NATIONAL BUREAU OF STANDARDS REPORT

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INVESTIGATION OF CARPET FLAMMABILITY TEST METHODS

NBS

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

NATIONAL BUREAU OF STANDARDS

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INVESTIGATION OF CARPET FLAMMABILITY TEST METHODS

by
Clayton Huggett and T. G. Lee

Prepared for:

Department of Health, Education, and Welfare
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FOREWORD

In 1970, the Office of Flammable Fabrics and the Fire Research Section of the Building Research Division, National Bureau of Standards, initiated a joint program to investigate the spread of fires through building corridors. The primary interest of the Office of Flammable Fabrics is in the contribution of carpets, upholstered furniture and other textile-related products to fire spread and hazard to life. The Fire Research Section is concerned with the effects of building design and structural materials on fire safety. The program includes full-scale fire experiments in a simulated room and corridor test structure and supporting laboratory investigations.

Early in 1971, the Department of Health, Education, and Welfare requested the advice of NBS in establishing flammability standards for floor covering materials to be used in medical and educational facilities constructed under the Department's jurisdiction. HEW agreed to support the long range program designed to characterize the hazards in building fires. At the same time, recognizing HEW's urgent needs for interim standards for floor coverings, it was agreed that the NBS program would be expanded to include an immediate study of the suitability of existing floor covering test methods. This is the first report prepared as part of the expanded program. It contains a preliminary evaluation of the Floor Covering Chamber Test (UL Subject 992).

The cooperation of the Carpet and Rug institute in supplying floor covering materials and the Underwriters' Laboratories, the Wisconsin Research Institute, Hercules, Inc., and Southwest Research Institute in conducting tests and furnishing supporting information is greatfully acknowledged.

ABSTRACT

A brief inter-laboratory study of the Floor Covering Chamber Test (UL Subject 992) was carried out. Four laboratories participated; five carpet assemblies were tested in quadruplicate in each laboratory. Based on this limited evaluation the Chamber Test, at the present state of development, shows unsatisfactory reproducibility between laboratory and insufficient ability to discriminate among the carpets tested. The pill test (DOD FF 1-70), the radiant panel test (ASTM E162-67), and the tunnel test (ASTM E84-68) are discussed in relation to the chamber test. Preliminary full scale corridor fire experiments with carpet are described briefly. None of the test methods considered have been shown, at the present time, to provide a reliable measure of the hazard contribution of floor coverings in building fires.

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INVESTIGATION OF CARPET FLAMMABILITY TEST METHODS

I. INTRODUCTION

Under many fire conditions, most carpets are difficult to ignite and burn slowly. They are not usually considered to be a primary source of fire hazard. However, in a building fire involving other fuel sources, a carpet will burn, contributing to fire spread and evolving smoke and toxic gases. Recent experience has shown that the contribution of the carpet can be a serious hazard to life and property. A test method or series of test methods is needed to characterize the total hazard potential of floor covering in a building fire environment.

An acceptable fire hazard test method must meet three requirements:

a. It must be both repeatable and reproducible, permitting different operators in different laboratories to obtain the same results within a known and acceptable level of precision when they follow the same written procedure;

b. It must correlate with the hazard being evaluated. This correlation can be established by comparison with real fire experience or with the results of full-scale tests closely simulating real fires. It may also be possible to establish a correlation by a detailed analysis of the real fire environment and the simulation of the critical aspects of this environment in the laboratory using experimentally established scaling laws;

c. It should be simple and economical to operate, consistent with the requirements of a) and b) above.

Four flammability test methods for floor coverings are currently in general use in this country:

a. The Methenamine Pill Test (DOC FF 1-70) [1]*

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* Number in square brackets indicate references listed at the end of the report.

b. The Steiner Tunnel Test (ASTM E-84) [2]

c. The Radiant Panel Test (ASTM E-162) [3]

d. The Floor Covering Chamber Test (UL Subject 922) [4]

The Pill Test can be used to screen out easily ignited carpet materials. The test provides assurance that the floor covering will not be the primary site of ignition from a small ignition source, but it does not characterize the behavior of the material in a fully developed building fire. The principal difference between the environment of the pill test and a real fire environment is that in the latter case the carpet ahead of the flame front is subjected to radiative and convective heat fluxes which raise the temperature of the carpet and render it more susceptible to pyrolysis and combustion. A valid laboratory test should model these energy fluxes. The problem is further compilcated since the energy fluxes are not properties of the carpet alone, but will depend on such environmental parameters as the dimensions, wall and ceiling material, and fuel loading of the room, the amount of ventilation, and the thermophysical properties of the carpet, underlayment, and floor.

The Tunnel Test was developed originally for the evaluation of rigid surface construction materials, particularly wall and ceiling materials. Its use for flexible floor coverings has been criticized because the mounting of the test specimen in the ceiling of the tunnel presents operaitonal problems and does not represent the normal use configuration for such materials.

The Radiant Panel Test has been used extensively for the evaluation of the flammability properties of rigid materials, where limited correlation with the tunnel test has been established.[15] The test shows good ability to differentiate among flexible floor covering materials, but no correlation with other test methods or real life hazards has been established.

The Chamber Test, developed recently by Underwriters' Laboratories with support by the U.S. Public Health Service, is intuitively attractive since the sample is placed in a normal position on the floor of the chamber. However, no information on reproducibility between laboratories has been published and the relationships of the flame propagation index defined by the test to real life hazard has not been established.

This report describes the results of an interlaboratory evaluation program on the chamber test, together with a limited comparison of these results with the results of other test methods and a discussion of the suitability of the test methods for the characterization of hazards from floor coverings in building fires.

II. INTERLABORATORY EVALUATION OF THE FLOOR COVERING CHAMBER TEST METHOD

Interlaboratory comparison tests are indispensable in evaluating a test method to insure (a) that the description of the test procedure is clear and complete and (b) that the procedure gives results which are acceptable in terms of resolution (between materials), reproducibility (between laboratories) and repeatability (within laboratories). Such tests will not show whether the test is applicable in predicting real fire behavior.

The chamber test has been described by Underwriters' Laboratories [4]. Detailed drawings of the test apparatus have been made available [5], and a standard test procedure has been published [6].

Laboratories

Four chambers are known to be in operation at the present time. All were used in the present study. The participating laboratories were:

Hercules, Inc.; Research Triangle Park, North Carolina
Southwest Research Institute; San Antonio, Texas
Underwriter's Laboratories; Northbrook, Illinois
Wisconsin Research Institute; Janesville, Wisconsin.

Test Materials

Samples of carpets representative of types enjoying a significant portion of the market were submitted to NBS by the Carpet and Rug Institute (CRI). These were subjected to the pill and radiant panel tests and to physical and chemical examination. Three styles, which gave a good spread of performance in the radiant panel tests, were selected by NBS for the test program. Rolls of carpet were shipped directly from the mills to NBS. A rubberized 1/2 inch hair felt pad was also supplied by CRI.

Since the purpose of the program was to evaluate the test method rather than to evaluate carpets, no detailed

descriptions of the carpets are included in this report. The samples are designated as follows:

A. Woven, level loop commercial carpet, woven jute and cotton backing, 1/4 inch pile, pile weight 38 oz/yd^2, total weight 81 oz/yd^2.

B. Tufted, level loop commercial carpet, non-woven polypropylene backing, 1/8 inch pile, pile weight 20 oz/yd^2, 1/8 inch foam rubber attached pad, total weight 86 oz/yd^2.

C. Tufted, high-low loop residential carpet, woven polypropylene/jute backing, 1/16 inch and 5/16 inch pile, pile weight 32 oz/yd^2, total weight 63 oz/yd^2.

U. 1/2 inch rubberized hair felt pad, 56 oz/yd^2.

Carpets A and C were tested with and without the hair felt pad, making a total of five different assemblies. Each assembly was tested in quadruplicate by each laboratory.

All test specimens of a given style were cut from a single roll of carpet. The long dimension of the sample was cut parallel to that of the full roll. Specimen selection for each laboratory from within a roll was randomized and specimen location within the roll was recorded. The testing sequence for the twenty assemblies supplied to each laboratory was also randomized. This arrangement was selected to permit statistical estimates of within-laboratory repeatability and between-laboratory reproducibility with a reasonably small number of tests.

Test Procedures

All laboratories were asked to follow the procedures described by Underwriters' Laboratories "Standard Method of Test for Flame-Propagation Classification of Flooring and Floor Covering Materials," Subject 992, dated February 1971 [6]. The following modifications were requested by NBS.

a. Use of a more recent standard temperature curve furnished by Underwriters' Laboratories for calibration purposes [16].

b. Use of the equivalent of 0.50 ft^3/min. of methane or natural gas, corrected to a heating value of 1000 BTU/ft^3.

c) Use of a hot-wire anemometer for the measurement of air flow. Laboratory 3 used a vane type anemometer while the other laboratories used a hot wire type.

Instructions, data sheets and test specimens were shipped to the participants on May 17, 1970. All test results, including photographs of the burned specimens, were returned to NBS by June 25, 1971.

Experimental Results

The results of all test are summarized in Table 1. One of the purposes of the interlaboratory evaluation of the test method was to determine the degree of uncertainty of the resulting data. Table 2 summarizes the results in terms of the coefficient of variation of within-laboratory (repeatability) and between-laboratories (reproducibility) data.

Since the relatively large values of the flame spread index for materials A+U and C+U reported by Laboratory 3 would distort the results if combined with data from the other laboratories, the analysis was divided into two parts. The first excluded all data from Laboratory 3, while the other excluded all data on systems A+U and C+U. The results of the two analyses are similar.

The coefficient of variation of repeatability within a laboratory ranged between 7 and 20 percent. This may be due to specimen variability as well as to small variations in operating conditions from run to run. Material B with integral foam backing and material C+U gave the largest variation. Similar results in repeatability have been reported by the Wisconsin Research Institute [7, 8]. In these cases eight specimens were cut from each of two different carpets, four parallel to the roll direction and four in the transverse direction. Two samples were burned in each of the four principal directions. The indices reported, 2.63 ± 0.51, and 2.64 ± 0.14, gave coefficients of variation of 19.4 and 5.3 percent, in general agreement with the results of the present tests.

The coefficient of variation of reproducibility between laboratories ranged from 10 to 32 percent. Again, materials B and C+U gave the highest variation. Because of this relatively large variability and the small differences in flame propagation index among the materials used, the method could barely distinguish between two groups of materials; A, B, and C versus A+U and C+U. The test does not allow differentiation between the materials within the A, B, and C or A+U and C+U groups.

The materials selected for use in this interlaboratory program were chosen on the basis of radiant panel tests at NBS (Table 3) and preliminary chamber data supplied by Laboratory 3. It was expected that they would cover a wide range of values for the flame propagation index. Unfortunately, the results reported by the other laboratories failed to confirm the high indices. Because of the small number of laboratories and the limited number and flammability range of materials involved, the statistical results should be interpreted with some caution.

The cause of the discrepancies in results between Laboratory 3 and the other laboratories is not known. Variations in airflow and ignition source are possible factors.* Flame propagation rates (3 runs) for material A+U from Laboratories 3 and 4 are shown in Figure 1. Data from Laboratories 1 and 2 are in good agreement with that from Laboratory 4. At the early stages of burning, there is no noticeable difference among the four laboratories. Only after six or seven minutes do the curves for Laboratory 3 start to diverge from the others. All runs from Laboratory 3 resulted in full length burns whereas those from Laboratory 4 stopped at between 30 and 34 inches.

Calibration temperature curves obtained by all laboratories immediately before (p) and after (a) the test series are shown in Figure 2. Only Laboratory 1 appears to deviate significantly from the standard curve. Laboratories 2 and 4 show slightly higher temperatures, on the average, than Laboratory 3. Further evidence of satisfactory chamber temperature control is shown in Figure 3 where standard deviation for 10 runs at

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*Note added in proof:
Subsequent experiments carried out by Laboratory 3 support this explanation. Single experiments at an air flow velocity of 125 ft/min (standard velocity 100 ft/min) resulted in flame propagation indexes of 2.66 and 3.0 for carpets A+U and C+U respectively, in reasonable agreement with results reported by the other laboratories under standard conditions (Table 1). Since Laboratory 3 used a vane type anemometer and the other laboratories used hot wire anemometers, it is possible that differences in the air velocity measurement methods may have caused the discrepancies in results. These results indicate, for these carpet assemblies at least, that the flammability index is very sensitive to air velocity.

Laboratories 3 and 4 are plotted. Test results from Laboratory 1 were consistently low for all materials, suggesting that chamber temperature was a factor in this case.

The reproducibility and repeatability in this series of tests indicate the need for further standardization of equipment and operating procedure among laboratories. The variability among laboratories is graphically illustrated in Figure 4, which shows typical photographs of burned specimens of material C (left) and C+U (right) from Laboratories 1, 4 and 3 (top to bottom, respectively). Photographs of other burned specimens indicate that the burn pattern for each material is generally reproducible within a laboratory.

Discussion of the Floor Covering Chamber Test Method

Flame propagation indices of carpet systmes, as determined by the chamber test, fall largely into two groups; indices of less than four for carpets which are non-progagating within the chamber, and indices greater than 16 for carpets which burn the full length of the chamber. Very few systems have indices which fall between these limits. This bimodal distribution has been noted by Johnston [9] and others. Data on a sizeable number of tests performed since this original observation was made do not change the distribution pattern significantly. This discontinuity in the rating scale appears to be due, in part, to the method of calculating the index and, in part, to peculiarities of the test.

The flame propagation index, as defined by Underwriters' Laboratories, has the dimensions of length divided by time and thus represents a rate. The units are inches per minute. It would be satisfying to look upon the index as a measure of the average flame propagation rate, but an examination of the method of defining the index shows the inconsistency of this position. Three different formulas are used to calculate the index, depending on the rate and extent of burning of the carpet [6]:

A. For materials where the total distance of flame travel during the 24 minutes test period is less than 96 inches:

$$I = \frac{D}{T} = \frac{d+s}{T} = \frac{D}{12}$$

where

d = distance of flame travel in inches during the 12 minute flame "on" period.

s = additional distance of flame travel during the 12 minute flame "off" period.

T = 12 minutes.

This gives values of the index of less than 8. Since most carpets which are self extinguishing in the chamber burn less than 48 inches, most carpets in this group have indices less than 4. Very few carpets show significant flame propagation during the flame "off" period, so in most cases the index is equal to the average flame propagation rate during the 12 minute flame "on" period.

B_1. For materials where the flame travels the full 96 inch length of the chamber during the flame "on" period:

$$I = \frac{L}{T} + \frac{d}{t_1}$$

where

L = test specimen length, 96 inches.

t_1 = time in which the flame travels the length of the test chamber.

Then

$$I = \frac{96}{12} + \frac{96}{t_1} = 8 + \frac{96}{t_1} .$$

The second term is the average flame propagation rate. The quantity 8 has been added arbitrarily to the index as a penalty for propagation over the full length of the chamber. Materials in this group will have flame propagation indexes greater than 16.

B_2. For materials which do not burn the full length of the chamber during the flame "on" period, but continue to burn and reach the end of the chamber during the flame "off" period:

$$I = \frac{L}{T} + \frac{d}{t_2}$$

where

t_2 = 12 minutes, the flame "on" time.

Then

$$I = 8 + \frac{d}{12}$$

Again, the second term represents the average propagation rate during the flame "on" period and the quantity 8 is added arbitrarily. Index values will range between 8 and 16. Since, in general, d will be large for carpets which burn the length of the chamber, index values are concentrated in the upper part of the range.

Underwriters' Laboratories classifies floor coverings into groups based on three index ranges [4]:

1. Calculated Index 0<4.0
2. Calculated Index $\geq$4.0<8.0
3. Calculated Index $\geq$8.0<25.0

A more logical classification, based on their method of calculating the index, would be:

Group	Index Range	Distribution
A	$0<I<8.0$	60
B_2	$8.0\leq I<16.0$	4
B_1	$I\geq 16$	38

The distribution of 102 test results reported in reference [4], based on this method of classification, is summarized above.

The discontinuity in the index calculation is most readily seen by considering a chamber of indefinite length. Then a carpet which burned a total distance of 95 inches during the flame "on" period (Group A) would have an index of 7.9 while one which burned a total distance of 97 inches (Group B_1) would have an index of 16.1.

Use of the simple formula

$$I = d/t$$

for all tests provides a continuous rating scale. In effect, this method of index calculation takes an 8 unit "tuck' in the middle of the unused portion of the proposed rating scale. This formula ignores completely the effect of afterburning. Let us examine the consequences of this omission.

Of the 102 tests reported in reference [4], involving 35 styles of carpeting and 7 pile fibers, only six showed significant afterburning. These six tests involved 3 styles of nylon carpet. Additional tests performed since that time confirm the low incidence of afterburning.

We may also question the significance of afterburning as it relates to hazard. Carpet fires in buildings, involving carpets which pass the pill test, will be initiated by sizeable ignition sources from the burning of other, more combustible fuels. It is difficult to conceive of a real fire situation where this energy source would be cut off suddenly, leaving the carpet to burn by itself without support from other fuels as occurs in the chamber test. The consistency and significance of the test would be improved by eliminating the flame "off" period and calculating the index by the simple formula given above.

Even with the adoption of a continuous rating scale, the distribution of indices would remain strongly bimodal. The reason for this must be sought in the physical mechanisms controlling carpet performance in the chamber.

The carpet is ignited near one end of the chamber by direct impingement of the ignition flame on the pile surface. Flame spread outside the area of impingement depends on forward energy transfer from the advancing flame front, reinforced by convective and radiative energy fluxes from the chamber environment. If the total energy flux ahead of the flame front is less than some critical value needed to sustain combustion the flame propagation rate

will decrease, the energy release rate will fall, and the flame front will decay, leading to extinction within the chamber. If the total energy flux exceeds the critical value, the rate of energy release will increase, the flame front will accelerate, and the carpet will burn to the end of the chamber. These two modes of behavior are well illustrated by the flame spread curves shown in Figure 1 and in reference [4]. It is apparent that steady flame propagation will not occur in the chamber. Carpets will be divided into two groups, and the chamber resembles a large scale pill test. Conditions are somewhat more severe than in the pill test (with the exception of the moisture content of the carpet) because of radiative and convective energy feedback in the chamber, so it is to be expected that some carpets which "pass" the pill test will "fail" the chamber test.

It is to be expected that this critical energy balance in the chamber will be affected by minor variations in test configuration and operating parameters. This is illustrated by the data in Table 1 on carpets with separate pads. Here the chamber of Laboratory 3 produced an accelerated burning mode while the other three chambers showed a decaying mode, despite the fact that all four laboratories were nominally operating under the same conditions. Laboratory 3 even reported three accelerating burns and one decaying burn for material C+U (Table 1).*

The effect of pad and floor properties on the energy balance is easily interpreted. Good thermal contact between carpet and floor will increase the energy drain from the heated carpet surface, reducing the energy available to support combustion. This is illustrated by tests 43, 44, and 49 of reference [4] where adhering the carpet to the asbestos cement board floor with a refractory cement decreased the index from 16.2 to 1.7. An insulating pad will conserve heat in the carpet, promoting combustion and increasing the index, as shown by numerous examples.

The moisture content of the carpet will also affect the heat balance. Because of the high heat of vaporization of water, this can represent a significant heat sink, reducing the energy available to support combustion. More reproducible conditioning of test specimens than is provided for in the present test procedure should be required.

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*See footnote, Page 6.

Other parameters which can be expected to influence the heat balance in the chamber are air velocity and distribution, shape and intensity of the ignition source, chamber dimensions, and thermal diffusivity and emissivity of the chamber walls.

Some of these parameters have been investigated in an industrial laboratory using a simulated chamber which permitted variations in test configuration [10]. While the data are not strictly comparable with data obtained in the chamber, they are included here to indicate the effect of variations in operating parameters on test results that can be observed in this type of test. The results are reported in terms of the average burning rate (d/t). Use of the Underwriters' Index would accentuate the variation in results.

Figure 5 shows the effect of air velocity on the burning rate of a particular carpet. In this case the index at the standard air velocity of 100 ft/min is well below the critical region where transition to accelerated burning takes place (d/t = 8) so minor fluctuations in air velocity would not be expected to have a large effect on the results.* Figure 6 shows the effect of ignition source intensity for the same carpet. Here the standard ignition source of 500 Btu/min is precisely in the critical region and a small decrease in intensity could be expected to cause a transition from an accelerating to a decaying combustion mode. The effects of variation in chamber width and height for the same carpet are shown in Figure 7. It appears that the apparent performance of a carpet can be affected strongly by the arbitrarily chosen dimensions of the test chamber.

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*Note added in proof:
The direction of the effect is opposite to that reported by Laboratory 3 (footnote P. 6). A possible explanation is the following: For carpets which are non-propagating in the chamber, burning is largely due to impingement of the ignition flame on the pile surface. Increased air velocity will deflect the flame further down the chamber, lengthening the distance burned and increasing the flame propagation index. For carpets which propagate the length of the chamber (and pass the pill test), convective and radiative flux to the carpet surface must supply the additional energy needed to sustain propagation. An increased air flow will cool the chamber, reducing the energy flux and decreasing the flame propagation index.

III. COMPARISON WITH RESULTS OF OTHER TEST METHODS

Laboratory Tests

The carpet assemblies used in the chamber experiments were subjected to the pill and radiant panel tests. In addition, carpet A was tested in the Steiner Tunnel (ASTM E-84) at Underwriters' Laboratories. The results are summarized in Table 3.

The pill test was carried out on the front and back faces of the carpet, as recommended by the Carpet and Rug Institute. All carpets passed the test in both modes. The hair felt pad failed the test, but its presence had no significant effect on the results when carpet and pad assemblies were tested on the pile face.

In contrast to the chamber test method, the radiant panel test (ASTM E-162) showed significant differences in the flammability behavior of the three carpets (Table 3). The rank order differed from that of the chamber test, but in the latter test the differences were not statistically significant. The addition of a pad, on the other hand, had a minor effect on the results of the radiant panel test in contrast to the chamber test results. When carpet A was cemented to the asbestos board backing with a refractory cement in the same manner as used in the tunnel test, the index was reduced to 57.

A single run in the Steiner Tunnel gave a flame spread rating of 40 for carpet A, in reasonable agreement with the radiant panel test when the sample was mounted in similar fashion using a refractory cement. This can be compared to the value of 145 obtained with the radiant panel when the carpet was wired to the support. Red oak, with a flame spread rate arbitrarily set at 100, is used as a standard for E-84. When tested by E-162, the flame spread of red oak is within the range 80-120. Additional studies of the tunnel test are planned for the next phase of the NBS program.

Full Scale Corridor Experiments

In order to obtain a better insight into the behavior of carpets under conditions simulating a real building fire, full scale experiments are being carried out in a corridor test facility at NBS. This consists of a 30 ft. x 8 ft. x 8 ft. corridor with an 8 ft. x 8 ft. fire room opening into the side near one end. The side walls of the

corridor are of gypsum board and the floor is masonry. Air flow in the corridor can be controlled by a fan and damper system. The corridor is instrumented at numerous points for the measurement of temperature, heat flux, radiation, air flow and smoke density. Fires are initiated by burning wood cribs in the fire room. The fuel loading is approximately 3 lb/ft^2 and the maximum fuel consumption rate corresponds to an energy output of approximately 80,000 Btu/min. Two small openings in the fire room wall admit air and create a natural draft into the corridor in the absence of any forced convection.

All carpet experiments to date have used carpet A with the hair felt pad. In preliminary experiments, small pieces of carpet on the floor under a combustible ceiling were observed to smoke and then burst into flame without direct contact with a flaming ignition source.

A series of experiments was carried out, varying the floor and ceiling materials and the air flow in the corridor. The results are summarized in Table 4. Motion pictures were made of all experiments. A detailed analysis will be published in a future report.

In experiment 330, with combustible floor and ceiling, the room fire caused ignition in the corridor, first on the ceiling and followed almost immediately by ignition of the carpet. The fire spread rapidly and reached the end of the 30 ft corridor in approximately one minute. Flames approximately 18 inches high were observed to "roll" down the surface of the carpet. Dense black smoke was generated by the carpet fire. The fire was extinguished shortly after it reached the end of the corridor. The carpet fire was confined almost completely to the surface pile. A short distance from the fire room door the carpet backing was not discolored and the combustible pad was entirely unaffected. If the fire had been allowed to continue the backing and pad would undoubtedly have become involved, but the fire was judged to have developed highly lethal conditions at the time when it was extinguished.

Experiment 332 duplicated the condition of 330 except that the brick floor was left bare. Ignition of the ceiling was much slower, the fire was less violent, and the smoke density was much lower.

In Experiment 333 a painted gypsum board ceiling was used. The principal source of fuel in the corridor was the carpet and pad. Ignition was slower than in 330, but

vigorous flaming developed on the carpet surface and spread the length of the corridor. Dense smoke was generated and conditions were judged to be highly hazardous.

In these three experiments the only air flow in the corridor was due to the natural draft through the small openings into the fire room and out the partially open end of the corridor. In experiment 334 the configuration of 330 was repeated but a forced air flow of approximately 85 ft/min from the fire room end was imposed on the natural draft in the corridor. Ignition was greatly delayed, presumably because of increased heat loss from the corridor, but when ignition occurred the fire was the most violent and fast spreading of the series. The carpet backing was discolored, indicating a deeper involvement of the carpet. Presumably the longer ignition delay allowed a deeper penetration of the thermal wave into the carpet and ceiling material, resulting in more rapid combustion once ignition conditions were reached. Radiation fluxes in the range of 2 to 4 watts/cm^2 were measured at the carpet surface ahead of the advancing flame front.*

Somewhat similar corridor experiments have been performed at the Illinois Institute of Technology Research Institute under sponsorship of the Carpet and Rug Institute [11, 12]. While details of these experiments have not been released, preliminary and partial information indicates significant differences in test conditions and performance.

The ignition source in these experiments was a gas diffusion flame with an output of 125,000 Btu/min. in a fire room opening onto the side of the closed end of the corridor. This source provided a "square wave" energy

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*Note added in proof:
Two additional experiments, completed after the report was written, duplicated the conditions of experiments 330 and 333 except that carpet A was used without a pad. With a non-combustible ceiling the carpet ignited and burned a distance of about 15 ft down the corridor. Beyond that point the pile surface was discolored but there was very little loss in weight. With a combustible ceiling, ignition was delayed (5.5 min. vs. 2.5 min. in experiment 330) but the carpet burned the length of the corridor with a travel time similar to that observed with a pad.

input, in contrast to the gradual buildup characteristic of the wood crib ignition source used at NBS. No air supply for the gas burner is provided other than air drawn in from the corridor. The air flows in the open end of the corridor, down the length of the corridor along the floor, and into the fire room. Hot combustion products flow out in the opposite direction along the ceiling. Thus a current of cool air, filling the lower half of the corridor, is drawn over the surface of the carpet in a direction opposite to the direction of fire spread.

Ten experiments were conducted using six different carpet styles with and without pads. No instance of fire spread over the entire 24 foot carpeted section of the corridor was observed during the 20 minute test period. Burn distances ranged from 6.5 ft to 13.5 ft. While none of the carpets or pads used in the IITRI tests was identical with the one used at NBS, one IITRI assembly corresponds closely in general description. While details of the IITRI experiments are lacking and much further work on the variables of corridor fire behavior is planned at NBS, the differences in ventilation and corridor construction appear at this time to offer the most probably explanation for the differences observed in the two series of experiments.

IV. FIRE HAZARDS OF CARPETS IN BUILDING FIRES

Much of the difficulty in relating test results to real-fire hazards rests in the variability of building fires. Obviously, no two real fires are alike. At one extreme, a small fire may not spread beyond the room of origin and poses no threat to occupants in other parts of the building. At the other extreme, a general conflagration may generate lethal conditions throughout the building, and the contribution of the floor covering becomes a minor factor. At an intermediate level, however, there are indications that the floor covering may play a major role in the development of hazardous conditions. It provides a pathway for fire spread, contributes fuel to fire development, and generates large quantities of lethal smoke and gas. A number of recent building fires appear to fall in this category.

A test method for use in establishing a safety standard must provide an accurate measure of the potential hazard the standard is designed to control. First, it must provide assurance that the desired degree of protection has in fact been achieved; and second, it should not

place unnecessary restrictions on the use of materials which may be attractive for economic or aesthetic reasons. A method which provides a continuous scale of hazard potential may be preferable to a go/no-go test since it permits setting different levels of protection for different situations.

Smoke and Toxic Gas

Smoke and toxic gas have been identified as major sources of hazard in building fires. Of the test methods discussed in this report, only the tunnel test pretends to provide a measure of smoke development. An integrated value of light absorption in the exit stack over the duration of the experiment is used to compare materials. Since the quantity of smoke is a non-linear function of the light absorption, such comparisons are obviously inaccurate.

The NBS smoke density chamber [13] determines the optical density of the smoke, a more quantitative measure of smoke at least at moderate optical densities, but correlation between the behavior of the small laboratory samples and materials in full scale fires has not been established. Plans have been made to include smoke measurement equipment in the stack of the floor covering chamber furnace. An integrated value of optical density obtained from such a system could provide a useful means of comparing materials. However, the quantity of smoke measured should be related to the quantity of material burned in the test. Correlation with real fire behavior would still have to be established.

Significance of the Methenamine Pill Test

The pill test provides a measure of the ease of ignition of a carpet by a small ignition source and of the self-propagating properties of the resulting flame front. Almost no radiant or convective energy feedback occurs from the walls or combustion gases; the energy necessary to sustain the combustion after the pill has burned out must come directly from the advancing flame front. When this energy flux is less than the critical flux required to support combustion, burning ceases and the sample passes the test.

When a carpet is exposed to a larger ignition source in a building fire, energy input to the carpet ahead of the flame front raises its temperature and reduces the amount of energy which must be provided by the flame front to sustain combustion. This effect has been demonstrated

in the laboratory where a carpet which passed the standard pill test failed when the test was performed under an infrared lamp. Radiation appears to be the principal means of energy transfer ahead of the flame. Convection of cool gases over the floor may actually cause a heat loss from the carpet surface, as suggested by the IITRI corridor experiments.

Since the time of exposure to the burning pill is short, of the order of one to two minutes, the thermal wave does not penetrate deeply into the carpet and heat loss through the base of the carpet is small. Consequently, the presence or absence of a pad usually has little effect on the results. In a few cases, particularly when the carpet melts and allows the burning pill to penetrate the back of the carpet, failures have been observed on a textured pad but not on smooth, dense surfaces.

The chamber test appears to provide a radiation exposure intermediate between that of the pill test and the NBS corridor experiments. Because of the longer exposure time in the chamber test, heat loss through the base of the carpet becomes more significant and the presence and properties of the pad can have a significant effect on results. Underwriters' Laboratories has demonstrated the effect of changes in the emissivity or reflectivity of the chamber wall and ceiling on the flame propagation index [4]. Further studies of the thermophysical properties of floor covering systems and their effect on combustion properties are planned as part of the present program.

The corridor experiments and other observations suggest that rapid fire spread over the pile surface of the carpet occurs first in a building fire, followed at a later stage by involvement of the backing and pad. The attached pad has been cited as a major factor in the Harmar House fire, and there is no question but that it contributed substantially to smoke formation and the intensity of the fire. It is probable, however, that the initial rapid fire spread occurred over the pile surface. This view is supported by the reports of eye witnesses who described a sheet of flame moving down the corridor floor [14]. If this description of the fire spread mechanism is correct, application of the pill test to the back side of the carpet can have little relevance to the assessment of hazard potential.

A suitable test method for the evaluation of the hazard potential of floor covering systems in building fires must model the environment to which the floor covering is exposed in real fires. The characterization of such environments is a major objective of the corridor experiment program now underway at NBS.

V. CONCLUSIONS

Based on the information available at the present time, the following conclusions can be drawn:

For the Chamber Test

1. The Floor Covering Chamber Test (UL Subject 992), at its present state of development, does not show satisfactory reproducibility between laboratories in the range of materials examined by the present interlaboratory comparison program.

2. The test separates floor covering systems into two groups; those which are non-propagating within the chamber and have flame propagation indices less than 8, and those which burn the full length of the chamber with indices greater than 16. Very few systems fall between these limits.

3. The test did not differentiate among the different materials within the above groups which were used in the present study.

4. The test is sensitive to the presence of a pad. If it is to be used for evaluating carpets, the test should be performed on the complete floor covering system.

5. The test results appear to be quite sensitive to such parameters as chamber dimensions, air velocity, and ignition intensity.

6. Further development and standardization of the chamber test may provide a useful tool for characterizing the flammability properties of floor coverings.

In General

1. The chamber test flame propagation index shows a qualitative correlation with the methenamine pill test.

2. Corridor experiments performed at NBS and at IITRI show differences in carpet flammability behavior that may be due to differences in test conditions in the two sets of experiments.

3. Preliminary corridor fire experiments suggest that fire spread over the pile surface of the carpet, intensified by energy flux to the surface from other sources, is a principal factor in the development of hazardous conditions.

4. Application of the pill test to the back side of the carpet is not an appropriate measure of hazard potential in building fires.

5. None of the test methods discussed in this report have been shown, at the present time, to provide a reliable measure of the hazard contribution of floor coverings in building fires.

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13. "A Method for Measuring Smoke from Burning Materials," D. Gross, J. J. Loftus and A. F. Robertson, ASTM Special Technical Publication 422, 1967.

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Table 1

FLAME PROPAGATION INDEX OF CARPETS BY LABORATORIES*

Laboratories	Carpet System A		Carpet System B		Carpet System C		Carpet System A + U		Carpet System C + U	
# 4	0.75		1.25		1.33		2.75		2.66	
	1.0		1.25		1.17		2.75		2.75	
	1.0		1.25		1.25		2.83		2.42	
	0.85		.66		1.17		2.33		2.25	
		0.90		1.10		1.23		2.67		2.52
		0.12		0.30		0.08		0.23		0.23
# 1	0.83		0.58		0.92		2.16		1.66	
	0.75		1.17		1.00		2.92		1.75	
	0.83		1.08		1.08		2.16		1.58	
	0.75		.92		1.08		2.58		1.75	
		0.79		0.94		1.02		2.46		1.69
		0.05		0.26		0.08		0.37		0.08
# 3	0.92		1.58		1.25		17.07		21.08	
	0.75		1.66		1.25		10.92		19.88	
	0.92		1.83		1.25		11.50		20.53	
	1.08		1.33		1.33		13.33		3.66	
		0.92		1.60		1.27		13.21		16.29
		0.13		0.21		0.04		2.77		8.43
#2	1.08		1.50		1.17		2.83		2.67	
	.83		1.67		1.33		2.83		2.83	
	1.17		1.50		1.17		2.50		2.16	
	1.0		1.67		1.08		2.67		4.00	
		1.02		1.59		1.19		2.71		2.92
		.14		.10		.10		.16		.78

* Values placed to the right of the column are means of 4 runs and their standard deviation.

Table 2

Summary of Statistical Analysis

	3 Labs. and 5 materials					4 labs. and 3 materials		
Materials	A	B	C	A+U	C+U	A	B	C
Mean (flame prop. index)	0.9	1.2	1.1	2.6	2.3	0.9	1.3	1.2
Coefficient of Variation, ±%								
Within Lab. * (repeatibility)	12	19	8	10	20	13	17	7
Between labs. ** (reproducibility)	17	32	12	10	32	15	30	11

* Between single determinations in a single laboratory

** Between single determinations in different laboratories

Table 3

Results of Pill, Radiant Panel, Chamber and Tunnel Tests

Tests	Carpet System					
	A	B	C	A+U	C+U	U
Pill[a]	P	P	P	P	P	F
Tunnel	40					
Radiant Panel[b]						
Wired to support	145 ± 13	284 ± 48	404 ± 16	150 ± 10	445 ± 92	
Cemented to support	59 ± 11					
Chamber[c]						
Lab 1	0.79	0.94	1.02	2.46	1.69	
2	1.02	1.59	1.19	2.71	2.92	
3	0.92	1.60	1.27	13.31	16.29	
4	0.90	1.10	1.23	2.67	2.52	
Mean & Std. Dev.	0.91 ± 0.11	1.31 ± 0.22	1.18 ± 0.07	2.61 ± 0.25[d]	2.37 ± 0.36[d]	

a - Tested on both sides except A+U and C+U. P = passed, F = failed.
b - Radiant Panel - Means and standard deviation based on 5 tests except carpet C, with only 3 tests.
c - Chamber Data - Average of 4 tests per laboratory.
d - Laboratories 1, 2, and 4 only included in averages.

Table 4

Summary of Corridor Experiments

Experiment Number	Floor	Ceiling	Forced Air Velocity ft/min	Corridor Ignition time min	Corridor Travel time min
330	A+U carpet	Particle Board	0	2.5	1.0
332	brick	Particle Board	0	9.3	
333	A+U carpet	Gypsum	0	7.8	4.0
334	A+U carpet	Particle Board	85	9.5	0.5

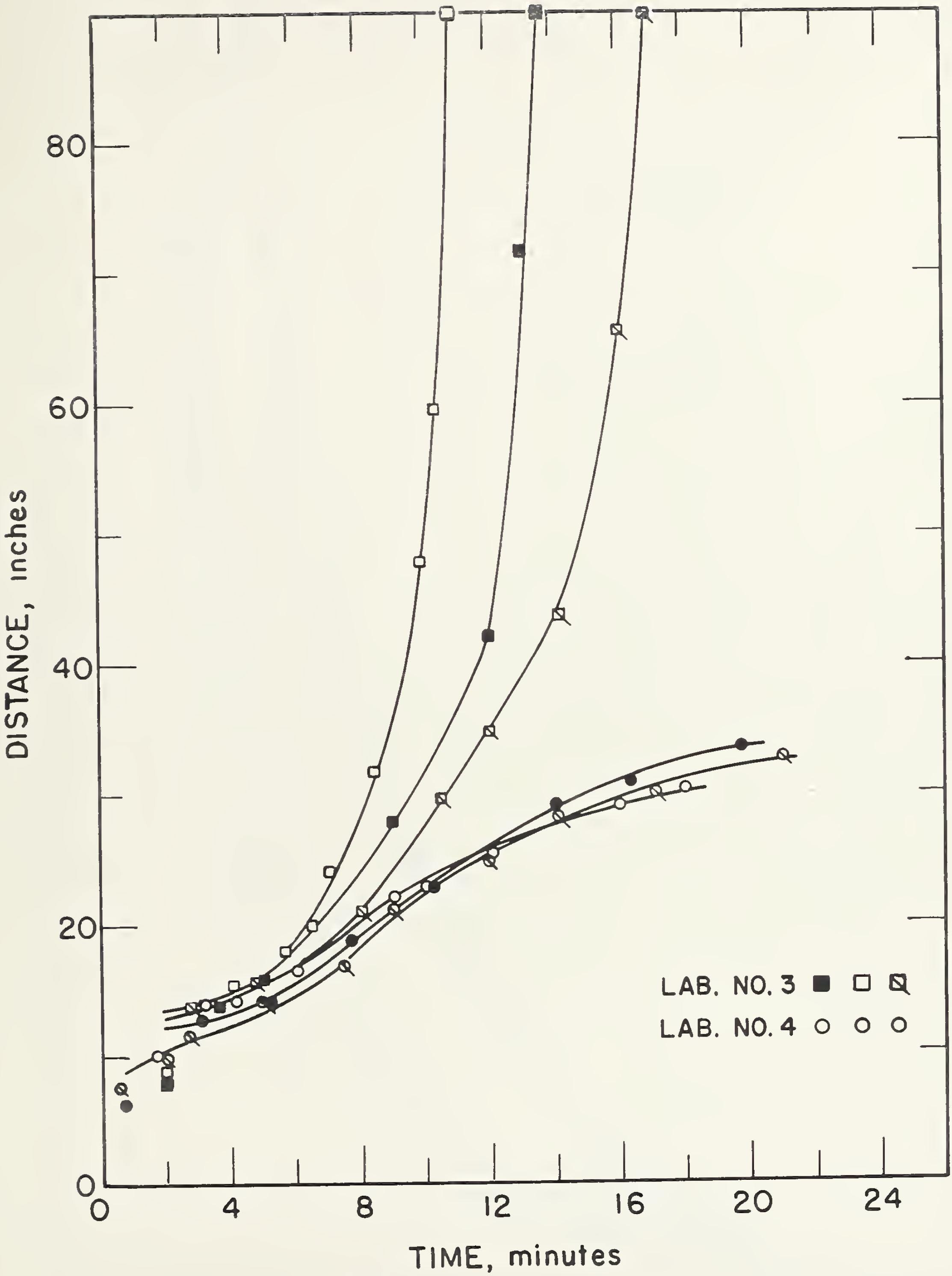

Figure 1 Flame propagation Rates for Material A+U, Laboratories 3 and 4.

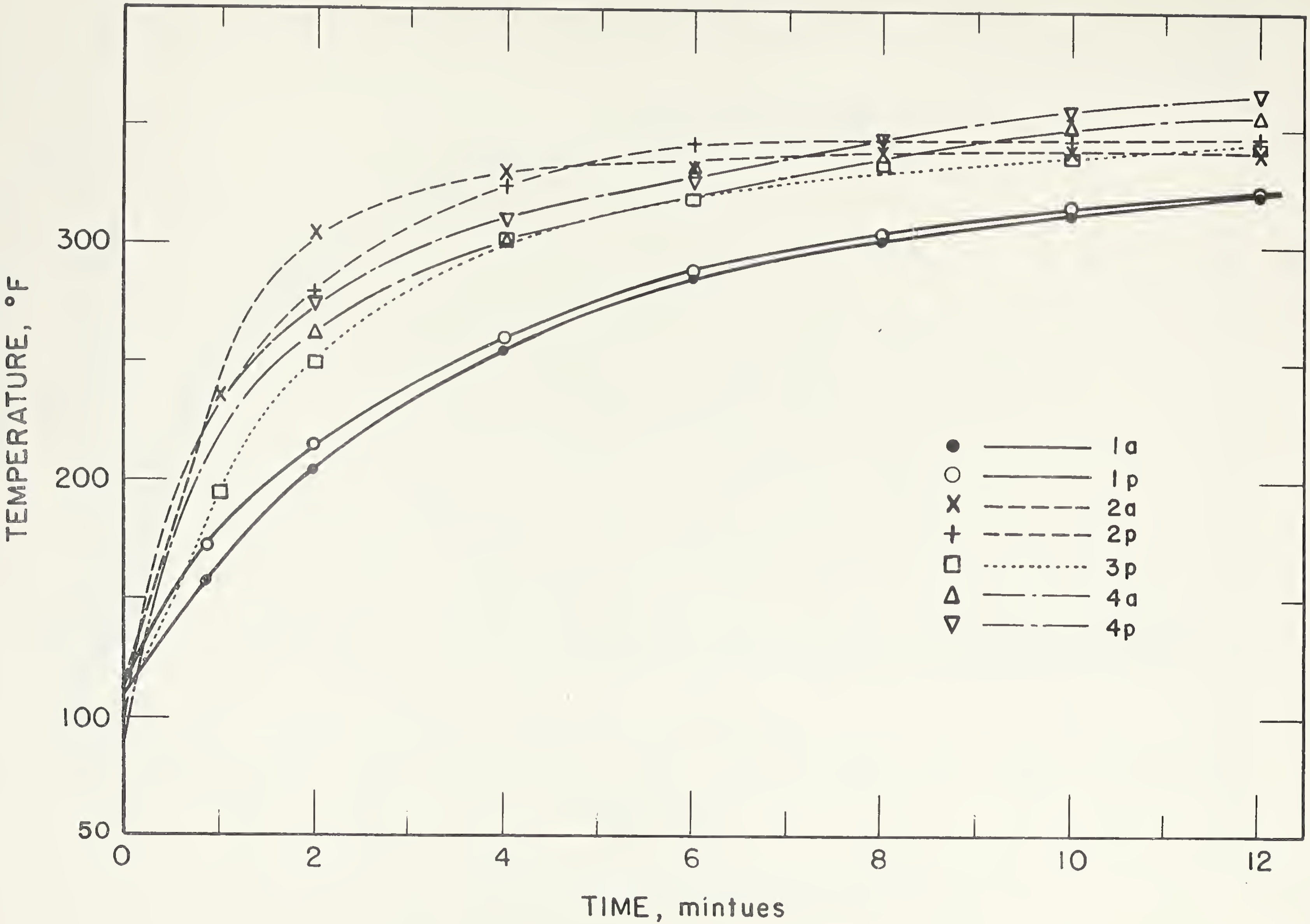

Figure 2 Chamber Calibration Curves of Laboratories

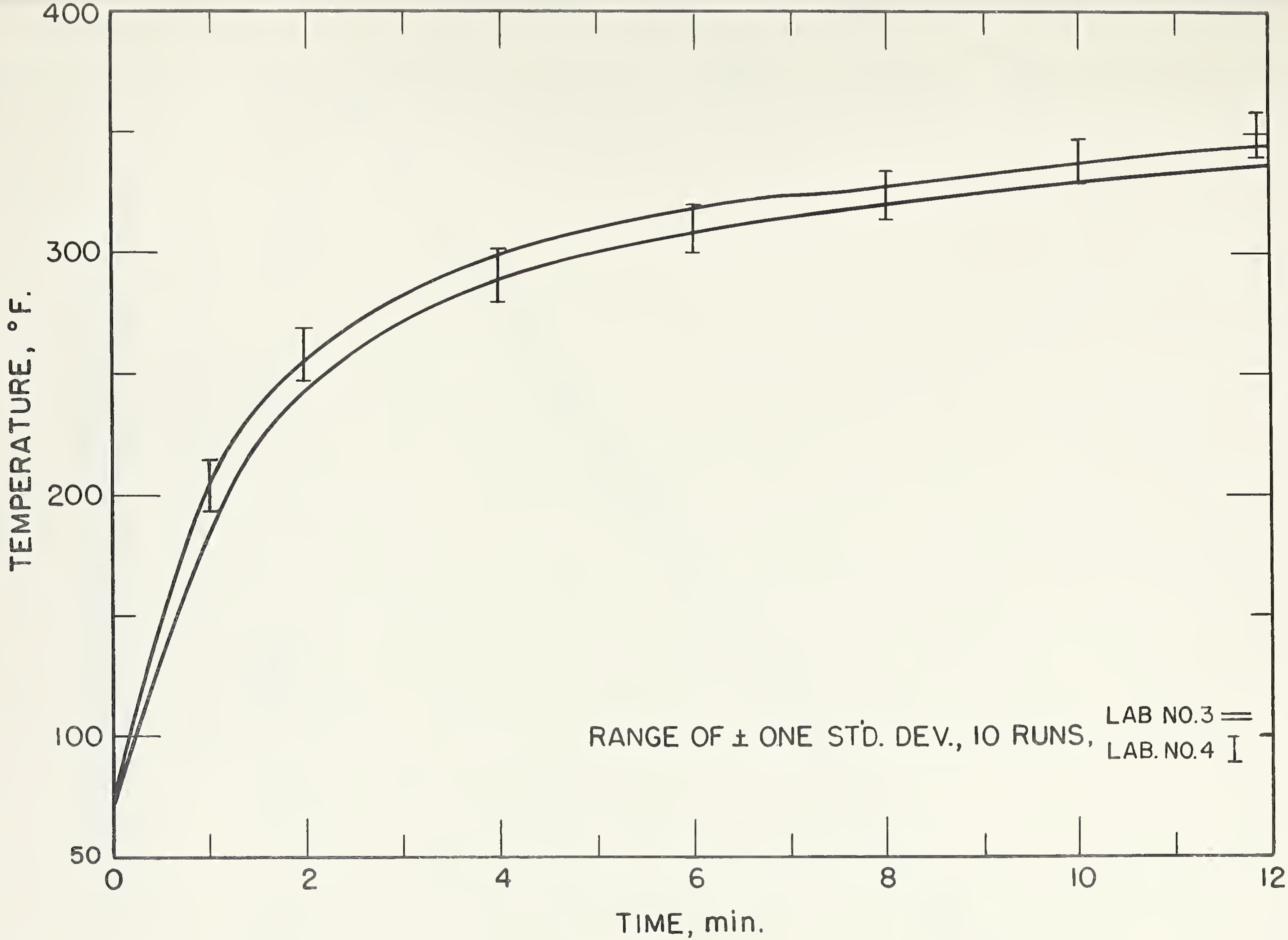

Figure 3 Chamber Calibrations, Laboratories 3 and 4.

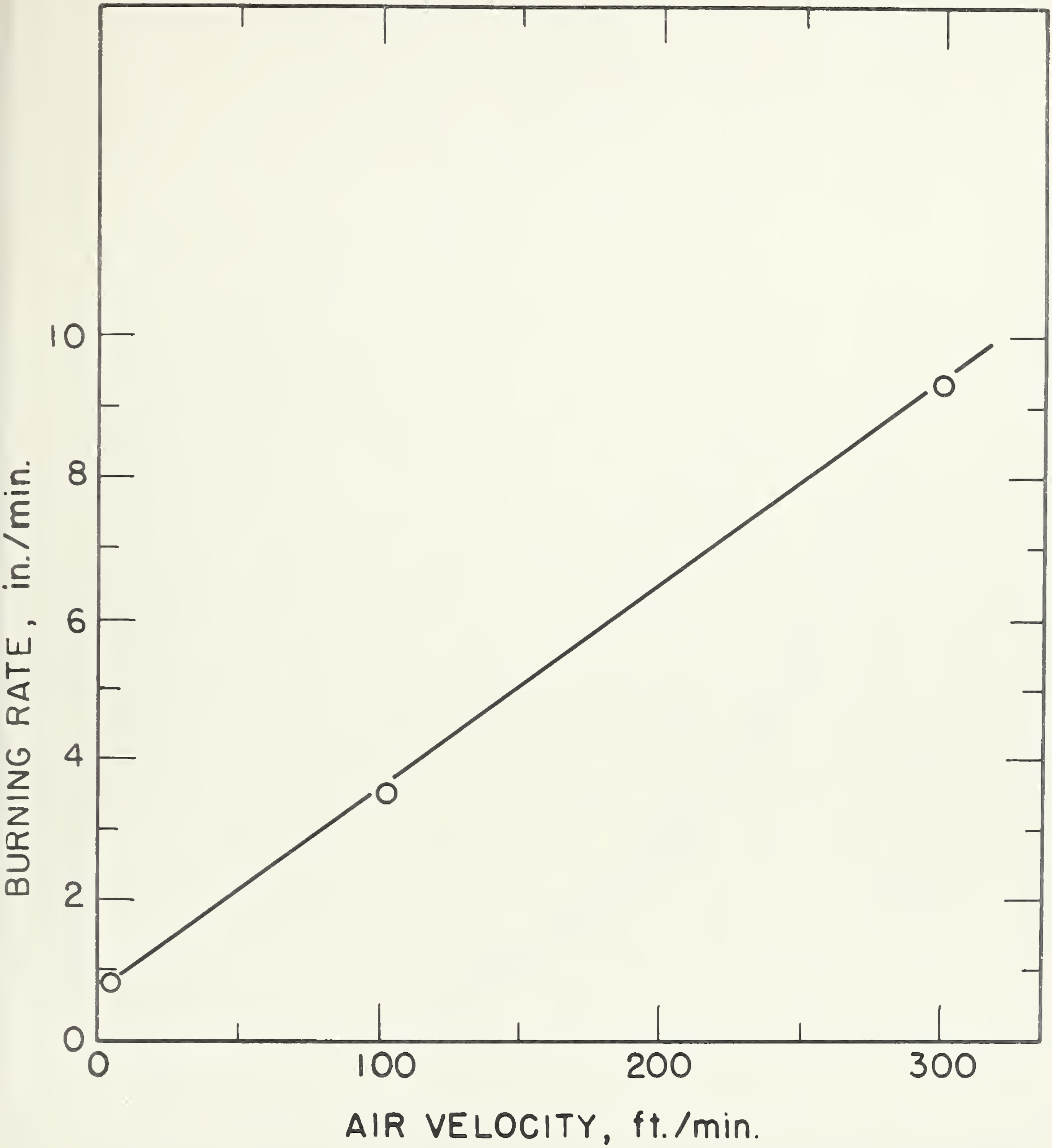

Figure 5 Effect of Air Velocity on Burning Rate of Simulated Chamber Test Data from Man Made Fiber Producers Association [10].

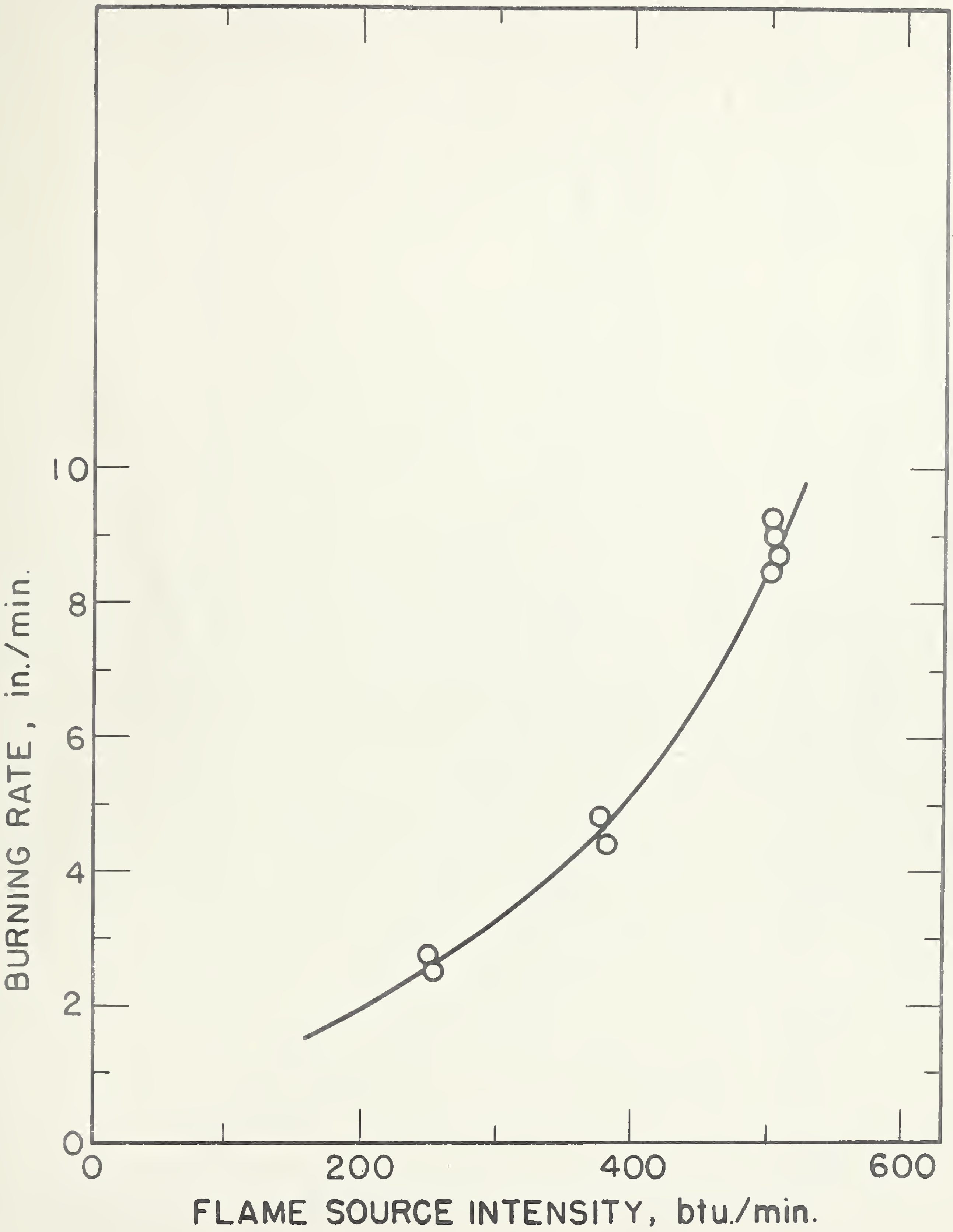

Figure 6 Effect of Flame Source Intensity on Burning Rate of Simulated Chamber Test Data from Man Made Fiber Producers Association [10].

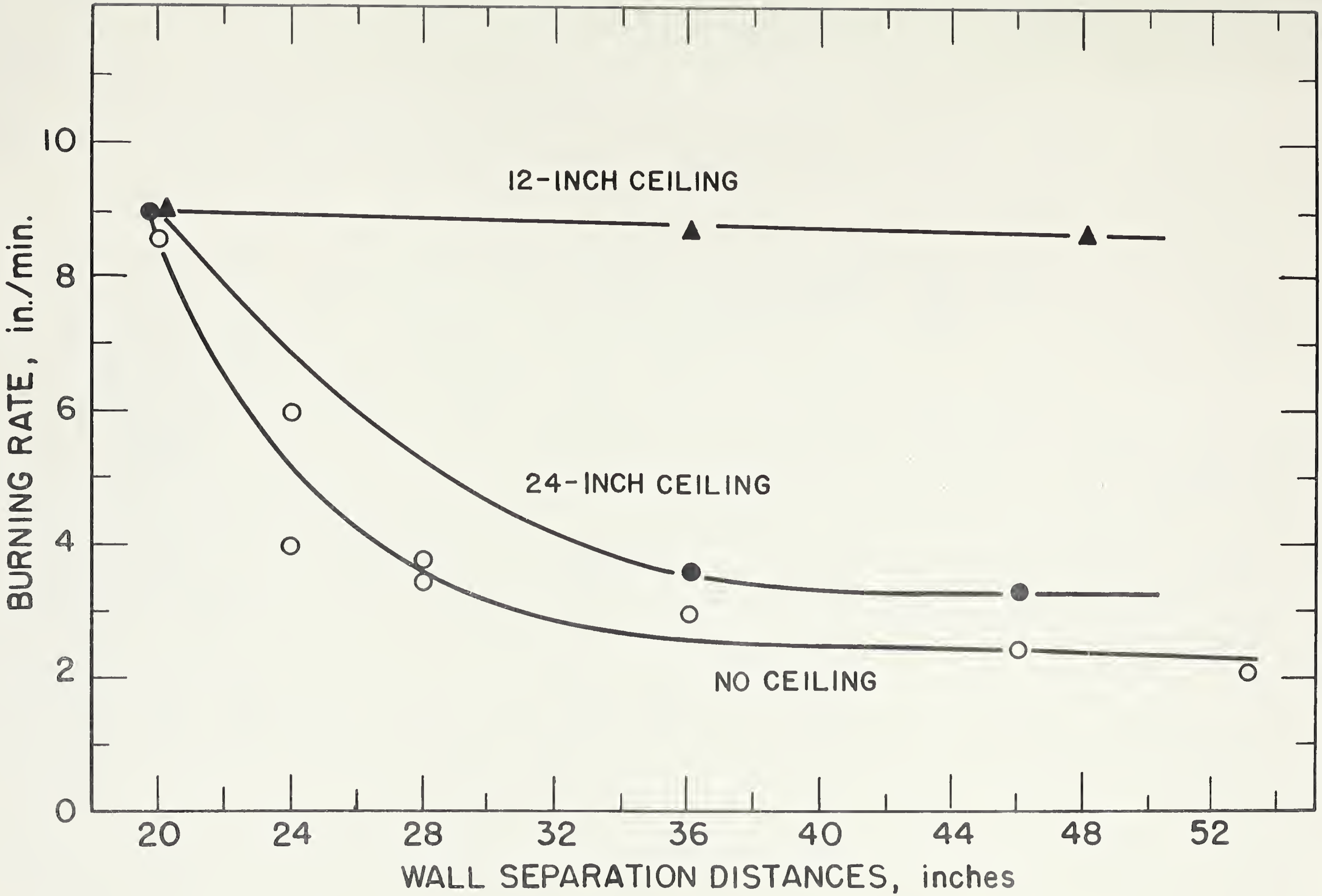

Figure 7 Effect of Ceiling Height and Wall Separation of Chamber on Burning Rate Data from Man Made Fiber Producers Association [10].

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