessive. In both constructions, an appreciable amount of smoke resulting in an optical density of 0.065 per foot, had penetrated the adjacent apartment and the room above after approximately 20 and 45 minutes, respectively.

2. There was no evidence of rupture, collapse, or other structural failure within the boundary of a floor or roof assembly during test. However, an appreciable vertical deflection of the floor system in Test No. 1 was recorded. In the absence of established deflection limits for fire-exposed building assemblies, proposed criteria based on laboratory fire endurance tests on floors and roof assemblies were applied, and, based on the assumptions used, "load failure" was arbitrarily considered to have occurred in Test No. 1.

   The test plan did not include design load stressing of the unprotected exterior columns. However, in light of the temperatures recorded on the column adjacent to the fire window, serious consideration should be given to the protection of a column in such a location.

3. The contribution of heat, smoke and toxic combustion products of the construction materials was not quantitatively evaluated. However, it is estimated that each floor system provided the equivalent of 2 psf of combustible load. Of the other materials used, the asphalt-impregnated paper/glass fiber composite party wall should be expected to supply a significant quantity of heat (and black smoke). Also, the prolonged burning of the foam polystyrene core of the aluminum-faced sandwich panel permitted slow fire propagation in Test No. 3.

## 8. Acknowledgements

The successful completion of the burnout test program was accomplished through the "team" efforts of many members of the Fire Research Section. In particular, Bill Bailey, Garnett Robinson and Mel Womble were responsible for completing the many tasks during the instrumentation, assembly, test performance and disassembly phases, and in spite of tight scheduling. During the tests, data were carefully taken by Tom Lee, Joe Loftus, Stan Rodak and Harry Shoub.

The generous help of Dr. John Rockett and Larry Orloff representing the Factory Mutual Research Associate Program at NBS, and of Messrs. Cliff Carlson, Mel Abrams and Sam Selvaggio, of the Portland Cement Association, is gratefully acknowledged.

Thanks are due Les Furlow and John Watkins of the Photographic Services Section, NBS, for their efficient and successful filming of the fire tests despite the uncertainties associated with fire behavior in the field.

Finally, the entire staff of the Research Department, Pratt Institute School of Architecture, Professors John Callender and Ed Shiffer, Mr. Bob Davison and Miss Pat Wilson, were very generous in providing assistance, and in making our task less arduous than it would otherwise have been.

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Fig. 1. Test Building
Viewed from Southwest

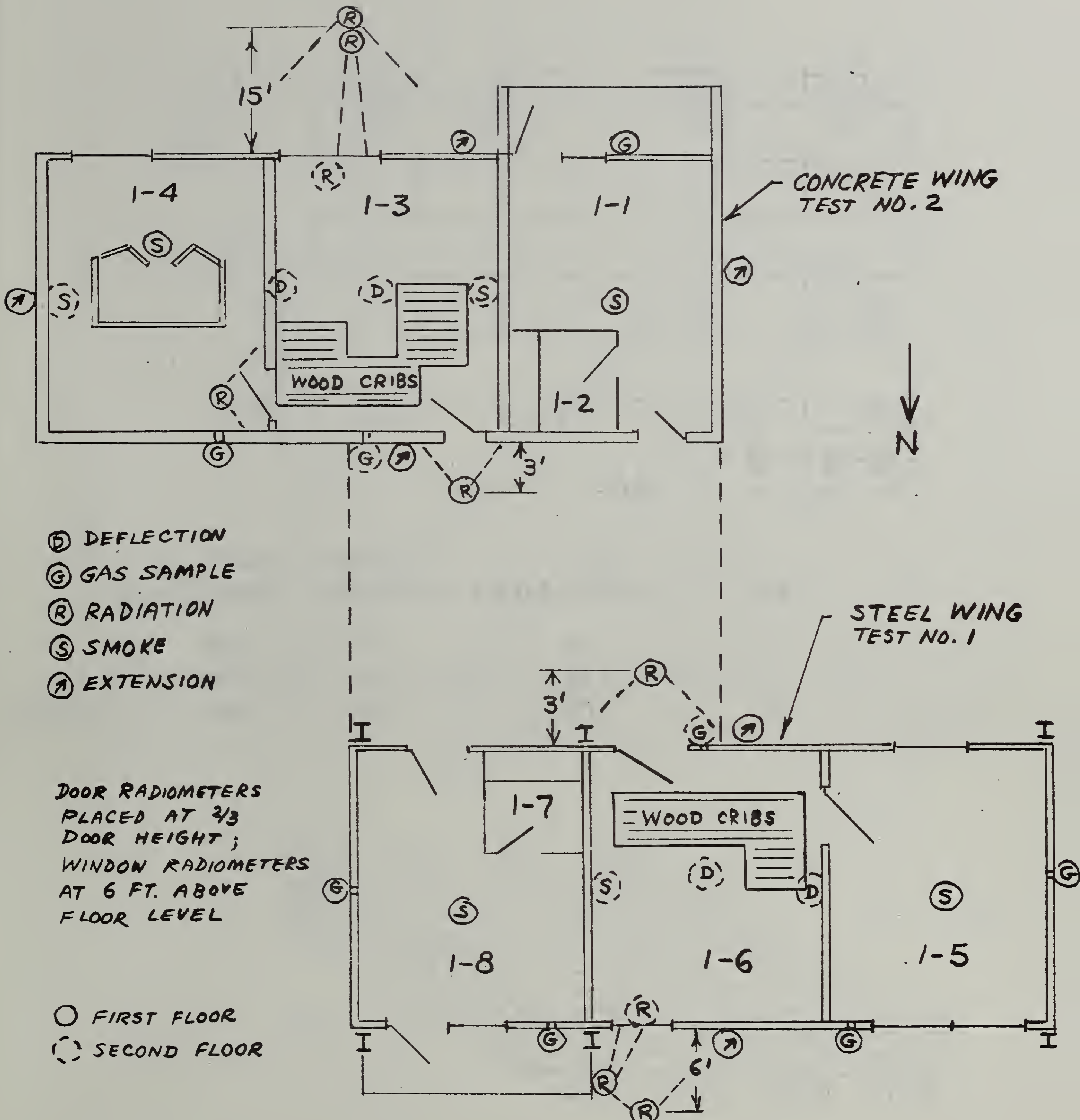
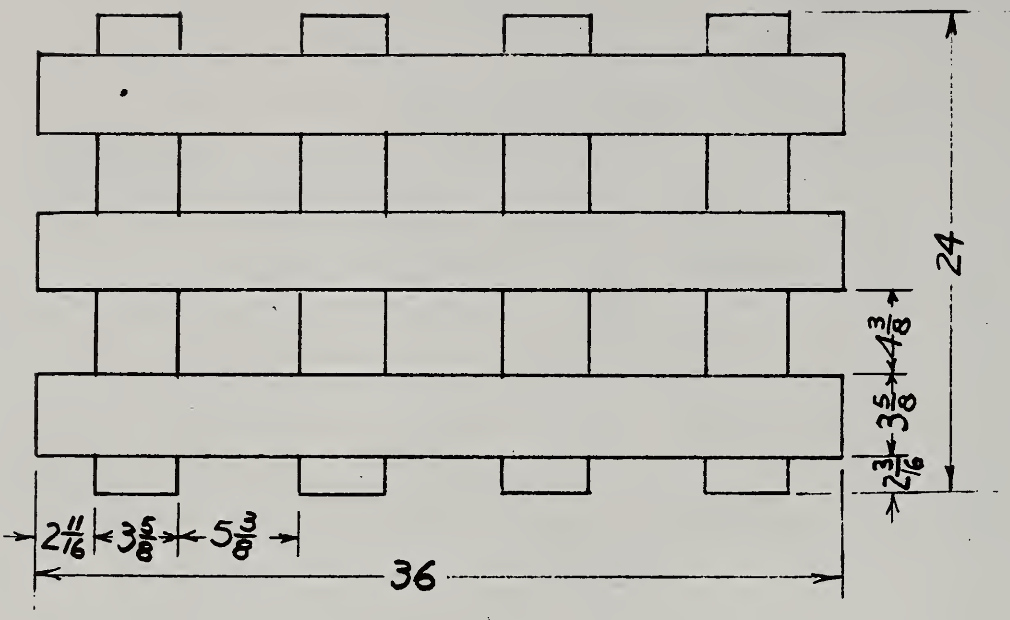



FIG. 2 INSTRUMENTATION ARRANGEMENT - SCHEMATIC

ALL DOORS AND WINDOWS CLOSED DURING TEST EXCEPT FOR WINDOW IN FIRE ROOM WHICH WAS PARTIALLY OPEN




| TEST | NO. OF LAYERS | APPROX. WEIGHT, LB EACH CRIB | TOTAL (5 CRIBS) |
|---|---|---|---|
| 1 | 13 | 137 | 685 |
| 2 | 14 | 148 | 740 |
| 3 | 14 | 148 | 740 |

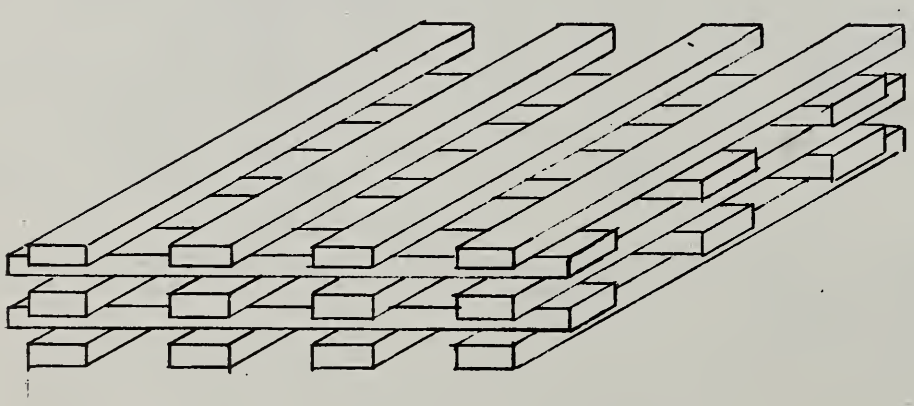


FIG. 3 CONSTRUCTION OF WOOD CRIB

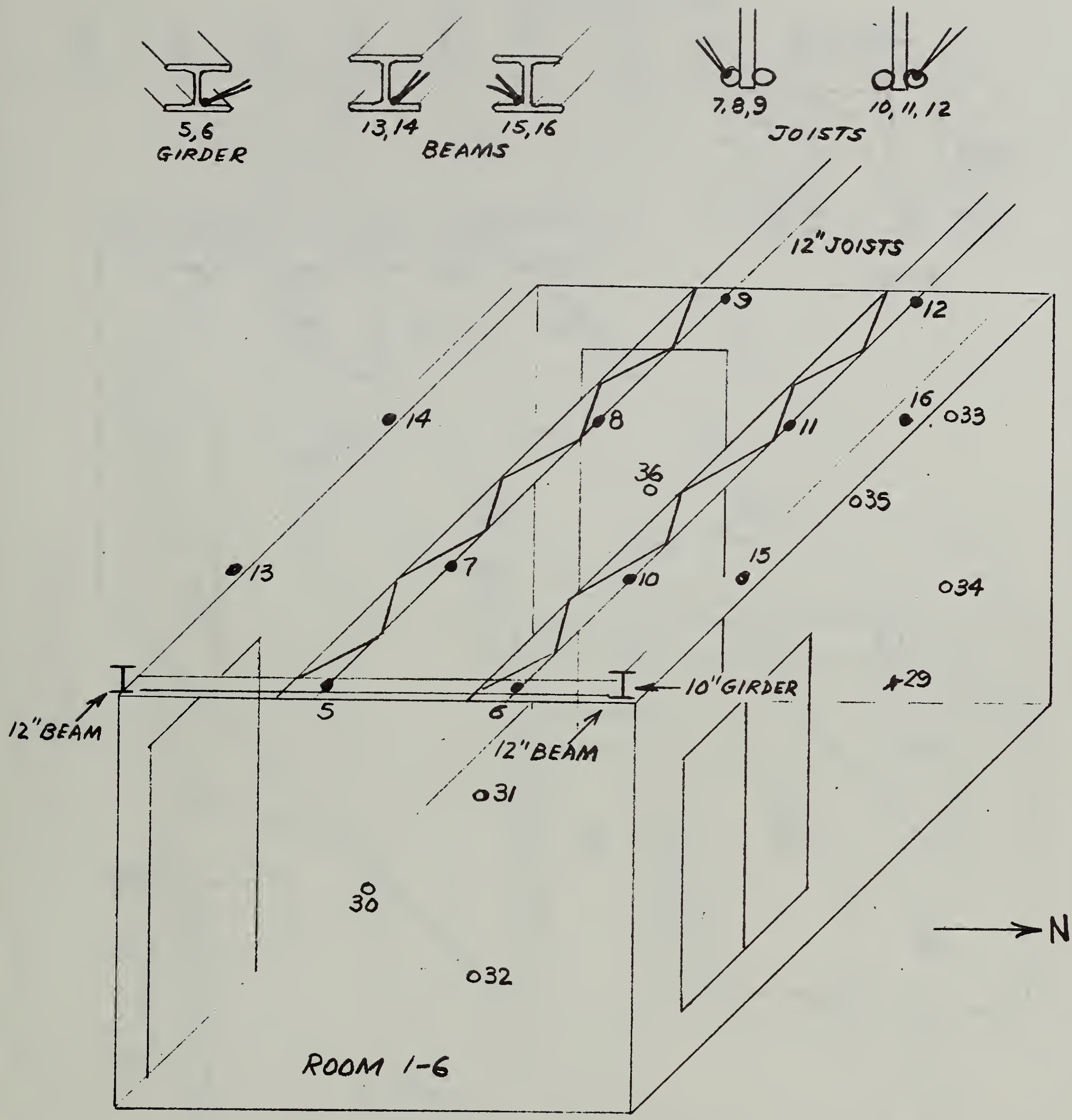



FIG. 4 LOCATION OF THERMOCOUPLES, TEST 1

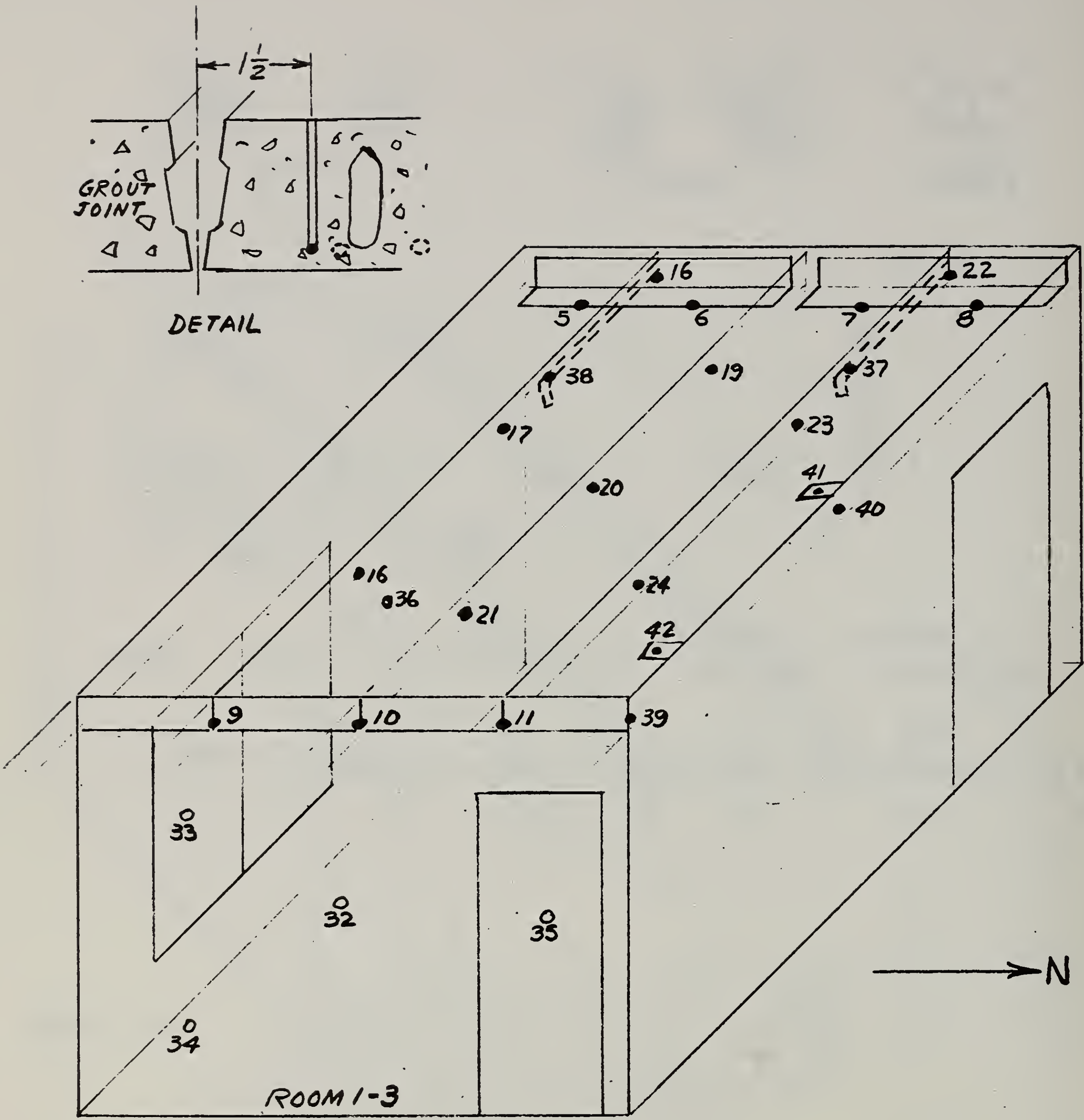



FIG. 5 LOCATION OF THERMOCOUPLES, TEST 2

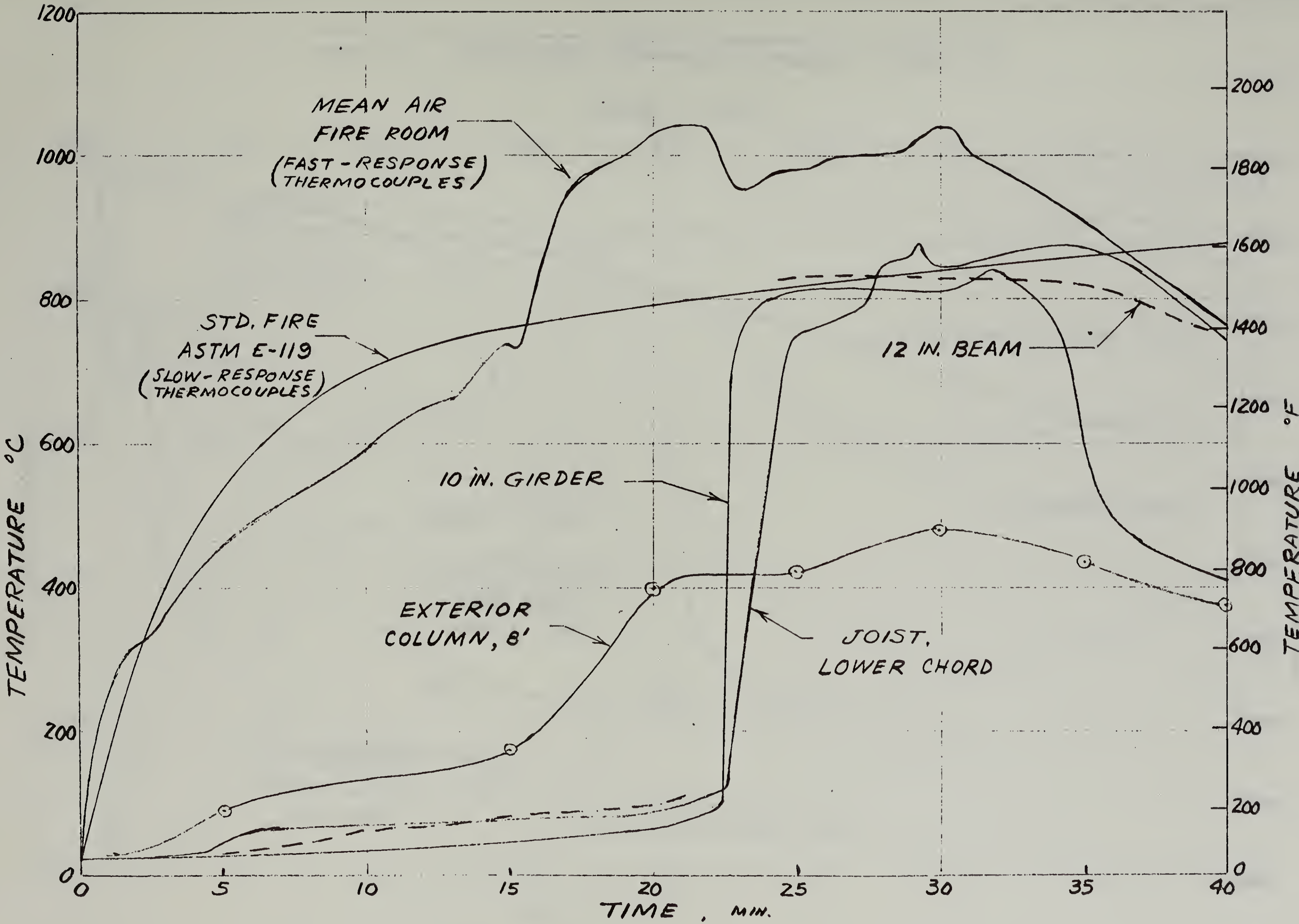



FIG. 6 SELECTED TEMPERATURES, TEST 1

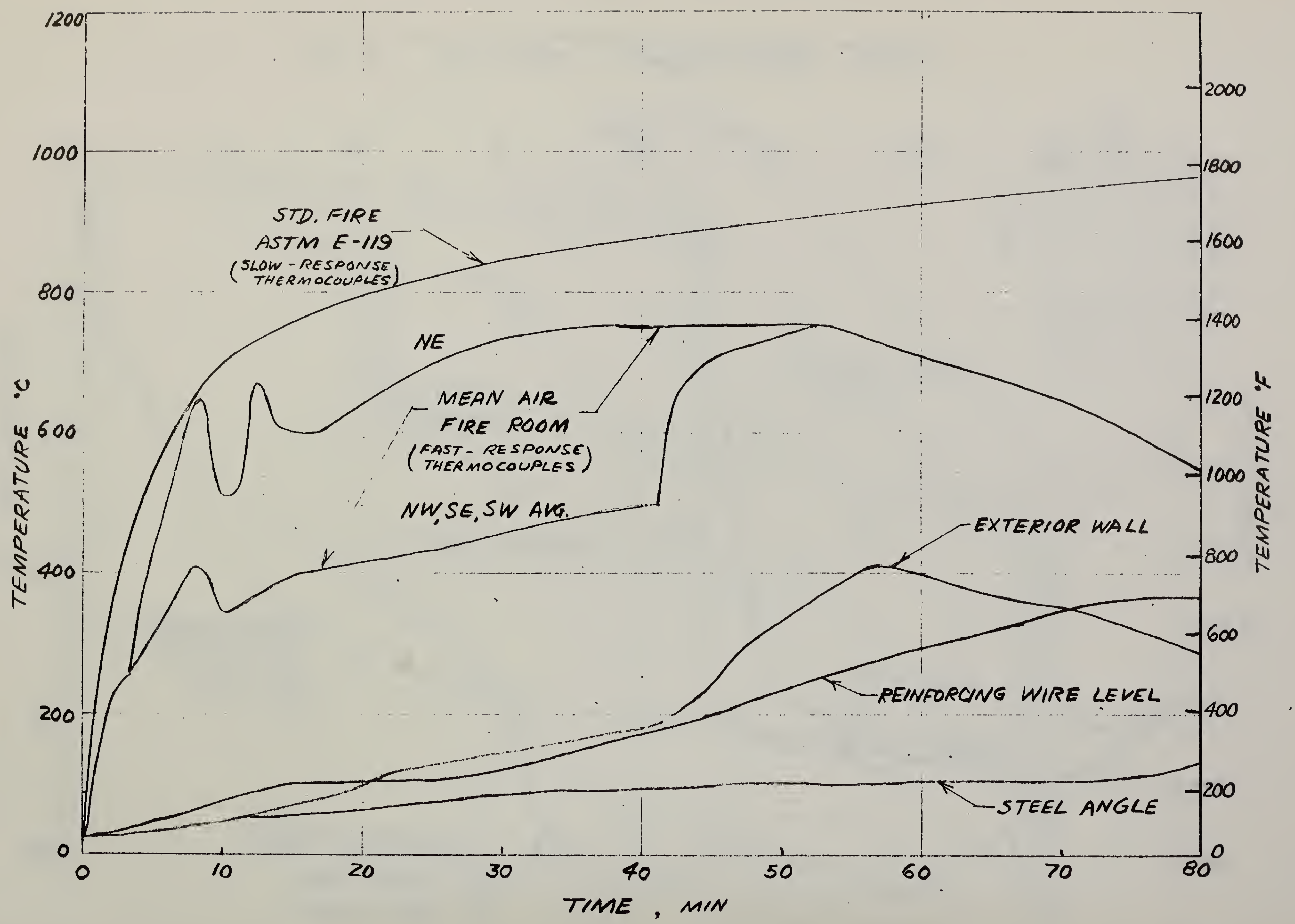



FIG. 7 SELECTED TEMPERATURES, TEST 2

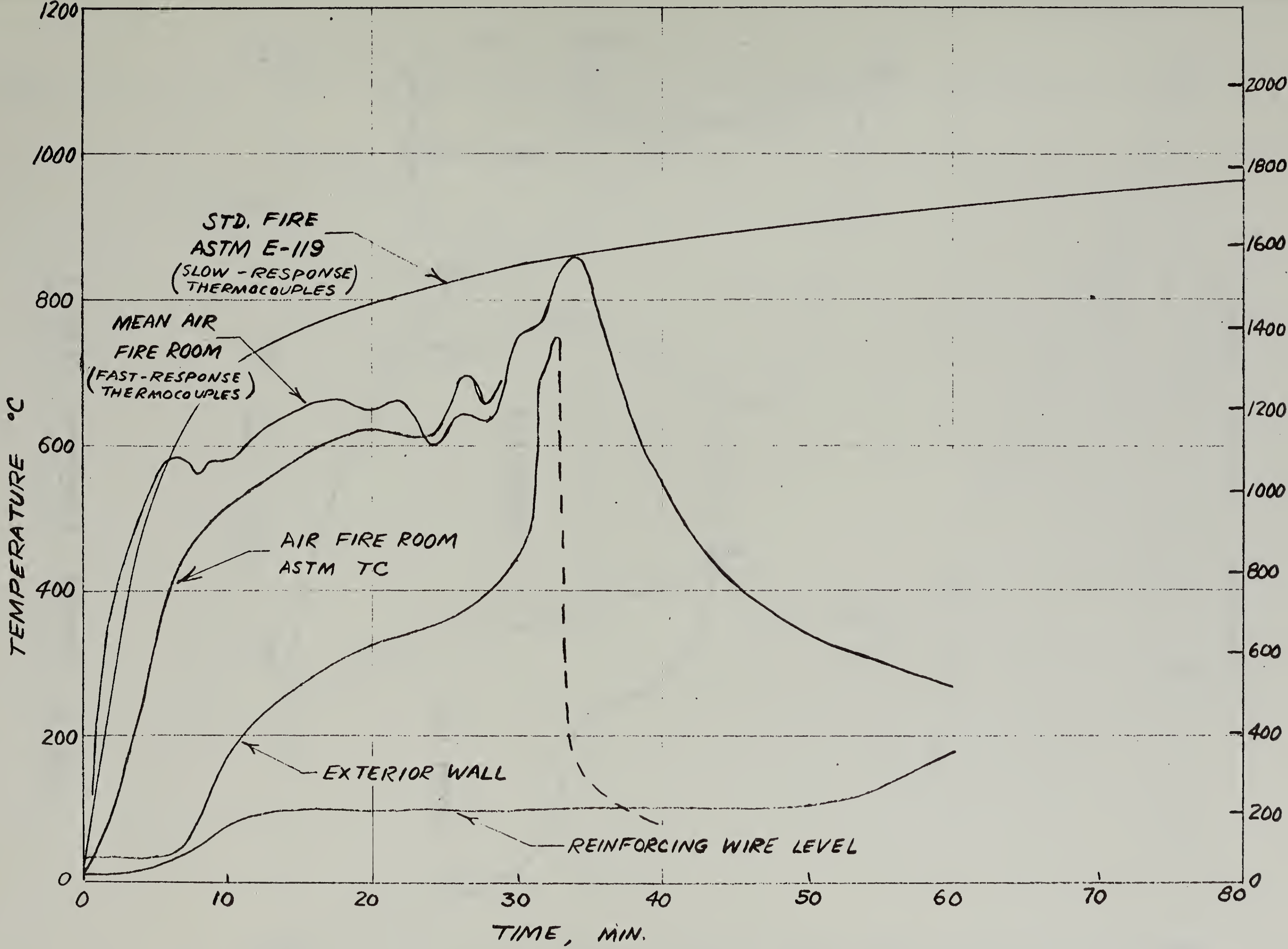



FIG. 8 SELECTED TEMPERATURES , TEST 3

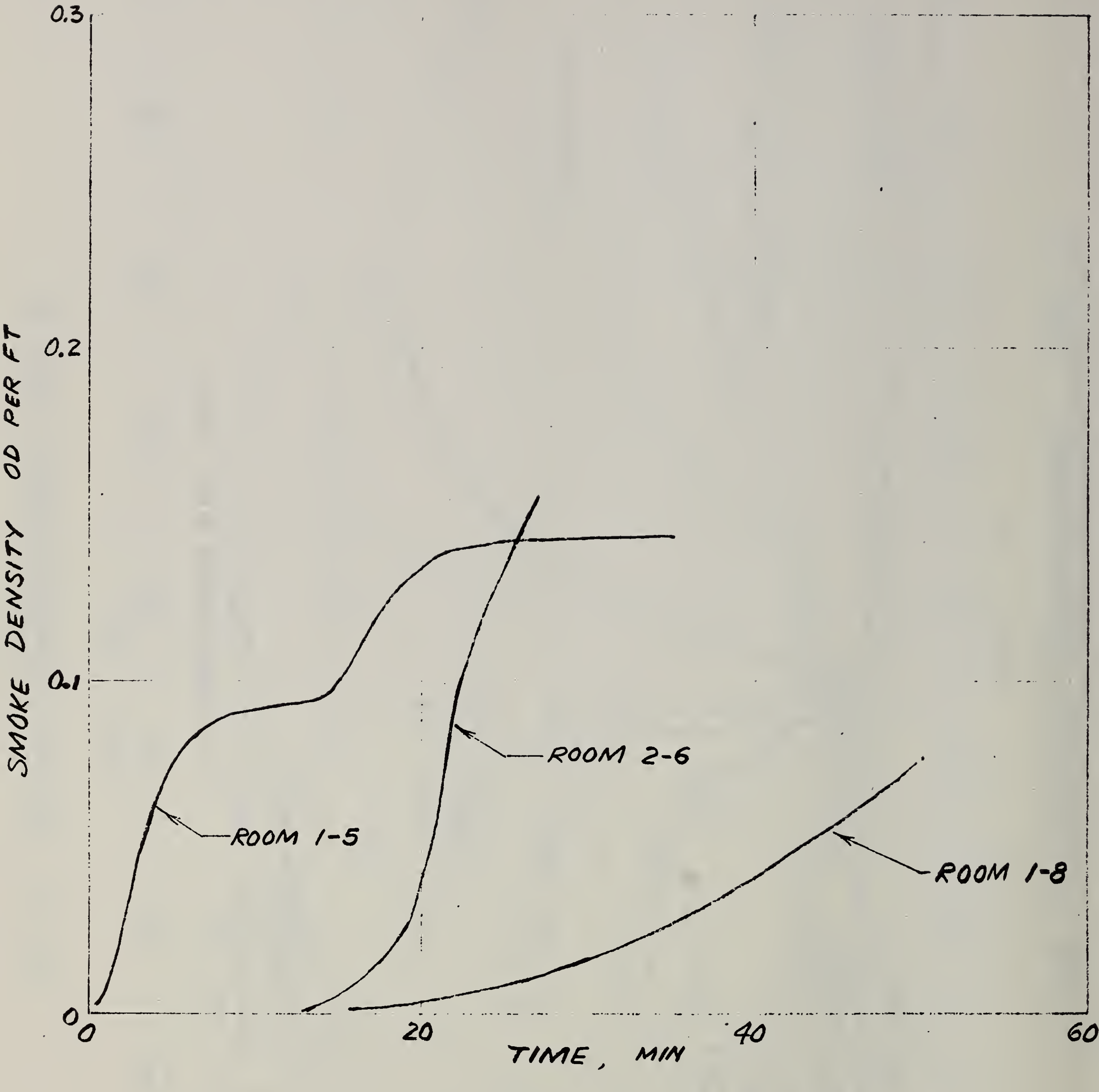
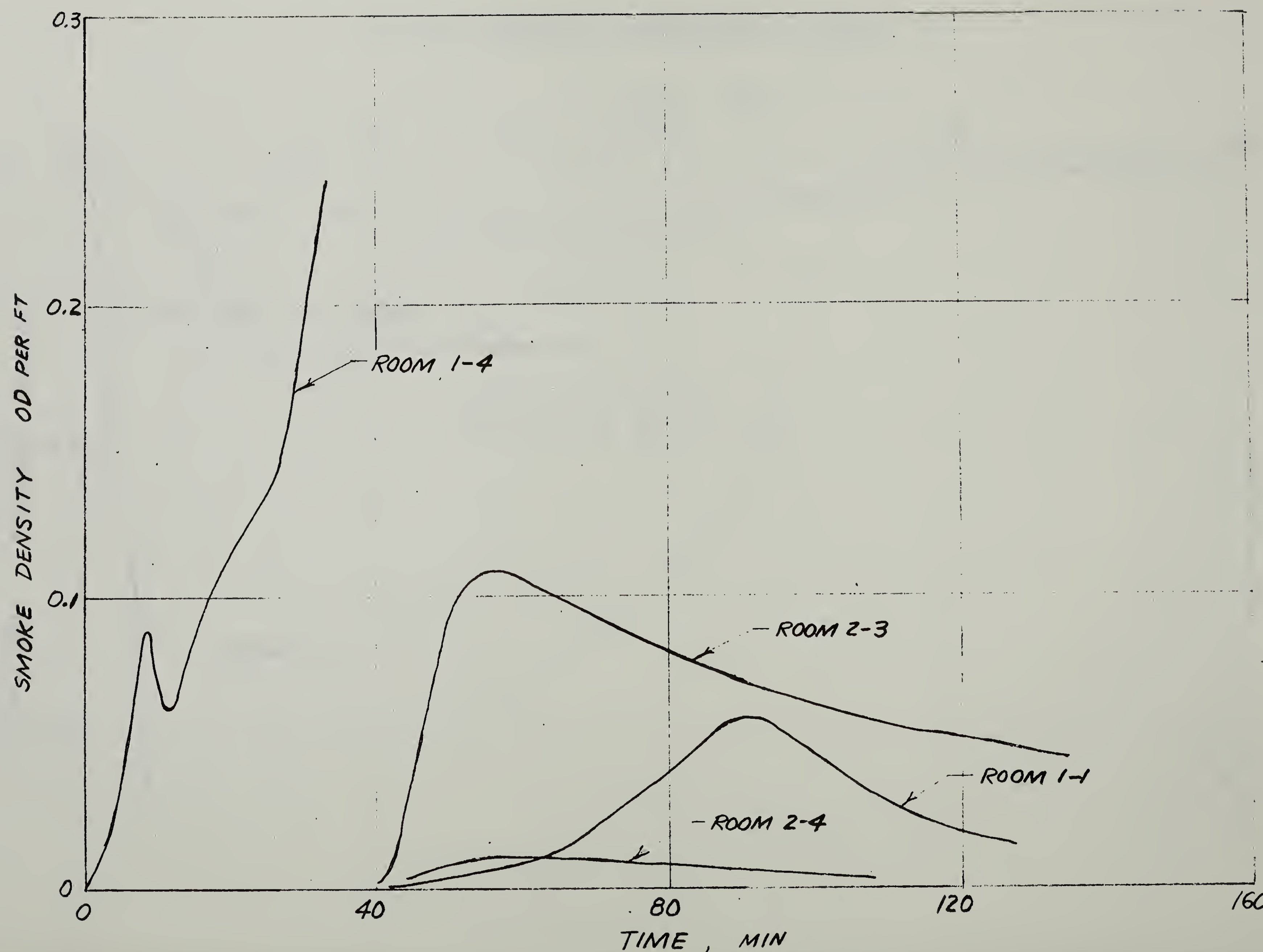



FIG. 9 SMOKE DENSITY, TEST 1



SMOKE DENSITY OD PER FT
0.3
0.2
0.1
0
ROOM 1-4
ROOM 2-3
ROOM 1-1
ROOM 2-4
0
40
80
120
160
TIME, MIN

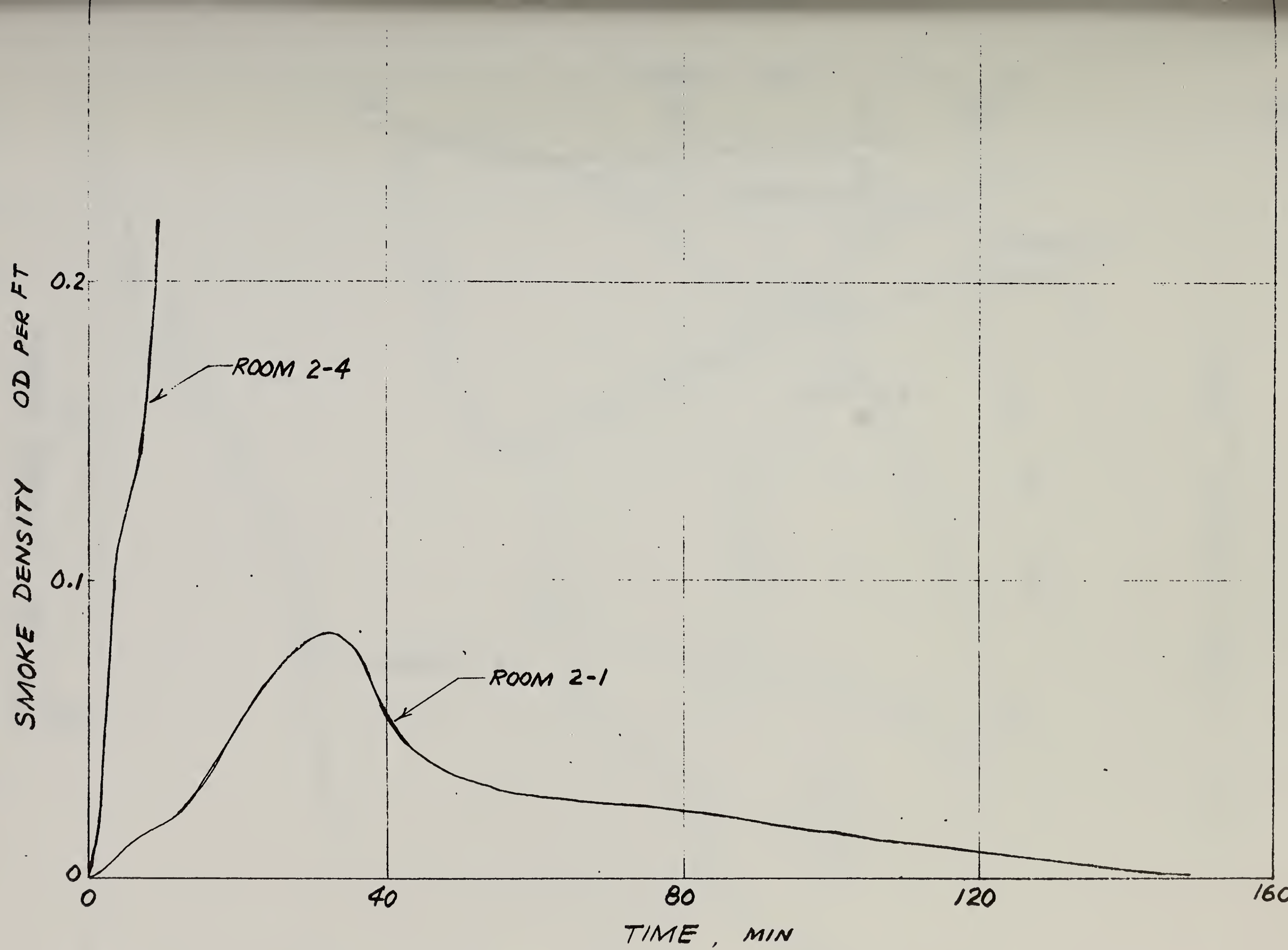



FIG. 11 SMOKE DENSITY, TEST 3

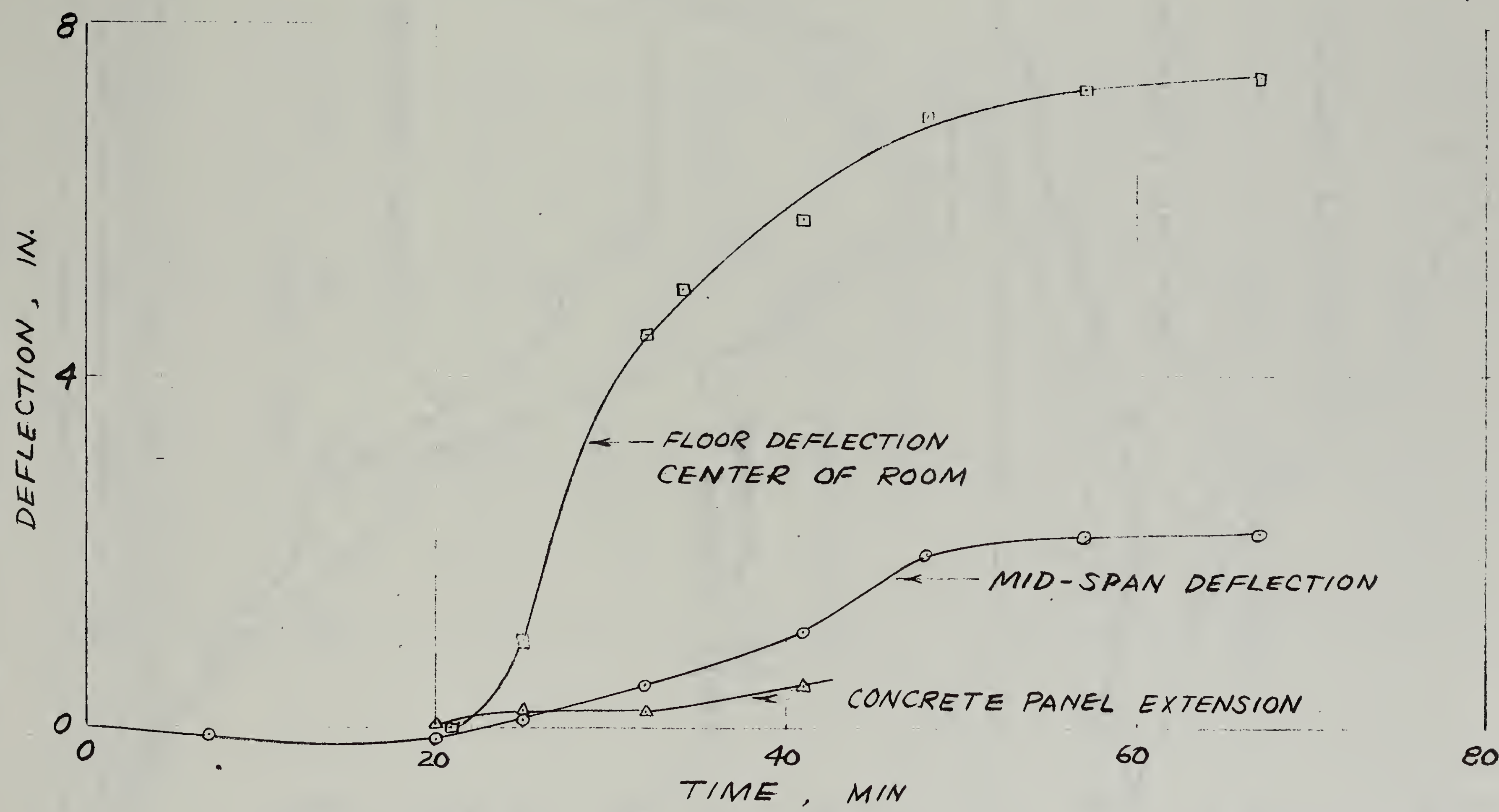



FIG. 12 DEFLECTIONS, TEST 1

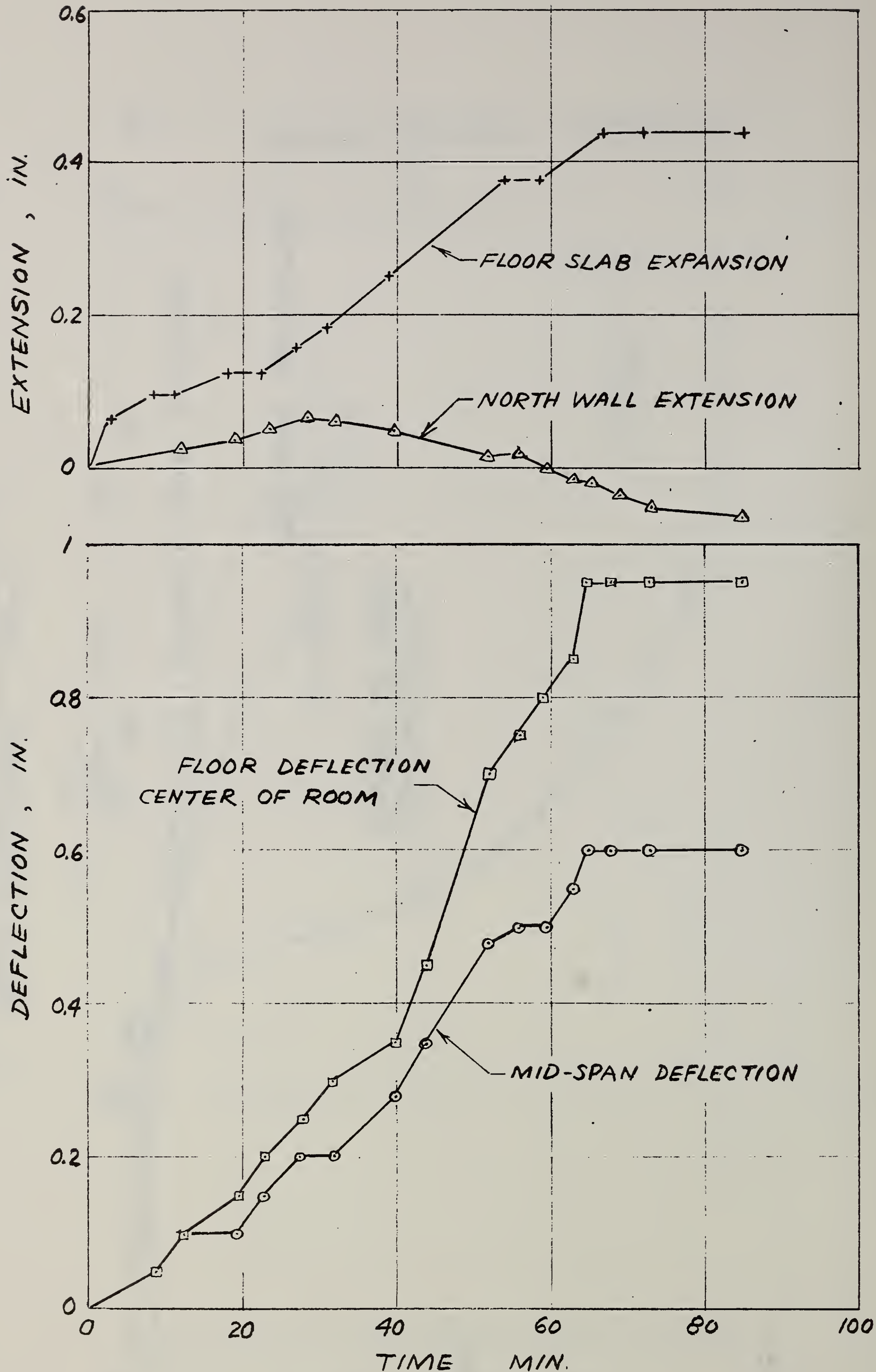



FIG. 13 DEFLECTIONS , TEST 2

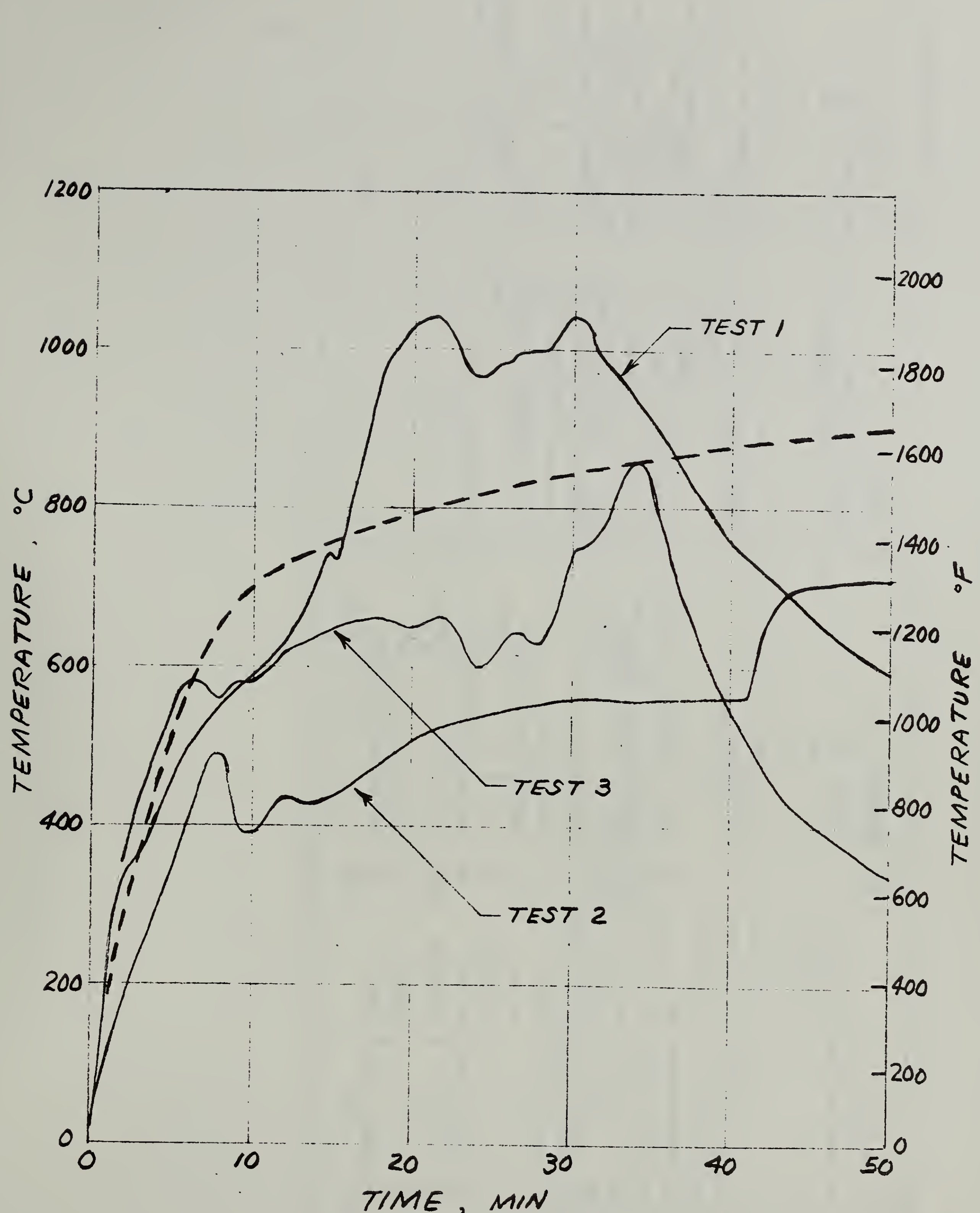



FIG. 14 COMPARISON OF FIRE ROOM MEAN AIR TEMPERATURE

—— MEASURED WITH FAST-RESPONSE THERMOCOUPLES, 1 FT. BELOW CEILING

– – – ASTM E-119 FIRE EXPOSURE. SLOW-RESPONSE THERMOCOUPLES PRESCRIBED

Table 1. Location of Thermocouples

**TEST No. 1**

| TC No. | Location | TC No. | Location |
|---|---|---|---|
| 1. | Room Air NE | 19. | Exterior Column 8 ft Outer |
| 2. | " " NW | 20. | " " 8 ft Inner |
| 3. | " " SE | 21. | " " 11 ft Outer |
| 4. | " " SW | 22. | " " 11 ft Inner |
| 5. | 10 in. Girder SE | 23. | " " 14 ft Outer |
| 6. | " " NE | 24. | " " 14 ft Inner |
| 7. | South Joist E | 25. | Room 2-6 Floor NE |
| 8. | " " Center | 26. | " " " NW |
| 9. | " " W | 27. | " " " SE |
| 10. | North Joist E | 28. | " " " SW |
| 11. | " " Center | 29. | Exterior (Conc.)Wall, Center |
| 12. | " " W | 30. | Room 1-8 Wall, Center |
| 13. | South 12 in. Beam E | 31. | " " " N, Top |
| 14. | " " " " W | 32. | " " " N, Bottom |
| 15. | North 12 in. Beam E | 33. | Room 1-5 Wall, N, Top |
| 16. | " " " " W | 34. | " " " N, Bottom |
| 17. | Exterior Column 5 ft Outer | 35. | " " " Center |
| 18. | " " 5 ft Inner | 36. | Room 1-5 Door, Center |

**TEST No. 2**

| TC No. | Location | | TC No. | Location |
|---|---|---|---|---|
| 1. | Room Air NE | | 25. | Room 2-3 Floor NE |
| 2. | " " NW | | 26. | " " " NW |
| 3. | " " SE | | 27. | " " " SE |
| 4. | " " SW | | 28. | " " " SW |
| 5. | Steel Angle | South | 29. | Room 1-1 Wall, S, Top |
| 6. | " " | South | 30. | " " " S, Bottom |
| 7. | " " | North | 31. | " " " Center |
| 8. | " " | North | 32. | Room 1-4 Wall Center |
| 9. | Reinforcing Wire Level | East | 33. | " " " S, Top |
| 10. | " " " | East | 34. | " " " S, Bottom |
| 12. | Room 1-4 Air | | 35. | Room 1-4 Door, Center |
| 13. | Room 1-3 Floor | | 36. | Exterior(S'wich)Wall,Center |
| 17. | Reinforcing Wire Level | South | 37. | No. 3 Bar, Grout Joint, W |
| 18. | " " " | South | 40. | " " " " " N ,Center |
| 19. | Reinforcing Wire Level | Center | 41. | Steel Strap N, Center |
| 20. | " " " | Center | 42. | " " NE |
| 21. | " " " | Center | | |
| 22. | Reinforcing Wire Level | North | | |
| 23. | " " " | North | | |
| 24. | " " " | North | | |

**TEST No. 3**

| TC No. | Location |
|---|---|
| 44. | Room Air NE |
| 45. | " " NW |
| 42. | " " SE |
| 41. | " " SW |
| 46. | Room Air NW (ASTM-type) |
| 43. | " " SE ( " " ) |
| 47. | Reinforcing Wire Level, Ceiling, Center |
| 48. | Room 2-1 Wall, center |
| 49. | " " " , Air |
| 50. | Room 2-4 Door, center |
| 51. | " " Wall, center |
| 52. | " " Air |
| 53. | Exterior(S'wich) Panel |
| 54. | Fire Room, 1 ft, Bare TC |

Table 2. Selected Temperatures and Times

| TEST | Maximum Partition Temperature and Corresponding Time | | | | Time to 250 °F Temp. Rise on Door | Time to 150 °F Air Temp. in Adjoining Room | Maximum Air Temperature and Corresponding Time | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Adjoining Room | | Adjoining Apt. | | | | Adjoining Room | | Adjoining Apt. | |
| | Temp. °F | Time min | Temp. °F | Time min | | | Temp. °F | Time min | Temp. °F | Time min |
| 1 | 238 | 105 | >156 | >150 | 10 | 26 | 235 | 41 | 108 | 31 |
| 2 | 206 | 120 | 176 | 170 | 15 | 42 | 205 | 72 | 84+ | 78+ |
| 3 | 290 | 75 | 156 | 90 | 7-1/2 | 31 | 230 | 101 | 86 | 160 |

Table 3. Maximum Radiation Levels

| | Fire Room Window | | | | | Room Above (or roof) | Exterior Door |
|---|---|---|---|---|---|---|---|
| | Blackbody Temperature °C | Radiation Intensity $w/cm^2$ | Irradiance I $w/cm^2$ | Configuration Factor F | I/F $w/cm^2$ | Irradiance $w/cm^2$ | Irradiance $w/cm^2$ |
| Test No. 1 | 900 | 10.7 | 3.4 | .148 | 23 | >1.4 | .96 |
| Test No. 3 | 920 | 11.5 | .25 | .0224 | 11 | .17 | .37 |

Table 4. Maximum Gas Concentrations Indicated by Draeger and MSA Colorimetric Tubes.

| Test No. | Room | Time | Concentration | | |
|---|---|---|---|---|---|
| | | | CO | $CO_2$ | HCN |
| | | Min | ppm | % | ppm |
| 1 | 1-5 | 25,47 | | | 30 |
| | | 50 | 7500 | | |
| | 1-8 | | No positive readings | | |
| | 2-6 | 52 | 2500 | | |
| | | 54 | | | 5 |
| 2 | 1-1 | 72 | 70 | | |
| | 1-4 | 27,69 | 700 | | |
| | | 62,70 | | 8 | |
| | | 58,63 | | | 50 |
| | 2-3 | 33 | 150 | | |
| 3 | 2-3 | 3 | 10,000 | | |
| | | 5-1/2 | | 13 | |
| | | 21 | | | 25 |
| | 2-4 | 10 | 3,000 | | |
| | | 50 | | 4 | |
| | | 26 | | | 25 |

Table 5. Time to Reach Smoke Density 0.065 per foot

| Location in relation to fire room | Test No. 1 | Test No. 2 | Test No. 3 |
|---|---|---|---|
| Adjacent Room (Same Apartment) | 4 min | 7 min | 2 min |
| Adjacent Apartment | 21 min | not reached | 24 min |
| Room Above | 47 min | 47 min | not applicable |

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