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NATIONAL BUREAU OF STANDARDS REPORT

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9586

FIRE ENDURANCE OF PARTITIONS AND ROOF DECKS

of

FIRE-RETARDANT TREATED AND UNTREATED WOOD

by

Harry Shoub

(421.02)

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

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U.S. DEPARTMENT OF COMMERCE

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Abstract

Fire endurance tests were performed at the National Bureau of Standards on wood-framed gypsum board partitions and all wood plank-and-beam roof decks. Some of the specimens were made with fire-retardant-treated wood, which, however, did not prevent their participation in the fire to which they were exposed and did not measurably enhance their fire endurance (as distinguished from flame spread) properties over those of structures of untreated wood similarly made and tested.

The one-hour fire resistance rating previously established for partitions of 5/8-in. gypsum board was confirmed for structures with both treated and untreated framing. The 2-in. thick plank roof decks failed under the applied loads and also by flame penetration in less than an hour.

As the roof decks were shown to contribute significant heat to the test fire, consideration was given to the extent of this contribution, and to the validity of comparing fire tests of structures of noncombustible materials with those that are combustible.

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1. Introduction

Although building codes generally restrict the use of wood in structures to those not required to be noncombustible, certain exceptions are made for fire-retardant-treated lumber products. Most of the model building codes permit the use of fire-retardant-treated wood for framing nonloadbearing partitions and for certain roof constructions in fire-resistant and noncombustible buildings. Also, in some instances, an increase in building area of combustible types is allowed when treated wood is used.

The use of fire-retardant-treated wood is also recognized by many insurance rating bureaus as a basis of assigning rates on certain structures made of this material comparable to the rates set for similar structures of noncombustible materials. Treated wood is used in special applications such as temporary buildings and decorative ceilings, and has been allowed as an alternate to steel in metal-clad buildings.

As the U. S. Public Health Service has under consideration the use of wood constructions in buildings to be erected under their cognizance, that agency sponsored tests at the National Bureau of Standards to determine the fire resistive characteristics of such structures.

In the trials conducted by the Fire Research Section, five structures, three wood-framed partitions with gypsum board facings and two wood beam-and-plank roof decks, were subjected to standard fire endurance tests. Fire-retardant-treated lumber was employed for two of the partitions and one roof deck in an effort to determine what effect this processing would have on the fire performance of the structures.

With a fire resistance rating already established for the partition of ordinary construction, and the behavior of the roof deck fairly predictable from available test results on the burning rate of wood, these assemblies were, however, included in the series of tests as controls and as further checks on the accepted data for the structures, and their reproducibility. Also, in the investigation of aspects of the fire endurance performance of the specimens, consideration was given to the criteria and the test method by which this performance is determined.

2. Description of Test Structures

The test structures, both partitions and roof decks, were constructed by Bureau carpenters and roofers using commercially-supplied materials. The quality of the workmanship, which was under continual check, was at least as good as, and often superior to that provided in ordinary building practice.

a. Partitions

The partitions, 10-ft high and 16-ft long, were constructed of 5/8-in. Type X gypsum wallboards (ASTM C 36) in 4- by 10-ft sheets applied to a framing of 2- by 4-in. wood studs on 16-in. centers. They were mounted in a furnace test frame having an opening the length of the partitions but with an approximately 3-in. greater height which was filled in at the bottom of the opening with two layers of 2- by 10-in. plank, the fire-exposed surfaces of which were covered by strips of gypsum board. In addition to 2- by 4-in. plates (single at bottom and double top), fire stops of the same wood were placed at 4- and 8-ft levels. A vinyl baseboard cove was applied with adhesive on both sides of the partition. All lumber used was Douglas fir, No. 2 common or better. The boards were applied with 1-7/8 in. 6d coated common nails, 7 in. on centers. Joints between boards were taped, and both joints and nail heads were spackled. The construction was designed to duplicate that of a partition having an established fire resistance rate of 1 hr. [1][1/]

While the partitions were all of similar construction, No. 1 was made of untreated wood while fire-retardant-treated wood was used for the framing of No. 2 and 3. The treatment of the wood was by a commercial process approved, as evidenced by application of labels, by recognized fire testing laboratories (Underwriters' and Factory Mutual).

Partition No. 3 was further distinguished by the installation of electrical and combined vacuum-oxygen receptacles on both sides of the wall. Electrical connections were by BX cable, with the upper row of outlets on a separate circuit. The vacuum and oxygen outlets were connected to 3/8-in. copper tubing brought out of the wall at the base of the unexposed side.

1/ Figures in brackets indicate the references on p.13 of this report.

The details of construction of the partitions and the location of the thermocouples on the unexposed surface are shown in Fig. 1. The arrangement of the fittings in partition No. 3 is indicated in Fig. 2. The test numbers (453 etc.) shown are included for identification of these tests in the Bureau series.

The 2- by 4's used in the partitions were specified to be kiln dried under the terms of the purchase order, and were so delivered, their moisture content running about 7 percent, as determined from weighings made before and after drying at 105 °C. The density of the wood was approximately 31 lb/ft^3, a value consistent with those determined for wood of this species and moisture content. The material was somewhat better, in that there were less knots and other imperfections, than wood commonly used in construction, having been supplied in D grade rather than No. 2 Common. The treated 2- by 4's were construction grade, with a moisture content of 9 percent and a density of 40 to 45 lb/ft^3.

b. Roof Decks

Two roof decks, each 13-1/2 by 18 ft, were built into the top of the NBS floor testing furnace. The decks were constructed of nominal 2-in. tongue-and groove roofing laid transversely over the furnace opening and supported by a 6- by 10-in. central beam resting on steel stirrups at either end of the furnace. The roof planks were attached, with four 16d common nails at each bearing, to the beam and to nailing strips at either end, bolted to the furnace frame. Gypsum board covers were applied to the nailing strips, but to no other part of the structure, to offer protection to the strips during fire exposure. This was done on the assumption that in actual building practice a plaster or gypsum board wall would be brought up to contact with the underside of the roof deck. The roof planks were drawn together with clamps before nailing to minimize the width of the joints between boards. The underside of the roof deck, in place in the furnace, can be seen in Fig. 3.

Three-ply roofing, consisting of UL labeled 15-lb saturated felt and a maximum of 120 $lb/100\ ft^2$ of hot mopping asphalt, was applied to both of the deck structures. No gravel surfacing or metal edge flashing was used. The roofing was laid transversely, parallel to the wood planks. Roof deck details are shown in Fig. 4.

The two roof decks were of identical construction, except that the second was entirely of fire-retardant-treated lumber. The material was processed similarly to the wood used in the partitions. Attached to each piece of planking was a UL label listing the fire hazard classification of the material as follows: "flame spread 15, fuel contributed 15, and smoke developed 0." NCF grade was also indicated.

The moisture content of the untreated wood was 17 to 20 percent for the roof decking and 22 percent for the beam. Kiln-dried lumber had been specified on the order, but apparently was not furnished.

In the interval between construction of the roof deck and performing the test, some drying of the wood was achieved by the use of space heaters in the furnace chamber. Measurements made on the under surface of the roof planks with a TAG Moisture Meter showed a final moisture content of 12 to 13 percent. The moisture in the beam was reduced to under 19 percent as measured by a relative humidity gage probe inserted into the center of the wood at a point 18 in. from one end.

Under the provisions of the standard applicable at the time of these tests, wood for use in a structure in a fire test was required to be in equilibrium with a relative humidity of not more than 70 percent, which at 70 to 80 ^{o}F corresponds to a moisture content of 13 percent. The urgency of the tests did not allow the time for this condition to be met.

The fire-retardant treated wood was supplied in a much drier condition, the moisture content of the decking being less than 7 percent and that of the beam approximately 14 percent. Density of the roof decking ranged from 29 to 41 lb/ft^3, with light and heavy pieces occurring in both the treated and untreated samples. The two beams were of comparable density, 31 lb/ft^3 untreated and 32 lb/ft^3 treated. All of the lumber supplied for the roof decks was construction grade.

3. Test Method and Equipment

The tests of both the partitions and roof decks were made in accordance with the requirements of the Standard Methods of Fire Tests of Building Construction and Materials, American Society for Testing and Materials E 119-61. Under this procedure, one side of a partition or the underside of a roof structure is exposed to a fire in a furnace suitable for test of the type of structure, and controlled to conform as closely as possible to a time-temperature schedule defined by points as follows:

1000 °F	(538 °C)	at 5 min
1300 °F	(705 °C)	at 10 min
1550 °F	(843 °C)	at 30 min
1700 °F	(927 °C)	at 1 hr
1850 °F	(1010 °C)	at 2 hr

The temperatures in either furnace were determined from 12 thermocouples mounted in iron pipes symmetrically distributed within the furnace chamber. The readings of furnace temperature were recorded automatically at intervals of 5 min or less throughout the tests.

The fire endurance of a structure of either kind is limited to that required to reach the first occurring of any of the following criteria of failure:

1. Failure to sustain the applied load.

2. Passage of flame or gas through the structure to the unexposed surface hot enough to ignite cotton waste.

3. A temperature rise of 250 degrees F (139 degrees C) average or 325 degrees F (181 degrees C) at one point, above the initial temperature on the unexposed surface.

Temperatures on the unexposed surfaces of the structures were measured with chromel-alumel thermocouples, and were recorded in similar manner and at the same time as the furnace temperatures. The disposition of the thirteen thermocouples used on each of the partitions and the eleven on top of the roof decks is indicated in Figs. 1 and 3, respectively. As specified in the standards, each of the thermocouples was covered with a 6- by 6- by 0.4-in felted asbestos pad.

The furnaces were gas fired, with the fuel input variable to control the furnace time-temperature curve in conformity with that of the standard. Details of the NBS wall or panel furnace, in which a partition under test would form the closure of the open side, can be seen in Fig. 5. The furnace used at the Bureau for the testing of floor-and-ceiling assemblies was also used for the roof decks, where they formed the top of the test chamber. The design of this furnace is shown in Fig. 6.

As required on partitions Nos. 1 and 2 and both roof decks, load was applied to the structures by means of hydraulic jacks. For the partitions, the load was 600 lb/lineal ft, or 9600 lb total, supplied by four jacks built into the furnace test frame and acting on the beam supporting the base of the partition. Load on the roof decks was furnished by four overhead jacks acting on a special distributing mechanism to apply the load uniformly at 36 points. For these structures, a load of 25 lb/ft^2 was used, which with the addition of the dead load of the roof, was intended to provide a unit stress of 1350 lb in the beam.

Deflection, that is, bowing of the partitions was determined by measuring the distance at midheight from the unexposed face of the structure to three wires vertically suspended in front of the center and quarter points of the unexposed surface. On the roof decks, deflection measurements were made at five positions, on the beam at its center and quarter points, and on the deck planks at the quarter points of the transverse axis of the structure.

Where load was required, it was applied prior to the start of the tests. In partition No. 3, which was tested without load, the electrical circuits were energized and air at 50 psi was supplied to the oxygen outlets.

4. Results of Tests

The results of the tests, in terms of average and one-point maximum temperatures on the unexposed surfaces of the structures, are shown in Figs. 1 and 2 for the three partitions and 4 for the roof decks. Deflections of the two roof decks during fire exposure, measured on the beam at the center of its span, are presented in Fig. 7.

The severity of the fire exposure in all five of the tests, as indicated by the furnace average temperature curves in Figs. 1, 2 and 4 was so close to the standard furnace time-temperature curve of ASTM E 119 as to preclude the necessity for adjusting the observed times to failure to compensate for furnace deviation. The greatest amount of correction computed in accordance with the Standard, would add approximately 40 sec to the fire endurance time of roof deck No. 2.

a. Partitions

Fire endurance times for the three partitions ranged from 60.4 to 62.7 min, with failure in each case occurring by temperature rise on the unexposed surface. In partitions 2 and 3, the limiting one-point temperature rise was attained first, but in all cases the average and one-point temperature rise criteria of failure were observed within an interval of several minutes.

Initial flaming on the exposed sides of the structures was noted soon after the start of the tests, and represented the burning of the facing material on the gypsum panels. Flaming at the board joints, indicative of combustion of the studs, occurred before 30 min in partition No. 1 with untreated wood, and was definitely established in the later stages of the tests of the two partitions with fire-retardant-treated framing. On these, the characteristic odor and crackling sound of burning wood had been noted earlier in the tests. Fig. 8 (at 57 min) and Fig. 9 (58 min) show the flaming at the gypsum board joints of partitions Nos. 1 and 3, respectively.

Light smoke, commensurate with the small amount of combustibles involved, was noted in the furnace room during the tests of all three of these structures. However, upon removal of a partition from the furnace immediately after its test, a considerable volume of smoke was produced by the burning of the wood frame members, large areas of which were exposed by the falling away of portions of the gypsum board cover. The charred condition of the fire-retardant-treated framing of partition No. 2, with some residual burning still occurring at the upper right, can be seen in Fig. 10.

In partition No. 3, the electric circuits became inoperative within 6 min after the start. At 30 min, the pressure of the air supplying the oxygen outlets began falling, indicating probable leakage in the joints of the copper tubing. The pressure loss, however, was not rapid, as a residual pressure of about 10 psi remained at the end of the test. Acid fumes, noted here, but not present in the tests of the other two partitions, could have developed from the heating of plastic parts in the electrical fittings, and from the wiring insulation. There was discoloration and smoke at the various outlets, but in no case was the transmission of heat through these units sufficient to ignite cotton waste held against the face plates on the unexposed surface.

Partitions Nos. 1 and 2, which were subjected to load, showed considerable outward bowing toward the conclusion of the tests. On No. 1, the deflection was approximately 3-1/2 in. at the center and 2 in. at the quarter points along the horizontal center line, while No. 2 had a rather uniform 4-in. bow on the whole of this axis. The third partition, which was not load-bearing, showed only a little bowing, the maximum deflection being about 1/2 in.

b. Roof decks

The fire endurance of the roof decks was limited by beam load carrying performance to 49-1/2 min for deck No. 1 (untreated) and 43 min for deck No. 2 (treated wood). Failure by breaking through of flame occurred at 51 min and 46 min for decks Nos. 1 and 2, respectively. In both cases, the load was removed from the structures within 1 min after flame-through was noted. The fire exposure, however, was continued for a short interval after failure until limiting temperature rises were observed. These occurred, by one-point maximums, at 55 min and 49 min for roof decks Nos. 1 and 2 respectively. The maximum temperatures were localized in the areas burned through, with temperatures on the rest of the deck surface remaining well below the established criteria of failure.

The odor of burning wood and considerable smoke was noted near the beginning of the tests of both partitions. Charring and visible flaming on the fire exposed surface occurred before 5 min on the fire-retardant-treated deck as well as on the one of untreated wood. At 15 min after the start, the roof deck of untreated wood was completely involved, and at 23 min the treated deck was burning vigorously over the entire exposed surface. The built-up roofing over the decks generally remained intact until the last stages of the tests, and offered a rather good barrier to the passage of smoke, allowing escape only at the edges.

The considerable downward deflection of the decks resulted from loss of strength in their supporting beam from heating and reduction of cross section by charring, the extent of which in the treated beam, can be seen in Fig. 11. As measured at the center point, the deflection of the untreated wood deck was slightly greater than that of the treated wood specimen up to about 40 min fire exposure, at which time the rate of deflection of the treated structure increased beyond that of the first roof deck. Maximum deflections, just prior to load removal, were 6-1/4 in. for deck No. 1, and 7 in. for No. 2. After the load was removed, the beam on deck No. 1 showed some recovery, with a final deflection of about 4 in. This did not occur, however, on the roof deck of fire-retardant-treated wood. Deflections somewhat greater than those on the beams were noted at the deck measuring points. In part, these were attributable to the pulling away of the roof plank end supports from their attachment to the furnace frame during the course of the tests.

5. Discussion of Results

From the tests described herein, it is evident that fire-retardant-treated wood of the type used will contribute fuel to a fire, at least if relatively large, and its use will not provide an increase of fire resistance, as determined by the standard fire endurance tests, ASTM E 119.

What the wood can provide is increased resistance to flame spread across a surface, a characteristic defined by surface flammability tests [2] and [3]. This, however, is not fire endurance, and appears to have little bearing on the penetration of a structure by heat and fire, which is the basis of the required structural fire resistance ratings established in building codes and insurance regulations.

That fire-retardant-treated wood will burn is evidenced in a number of publications in the fire protection literature. To cite a few: Bramhall states that in the fire tube test, ASTM E 69, if the temperature at the top of the fire tube exceeded 315 °C (600 °F), the fire retardant could not suppress the flame, and the specimen would be essentially destroyed [4]. The Fire Protection Handbook declares that treatment is not effective in increasing the resistance of wood to sustained fire exposure, and that no treatment will entirely eliminate the fuel contribution of wood to a fire in progress [5]. Eickner, of the Forest Products Laboratory, says that the principal advantage of fire-retardant treatment for wood lies in the reduction of its surface flame spread characteristic [6], and this is the basic claim made for the material by the Underwriters' Laboratories, Inc. [7].

It has been established that fire-retardant treatment causes a greater production of charcoal in the wood and reduces the temperature at which char occurs. From this, it is possible to indicate the extent of treatment penetration by heating small thin sections of the wood to 220 °F for 20 min. Under these conditions char will have been produced in any treated portions while the untreated retains its normal appearance. The result of this simple investigation can be seen in Fig. 12. Note that the sections of both the 2- by 4 and roof deck lumber show hardly more than peripheral discoloration.

It is apparent in these tests of partitions, both with untreated and fire-retardant treated framing, that the principal factor in their fire endurance was the insulating characteristic of the gypsum board finish which protected the studs. It has already been established that 1/2-in. gypsum board will offer 15 min protection to studs, the time taken as that to limiting 250 degree F average or 325 degree F one-point temperature rise on the face of the wood [8]. The use of 5/8-in. Type X gypsum board apparently increases this protective period to the extent that the studs retain sufficient strength to support the structure until the heat transmission through the panels is such as to cause a limiting temperature rise on the unexposed surface, or about one hr for gypsum boards of this type and thickness. As already noted, the use of fire-retardant wood did not increase the fire endurance of the partitions. Also, cutting the boards for the installation of a number of electrical and convenience outlets, partition No. 3, did not appear to be a detriment to the resistance, at least with the workmanship achieved. Loading of the partitions also did not seem to affect their fire endurance, as failure in each case was by limiting temperature rise. From the extent of bowing on the loaded structures, however, it was obvious that, if the temperature rise had not been attained, structural failure was imminent.

The failures of the roof decks by flames burning through to the unexposed surface occurred at single points. The whole of the decking, however, was involved, and an examination of the depth of char, the totality of which can be seen in Fig. 13, indicated that the fire soon would have broken through over much of the deck area. In the deck with treated wood, a second flame-through did take place 1-1/2 min after the first. At about this time the test was discontinued. Flaming continued on both decks after the fire exposure was stopped, and was extinguished only with considerable application of water.

The char penetration rate of untreated wood subjected to the conditions of the standard fire endurance test has been found to be about 1/40 in./min [9]. In these tests of roof decks, this rate was slightly exceeded in the areas of failure, but considering the average penetration of the deck as a whole, the figure appears to have ample validity.

Small differences in the results of fire endurance tests of comparable structures are usually attributable to experimental error and lack of refinement of the testing techniques. If any significance can be imputed to the apparent superiority in performance of the untreated wood roof deck over that of the treated structure (49-1/2 min vs 43 min endurance), it may be explained by the greater moisture content of the untreated wood. While it is generally held that treated wood, because of retention by its chemicals, has more moisture than untreated, in this case the treated material was supplied in a very dry condition (7-9 percent moisture). The untreated decking, although specified to be kiln-dried, had a high moisture content (17-20 percent). This was reduced by heating the underside of the structure prior to the test. Final measurements made on the exposed under surface indicated the moisture content to be 12-13 percent.

In the absence of any definitive requirement in the standard fire test (ASTM E 119), the criterion of load failure, which was the determining factor in the endurance of the roof decks, has been taken as the time when both a limiting total deflection and hourly rate of deflection are achieved [10]. These are based on the span length and the depth of the supporting structural component. For the beams in these tests, the limits were a deflection of 5.7 in. and a rate of 30.5 in./hr. With both roof decks, the rate of deflection limit was reached before the allowable total deflection, occurring at approximately 49 min for deck No. 1 and 43 min for No. 2.

Some observations may be in order on the adequacy of the test method as applied to structures made wholly or in part of combustible materials, in which category fire-retardant-treated wood of the type here tested must be included. As these materials contribute fuel to the fire in the test furnace, they lower the demand for externally supplied fuel required to maintain the standard time-temperature relationship. It follows then that the exposure to which a combustible structure is subjected is not as severe as that applied to a noncombustible structure which does not supply part of the furnace fuel. This serves to enhance the endurance manifested by combustible structures over that which they would attain if tested with the same fuel input to the furnace required for wholly noncombustible building elements.

In the case of the three partitions tested, the combustible framing represented only a small portion of the mass of the structures. With the roof decks, however, the whole of the structure was combustible. Our records show that gas consumption in prior tests of noncombustible structures averaged about 9900 ft^3/hr, with little variation in the rate between the tests, whatever their duration. Among the structures tested were a steel deck floor with concrete topping and plaster protection on the under side, a precast cellular concrete deck, and gypsum concrete decks on steel beams or concrete joists. Applying the average rate of 9900 ft^3/hr, the gas consumption for the 49-min duration of the exposure of the fire-retardant treated deck would be 8100 ft^3. In the tests of the fire-retardant-treated deck, however, the fuel consumption was 5540 ft^3 of gas (calorific value approximately 1025 Btu/ft^3). Thus it would appear that the structure supplied the heat that would have been contributed by 2560 ft^3 of gas, or 2,624,000 Btu.

The approximate weight of the deck was 1000 lb, and an examination of the structure indicated that a fair estimate of the burned portion was at least 75 percent, or 750 lb. Using a potential calorific value of 8400 Btu/lb for the wood and 13,000 Btu/lb for charcoal, and assuming that combustion of fire-retardant-treated wood under the conditions of the Standard test results in a 37 percent residue of charcoal, as established by the Forest Products Laboratory [6], we find that the fuel contribution of the structure would be 2,660,000 Btu. That this is almost the same as the calorific value computed for the difference in gas consumption between tests of noncombustible structures and that of the roof deck here tested is hardly surprising. The heat to maintain the furnace to the required time-temperature curve has to be supplied from some source, and what is not provided by the gas input, must of necessity come from the structure under test.

6. Summary

From these tests, conducted to study the fire endurance characteristics of gypsum-board faced wood stud partitions and wood plank-and-beam roof decks, made of both fire-retardant-treated lumber and untreated lumber, certain summary comments appear warranted.

The 1-hr fire endurance rating established for partitions of 5/8-in. Type X gypsum board (ASTM C 36) on wood studs is justified, although the results of these tests indicated that the rating was achieved with little to spare as a margin of error. Also, the reported 1/40-in./min rate of char penetration in wood under the conditions of the standard ASTM E 119 test was valid for the roof deck structures here tested.

The fire endurance of both roof decks was approximately 3/4 hr, determined by their failure to sustain the applied load. Failure by flame through to the unexposed surface occurred only several minutes later in both cases. Limiting temperature rises, however, were noted only in the area where flame had broken through, indicating the insulating property of the wood even though almost completely charred.

A general conclusion to be drawn from the study is that fire-retardant-treated wood, as represented by the commercial UL and FM labeled products used in these tests burns and participates in a large fire. Another is that the standard test method for fire endurance favors structures of combustible material. These, because they contribute fuel to the furnace fire are subjected to an exposure that requires a lower external fuel input than that required to maintain the time-temperature relationship when noncombustible structures are tested. Similar conclusions were presented in a National Bureau of Standards report published in 1938 [11].

7. References

[1] Underwriters' Laboratories, Inc. Building Materials List, 1967, Design No. 5, p. 400.

[2] Standard Method of Test for Surface Burning Characteristics of Building Materials, American Society for Testing and Materials Designation E 84.

[3] Method of Test for Surface Flammability of Materials Using a Radiant Energy Source, American Society for Testing and Materials Designation E 162.

[4] G. Bramhall, Fire-Retardant Treatment of Wood, in Wood, Fire Behavior and Fire-Retardant Treatment, Canadian Wood Council, Ottawa, 1966, Part IV, p. 10.

[5] NFPA Handbook of Fire Protection, National Fire Protection Association, Boston, 1962, Section 6. p. 106.

[6] H. W. Eickner, Fire Retardant Treated Wood, Journal of Materials, Vol. 1, No. 3, Sept. 1966.

[7] Building Materials List, Underwriters' Laboratories, Inc., Chicago, Jan. 1967.

[8] Fire Resistance Classifications of Building Constructions, NBS Building Materials and Structures Report BMS 92, 1942, p. 35.

[9] Wood Handbook, Forest Products Laboratory, U. S. Department of Agriculture Handbook No. 72, 1955, p. 339.

[10] J. V. Ryan and A. F. Robertson, Proposed Criteria for Defining Load Failure of Beams, Floors and Roof Constructions During Fire Tests, National Bureau of Standards, J. Res. Vol 63C, No. 2, Oct-Dec 1959.

[11] Clement R. Brown, Fire Tests of Treated and Untreated Wood Partitions, National Bureau of Standards Research Paper RP 1076, NBS J. Res. Vol. 20, Feb 1938.

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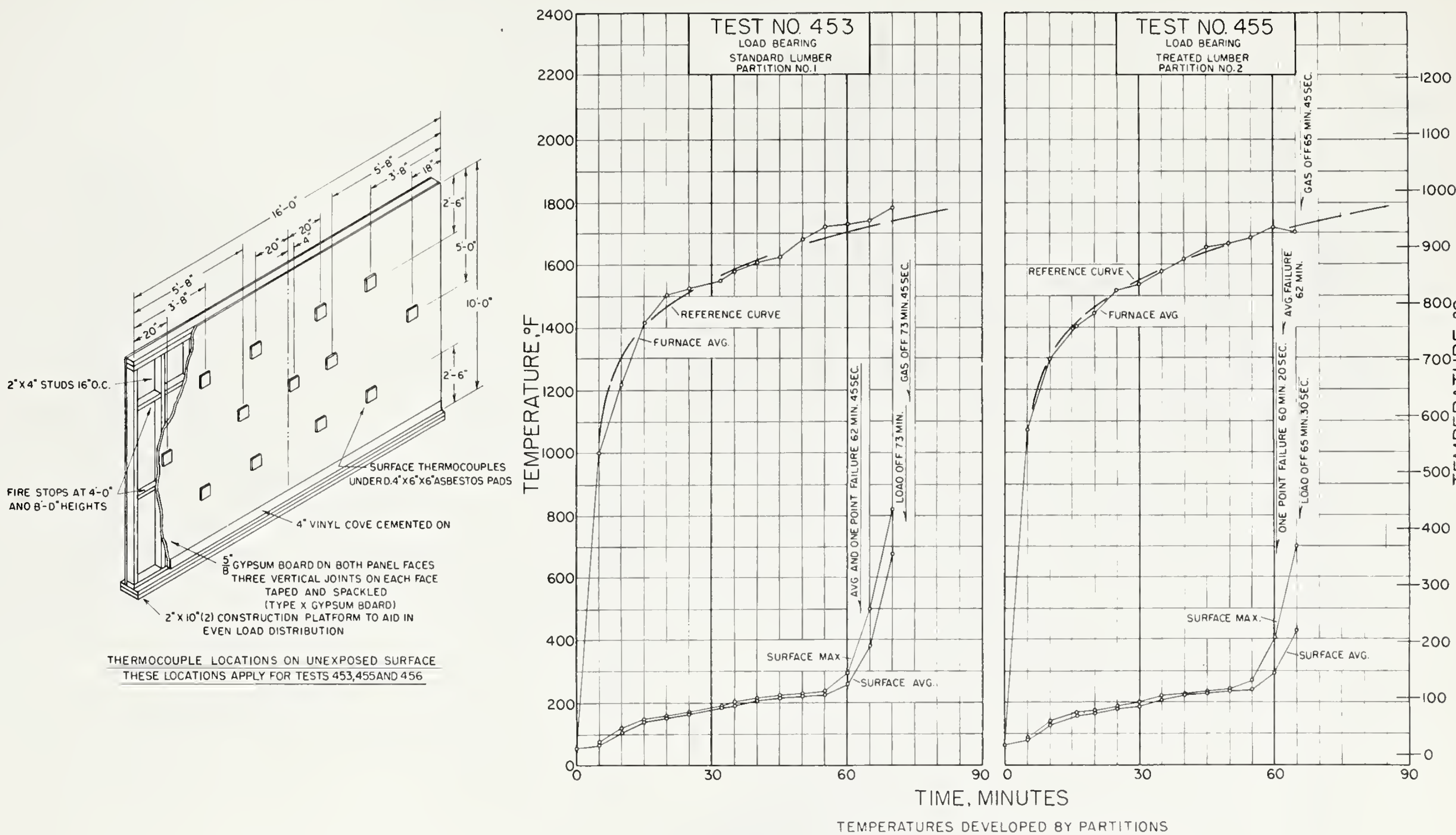
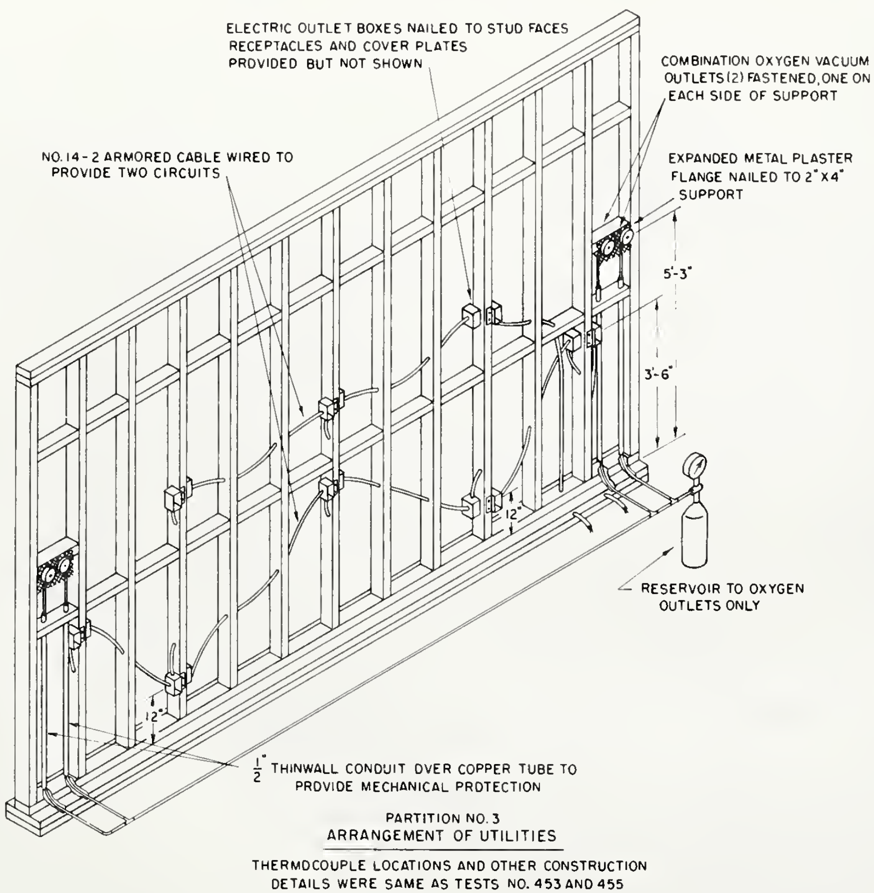


FIGURE 1. Construction details of partitions with thermocouple locations. Time-temperature curves for partitions Nos. 1 and 2.



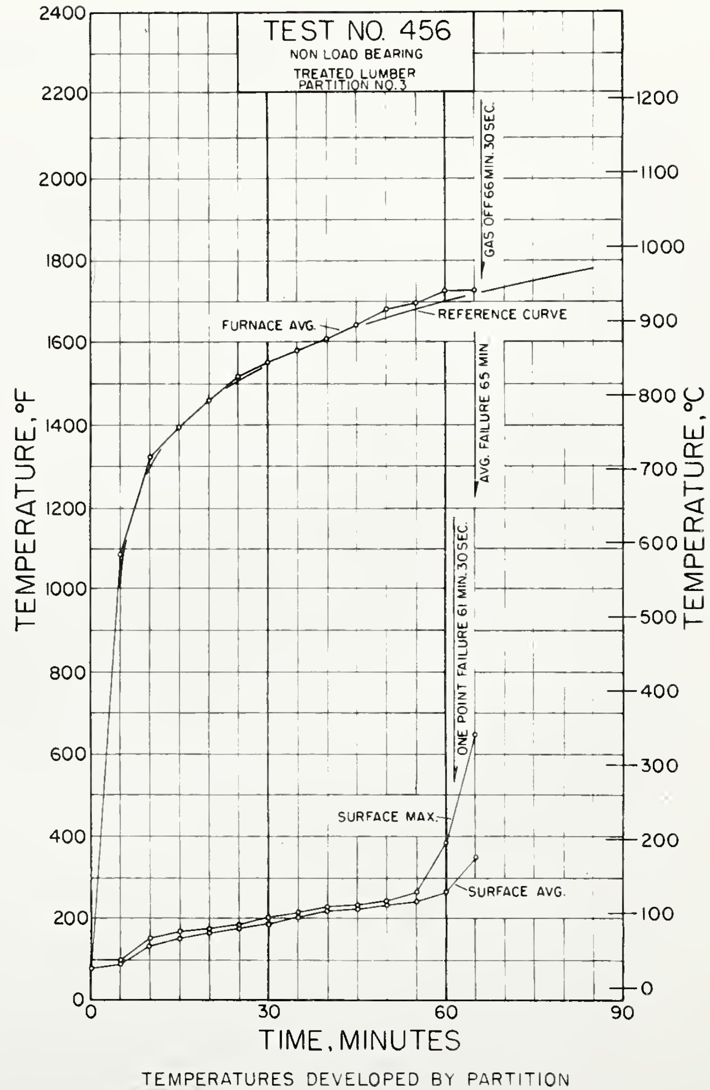
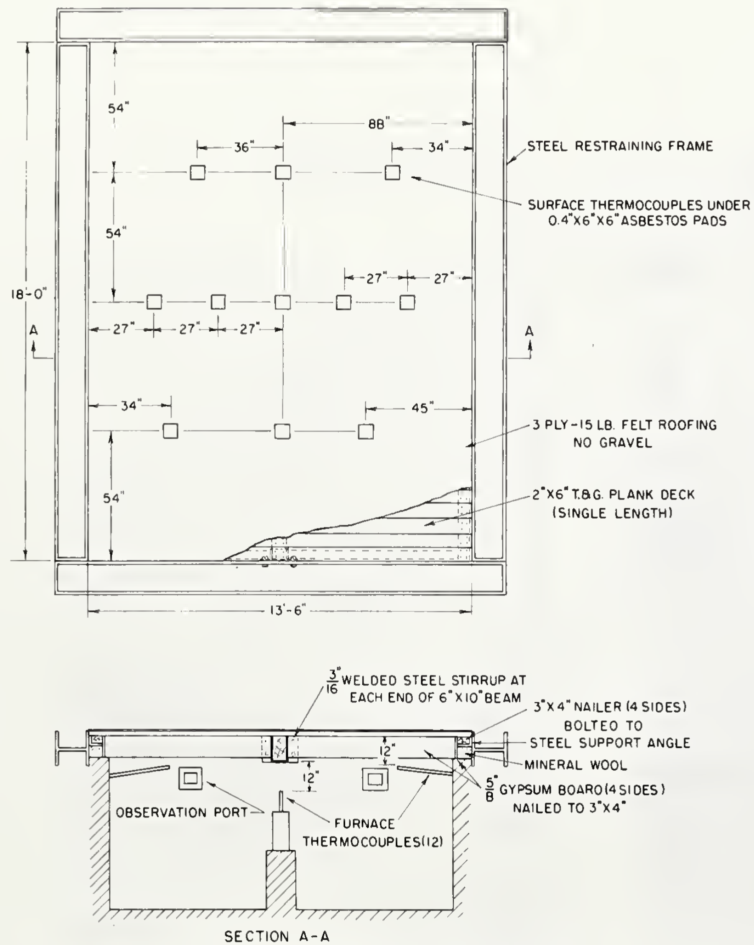
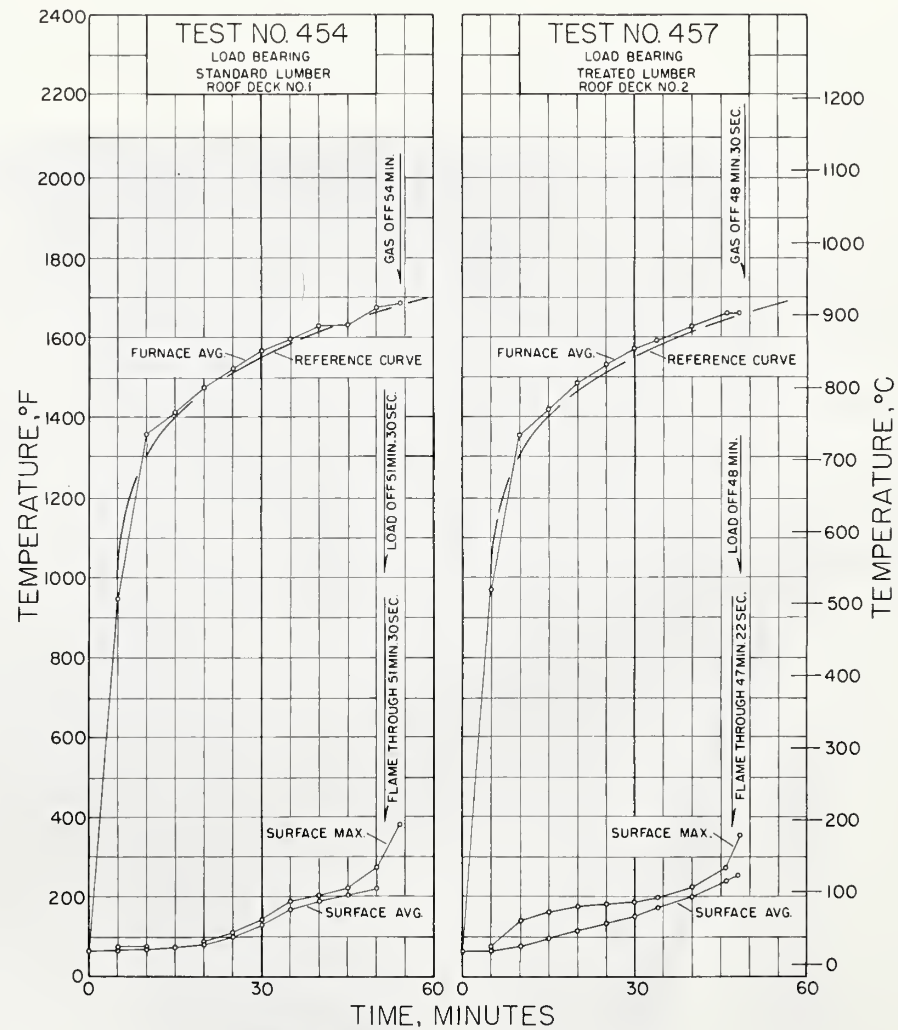


FIGURE 2. Arrangement of utilities and time-temperature curves for partition No. 3.

FIGURE 3. Roof deck mounted in furnace. View of portion of underside, showing beam.



CONSTRUCTION DETAILS AND THERMOCOUPLE LOCATIONS



TEMPERATURES DEVELOPED BY ROOF DECKS

FIGURE 4. Construction details of roof decks with thermocouple locations
Time-temperature curves for roof decks.

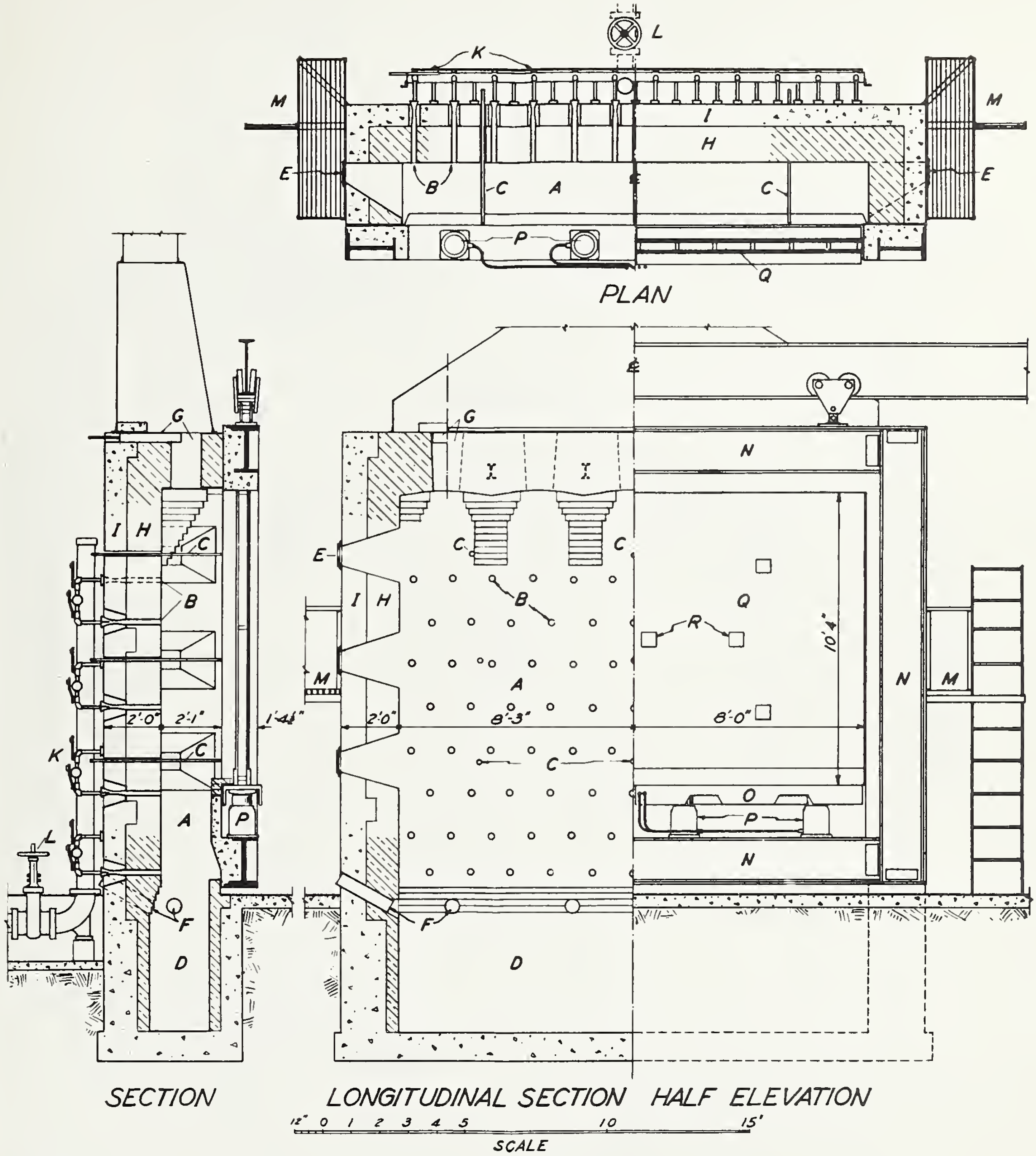


FIGURE 5 DETAILS OF WALL-TESTING FURNACE.

A, FURNACE CHAMBER; B, BURNERS; C, THERMOCOUPLE PROTECTION TUBES; D, PIT FOR DEBRIS; E, OBSERVATION WINDOWS; F, AIR INLETS; G, FLUE OUTLETS AND DAMPERS; H, FIREBRICK FURNACE LINING; I, REINFORCED CONCRETE FURNACE-SHELL; K, GAS COCKS; L, CONTROL VALVE; M, LADDERS AND PLATFORMS TO OBSERVATION WINDOWS; N, MOVABLE FIREPROOFED TEST FRAME; O, LOADING BEAM; P, HYDRAULIC JACKS; Q, TEST WALL; R, ASBESTOS FELTED PADS COVERING THERMOCOUPLES ON UNEXPOSED SURFACE OF TEST WALL.

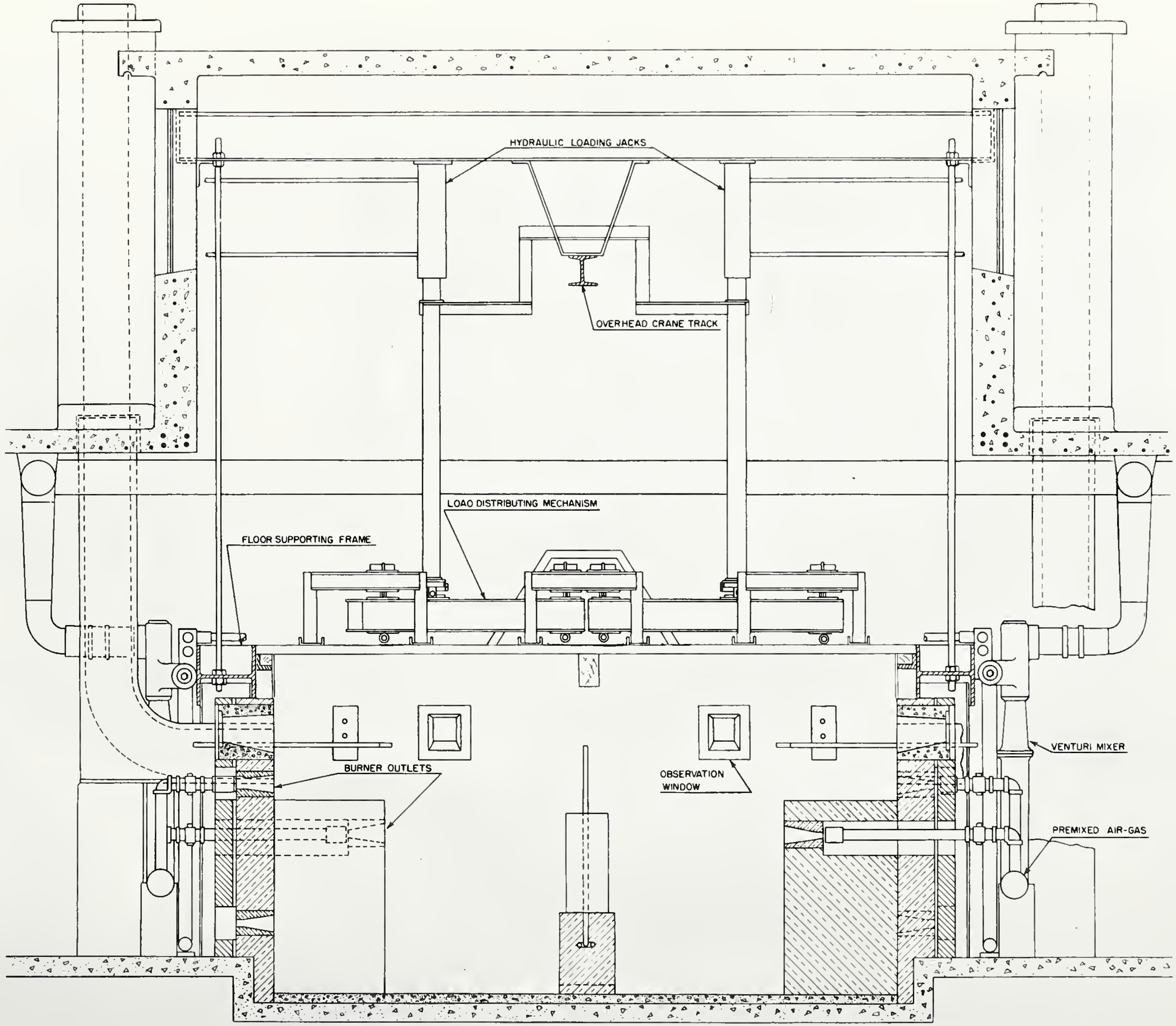


FIGURE 6. Section of the large floor-test furnace at NBS.

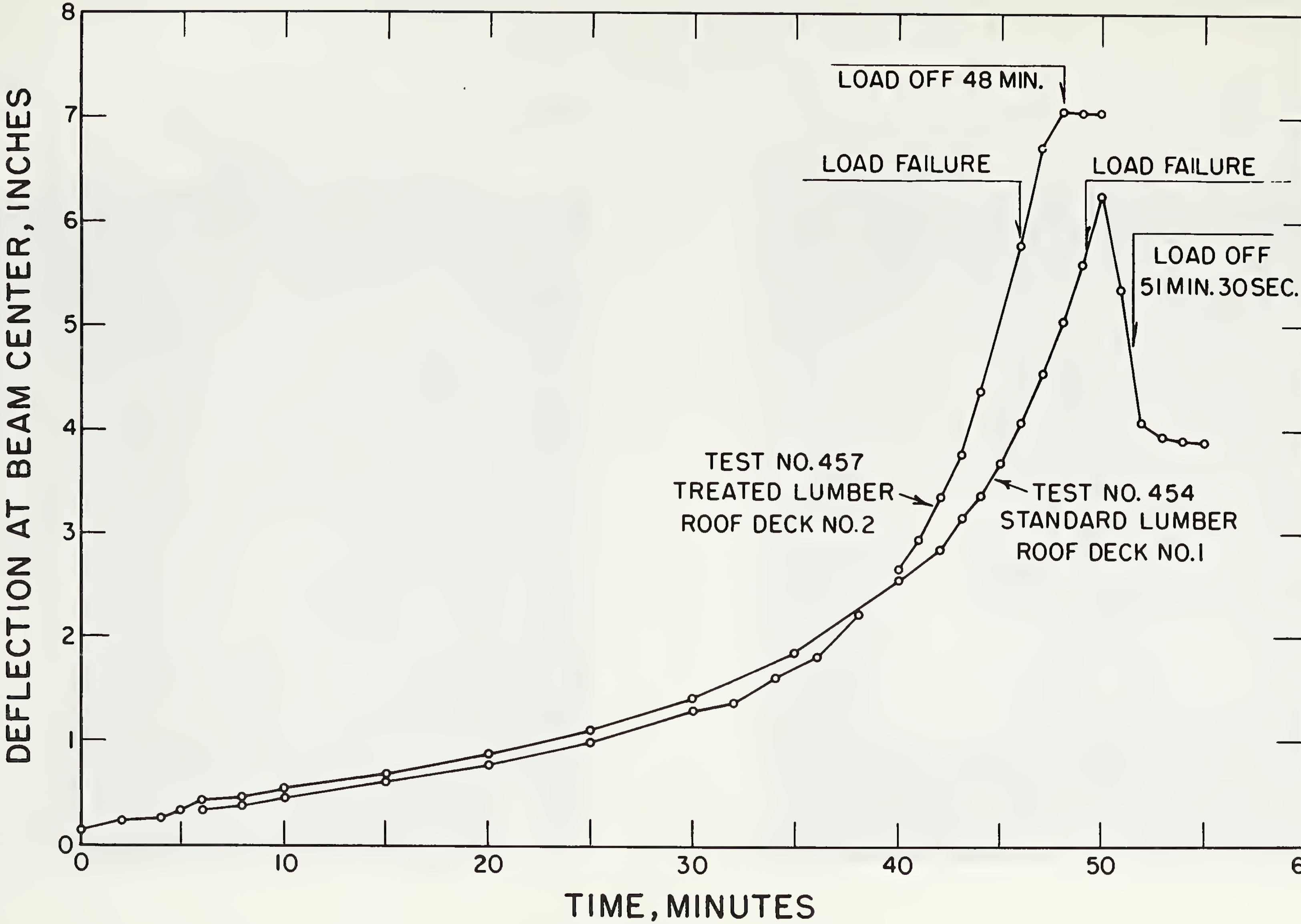


FIGURE 7. Deflections at the center of the roof decks.

FIGURE 8. Exposed surface of partition No. 1 (Untreated framing). Flames from studs through gypsum board joints; time 57 min.

FIGURE 9. Exposed surface of partition No. 3 (fire-retardant treated framing). Studs burning at joints between gypsum boards, time 58 min.

FIGURE 10. Exposed surface of partition No. 2, removed from furnace immediately after test.
Note condition of fire-retardant treated framing.

FIGURE 11. Cross section of fire-retardant treated beam and plank after test.
Unburned section shown for comparison.

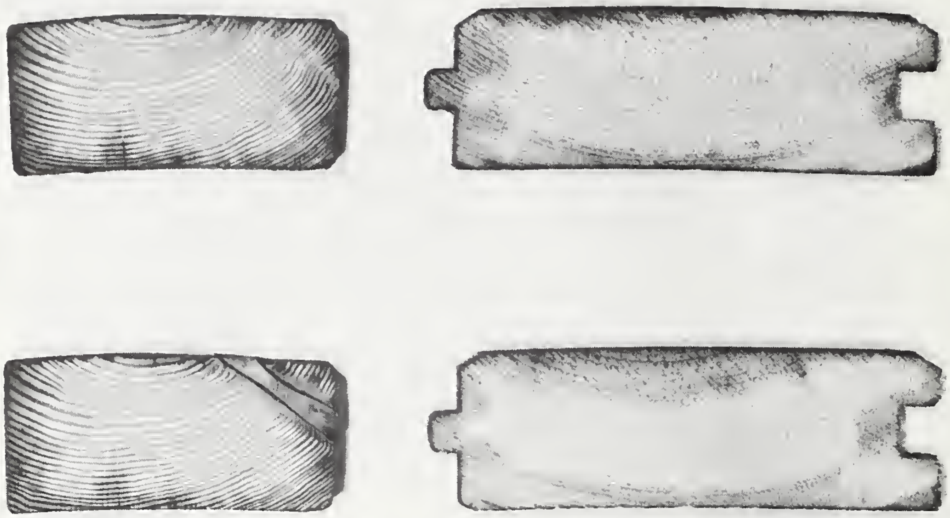


FIGURE 12. Sections of fire-retardant treated partition studs and roof deck planks heated to show extent of treatment penetration (charred areas).

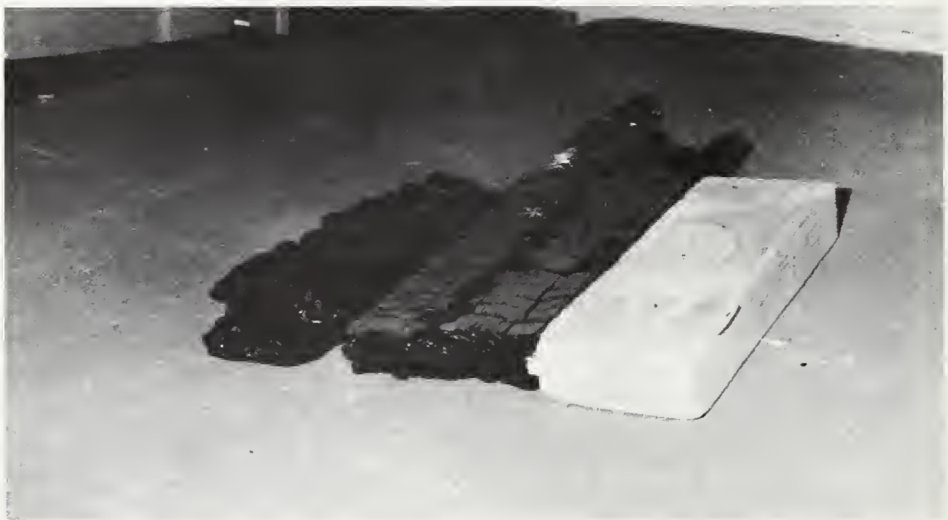


FIGURE 13. Fire-retardant-treated roof decking after test. Unburned sample for comparison.

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