NBSIR 81-2400

sis of Data From Room Fire Test of Parsons Tables and Comparison With Laboratory Test Methods for Flame Spread and Smoke Generation, Volume I

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Fire Research
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November 1981

Final Report

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BUREAU OF STANDARDS

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ANALYSIS OF DATA FROM ROOM FIRE TEST OF PARSONS TABLES AND COMPARISON WITH LABORATORY TEST METHODS FOR FLAME SPREAD AND SMOKE GENERATION, VOLUME I

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

PREFACE

This report deals with the analysis of data from 18 room fire tests conducted by L. H. Breden at the National Bureau of Standards. The report is presented in two volumes:

Volume 1 - contains the text of the report.

Volume 2 - reproduced only in microfiche format, contains the data listings corresponding to appendixes A, B, and C in volume 1.

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ANALYSIS OF DATA FROM ROOM FIRE TEST OF PARSONS TABLES AND COMPARISON WITH LABORATORY TEST METHODS FOR FLAME SPREAD AND SMOKE GENERATION

David D. Evans

Abstract

Data from a series of 18 room fire tests in which a Parsons table was the only combustible item were analyzed. Selected data from the tests were compared to laboratory fire test data from the ASTM E162 surface flammability test, and a modified smoke density test.

The flame spread index from the ASTM E162 test was not shown to be an dependable indicator of either the time for table fire involvement or room fire intensity. Results from the National Bureau of Standards smoke chamber using an MOD (mass optical density) method for data reduction were able to predict the smoke production rate and total smoke production from the table fires to within 34 percent and in several cases within 5 percent.

Key Words: ASTM E162; fire tests; flame spread; tables; plastics; smoke chamber.

1. INTRODUCTION

1.1 Furnishings Program

Fire codes and standards traditionally have dealt with selected fire performance requirements of construction and interior finish (ceiling, wall and floor covering) materials used in buildings. The use of these codes has resulted in buildings that can in most circumstances be expected to maintain their physical integrity when threatened by fire. Being confident that a building structure will survive an accidental fire, additional attention in recent years has been paid to the unique fire characteristics of the interior furnishings contained in the building. Usually it is the interior furnishings and not the construction materials that are the major contributors to the fire load for a building compartment. At present only two items of furnishings are required to comply with federal fire performance standards; carpets[1] and mattresses[2]. A proposed standard is also being considered for upholstered furniture[3]. However, these deal with ease of ignition of these materials when exposed to a small source of flame or heat and not with the contribution of the item to fire growth within a compartment.

One of the objectives of the Furnishings Flammability Program is the development of methods to assess the relative level of fire risk introduced by the use of different furnishings in a given situation. This is attempted by concurrently studying the behavior of furnishing materials (a) in small scale fire performance tests and (b) in a large room fire testing facility under simulated end use conditions. Usually, materials under study are subjected to a number of standard small scale fire performance tests. In addition, comparative data are also obtained using non-standard fire testing procedures undergoing development at National Bureau of Standards (NBS). Our goal is to develop means to predict the performance of products such as furnishings when involved in typical fire situations.

The room fires used to evaluate the performance of furnishings can have various degrees of sophistication. Room tests may range from an evaluation of a single isolated item of furnishing in a compartment, to a fully furnished compartment simulating an occupied space. For the

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[1] FF-1-70 and FF-2-70

[2] FF-4-70

[3] PFF-6-76

case of a single item test, the burning of an individual type of furnishing, e.g., a chair, table, or carpet, under the influence of the enclosure would be made. Since this test involves only one combustible furnishing, there is no opportunity to observe fire spread or interaction between different items of furnishings in the compartment. This lack of interaction makes the data from single item tests easier to analyze for comparison between different furnishings designs or materials of construction than test results from a more fully furnished compartment test, although this arrangement may not be typical or fully realistic. The fully furnished room burns are a primary source of data for fire growth and spread under conditions that reflect common usage of a particular set of furnishings, but do not permit analysis of the separate contributions of the contents.

1.2 Source of the Data

This report deals with the analysis of data obtained in a series of ventilated room burns of small utility tables constructed from different materials. These tests were conducted in the winter of 1974-75 by L. H. Breden in the then newly constructed room burn facility in Building 205 on the NBS Gaithersburg site. The raw test data from all of the tests were reduced to conventional units and tabular form in mid-1975 using a program written by J. Smith for use on the NBS Univac 1108*. This set of reduced data was placed on computer cards in Speed II format [1][4] for storage.

The analysis of the data from this set of room burns is based on the analysis of the data stored on the computer cards. These data were retrived from storage and dumped onto a hard disk compatible with the Interdata 732* system used in the Center for Fire Research (CFR) in

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*The identification of commercial products is made in order to specify adequately the experimental procedure, and does not imply recommendation or endorsement by the National Bureau of Standards.

[4] Numbers in brackets refer to the references listed in Section 6.

December 1977. Using this mini-computer system, the data files were edited to eliminate spurious values and to correct several data channels for sign errors. This report is the result of a detailed analysis of the edited data files integrated with test time measurements made by the author while reviewing video tape replays of most of the tests in the series.

1.3 Choice of Parsons Tables for Testing

The primary objective of the room fire tests conducted by L. Breden in 1974-75 was to obtain comparative fire performance data on several plastic and wood materials commonly used in furnishings. As comparative information about materials was the primary objective, single item room fire tests of a piece of furnishings constructed entirely from a single material were considered the best procedure to follow in order to produce useful data.

At the time the tests were performed, small plastic utility tables, commercially sold under the name Parsons tables and available in several types (see figure 1) were popular casual furnishings. These simply designed tables were in most cases fabricated from a single material. Through commercial purchases and contracted fabrications, a variety of these tables made from different plastic and wood-base materials were obtained for testing (see table 1). Thus, these tables were ideally suited for furnishing fire tests to compare different materials.

1.4 Description of Data Analysis

For each of the tables burned in the room burn facility, an attempt was made to obtain 117 separate channels of data to help assess the major fire characteristics. These data channels sampled the output of strategically located probes measuring gas temperature, surface temperature, mass loss gas velocity, gas composition, smoke density, heat flux, and radiation flux in the test facility at 20 second intervals. Using these data, a fairly complete characterization of each room fire could be made.

It has become common practice to obtain relative rankings among materials burned in enclosures based on the time a given event occurs following ignition. Generally these critical events are identified with the generation of untenable conditions within the enclosure. The earlier in the test untenable conditions are generated, the greater the presumed risk associated with the material. Tenability criteria for heat flux, gas temperature, smoke density, and carbon monoxide, carbon dioxide, and oxygen concentrations are discussed in detail by Budnick [2] and O'Neill [3].

Another approach taken in assigning relative risk ratings to test data is to neglect time altogether and only to consider the intensity of the fire. In this case, peak values of given measurements are used to rank materials and the greater the peak value the greater the assumed risk. For example, one may choose as the critical measurement, highest average ceiling temperatures, highest average gas temperatures in the upper half of the room, or highest heat flux to the floor.

In this report assessments of relative risk among the materials from the room test data will be given in terms of both integrating information throughout the fire and comparison of specific events during each fire. In some cases, this integration will be formal summing of measured values throughout the test. In others, substantial deviations over an extended period of time will be considered. To determine if substantial deviation exists among test measurements, an effort was made to determine measures of the repeatability of selected bench and full scale room measurements.

Relative risk ratings for materials or groupings of materials, in cases where a substantial difference is not established, are compared with ranking for the same materials from existing small scale fire tests. Of particular interest is the comparison of laboratory smoke chamber data for the Parsons table materials to the values of total smoke production calculated by integration of light attenuation by the combustion products leaving the room doorway.

In the analysis of the test data, only key data channels were utilized. The fire performance of each Parsons table could be characterized sufficiently by using several gas and enclosure temperature measurements along with table weight loss, doorway gas velocity, and doorway light obscuration measurements. A complete energy and mass balance for the room that might be of some academic interest and would involve the use of data from most of the sensors was not attempted. The primary benefit of such a calculation would be a check for consistency in the data set. Little would be added to the evaluation of the relative risk among the set of materials tested as a result of such a calculation. In addition, Tu and Babrauskas [4] in their work with steady gas fires in the same burn room facility have found that the instrumentation, especially in the room doorway, is too limited to yield accurate energy and mass balances.

2. ROOM FIRE TESTS

2.1 Facilities

2.1.1 Burn Room

The construction of a large room-corridor fire testing facility was completed in the summer of 1974. This facility occupies a major portion of building 205 on the NBS Gaithersburg, Maryland, site. The test data on which this report is based, were obtained from the first series of room fire tests performed in this facility. Therefore, secondary to obtaining room fire test data on the Parsons tables, this series of tests served as shake down trials for the facility itself.

Building 205, containing the room-corridor fire test facility is a large building constructed with two different ceiling heights 7.93 m (26 ft) and 10.97 m (36 ft). The general plan view of the 57 m (187 ft) by 26.6 m (87 ft) building is shown in figure 2. As noted in the figure, the building is equipped with a large exhaust hood through which combustion products generated in the room-corridor complex can be vented. An afterburner system is provided to clean these exhaust gases to reduce smoke and pollutants in the flow before it leaves the building. The air needed for combustion during room fires enters the building through open doorways and is drawn into the burn-rooms by natural convection. The exhaust hood at the end of the corridor carries combustion products away at a low velocity to reduce its effect on room fire air circulation. Air conditioning in building 205 maintains a nominal pretest average ambient temperature of 23°C with a relative humidity of 40 percent.

2.1.2 Fire Test Rooms

The rooms off the corridor used for full-scale burns may be considered representative of bedrooms or small living rooms. The corridor and room complex is shown in figure 3. Isolated views of two adjacent rooms used in the fire test of Parsons tables are shown in figures 4 and 5. The length of the room in which the tables were burned, farthest from the exhaust hood, was 3.50 m (11.5 ft). The smaller adjacent room was 3.05 m (10 ft) long and joined the corridor which measured 6.10 m (20 ft) in length. The width of both rooms was 3.4 m (11.2 ft) and the corridor was 2.44 m (8 ft) wide. All three had the same ceiling height of 2.44 m (8 ft). The two inline doorways measured 2.13 m (7 ft) high by 0.91 m (3 ft) wide.

The burn rooms were constructed with a 0.13 m thick concrete slab floor. Walls and ceilings were constructed of 16 mm type X gypsum wallboard applied on steel studs. All the interior surfaces of the rooms, including the floors were lined with 13 mm low density (928 kg/m^3) cement-asbestos board. The seams in the cement-asbestos boards were off-set slightly from the seams of the gypsum board beneath it in order to minimize air leakage through the structure. All joints, both gypsum and cement-asbestos, were spackled.

2.2 Instrumentation

The room-corridor test facility was instrumented with 88 thermocouples, 6 bidirectional velocity probes, one pitot-static tube, 7 light transmittance meters, 4 radiometers, 4 total heat flux meters, 6 gas sampling ports (2 each of CO_2, CO, and O_2), and a load cell. Test data were recorded by a digital data acquisition system at a rate of one scan of all instruments every 20 seconds. The locations of all measurement points are given in table 2. The locations of key sensors utilized in the data analysis are shown in figures 4 and 5. In addition to the standard measurement equipment listed above, several tests were recorded in color on video tape and 16 mm motion picture film. In conjunction with the combustion gas analysis, the reactions of live rats caged in the room adjacent to the burn room containing the fire were recorded. HCN measurements were attempted using a bubbler system sampling gases near the caged rats.

Most of the thermocouples used in the test facility were 18 gauge metallic-sheathed mineral insulated Chromel-Alumel (Type K). Thermocouples identified in table 2 as "quick response" used smaller diameter wire.

Radiometers and total heat flux meters were commercial Gardon-foil type water cooled units.

The six bidirectional velocity probes located in the doorway to measure gas inflow and outflow velocities were modeled after those developed by Heskestad [5]. These robust velocity probes are particularly good for obtaining low-velocity flow measurements under fire conditions which can involve water condensation, soot particulates, and flow reversals. McCaffrey and Heskestad [6] have provided calibration techniques for these probes. The probes used in the room-corridor facility were 12.7 mm in diameter.

Construction details for the light transmittance meters used to measure smoke obscuration in the doorway are shown schematically in figure 6. Each of the four horizontally placed tubes, measured light transmittance over a 1 m path length using an ordinary tungsten filament bulb as a light source and silicon photodiode as a detector. The spectral response of the detector is shown in figure 6. Each light transmittance meter was calibrated as follows:

1. A dark current voltage reading was obtained with the photodiode covered. This reading corresponded to zero percent light transmittance.

2. The photodiode was uncovered and the light source adjusted so that the photodiode output did not exceed its linear range. This voltage reading corresponded to 100 percent transmittance.

3. Filters of known optical density were placed between the light source and the photodiode and the output voltages recorded. These values were then used to cross check the linearity of the photodiode outputs.

Gas analysis for CO and CO_2 was performed with non-dispersive infrared instruments. A polarographic analyzer was used for O_2. Calibration curves were prepared for the CO and CO_2 instrument to correct the non-linear output using known gas samples. Traps were inserted in the sampling lines to protect the analyzers. As the sample was drawn from the room it traveled through stainless steel tubing and entered a glass wool trap at ambient temperature to remove the majority of the particulate matter. Stainless steel tubing connected this trap to two others; the first, a dry ice trap packed with glass wool to eliminate water, and the second, glass wool filter at ambient temperature to insure a clean flow into the analyzers. Copper or polyethylene tubing connected the last trap to the analyzer. The output of each analyzer was connected directly to the data acquisition system.

Analysis for HCN in the combustion gases was performed with a bubbler system. Two bubblers were used in series each containing 200 ml of 0.1 N NaOH. The flow rate through the bubblers averaged 2 liters/min. Analysis of the NaOH solution was done using both specific ion electrodes and the calorimetric technique according to Leithe. The stainless steel sample lines were kept as short as possible to minimize the absorption of HCN on the walls of the tubing or the collection of particulate matter.

Parsons table weight loss measurements were made using a platform suspended from a load cell located above the ceiling of the burn room. Three locations were used for the load cell platform corresponding to the three table fire positions - center of the room, along the east wall, and southeast corner. Water cooling and insulation were used to protect the load cell from the heat produced during the table tests. The load cell used had a range of 45.4 kg. The weight of the platform, zeroed out during the tests, was approximately 11.4 kg.

This series of tests were the first at NBS to employ the video tape recording system as a method of recording test events. This system was used in addition to the still and motion picture records normally produced. These video recordings proved to be an invaluable aid in the data reduction process. A summary of times for key events occurring during the table burns given in table 3 was prepared by viewing the video tape records.

2.3 Animal Exposure

To aid in the assessment of the toxicological hazard associated with the combustion products from the table fires, several tests were run in which rats caged in the room adjacent to the room fire were exposed to the combustion products. These were the first tests run at NBS in which animals were used for toxicological measurements of combustion products from a room fire. The detailed test description and data analysis associated with this phase of the Parsons tables tests is being prepared by Birky et al [7] under the Center for Fire Research, Program for Toxicology of Combustion Products.

Briefly, to assess the toxicological hazard of the combustion product, male rats were placed in a partitioned metal cage located 1.8 m from the burn room door and 1.5 m above the floor. A thermocouple was placed in front of the cage to monitor the temperature of the gases flowing from the burn room and through the cage. Continuous gas composition measurements were also made on gas drawn from the 1.5 m level near the cage. An effort was made to measure CO_2, O_2, CO, and HCN. These measurements were to be related to the physiology of the rats. For example, in the report in preparation by Birky [7], carbon monoxide and oxygen measurements in the combustion products are correlated to carboxyhemoglobin and oxyhemoglobin measurements from the caged rats.

2.4 Parsons Tables

The Parsons tables used in this series of fire tests were typically 0.4 x 0.4 x 0.4 m in dimensions, although some variation in overall size and construction was found. Figure 1 shows photographs of four different Parsons tables. At the top, photograph A shows the most common plastic construction, while B shows the alternate tube construction. Photographs C and D show examples of the heavier wood Parsons table construction. A detailed listing down of table weights and measurements is given in table 4.

For this series of tests, the table could be located in one of three locations within the burn room; in the center, along the east wall, or in the southeast corner. With each change in position, the load cell and platform used to obtain table weights during the fire would be moved. Table 1 gives a list of the table locations within the room for each of the 18 tests. Additional information on table material and construction is also given in this table.

2.5 General Test Observations

The development of the fires involving the plastic Parsons tables were all similar. Based on the video tape records of the tests, several common key events could be identified. These major events were: establishment of sustained ignition, first dripping of flaming melt, establishment of major melting and flaming, table falling against screen surrounding the platform, and total table collapse. Figure 7 shows several still photographs of the fire growth during a Parsons table test. Table 3 records the test times for each of five key test events. These times were assigned based on the judgement of the author in viewing video tape recorded during some of the tests.

The ignition source used in all tests was 15 milliliters of heptane placed in a 51 mm diameter aluminum pan. The center of the pan was placed under one edge of the table top, usually adjoining the table leg. The effect of the burning heptane on the test measurements was minimal.

After the burning heptane established a sustained ignition on the edge of the plastic test table, melting plastic from the table top would drip into the small pan used to hold the igniting fluid. This plastic melt would burn, maintaining a flame in the pan even after the heptane was consumed. As fire spread on the table top, additional burning melt would drip onto the platform. A major fire would be established by the burning of the table structure and the pool of melted plastic on the platform below it. As the fire progressed the table would usually fall over against the retaining screen that surrounded the platform. Eventually the entire structure would be reduced to a pool of flaming melt on the floor of the platform. Many of these stages of burn can be seen clearly in the photographs in figure 7. The time from ignition to table collape was approximately 300 s (5 min).

3. SMALL SCALE TESTS

As the major objective of this series of tests was to compare full scale fire performance of materials used in furnishings with results of small laboratory fire tests, each table material was evaluated by several small material fire tests popular at the time. L. Breden and D. Schmulling supplied data from the following: a modified smoke density chamber test (now ASTM E662/NFPA 258), and ASTM E162 test for surface flammability.

3.1 Smoke Test Measurements

The smoke density chamber test was used to evaluate the smoke production characteristics of each Parsons table material under flaming conditions. The test procedure used was that developed by Breden and Meisters [8]. In this procedure, a 76 mm x 76 mm specimen cut from the top of a Parsons table was supported horizontally in the 0.51 m^3 closed smoke chamber. The face of the specimen was exposed to a radiant heat flux of 25 kW/m^2 and ignited by a pilot flame. Continuous measurements of light obscuration over a 0.91 m vertical path and sample weight loss were made during the test.

The test data was reduced to the form of a time dependent mass optical density number (MOD) proposed by Seader [9] and defined as:

$$MOD\ (t) = \frac{V}{L\Delta m}\ \mathrm{Log}_{10}\ \frac{100}{T} \qquad (1)$$

where:

MOD (t) = Mass Optical Density at time t, $\frac{m^2}{kg}$

V = Chamber volume (0.51 m^3)

L = Light beam length through smoke (0.91 m)

Δm = Sample mass loss up to time t (kg)

T = % light transmittance at time t

t = time

The sample mass and light transmittance vary during a test making the values of Δm and T in equation 1 time dependent. The sample mass decreases as the sample burns producing smoke and other products of combustion. As smoke is produced and collected in the closed smoke chamber, the amount of transmitted light from the bottom to the top of the chamber decreases. After the initial transient period of the test, during which the sample ignites and the smoke produced begins to circulate through the chamber, the value of the MOD stabilizes at a plateau value. At the end of the test as the sample is consumed and smoke particles coagulate and are lost to the chamber walls, the MOD value decreases. Plateau values are indicated on the MOD curves for acrylic, polypropylene, ABS and polystyrene shown in figures 8, 9, 10 and 11 respectively.

When the Parsons table materials were tested in the smoke chamber by Breden, only the plateau values of MOD were recorded. Operationally, he established the plateau value of MOD for each material by calculating the MOD values at a 15 second interval during the smoke chamber test. The recurrence of four or five successive nearly equal MOD values established the plateau values for the material. Breden's average plateau values of MOD for five Parsons tables materials tested in the smoke chamber are recorded in table 5.

Fortunately, three excess Parsons tables, purchased with the initial lot used in the full scale tests were recovered from storage by the author. Recovery of these tables allowed a retesting of polypropylene, arcylic, and ABS materials in the smoke chamber to verify Breden's measurements. With the retesting a complete set of light obscuration and sample mass loss values as a function of time were obtained. With these data an alternate method for calculating MOD numbers from that recommended by Breden and Meisters [8] was examined.

With the retesting of materials it became obvious that Breden had used smaller specimens rather than the prescribed .076 m x .076 m specimens cut from the top of the Parsons table since the full size ABS and polypropylene samples generated enough smoke to overrange the light transmittance meter before the samples were consumed. Overranging the light transmittance meter while testing produces erroneous MOD values.

Seeing these results, a modest effort was made to determine the effect of sample size on the MOD vs time curve. One sample each of 0.005 m thick polypropylene in 0.013 m, 0.025 m, 0.05 m, 0.075 m square samples were tested in the smoke chamber tests. The results of these tests are shown in figure 12. The highest value of MOD were achieved with the 0.025 m square sample. This test also produced a reasonably stable plateau region. One could speculate that the relatively greater amounts of smoke produced by the larger samples produces higher smoke densities in the smoke chamber leading to a greater influence of coagulation and wall loss on the results. With the small .013 m square samples test inaccuracies would probably produce a large scatter in results. In addition, the burning time for this sample is shorter than the larger samples possibly because of greater edge effects and a plateau value of MOD is not achieved before the sample is consumed. At this time, no basic research has been published to determine how coagulation of smoke, wall losses, mixing, and recirculation through the hot zone in the smoke chamber affects the smoke chamber measurements. Obviously, sample size may have an important influence on smoke chamber measurements. Investigation of these effects are beyond the scope of this report. Further testing was performed on .025 m square samples of polypropylene, polystyrene, and ABS, and .05 m square samples of acrylic. These test results are shown in figures 8-11.

Using the raw data that was used to calculate the MOD vs time curve for the .025 m square sample of polypropylene shown in figure 12, an alternate method of MOD determination will be described. Figure 13 shows the optical density and sample mass curves from that test. Two additional broken lines in the figure indicate the rate of change of samples mass and optical density. A MOD value may be calculated using these changes by taking the ratio of the rate of change of optical density to the negative of the rate of change in sample mass and multiply the ratio by the smoke chamber constant 0.5574 m^2. For this method to produce a meaningful MOD value the slope should be measured over an interval during the test where both the optical density and sample mass curves are undergoing constant rates of change. It is unknown at this time what the shortest sustained interval for constant rates of change should be to produce useful results. The question has also been raised as to whether the lag time between smoke production by the sample and measurement in the smoke chamber light beam has an important effect on the MOD calculated by this method. For this calculation, the rate of change in mass loss for the center of the time interval in which the optical density curve was undergoing a constant rate of change was used to calculate the MOD. As recorded in figure 13 the MOD value calculated from the slopes of the curves was 396 m^2/kg; this is in good agreement with the 390 m^2/kg plateau value for the 0.025 m square sample recorded in figure 12.

Operationally, the method developed by Breden and Meisters [8] for calculating MOD values is preferred to the alternate ratio of slopes method. This is due largely to the fact that more judgement is required in drawing the slope that is required during the data analysis in the latter method, as compared to the selection of plateau region using the raw data.

In the discussions to follow, MOD values will refer to those calculated by the Breden and Meisters method unless indicated otherwise.

Table 6 shows a comparison of Breden's MOD values for the Parsons table materials with those obtained by the recent retesting. Agreement between test results for ABS and polypropylene is good. The recent measurements on acrylic results in a somewhat lower MOD value than measured by Breden. Even though the polystyrene foam could not be retested, the good correspondence for the other sets of data increases one's confidence in Breden's measurements for this material.

As will be discussed later, good agreement was found between MOD values for materials from Breden's work with the smoke chamber and values calculated from table fire data. The retesting described above was an effort to verify all parts of the test results associated with the set of encouraging smoke calculations which show a correspondence between small and large scale test results.

3.2 Surface Flammability ASTM E162

D. Schmulling supplied test data from the ASTM E162 test for most of the Parsons table materials. This test is used to characterize the surface flammability of materials [10]. Briefly, this test employs a 0.3 m x 0.45 m gas fired radiant panel in front of which an inclined 0.15 m x 0.45 m specimen of material is ignited on the top forward edge. Measurements of the flame spread rate down the sample and the air temperature rise in the exhaust duct above the sample are made. The results of the test are reported in the form of a flame spread index which combines the flame spread rate and a hot gas temperature rise measurement[5]. The test results for the flame spread index, and its components, the flame spread factor, and heat evolution factor are given in tables 7, 8, and 9 respectively.

Each table is divided into two parts: part a, lists the test data and part b, divides the materials into groups that are significantly different at the 95 percent confidence level as determined by the least significant difference method [11]. The groups are in order of fire risk based on this test. Within each grouping there is no statistically significant difference between the materials test performance at the 95 percent confidence level.

Based on the normal test result, the flame spread index (I_s), among the plastics, polystyrene is identified as a significantly better performer than the group, polypropylene, ABS, and acrylic (see table

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[5] $I_s = F_s \cdot Q$. See reference 10.

7b). Both of the wood materials were significantly better performers than the plastic materials. As the flame spread index is calculated from the product of two factors, it is instructive to look at the ranking of materials based on each factor separately.

The flame spread factor (F_s) from table 8b, ranks all the materials except polypropylene the same. Probably the ease with which the polypropylene melts, contributed to its significantly faster flame spread rate down the face of the sample. Looking at the heat evolution factors (Q) from table 9b, the easily melted materials, polypropylene and polystyrene, were ranked significantly lower than the ABS and acrylic materials. This result would be explained by a relatively larger amount of the polypropylene and polystyrene (compared to acrylic and ABS) that may have dripped from the holder to the floor and not become involved by flame or contributed to the exhaust air temperature rise.

Obviously the commonly used flame spread index (I_s) result from this surface flammability test is an integration of a material's performance in the test. This makes it difficult in some cases to determine if a material's index value is primarily influenced by flame spread or by heat release rate. In all cases it is difficult to determine what effects sample distortions, such as melting and dripping, might produce.

4. COMPARISON OF ROOM FIRE AND SMALL SCALE TEST RESULTS

The test results from two small scale laboratory flammability tests: the ASTM E162 test for surface flammability, and the ASTM E662 smoke density chamber modified to determine the MOD of horizontal specimens were discussed in the previous section. A comparison between these tests and the room fire data will be made to judge the usefulness of each test in assessing the expected fire performance of a material when used in a common furnishing item. The nature of the materials tested and the accumulated experimental data only permitted a weak evaluation of the surface flammability test. Although also troubled by incompleteness, the smoke chamber data were used successfully to quantitatively account for the smoke production from the burning table in the room fire tests.

4.1 Surface Flammability

One of the objectives of Breden's study of Parsons tables was to determine if existing flammability tests could be shown to correlate with any aspects of the room fire tests he conducted. This is, of course, the opposite of the normal procedure employed in fire research, by which specific small scale tests are designed to simulate specific room fire conditions or to correlate with larger tests which are more expensive to operate.

The ASTM E162 surface flammability test was intended to correlate with surface flame spread on materials with large areas of exposed plane surfaces, (e.g. ceilings, walls, wall-to-wall kitchen cabinets). Using Breden's tests an effort was made to examine possible correlations between ASTM E162 test data and both measurements of rate of fire involvement for the table and measurements of the room temperature increase.

4.1.1 Correlation with Table Fire Involvement

The only source of data from the tests to estimate the fire spread were the video tapes. As a measure of the rate of fire involvement for the table, the difference in times between the first dripping of material near the ignition source and the collapse of the table were used. These are two events that can be clearly identified in the video tapes and are listed in Test Event Times, table 3. The use of time difference between these two events helps to eliminate variations due to the initial ignition process and errors in timing because of delay in starting the video recording process. These end points, of first dripping and table collapse, were useful in this study because each of the plastic tables tested behaved similarily. They may not be useful for tests of rigid char forming materials. Table 10a presents a tabulation of this time difference for each test where sufficient data were available. The data from tests 3 through 8, all using the same type of polystyrene table can be used to compare the influence of room location on fire involvement rate and also serve as a measure of repeatability of the time difference. It can be seen that in each location the time difference is very repeatable having a within group standard deviation of 5 seconds. This establishes a least significant difference at the 95 percent confidence level of 16 seconds for the average values at each location among tests 3 through 8. Thus, from the set of data on polystyrene tables, fire involvement was significantly faster at the wall location than in the corner, which in turn was significantly faster than the middle of the room location. Seeing this significant difference because of table location within the room necessitates dividing the rest of the room data involving different table materials into corner and wall test groups.

Table 10b shows a ranking of materials in order of increasing risk based on the time difference between the first dripping of materials and the table collapse for wall and corner tests. For comparative purposes with the laboratory scale surface flammability data, the results for the polystyrene foam can be ignored because this material was not fully evaluated in the laboratory test[6]. Considering the other materials ranked in table 10b for the corner location, polypropylene was ranked as having the longest period of burning prior to collapse or least average rate of involvement. Polystyrene and acrylic were nearly equal but both had greater average rates of involvement than the polystyrene foam. ABS was identified as having the greatest average rate of involvement characterized by the time difference between the key events.

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[6] The ASTM E162 test run with polystyrene foam was terminated before completion for safety reasons because of the intensity of heat and smoke generation. (Personal communication with L. Breden, 4/17/78).

Comparing the relative ranking of materials from the room burn in the corner location with the results of the surface flammability test (tables 7, 8, 9), no exact agreement was found. Polypropylene showed the slowest table involvement in the room fire but was ranked lowest risk only by the heat evolution factor (Q factor). The heat evolution factor ranked polypropylene equally with polystyrene, where the room test data ranked polystyrene as equal to acrylic. The flame spread index ranked polystyrene the lowest risk and acrylic the greatest risk. Room fire results ranked their rate of fire involvement as comparable.

Even though imperfect, the heat release rate factor shows the best agreement with the measure of table fire involvement used for these tests. Rate of heat release measurements have for some time been identified as an important parameter in characterizing the fire performance of materials [12]. No individual, laboratory scale heat release rate test data are available for the Parsons table materials, so that a further evaluation of the importance of heat release rate measurement relative to the room fire data in this study cannot be made.

4.1.2 Correlation with Room Fire Intensity

Having demonstrated that there is little agreement between the ASTM E162 test results and the table fire involvement rate, as determined by the difference in time between first dripping and table collapse, a comparison of the data with a measure of the room fire intensity was made. As a measurement of the room fire intensity, the average gas temperture in the upper half of the room and the average ceiling temperature were calculated as a function of time throughout the test.

To calculate the average gas temperature in the upper half of the room data channels 5, 6, 9, 10, 13, 14, 17 were used. Their specific locations are given in table 2 and figures 4, 5 and 14. The failure of data channel 18 in all of the tests prevented the use of a completely symmetrical pattern in obtaining an average value. The data from these channels and the averages are recorded in Appendix A.

To calculate the average ceiling temperature data channels 45, 46, 51, 52, 55 were used. Their specific locations are given in table 2 and figure 4, 5, and 14. The failure of data channel 53 prevented the use of a completely symmetrical pattern in obtaining the average. Sensor 45 closest to 53 was used in its place. The data from these channels and the averages are recorded in Appendix A.

The data for the average gas temperature and average ceiling temperature as a function of time is presented in figures 15-26 for tests 6-8, and 10-18. No usable data were recorded in the other tests in the series.

Figures 15-26 demonstrate the close correspondence between average ceiling temperature and average gas temperatures in the room. The average temperature curves are similar in shape to the respective table mass loss rate curves shown in figures 27-37[7]. As is typically the case, all indicators of fire intensity within the room closely follow the mass loss rate. The two indicators of fire intensity to be examined are the average gas temperature in the upper part of the room and the average ceiling temperature.

Accepting the curves in figures 15-26 as a fair indication of the room fire intensity, a study of their repeatability was made. To assess the repeatability of the table fire test, successful data records from duplicate tests in the corner location and wall location were studied. Figures 16 and 17 (tests 7 and 8 respectively) show the results for a polystyrene table tested in the wall location. Figures 19 and 20 (tests 11 and 12 respectively) show the results for a polypropylene table tested in the corner location. These two sets of data were used to determine in an approximate way a gauge for the repeatability of wall and corner table tests.

[7]Test 15 is omitted because no table weights were recorded.

It is evident by comparing the sets of curves that the two tests conducted in the corner with a polypropylene table were more repeatable than the two tests where the polystyrene tables were burned in the wall location. Unfortunately, there are not enough data among the sets of successful room burn data files to separate out the possible interaction between table materials and room location. In the following analysis of repeatability, it will be assumed that the location within the room and not the material tested was the dominant source of variation.

An unsuccessful effort was made to quantify the repeatability of the table test data by trying to curve fit data for average ceiling temperature as a function of time from each test with a single simple function form $f = At^{n}e^{-\alpha t}$. It was hoped that variations in the three parameters A, n, α could be studied to generate expected error bands for experimental data. The attempt was unsuccessful because all the test cases could not be fit satisfactorily with this simple functional form.

Quantification of repeatability of the corner and wall location table tests was performed by studying various parameters of the average ceiling temperature curves (figures 15-26). To eliminate as much as possible variations in the ignition process and in initial ambient temperature, temperature parameters were taken as the difference between measured temperatures and 40°C plus initial ambient temperature. Similarily, all time parameters were taken as the difference between the test time and the time of the first temperature excursion in excess of 40°C plus initial ambient temperature. In this manner four parameters for each curve were calculated: the time to peak temperature; the peak temperature; the total duration for which ceiling temperatures were in excess of 40°C above the initial ambient temperature; and the area between the line at 40°C above the initial ambient temperature and the time-temperature test curve. Table 11 lists the values of these parameters for each of the ceiling temperature curves. In spite of the fact that only two test were available, calculated coefficients of variation for the key parameters are given in table 12 for the data from the wall location tests, numbers 7 and 8, and the corner tests, numbers 11 and 12.

With the reservation that the amount of replicate data from this series of tests is small, the repeatability of the corner tests as measured by the selected parameters was much better than for the tests in which Parsons tables were burned in the wall location. From table 12, it can be seen that the relative time for key events, such as peak time difference, repeats well in both corner and wall tests. The apparent greater variability of the wall tests is caused by the large variations of temperatures in the room, such as the peak temperature.

As the average ceiling temperature measurements and average gas temperature in the upper half of the room have been found to be similar, the comparisons between table materials burned at the same location within the room were limited to studies of the ceiling temperatures. Figures 38 and 39 present comparisons between the different materials burned in the wall and corner locations. The vertical bar limits attached to each curve at positions close to the peak in each curve, represent estimates of plus and minus one standard deviation of the local curve values. These standard deviations are calculated from the values of the coefficient of variation (COV) from the duplicate tests of tables in both the corner (COV = 13% for peak temperature difference) and the wall (COV = 37% for peak temperature difference) tests. The coefficient of variation measured for the peak values with one material are assumed to apply to other materials tested in the same room location and to other values along the time temperature adjacent to the peak. For ease of calculation a 20°C ambient was assumed for all test data in the calculation of vertical bar limits.

In figure 38, room temperatures for a short time may be significantly greater for the polystyrene foam material than the other two, but the large variations among these wall location tests make definite conclusions impossible. For tables tested in the corner, this is not the case. Figure 39 clearly identifies the polystyrene structural foam and polypropylene materials as producing significantly higher temperatures within the room than the other materials tested.

Generally it may be concluded that no correspondence has been demonstrated between a material performance in the E162 surface flammability test and its performance under fire conditions when incorporated into a Parsons table. The best comparison between the small scale data and the room fire is between the heat evolution factor (Q) and the rate of table fire involvement. From analysis of the room fire data, tables tested in the wall location were identified as becoming involved with fire significantly faster than with the corner or middle of the room location. Test run in the corner location may be considered more repeatable than those run with the table along the wall but quantification of the difference is difficult.

4.2 Smoke Production

In the previous section a correlation between selected room fire test data and the small scale surface flammability test was sought. For the analysis of smoke data from the room tests a more ambitious goal of prediction of large scale results from the laboratory test data will be examined.

The ASTM E662 smoke chamber test is a closed 0.51 m^3 box that serves as an accumulator or integrator for the smoke produced by the burning test specimen. A specimen mass loss measurement may also be made. In the room fire tests of the Parsons tables, a table mass loss measurement was made, but no physical method was supplied to collect the combustion products. Even though no physical accumulation of smoke was performed, data was collected on the flow rates of gases in and out of the room doorway and the amount of light obscuration caused by the smoke in the flow. A numerical integration of this doorway data could provide the same type of cumulative smoke data as collected in the smoke chamber but on a larger scale. In the same manner as detailed for the smoke chamber, the integrated smoke and table mass loss data can be used to calculate a room fire MOD value for the table material. A comparison between smoke chamber and room fire test MOD values will provide a good indication of the predictive power of the small scale test results.

To calculate the total (integrated) amount of smoke that flowed out of the room during the table burn, smoke was treated as if it were an ideal gas combustion product. That is, for a given amount of smoke, the smoke concentration was accepted as simply inversely proportional to the dispersed volume. The optical density per meter was taken as a measurement that was proportional to smoke concentration.

With these two assumptions, the total smoke production during the room test would be:

$$\text{Total Smoke} = \int_0^{\tau} \int_A \left(\frac{OD}{L}\right) \nu \, dA dt \qquad (2)$$

where: τ is the total test time

$\frac{OD}{L}$ is the optical density per meter

ν is the component of velocity of the gas flow normal to the plane of the doorway

A is the area of the doorway

Dividing equation 2 by the table mass loss (Δm) yields a MOD smoke number for the table material based on the room fire test:

$$MOD = \frac{\int_0^{\tau} \int_A \left(\frac{OD}{L}\right) \nu \, dA dt}{\Delta m} \qquad (3)$$

From the test data, four measurements of smoke concentration and six measurements of gas velocity were made in the doorway at positions shown in figure 14. Data from each probe were recorded once every twenty seconds. To perform the integration of velocity and optical density per meter over the area of the doorway, the smoke and velocity data were curve fit and all values were assumed uniform in the horizontal plane across the doorway. Straight line segments were used to interpolate values between adjacent data points. The end sets of straight line segments were simply extrapolated to the upper and lower door boundaries. MOD values were calculated every twenty seconds using the cumulative table mass loss.

Appendix B is a compilation of test data from the room fire. Values of doorway velocity, table mass, and doorway light transmittance are given on a 20 second time interval throughout the test. These data were available for tests 6-8, 10-14, 16-18. Only a fraction of these sets of test data were further analyzed to obtain MOD values. In test 6 the load cell and several velocity probes failed. In tests 10, 12, and 14 one or several smoke meters failed. Test 13 was not studied because the table burned was a combination of two materials, polypropylene and PVC, and no small scale test data were taken for the PVC. The remaining sets of test data were analyzed to calculate MOD values. Appendix C presents the time dependent MOD values calculated from the test data for tests 7, 8, 11, 16, 17, and 18. In addition to the MOD values, information on the rate of smoke generation at various times during the tests can be seen in the data for optical density flow (OD FLOW). These numbers represent the value of the area integral in equation 1 at different times during the test. The column "Total Flow" refers to the value of equation 1 at various test times.

Studying the MOD values in Appendix C, it can be seen that in each test the MOD values increase to a plateau value near the end of the test. Slight variations in the plateau value are caused by fluctuation in the mass loss measurement and incomplete recovery to 100 percent transmittance of the smoke meters.

Table 13 presents a comparison of MOD values for materials between those calculated from table fire data and those measured in the NBS smoke chamber test. The agreement between the two results for most tests is good. For test 11, the table fire MOD number of 670 m^2/kg can be identified as an overestimate of smoke production because the highest smoke meter in the doorway indicated a great amount of light absorption at the completion of the test as can be seen from the data in Appendix B. Even though the results from tests 8, 16, 17, 18 show excellent agreement with smoke chamber tests, test 7 only shows fair agreement. There appeared to be no anomalies in this set of data, so that the 34 percent deviation may represent estimate of the difference for this predictive calculation.

The good agreement between the smoke chamber test results reduced to an MOD form and the MOD numbers calculated from the room tests suggests that the MOD ratings of materials can be used to calculate the total expected smoke production from a furnishing item involved in a fire. This process can be exemplified by recasting the data presented in table 13 into another form. If one assumed that the entire table would be consumed in a fire, then the original weight of the table multiplied by the MOD number for the material measured in the smoke chamber will yield a prediction of the total expected smoke production. This total smoke production will be in terms of an optical density per length times a volume. In this case, the units will be m^2. Roughly this may be thought of as a smoke concentration times the volume of gas in which the smoke is mixed or a total effective particle area for light absorption. Table 14 compares predicted values for total smoke flow to measurements from the room fire taken from Appendix C.

Agreement between actual and predicted values is good and is similar to table 13 because for these plastic tables fires the tables burned were almost completely consumed. Therefore, the mass loss number used in table 13 was practically equal to the original table mass used in the calculation for table 13.

The results shown in table 14 suggest that a good assessment of maximum smoke production potential for furnished rooms can be made. Coupling this with an estimate of the volume in which this smoke will be dispersed allows one to calculate an estimate of the mean smoke obscuration. The calculation of light absorption from optical density numbers is of course very sensitive to the accuracy of the optical density measurement because of the logarithmic basis for the optical density measurement.

The MOD smoke number can be used in a way that standard smoke numbers (specific optical density [8]) cannot. If a good estimate or measurement of the burning rates of materials within a room are available, an evaluation of the rate of smoke production from the fire can be calculated. Simply the MOD smoke number is multiplied by the mass loss rate for the material in the room fire as a function of time to produce a curve of smoke generation rate as a function of time. Using the measured mass loss rate from Parsons table test data, comparisons of calculated and measured smoke generation rate are shown in figures 40 through 45 for tests 7, 8, 11, 16, 17, and 18. The agreement between calculated and measured values follows that for the total smoke production discussed above, as the total smoke production is simply an integration of the smoke generation rate vs time curve.

Even though the data from these sets of tests is meager, it has been demonstrated that the MOD method of smoke chamber data reduction has a potential for predicting the smoke generation from materials involved in fires. The agreement between the small and large scale test results for smoke generation in these tests involving a single furnishing item constructed entirely of one material is a first step. Additional testing of the applicability of the MOD numbers to room fires where more than one material and furnishing item is involved is clearly the next step.

5. CONCLUSIONS

Surface flammability data from the E162 radiant panel test was compared in several ways to the room fire data. No correlation was found between the flame spread index number from the E162 test and measurements of average upper room temperature or table fire involvement time. Even though imperfect, the heat release factor of the flame spread index number showed the best agreement with the table fire involvement times.

Measurements of smoke production from materials made in the NBS smoke chamber and reduced to a MOD number successfully account for the total smoke production and rate of smoke production from the table fires. In order to firmly establish the predictive power of the MOD number, additional room fire data should be obtained for cases where more than one item and material are burned.

The encouraging results from the study of smoke data from this series of tests reinforces the idea that prediction of large scale room fire data may be possible using results from selected small scale tests.

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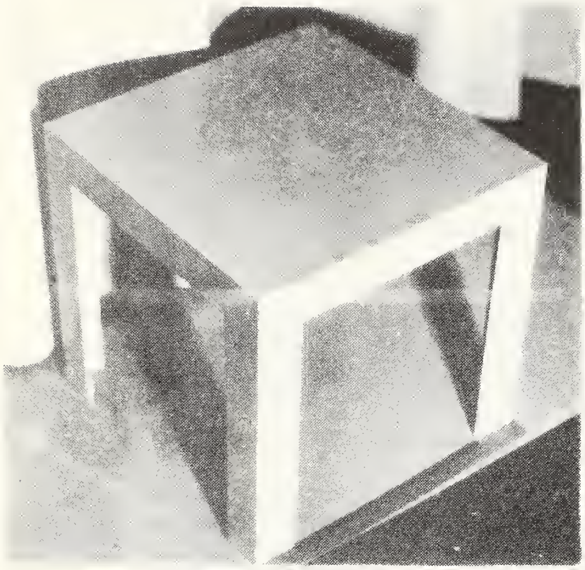
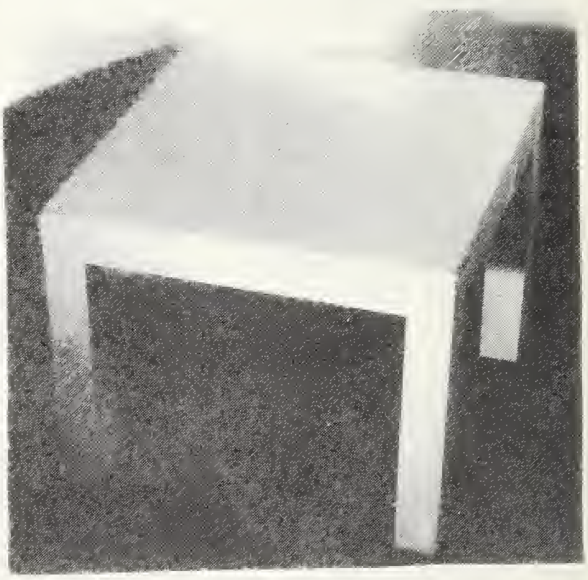


Type A

Type B (Tube Type)

Type C (Butcher Block)



Type D (Particle Board)

Figure 1. Parsons tables

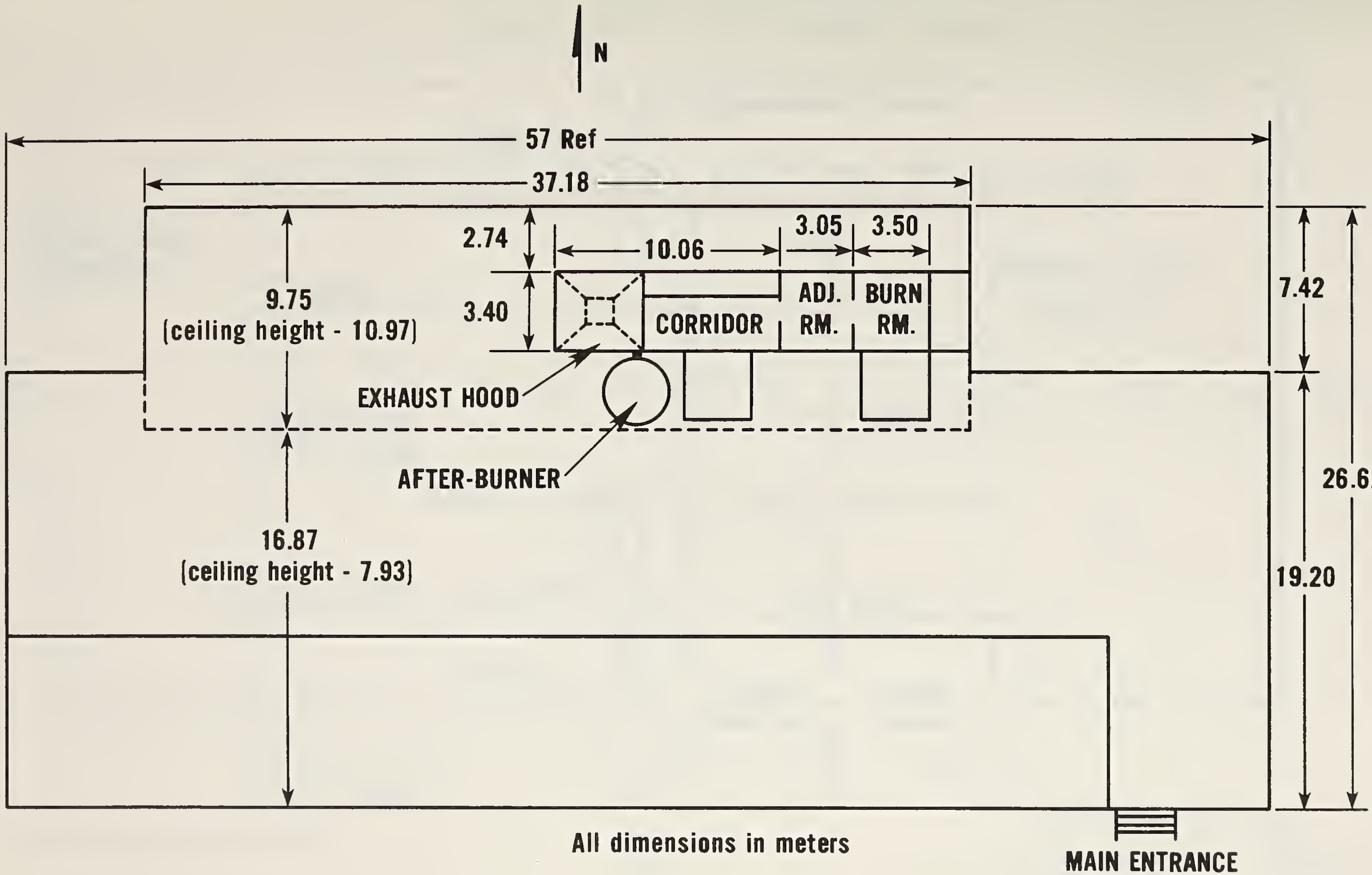


Figure 2. Plan view of building 205 test facility

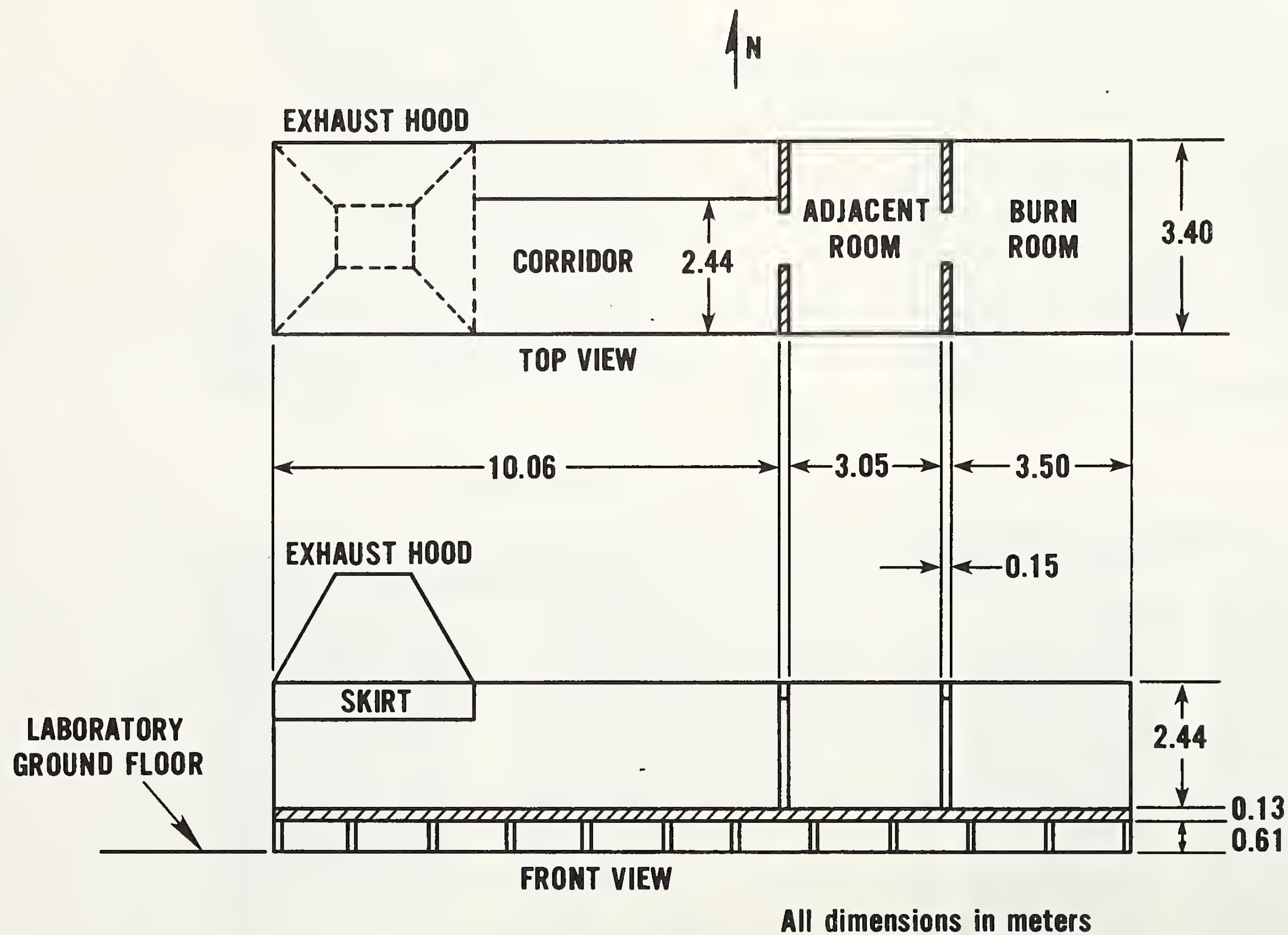


Figure 3. General view of room-corridor complex

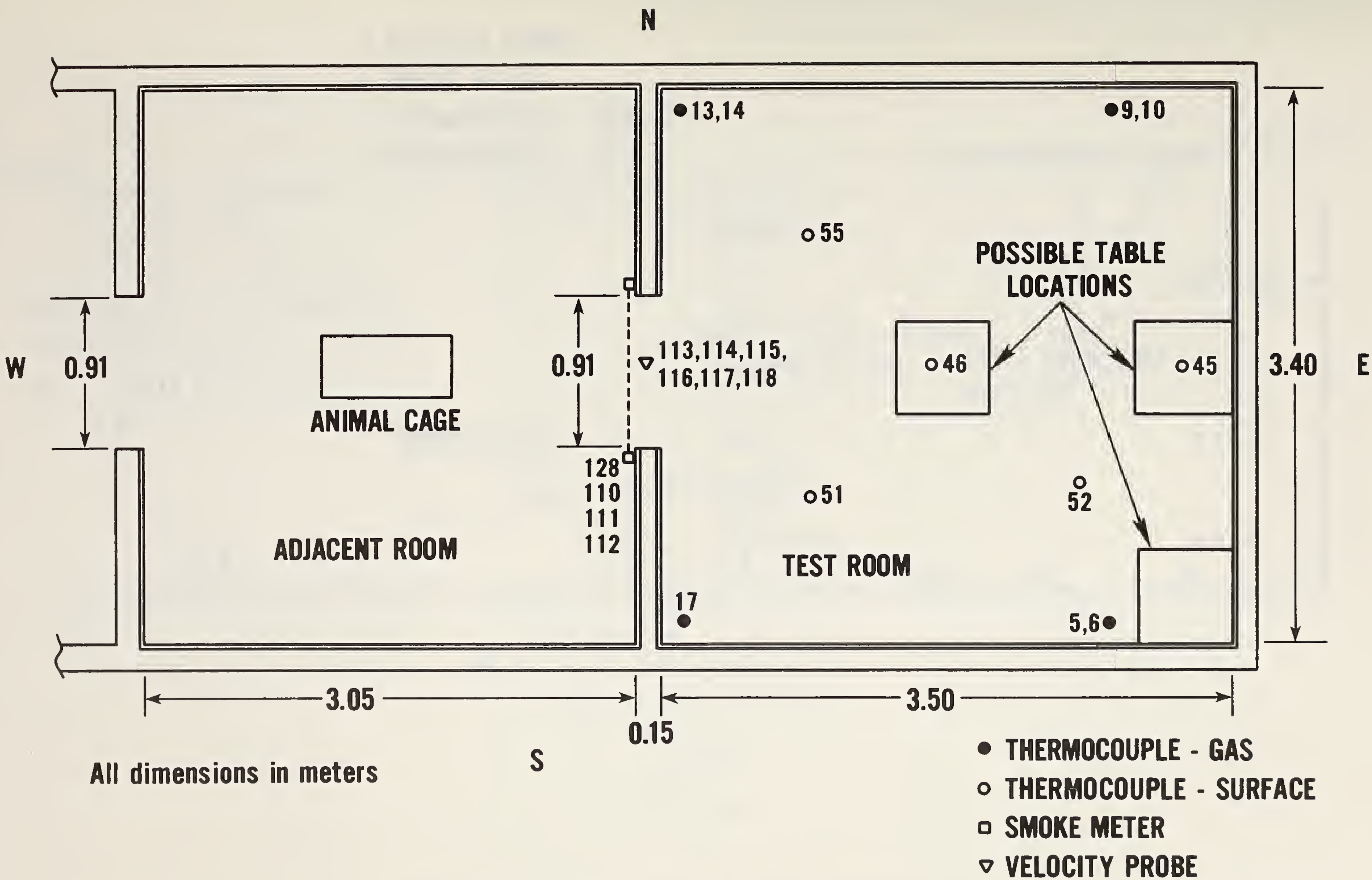


Figure 4. Plan view of test-rooms

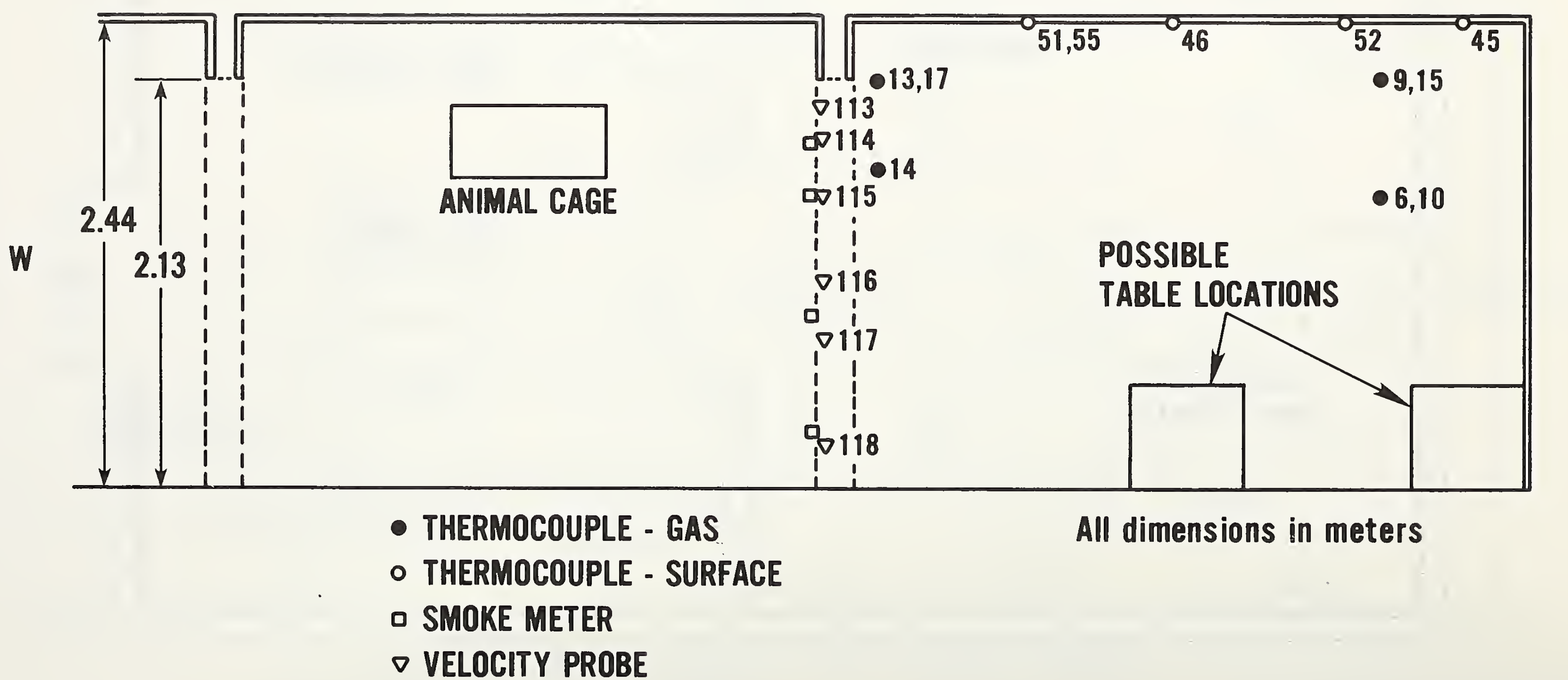


Figure 5. Elevation of test rooms

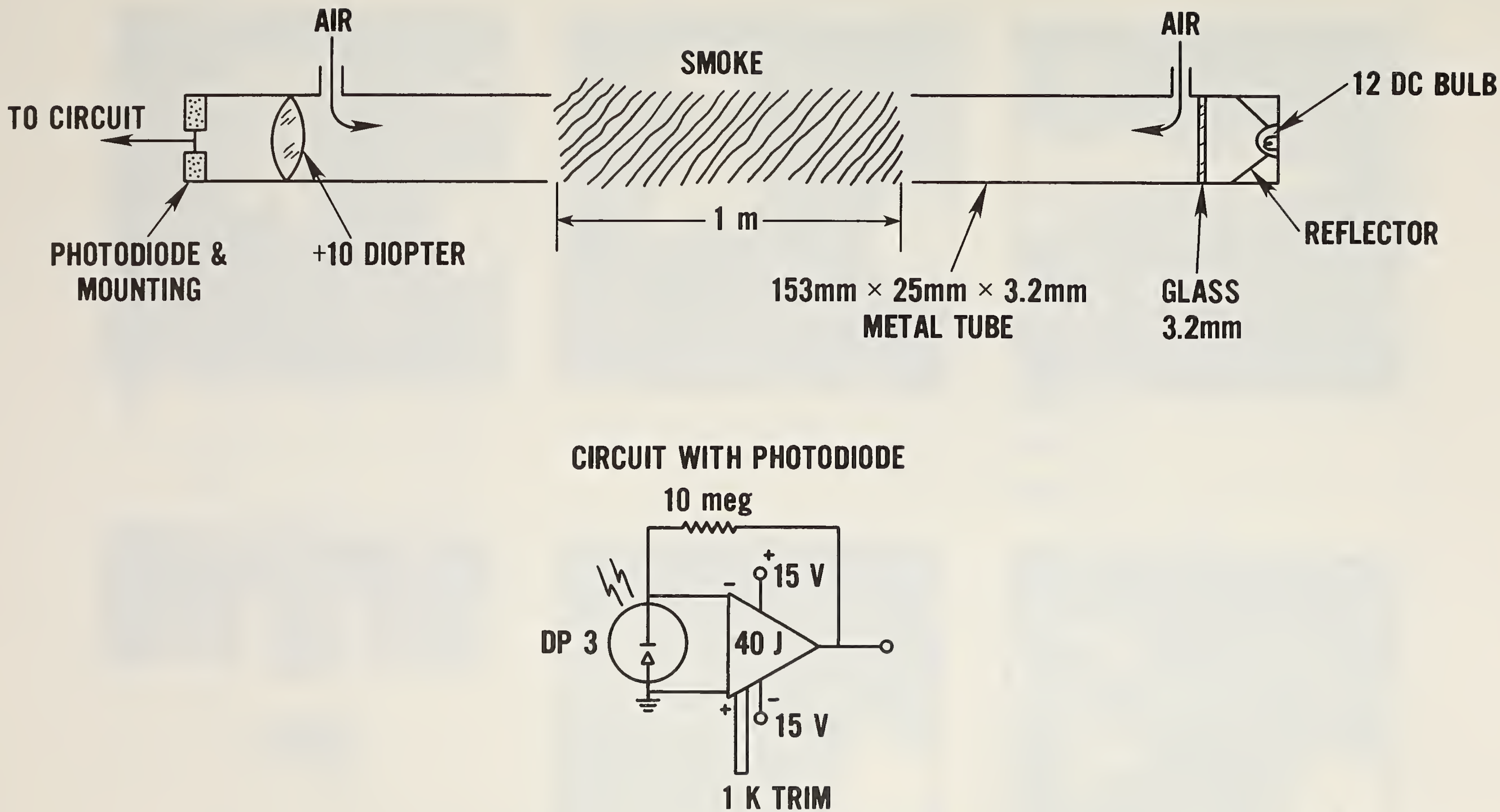


Figure 6. Schematic of smoke meter

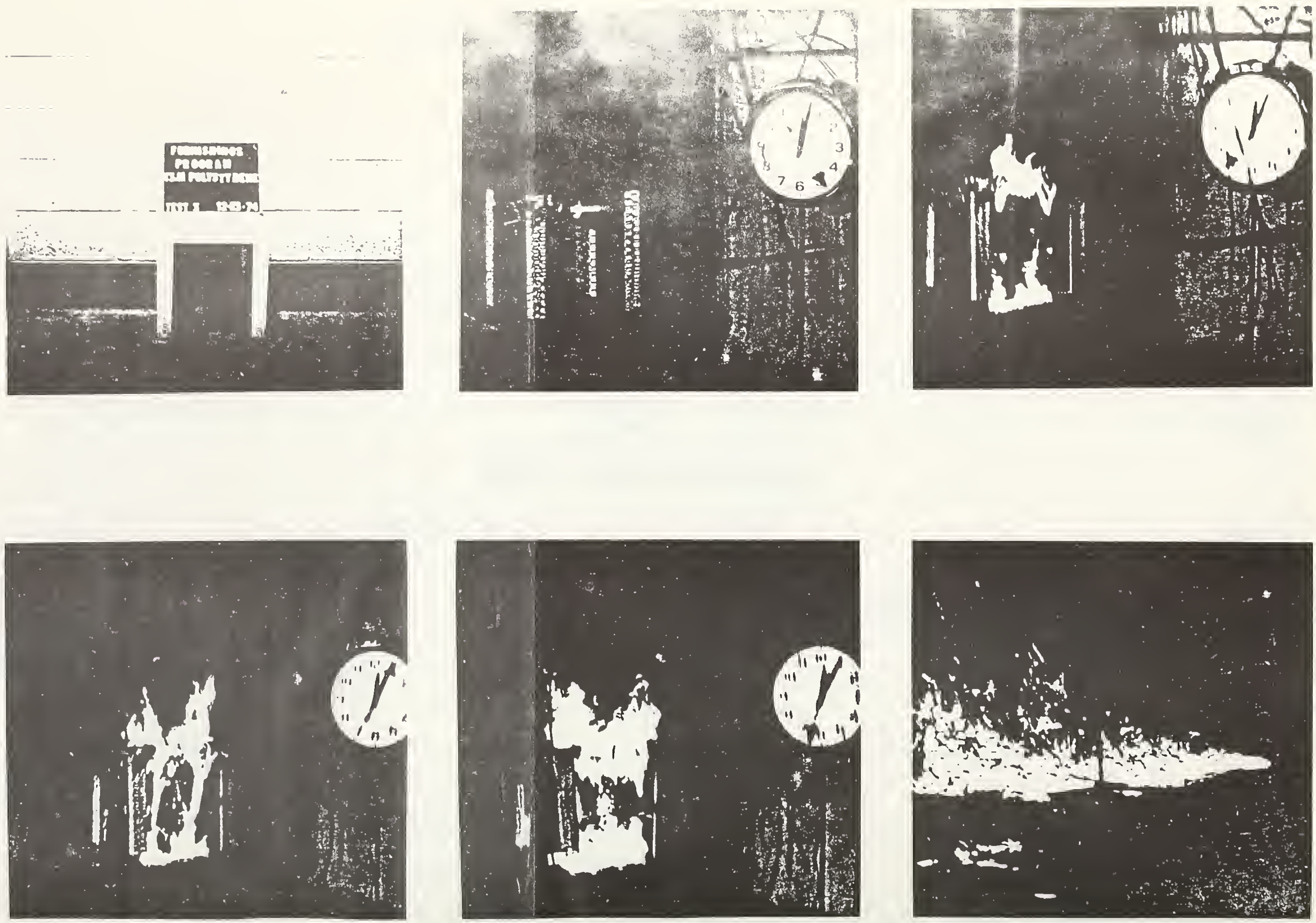


Figure 7. Burning of a Parsons table

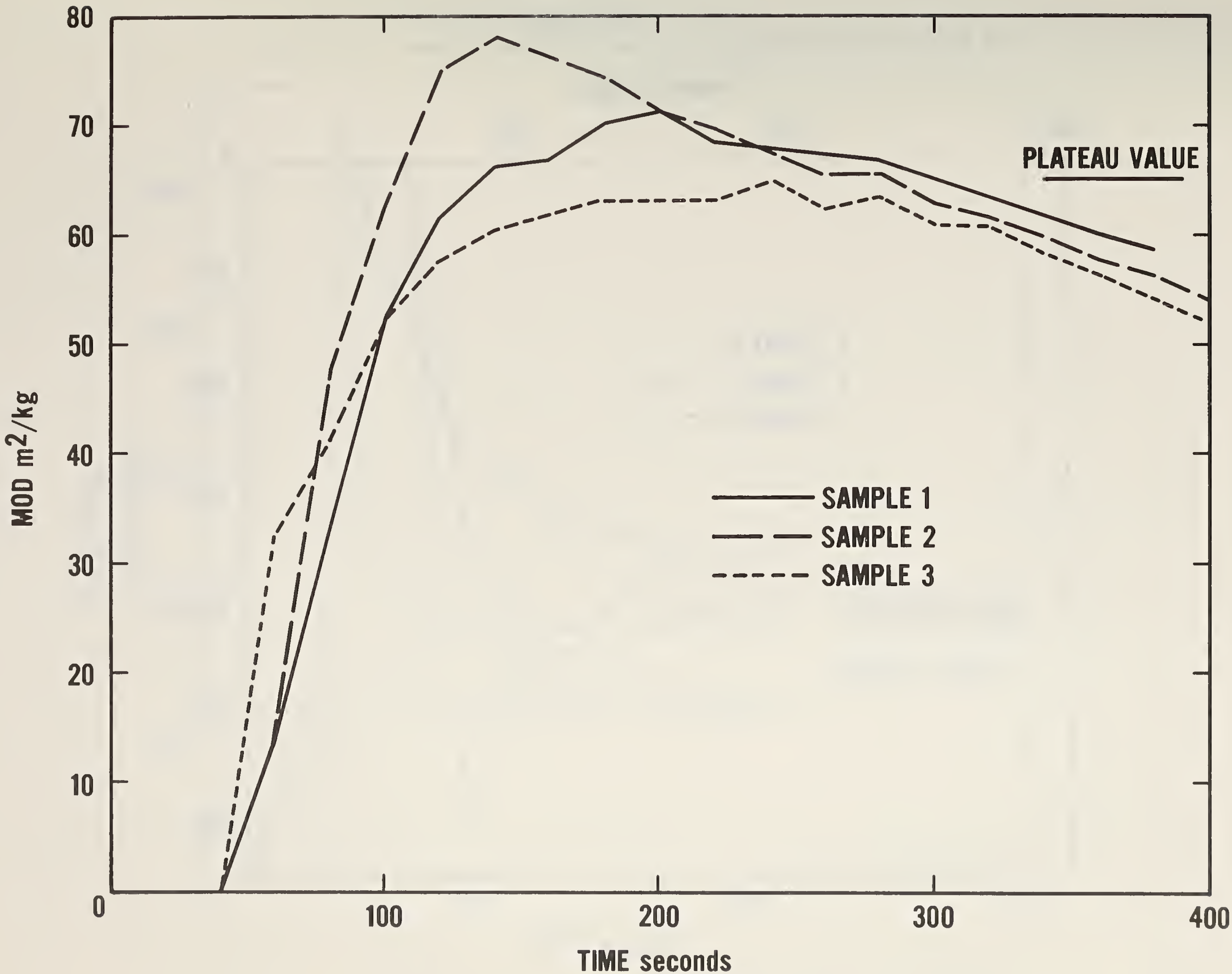


Figure 8. MOD test results for acrylic 0.05 m x 0.05 m specimen

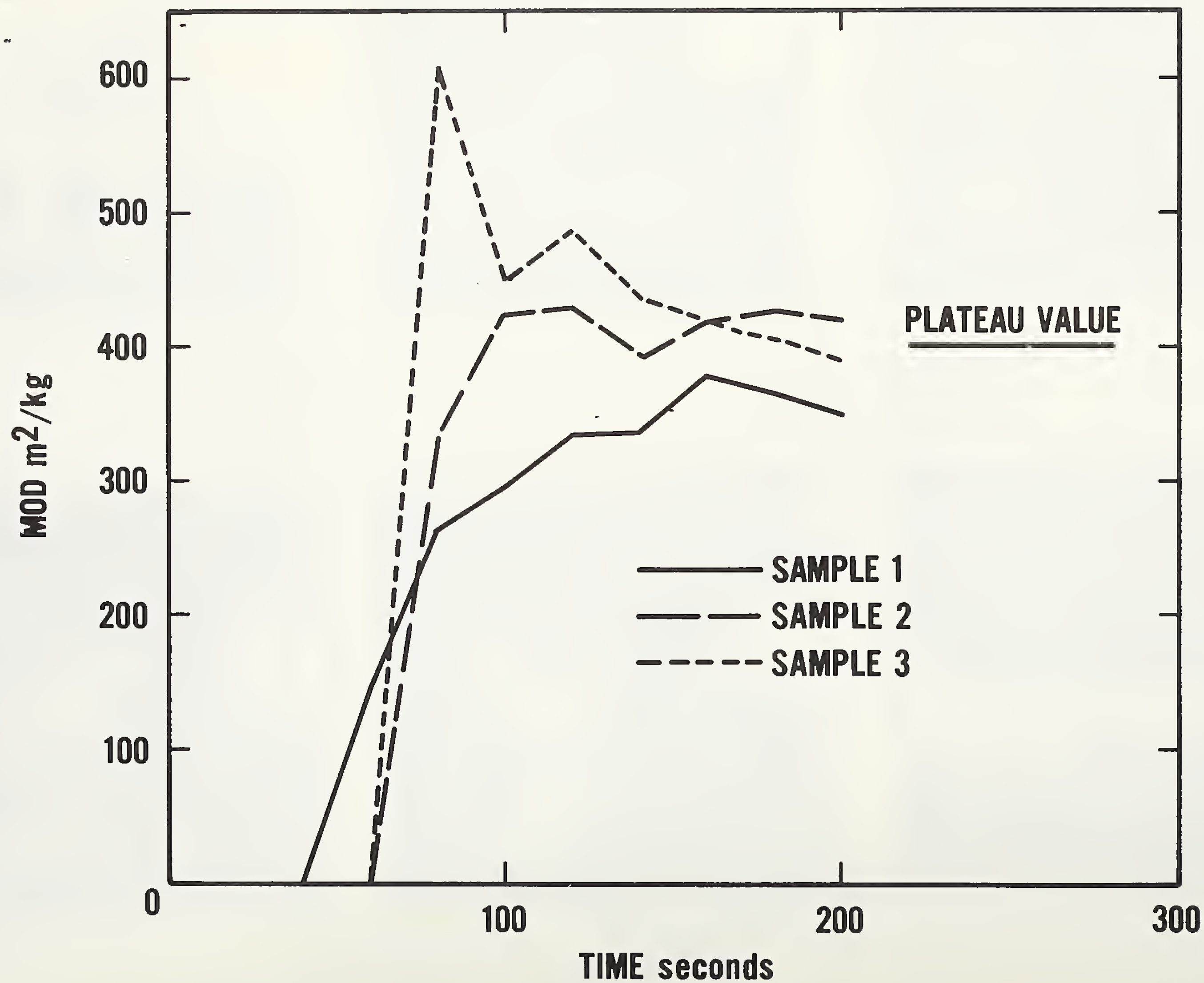


Figure 9. MOD test results for polypropylene 0.025 m x 0.025 m specimen

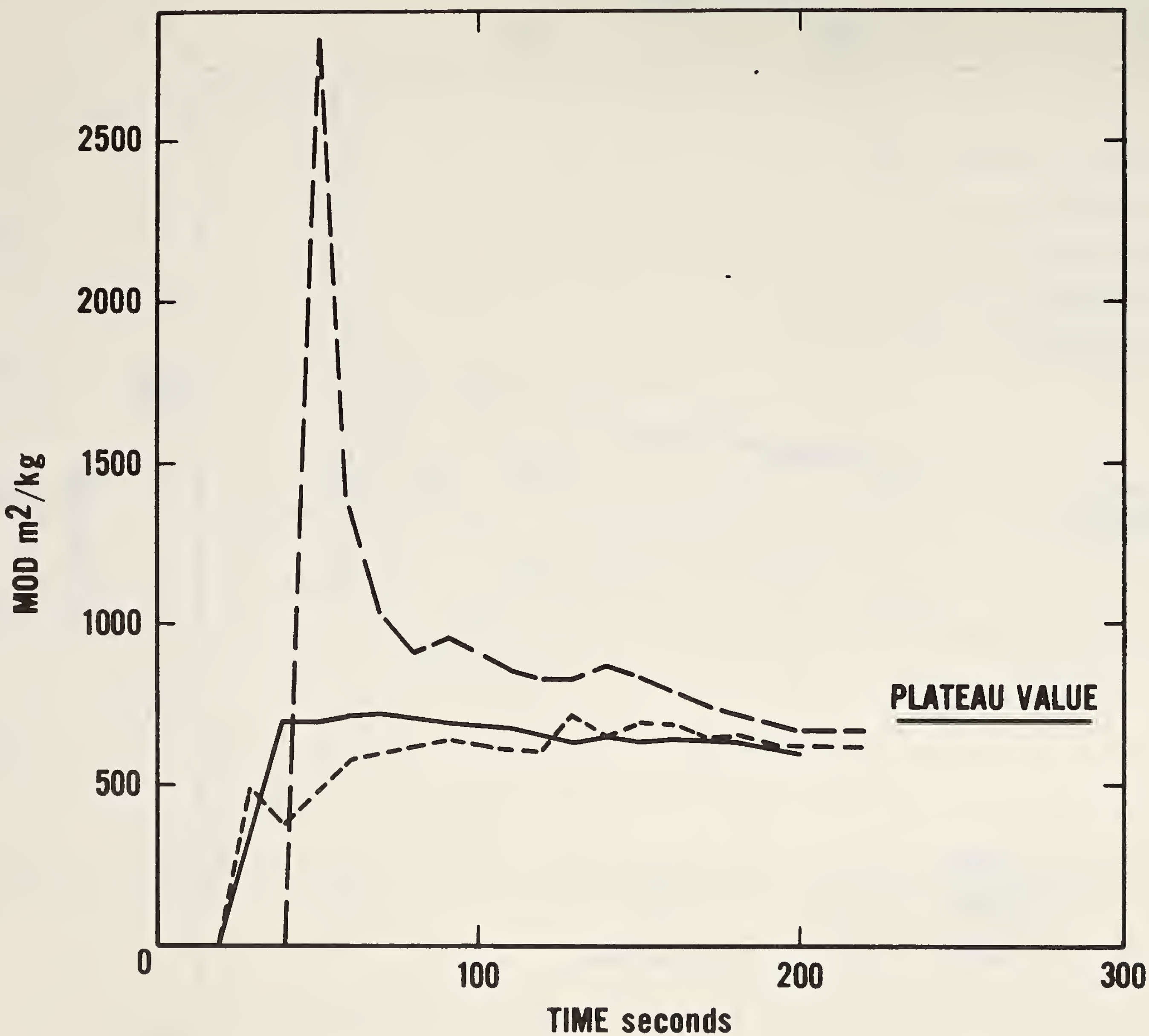


Figure 10. MOD test results for ABS, 0.025 m x 0.025 m specimen

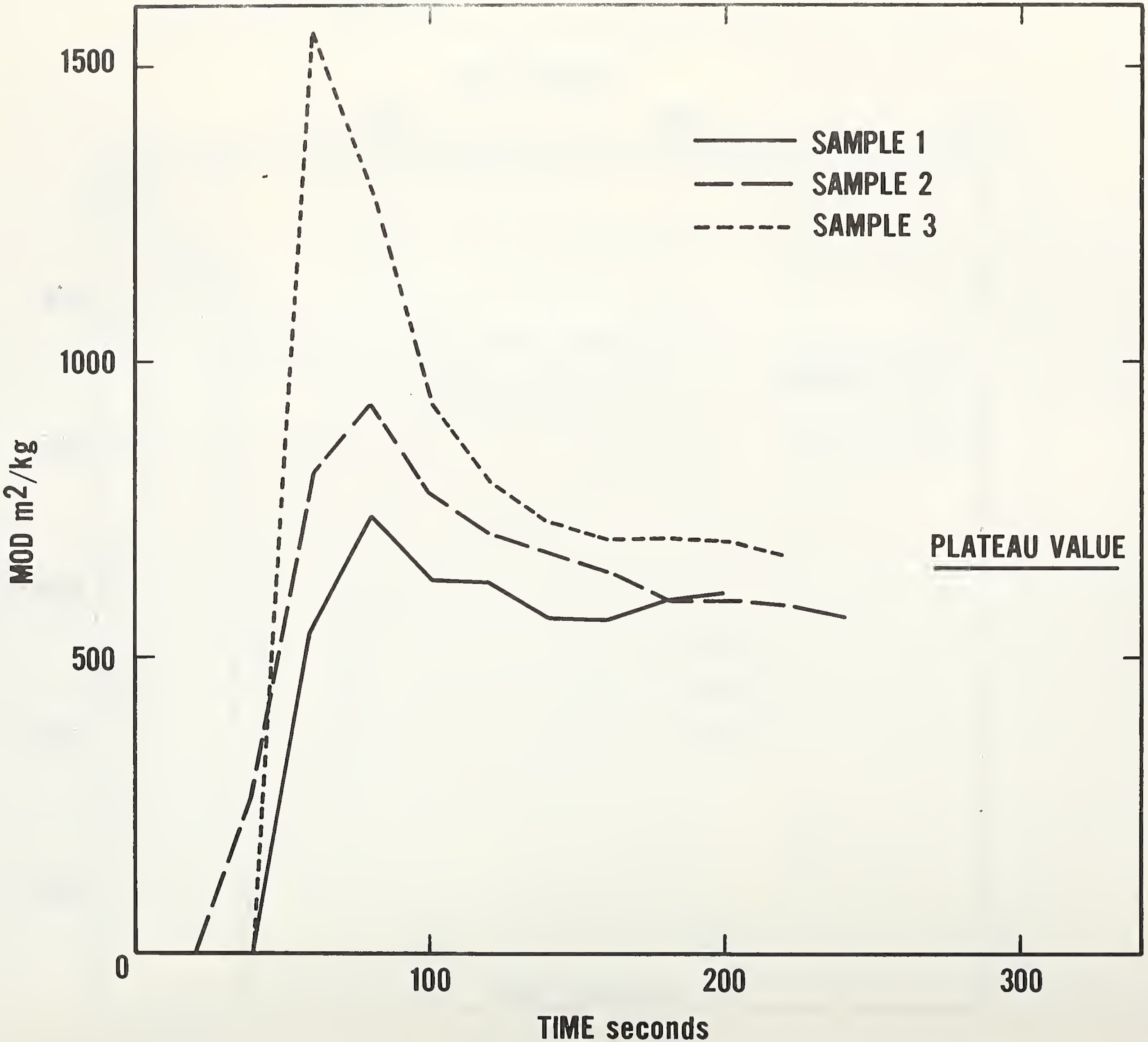


Figure 11. MOD test results for polystyrene 0.025 m x 0.025 m specimen

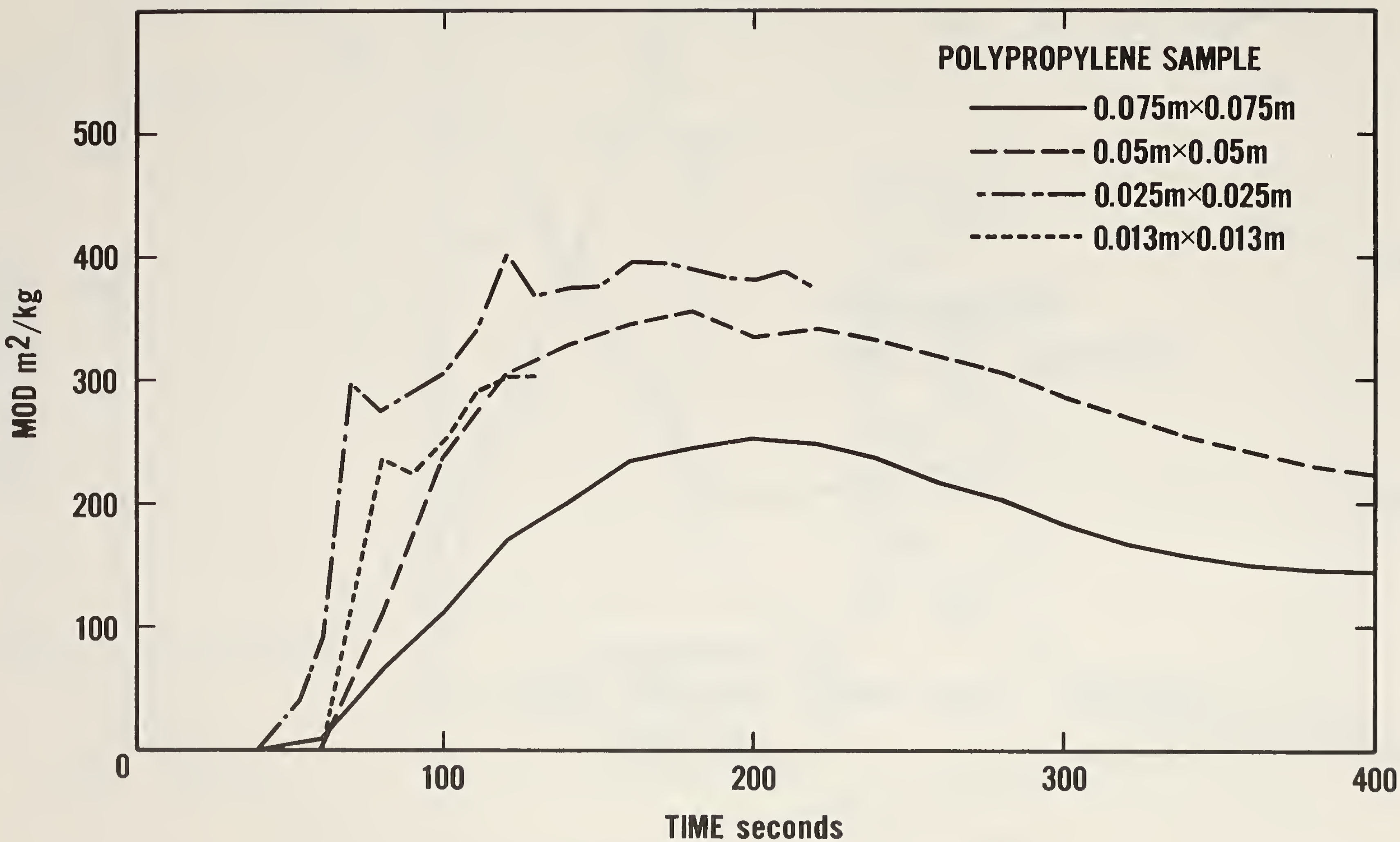


Figure 12. Effect of sample size of MOD value

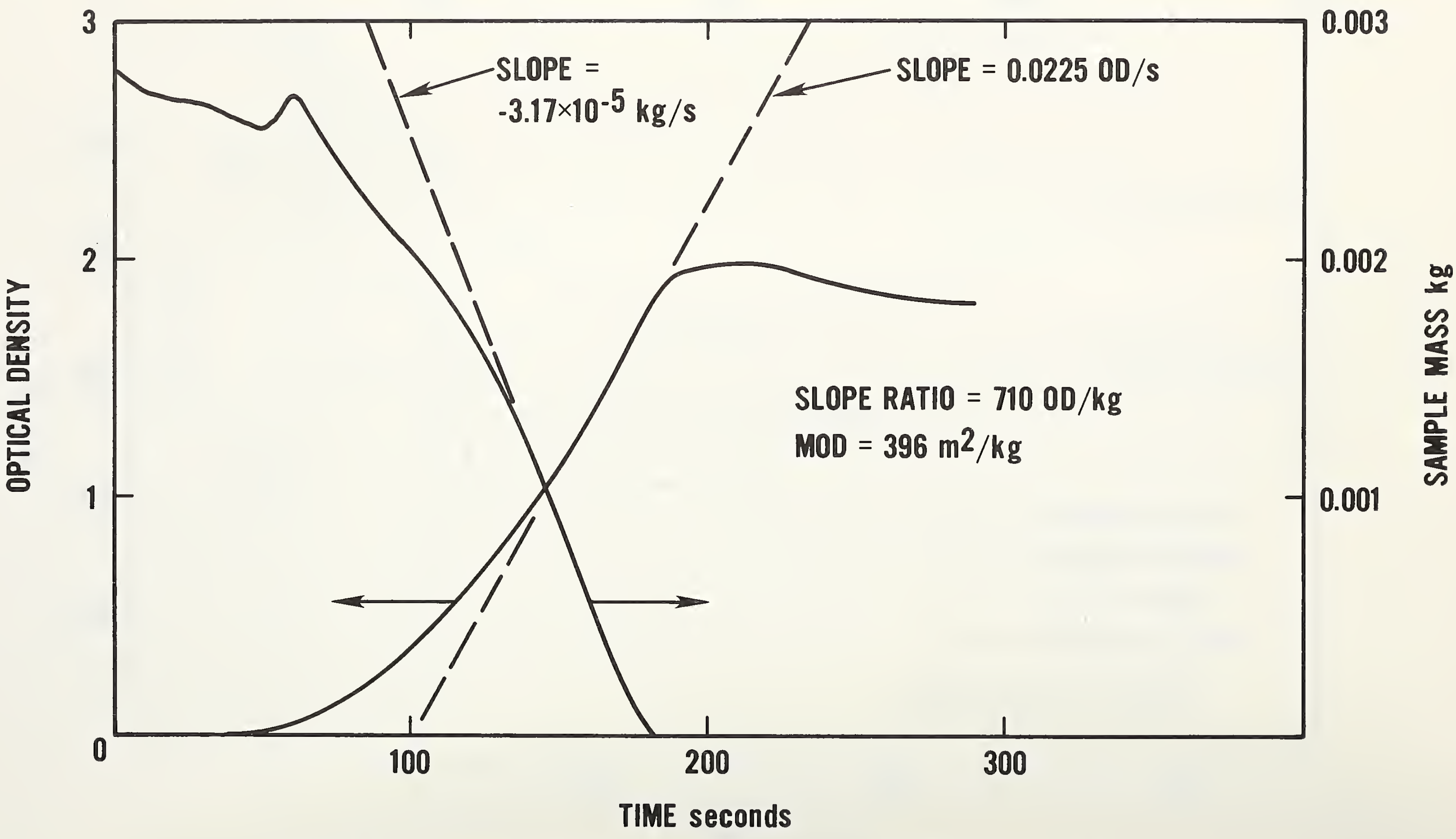


Figure 13. MOD calculated by ratio of slopes method for a 0.025 m square sample of polypropylene

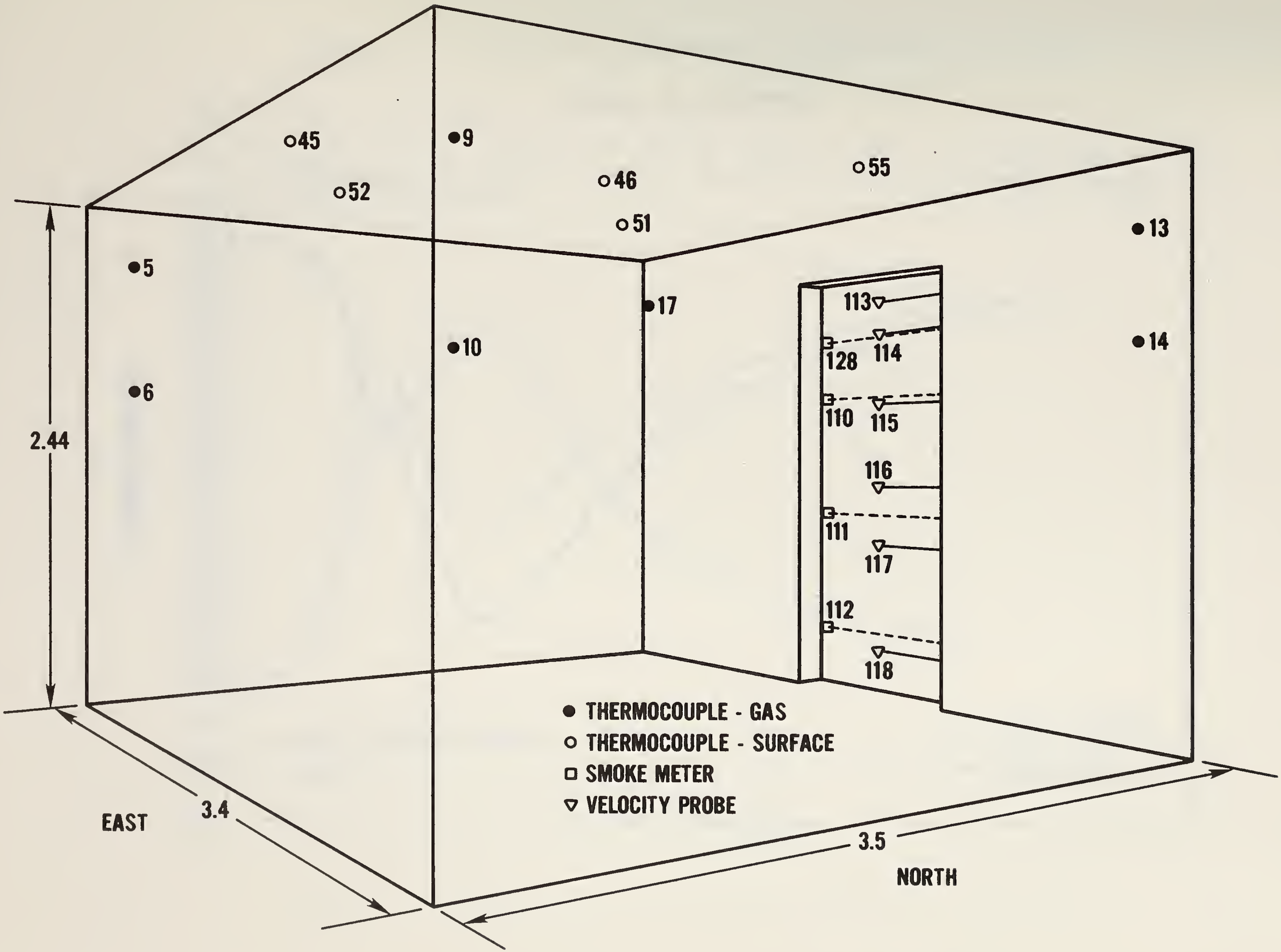


Figure 14. Perspective view of test room

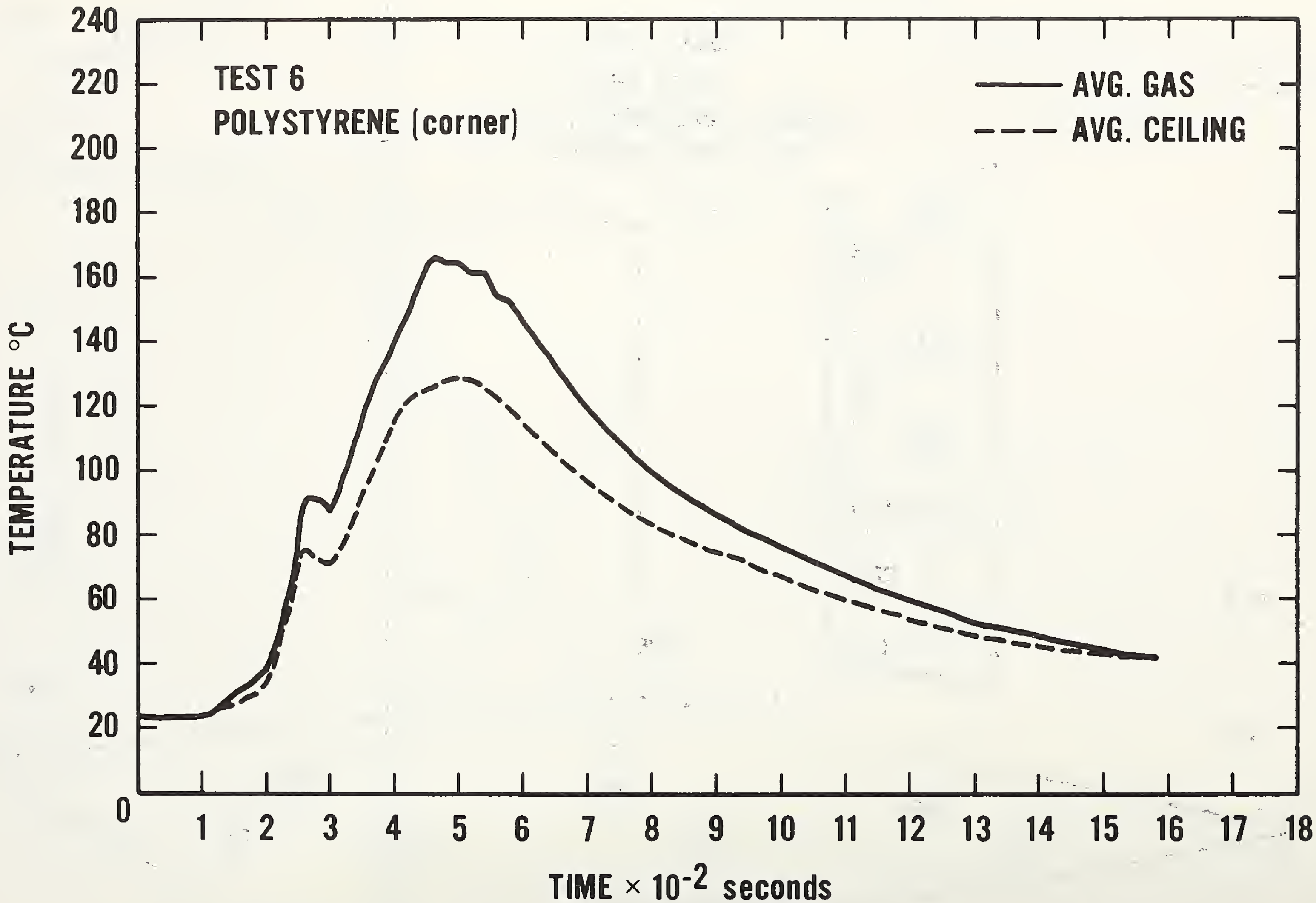


Figure 15. Average gas and ceiling temperatures for test 6

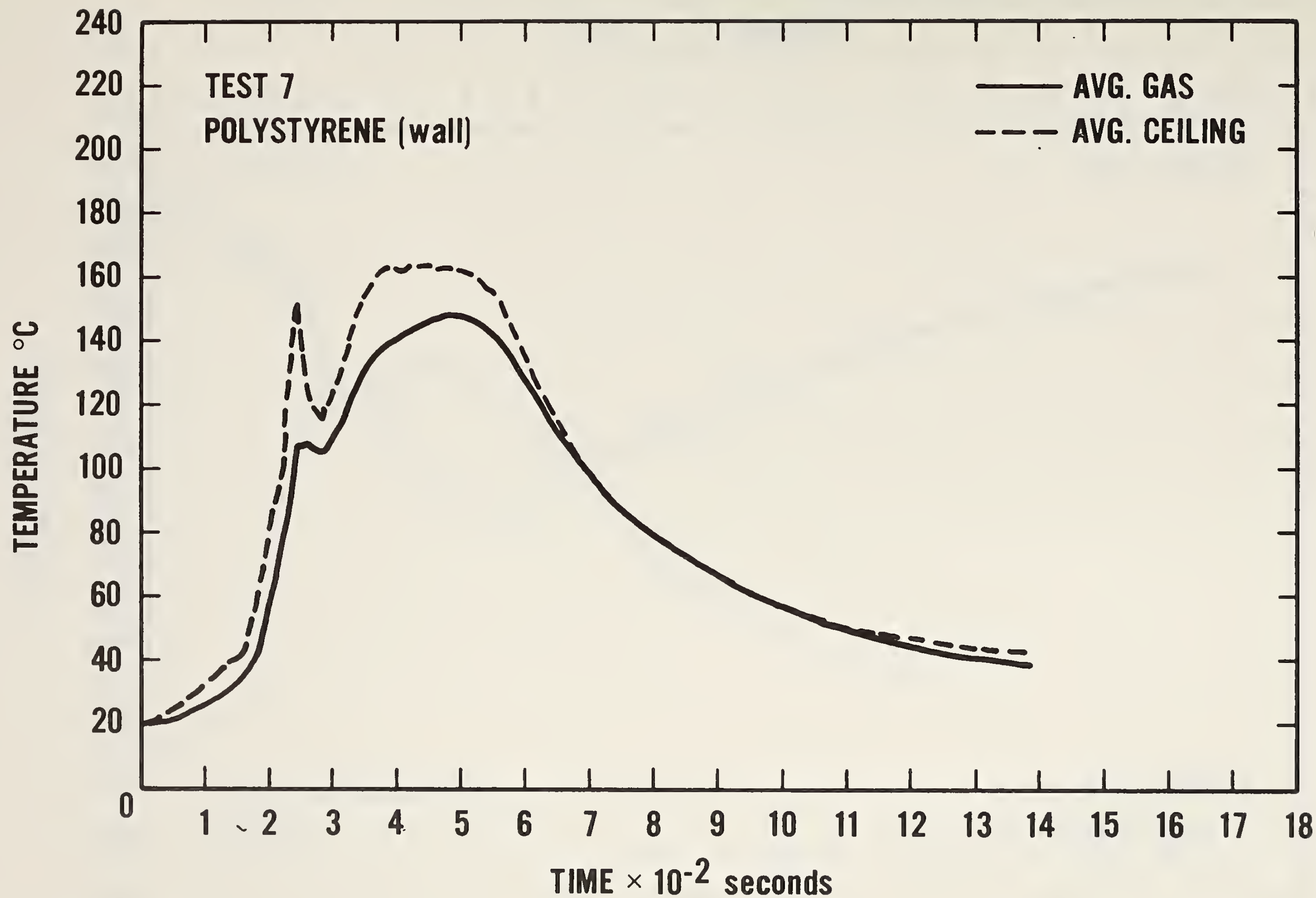


Figure 16. Average gas and ceiling temperatures for test 7

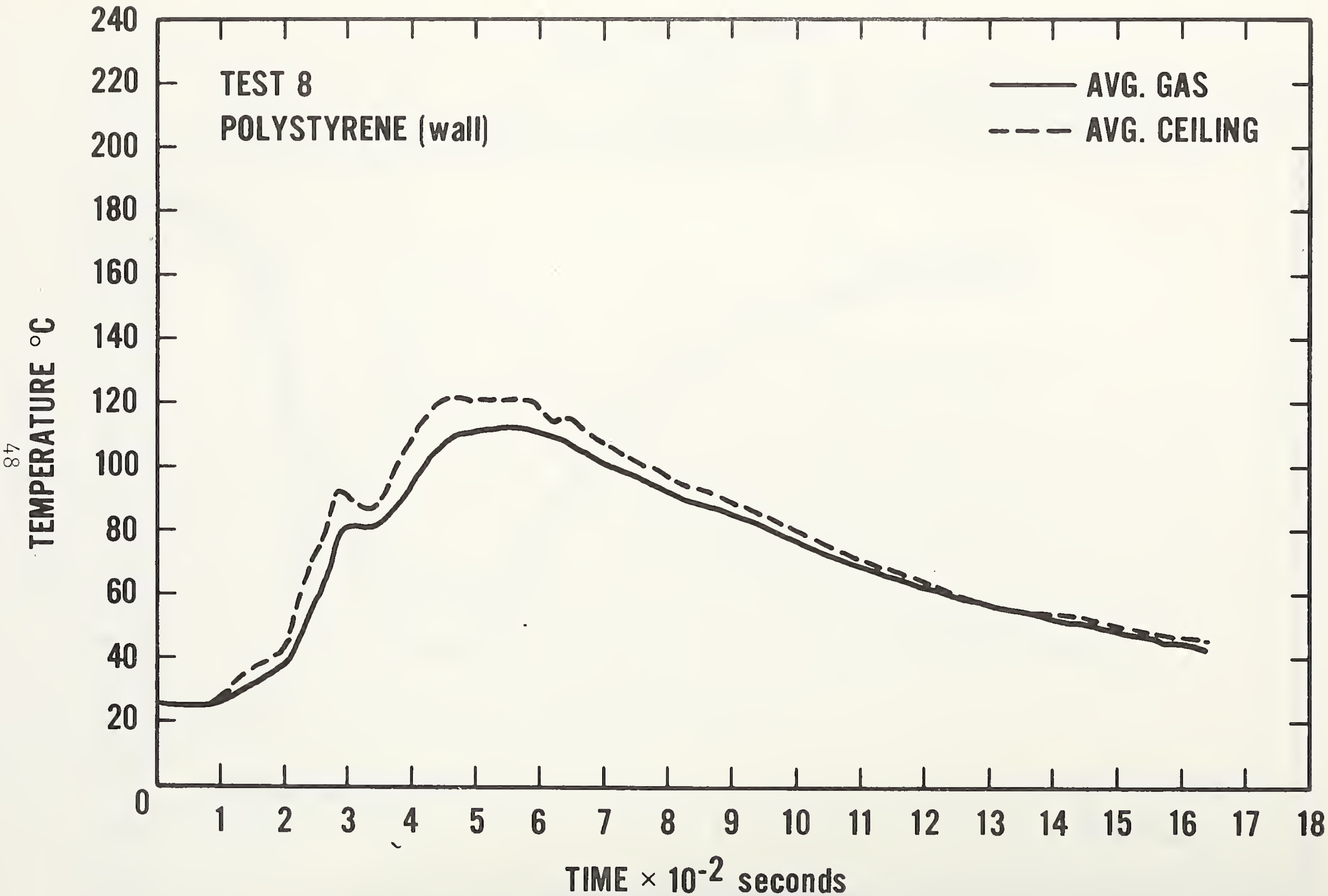


Figure 17. Average gas and ceiling temperatures for test 8

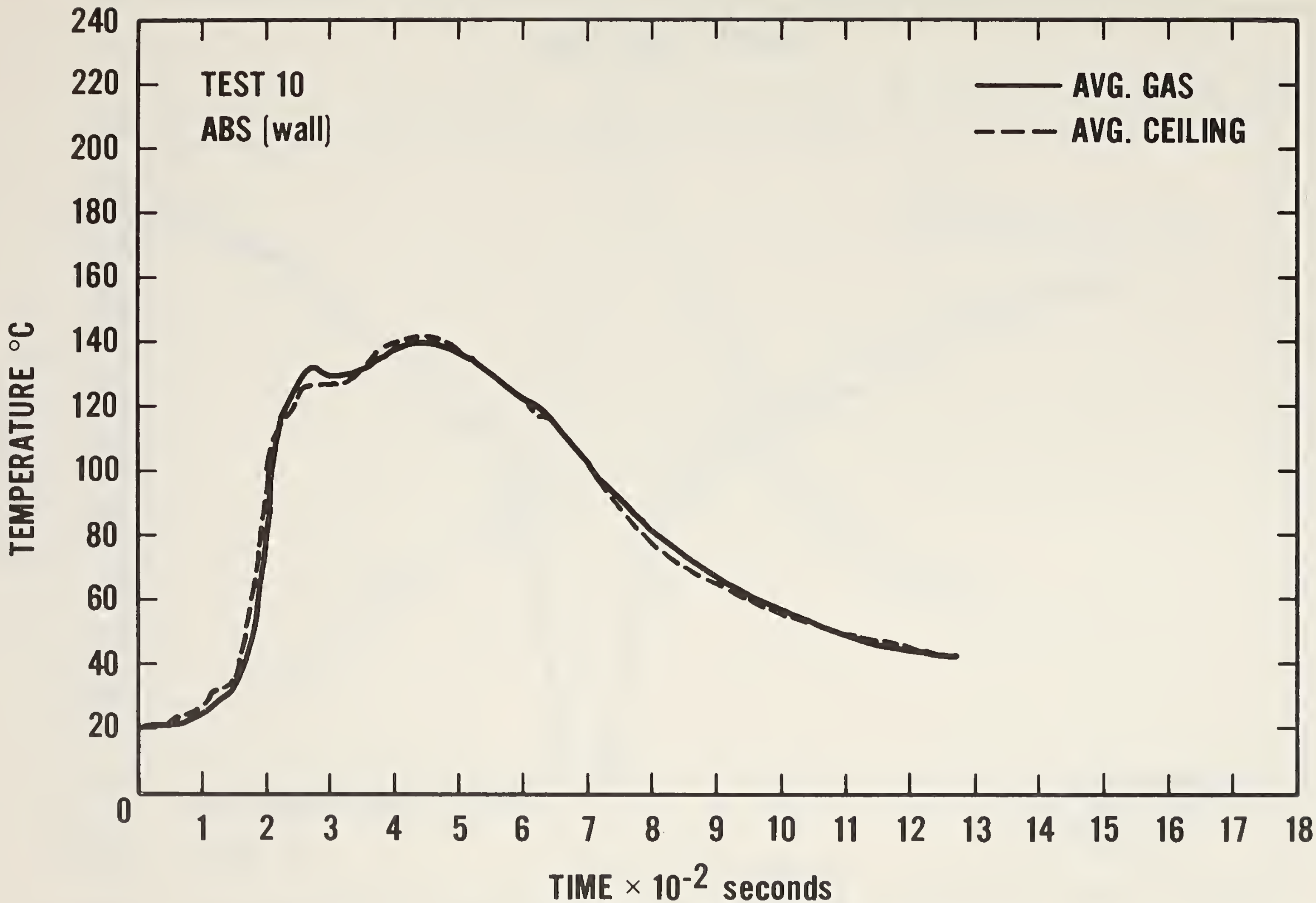


Figure 18. Average gas and ceiling temperatures for test 10

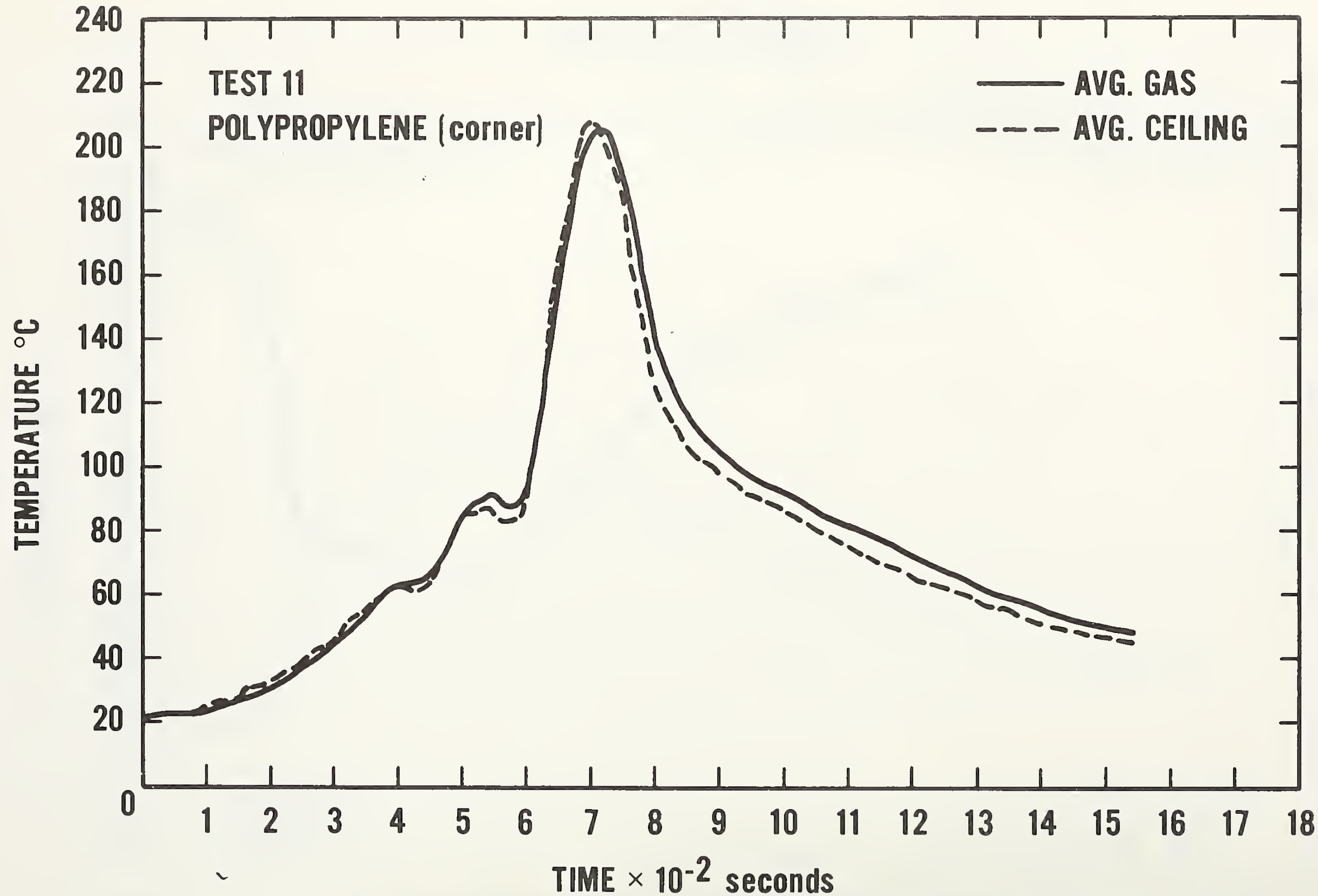


Figure 19. Average gas and ceiling temperatures for test 11

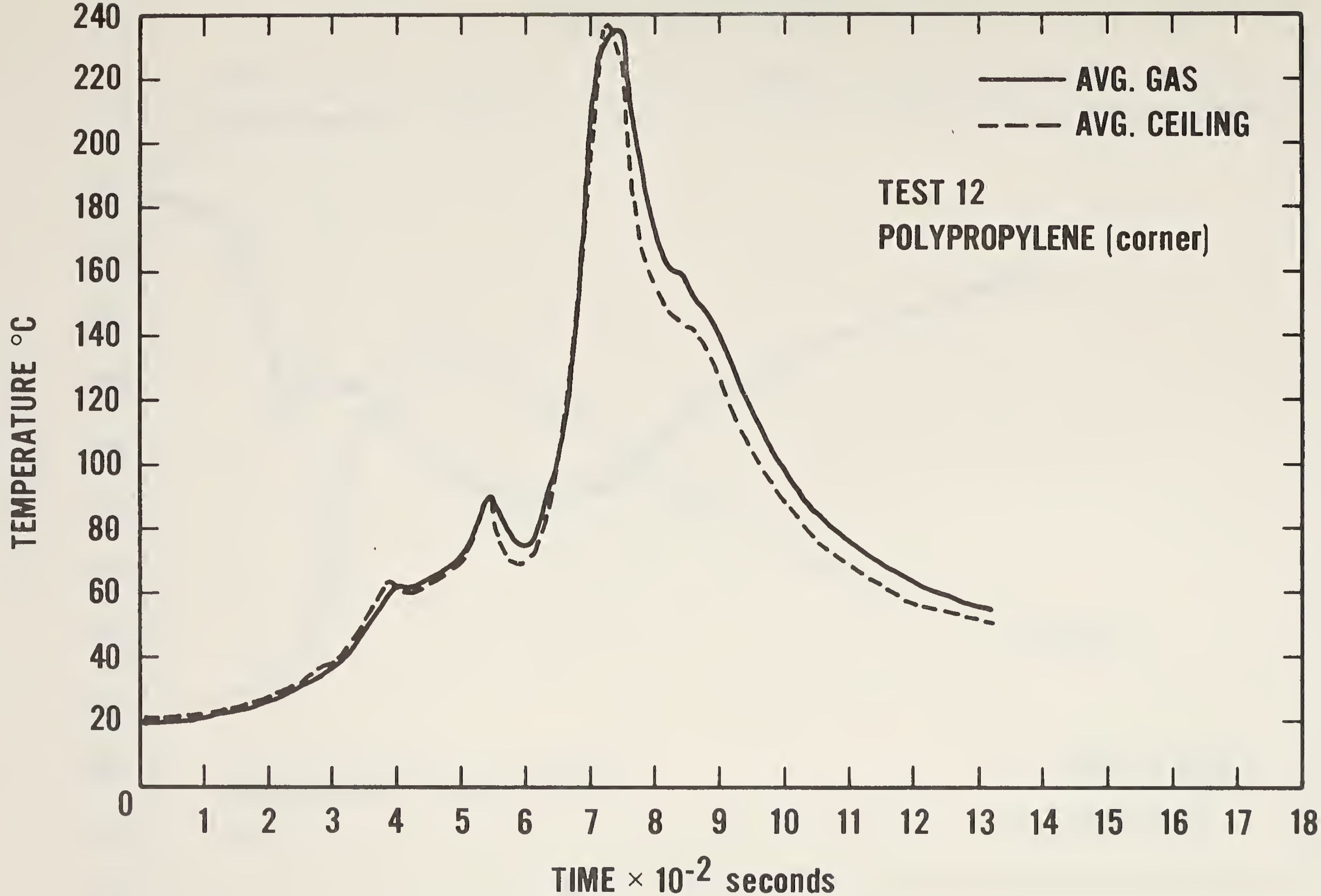


Figure 20. Average gas and ceiling temperatures for test 12

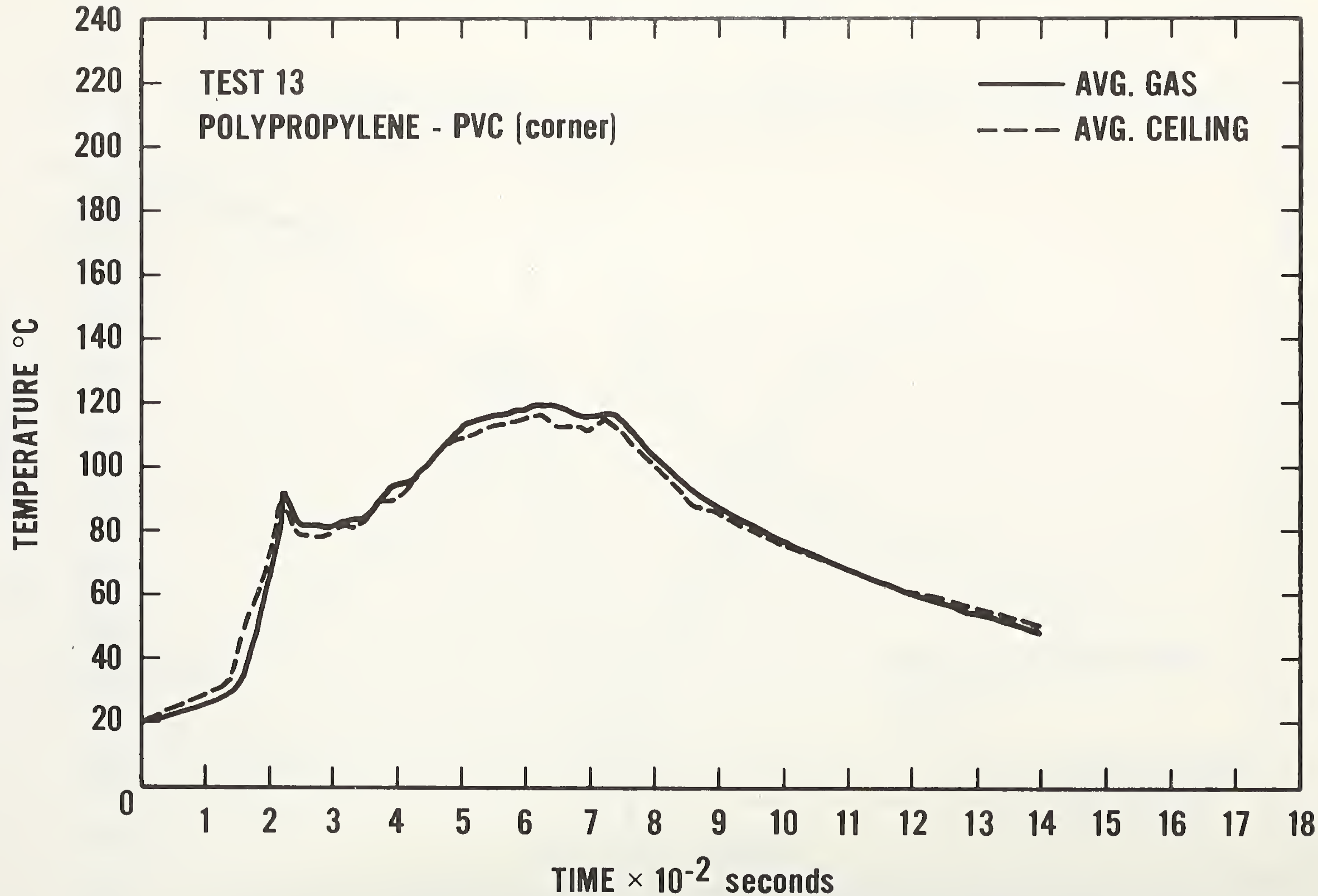


Figure 21. Average gas and ceiling temperatures for test 13

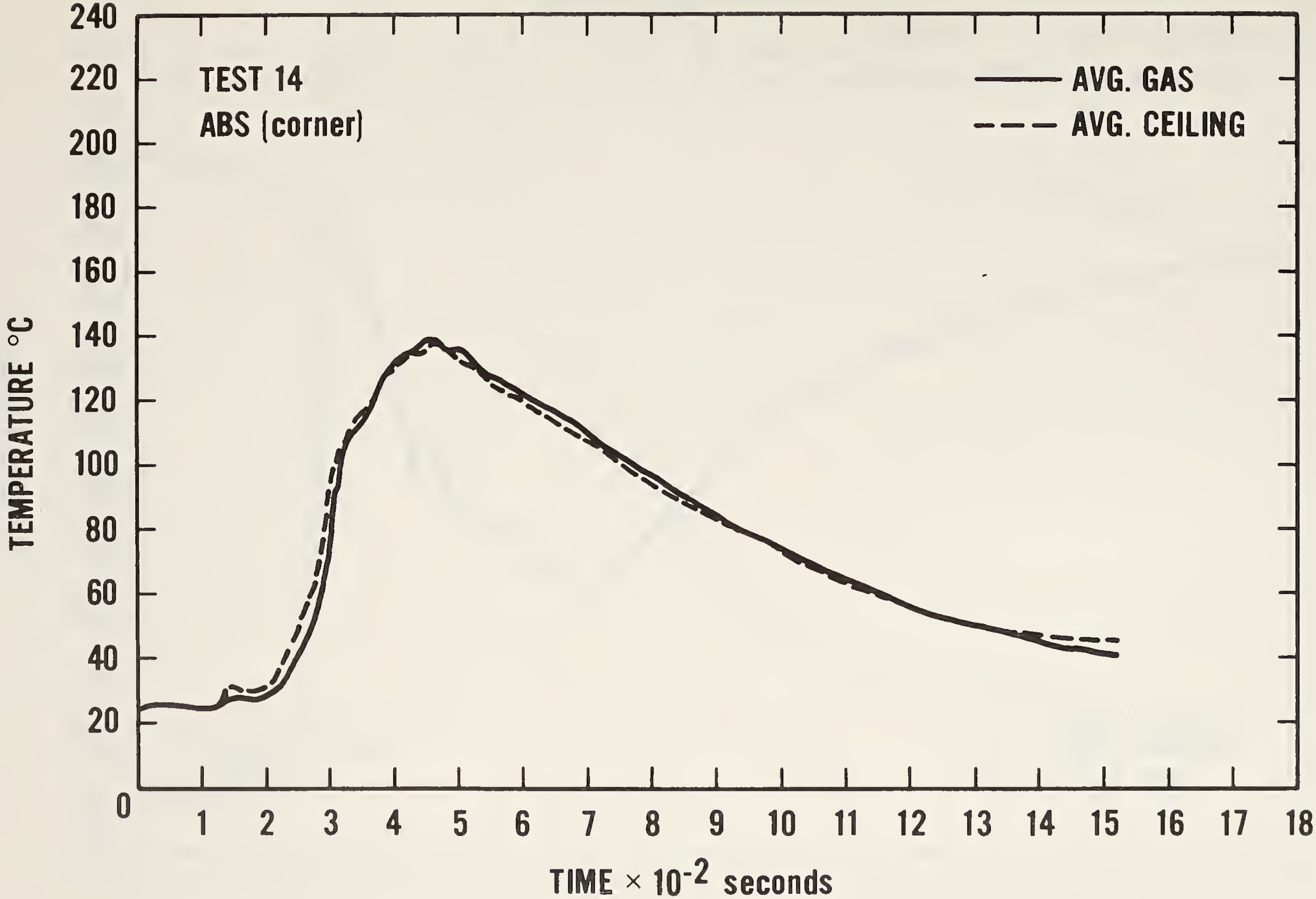


Figure 22. Average gas and ceiling temperatures for test 14

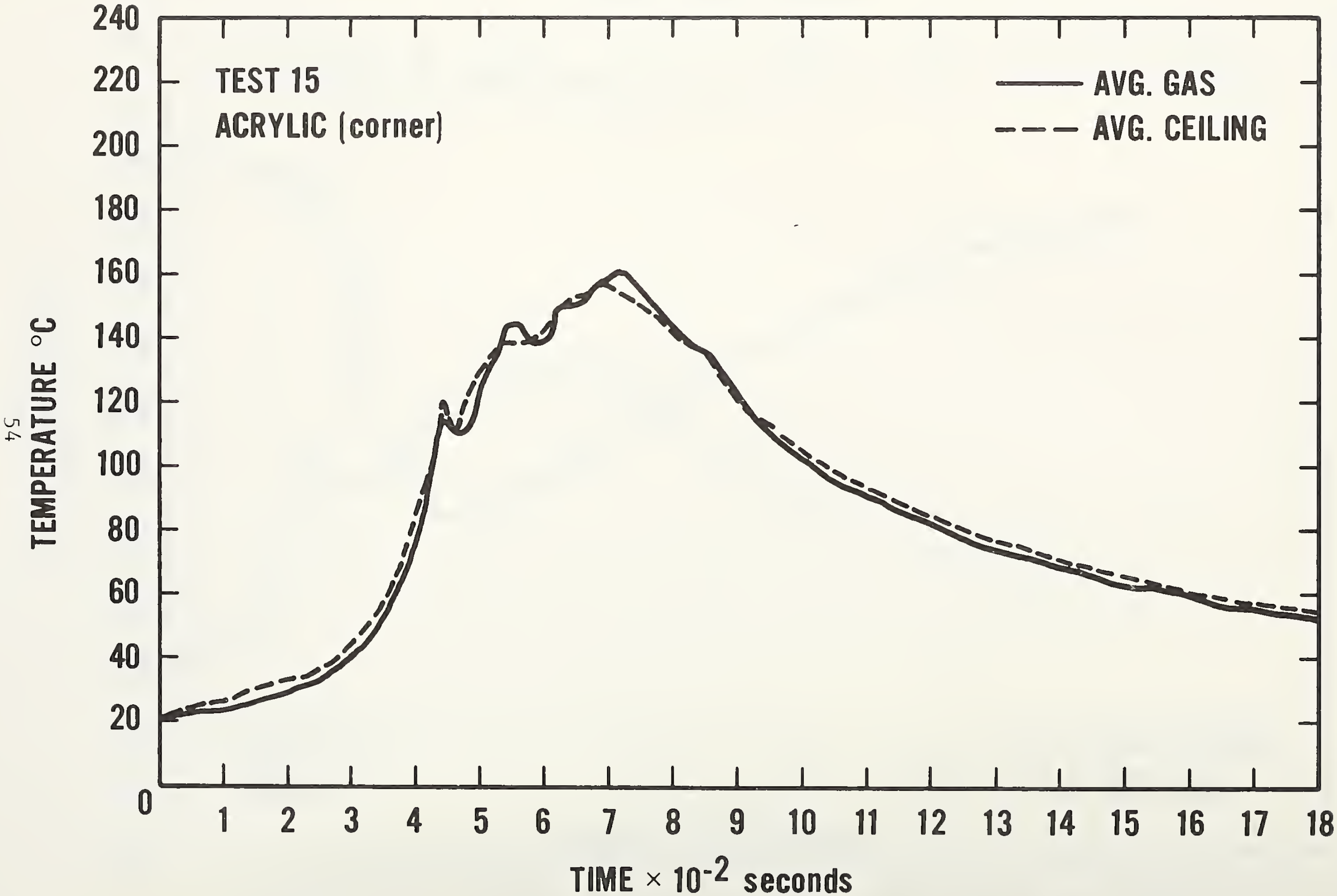


Figure 23. Average gas and ceiling temperatures for test 15

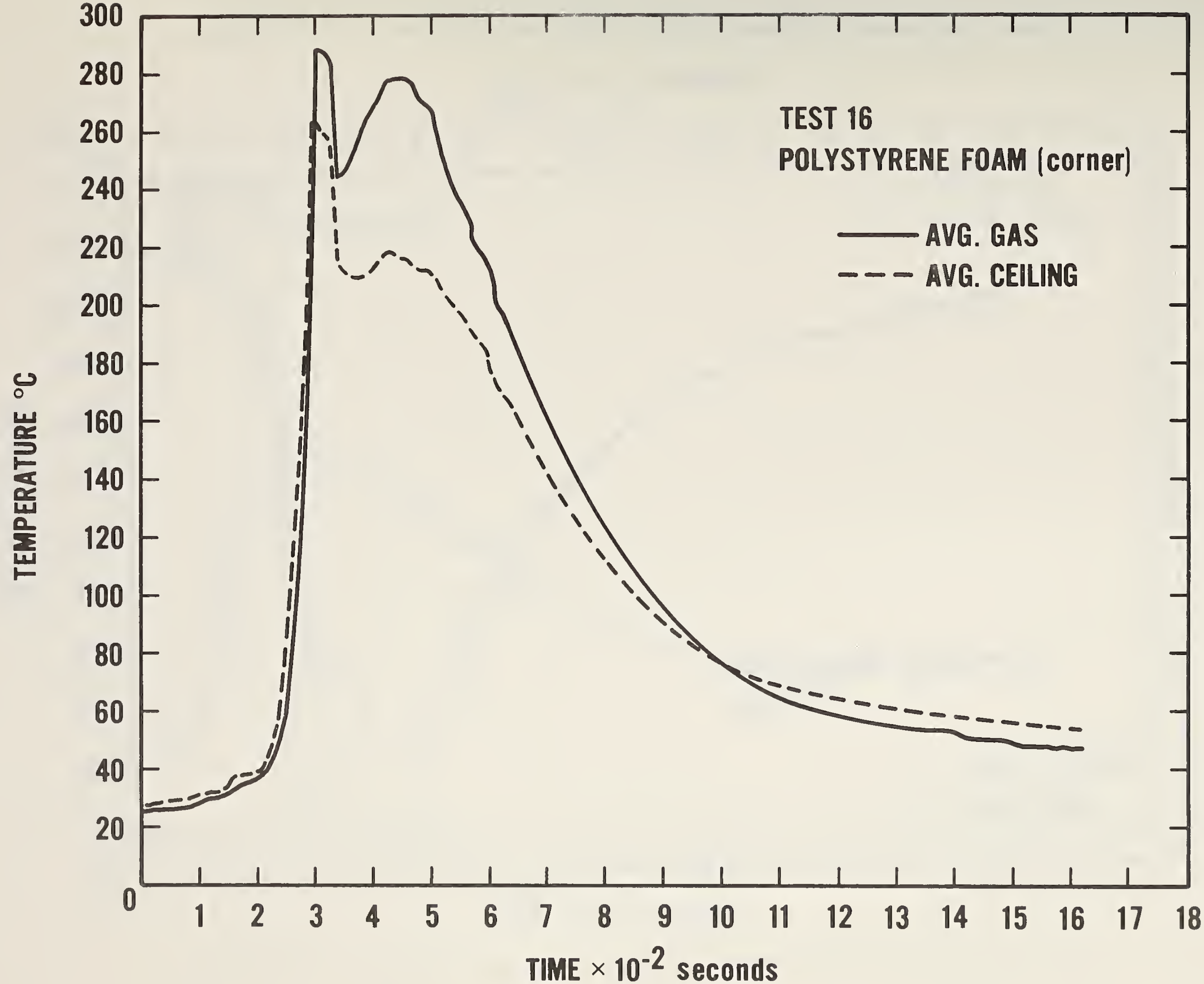


Figure 24. Average gas and ceiling temperatures for test 16

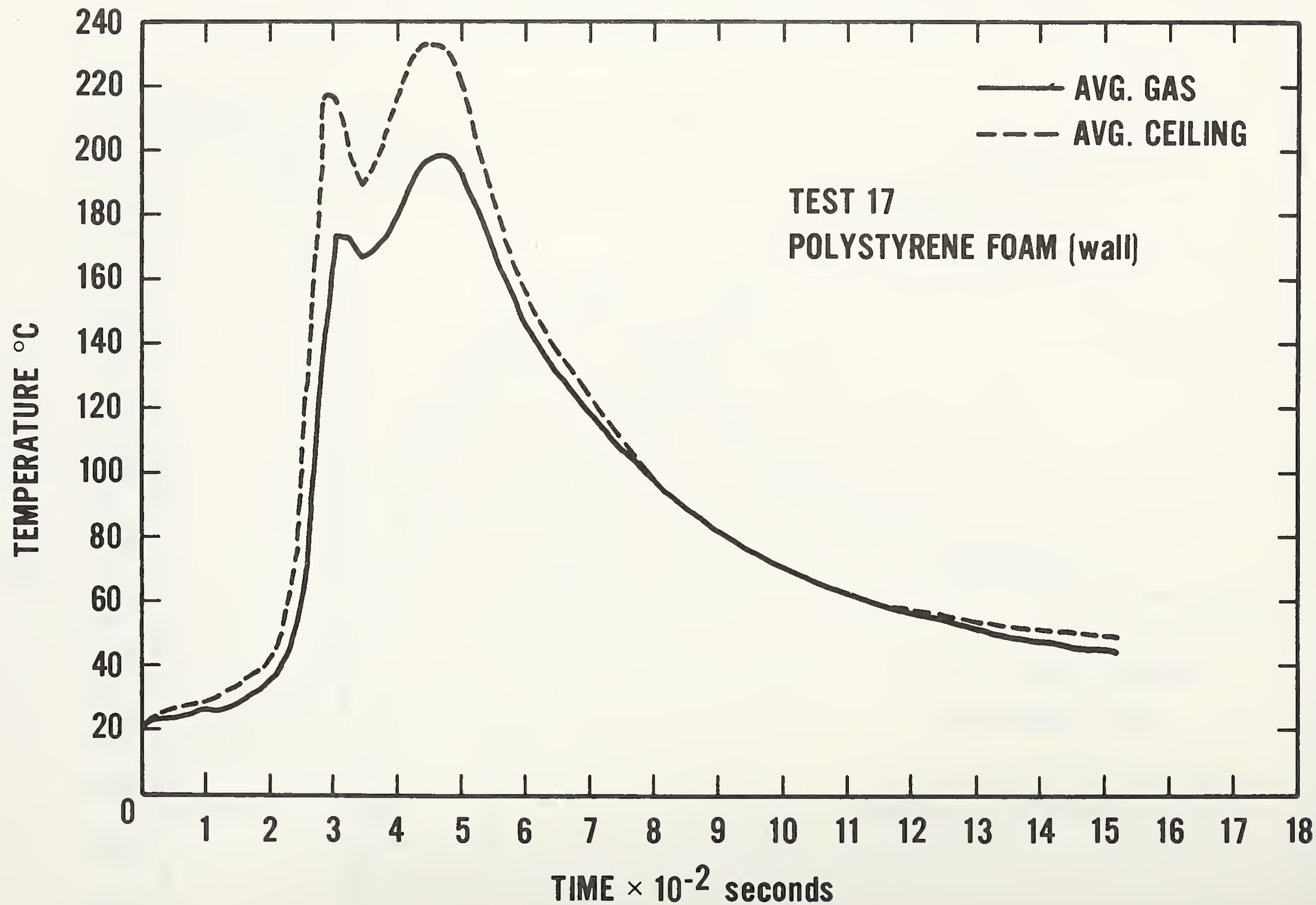


Figure 25. Average gas and ceiling temperatures for test 17

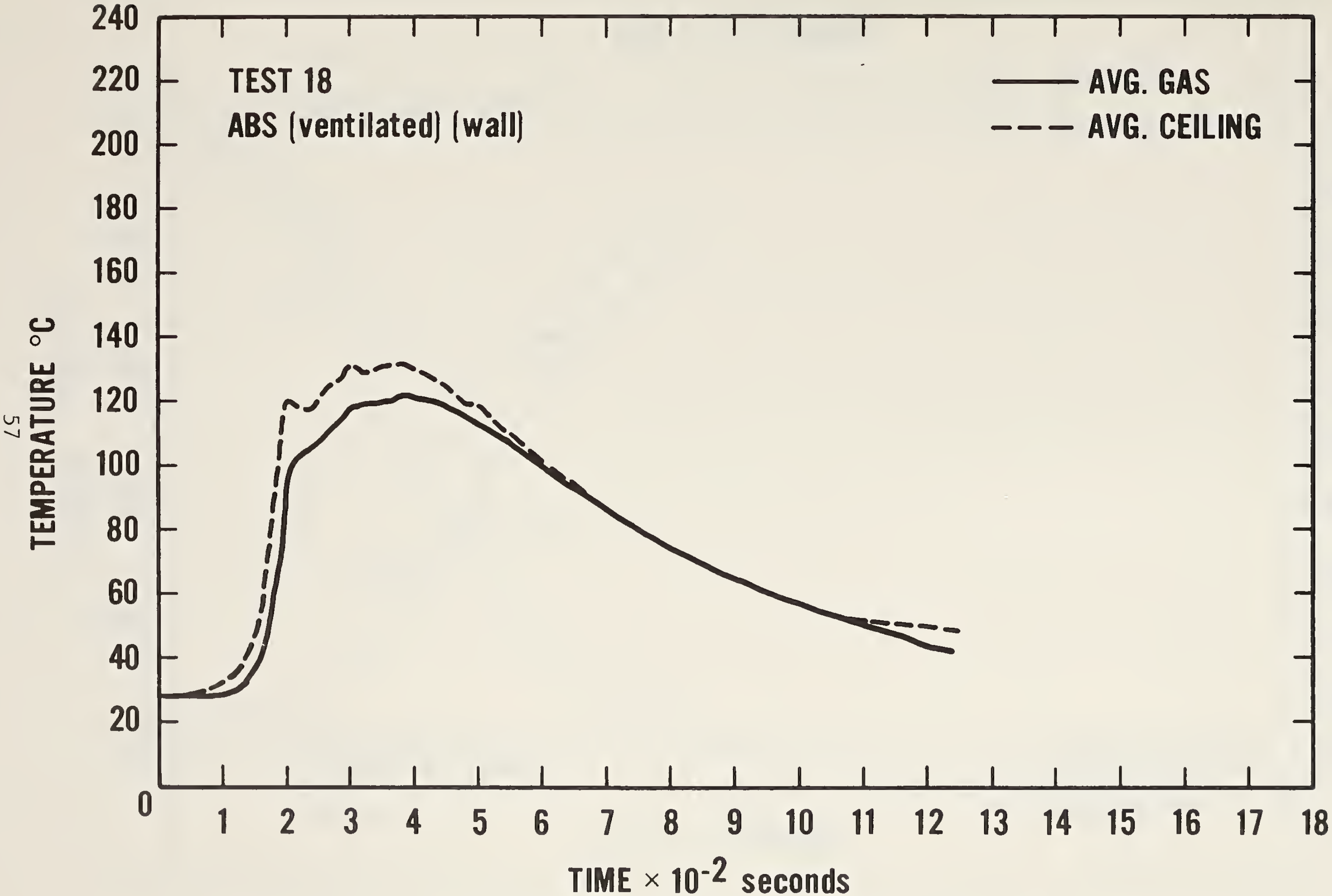


Figure 26. Average gas and ceiling temperatures for test 18

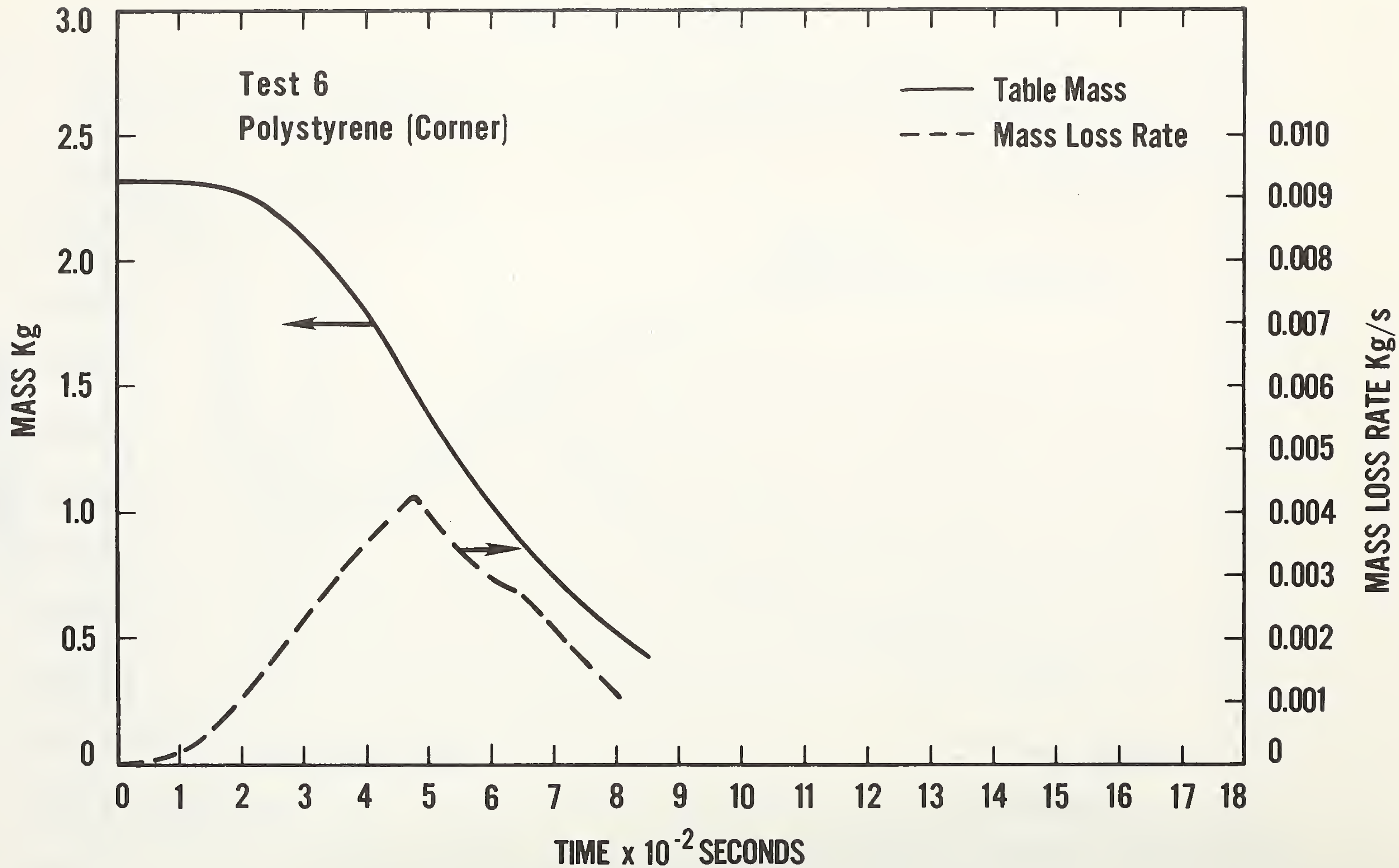


Figure 27. Table mass and mass loss rate for test 6

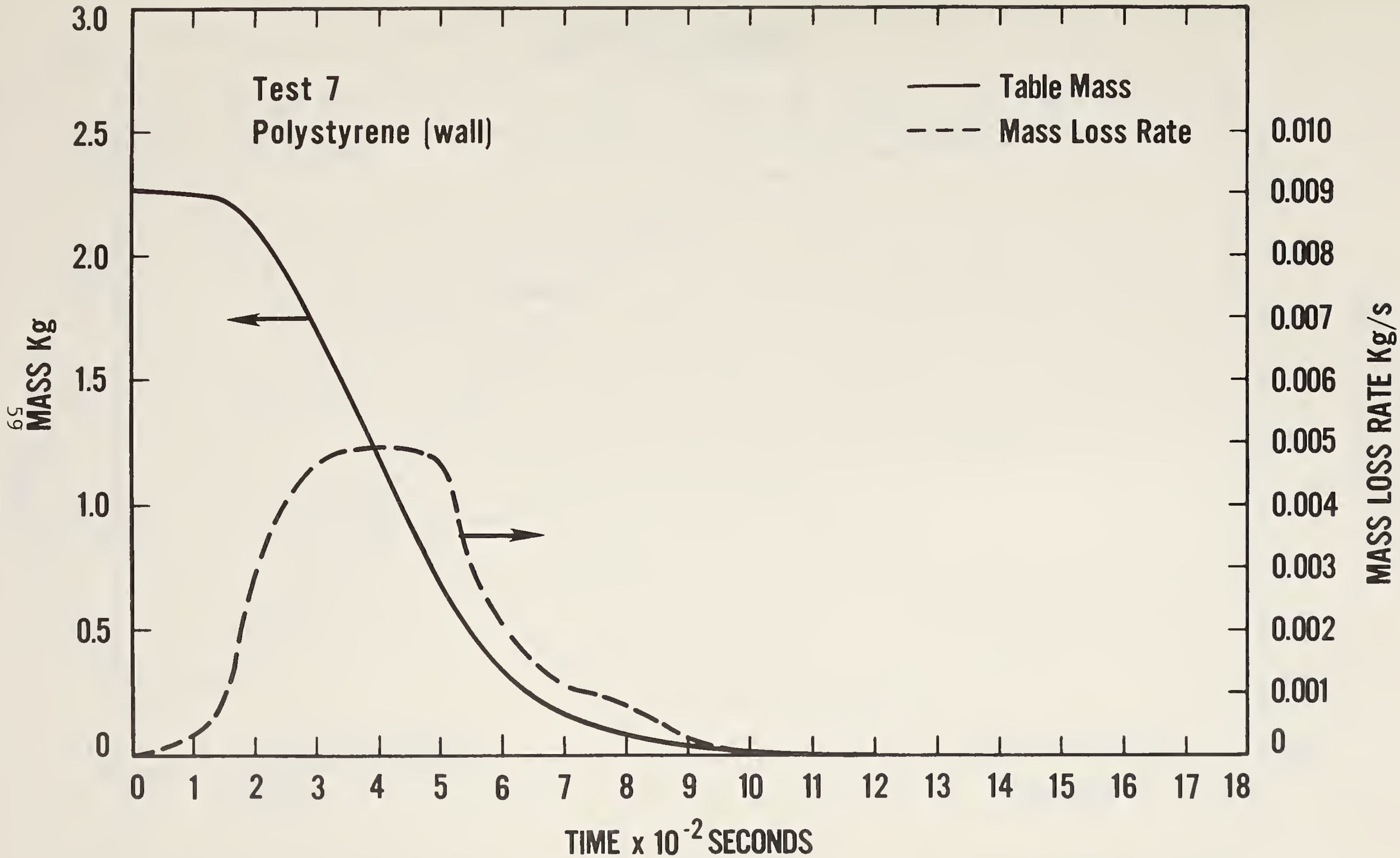


Figure 28. Table mass and mass loss rate for test 7

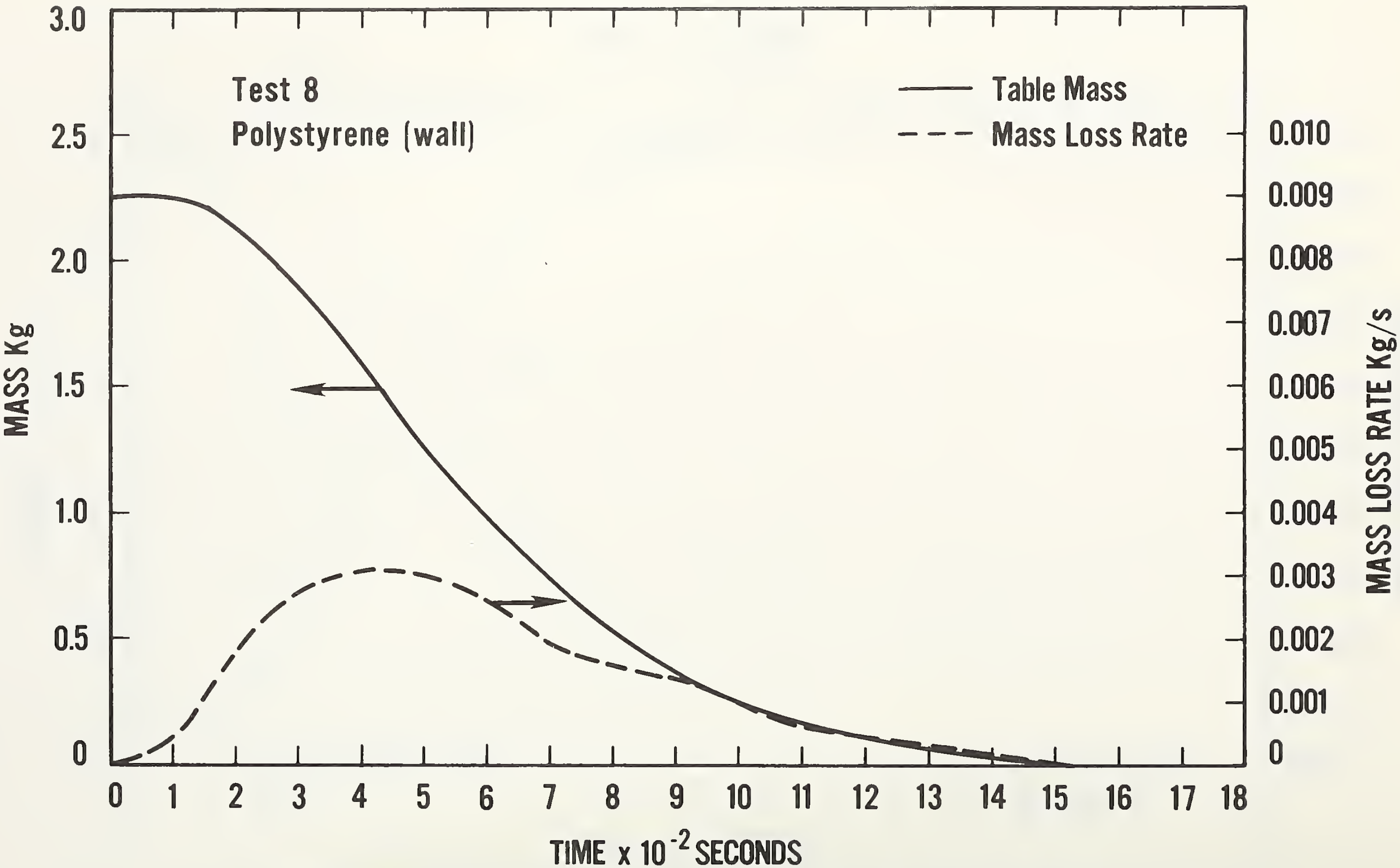


Figure 29. Table mass and mass loss rate for test 8

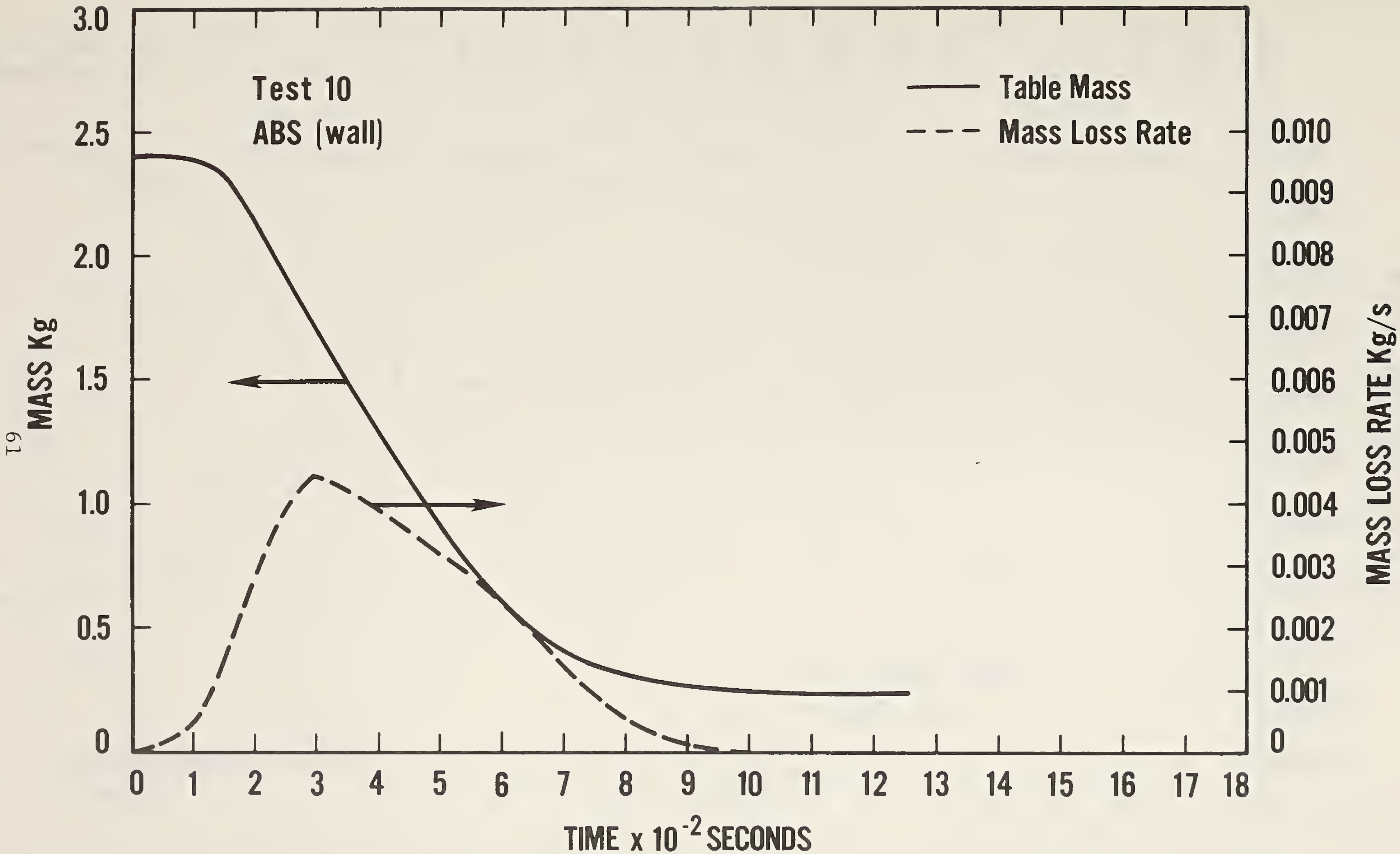


Figure 30. Table mass and mass loss rate for test 10

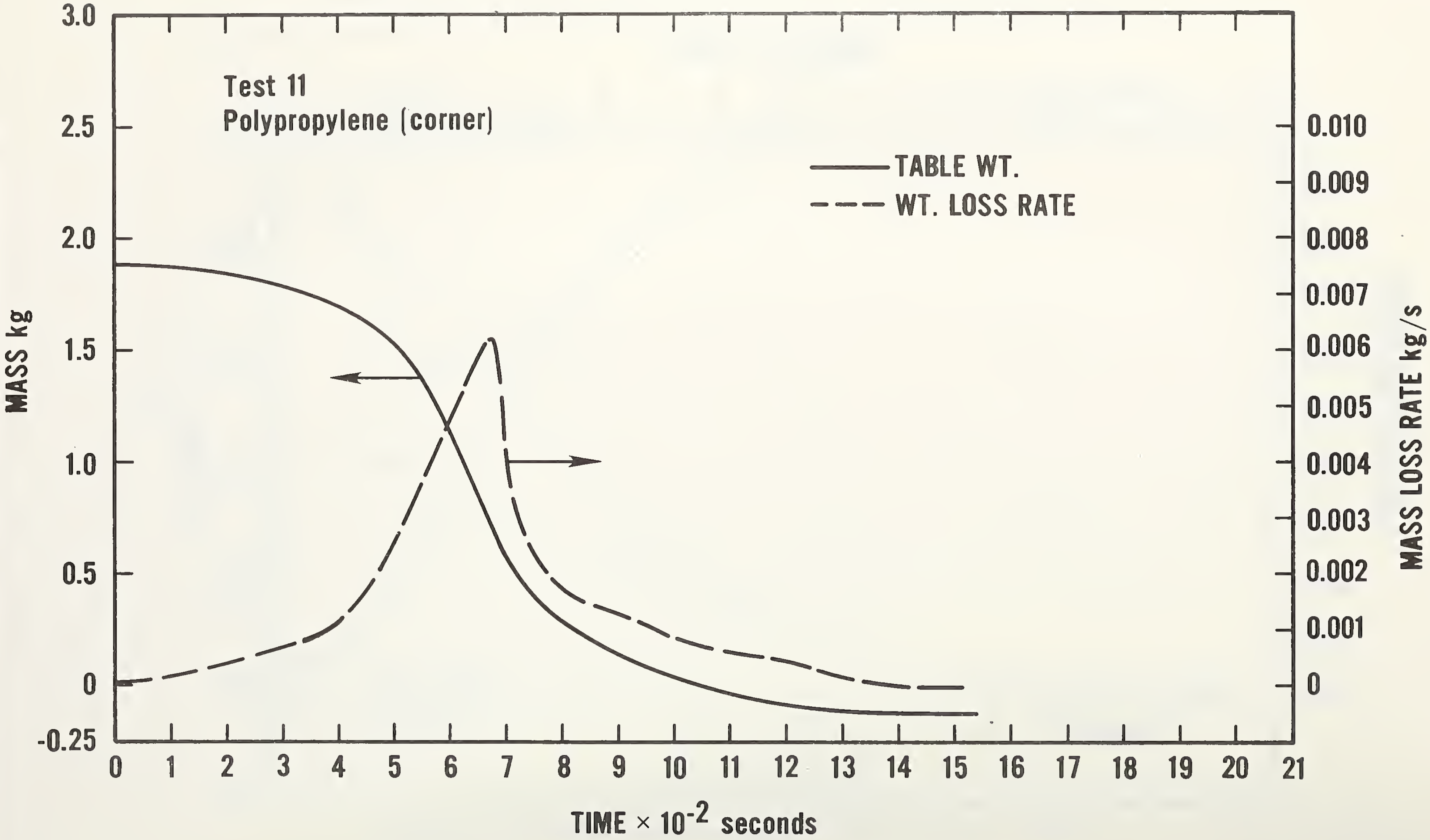


Figure 31. Table mass and mass loss rate for test 11

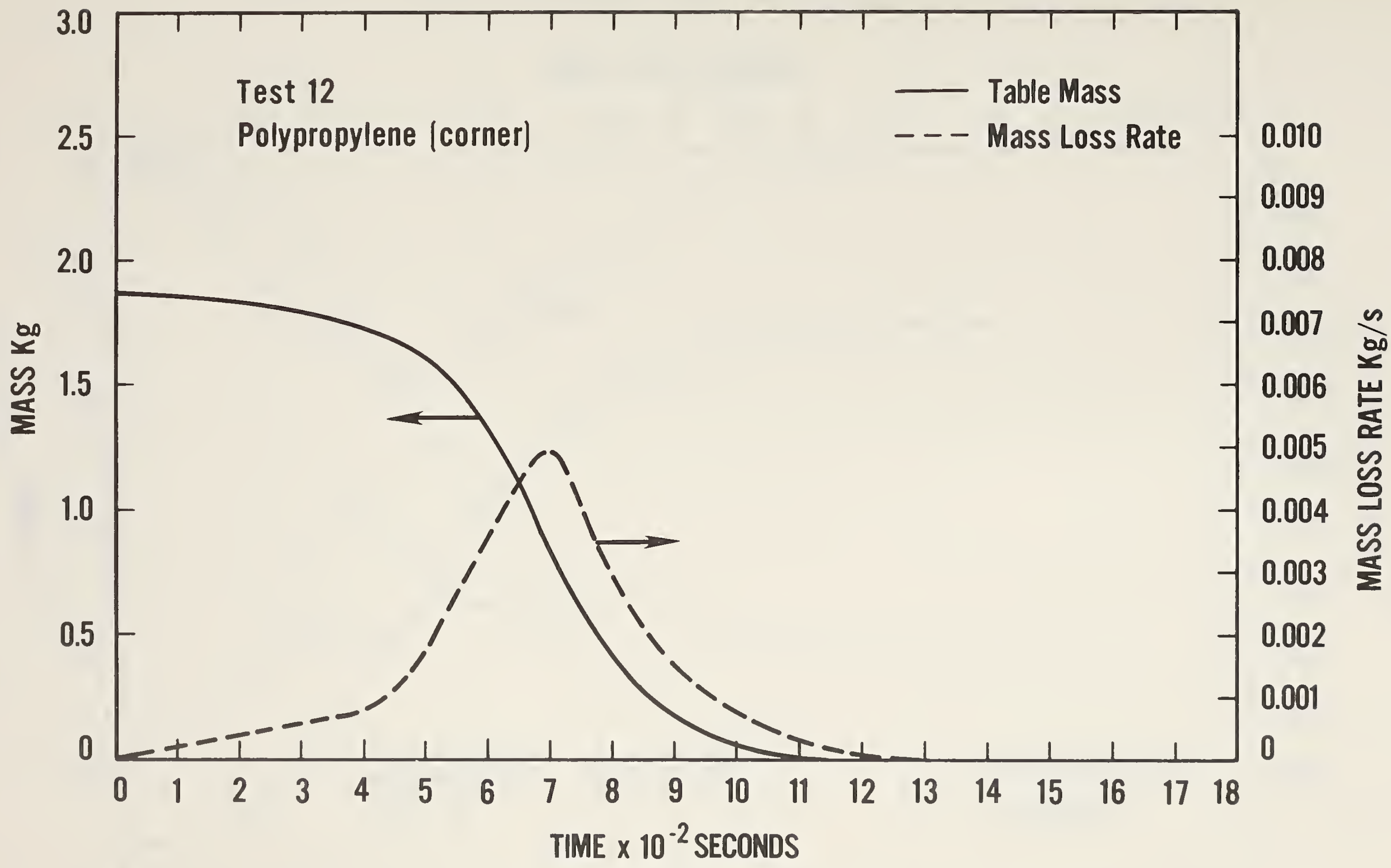


Figure 32. Table mass and mass loss rate for test 12

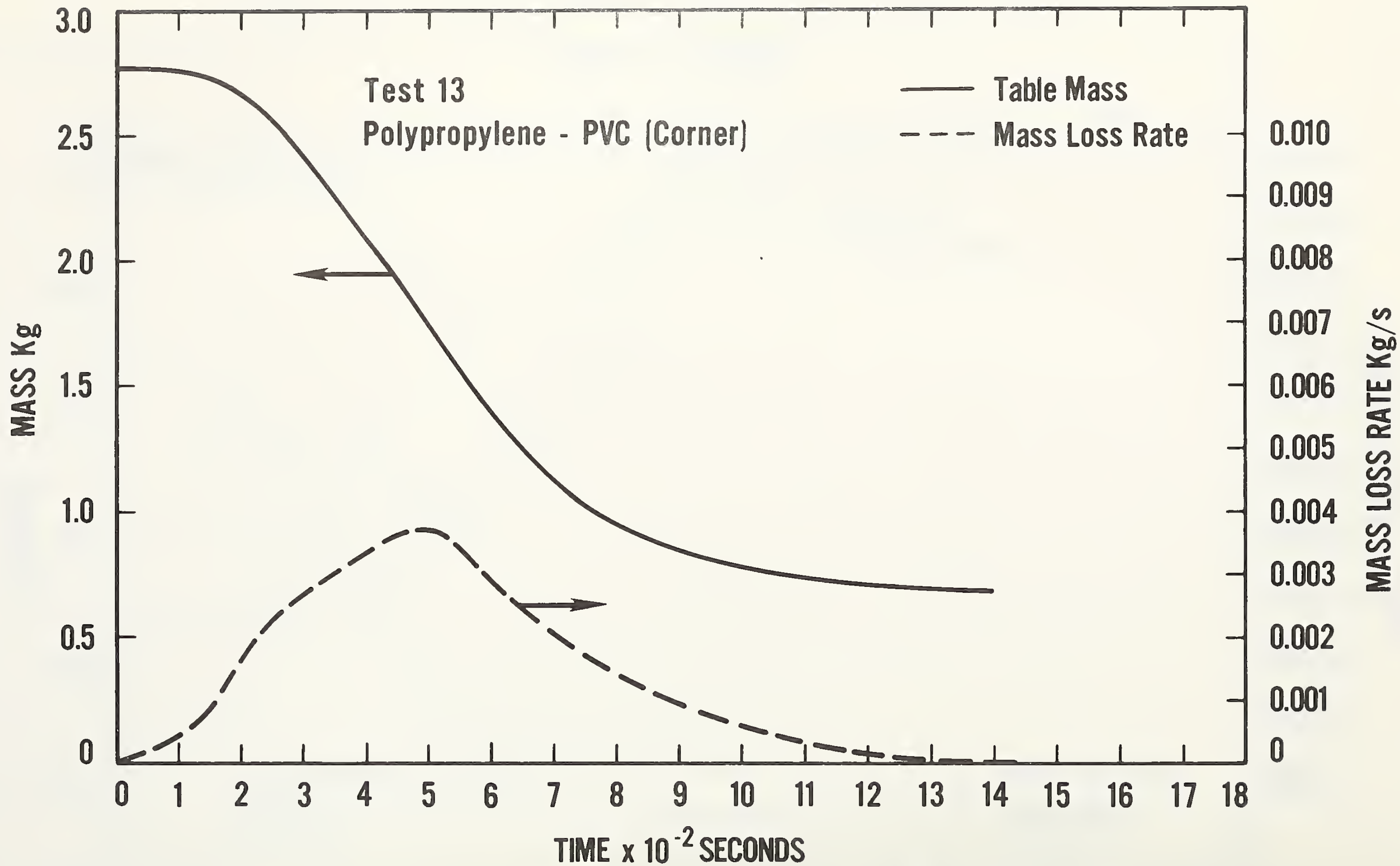


Figure 33. Table mass and mass loss rate for test 13

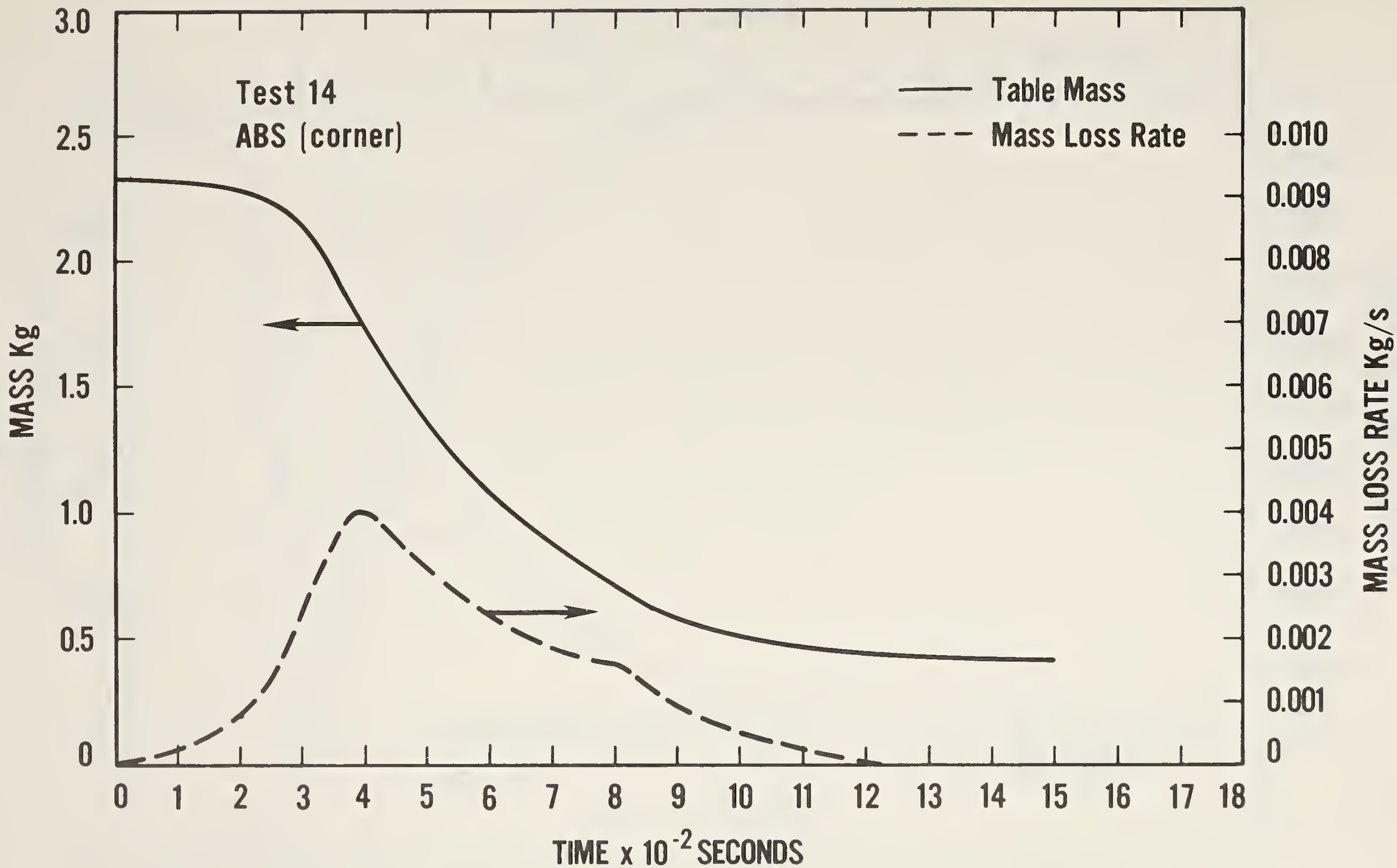


Figure 34. Table mass and mass loss rate for test 14

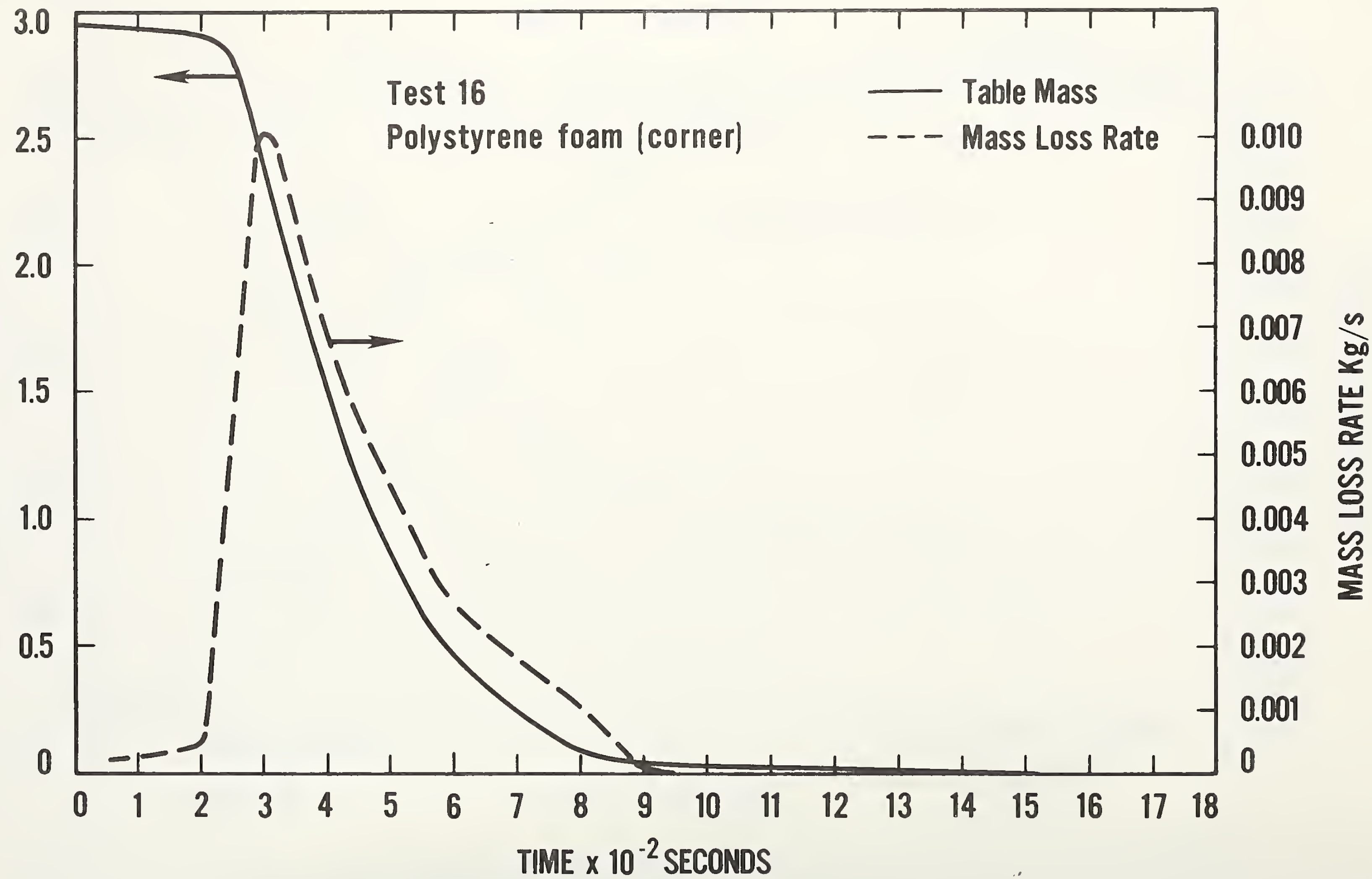


Figure 35. Table mass and mass loss rate for test 16

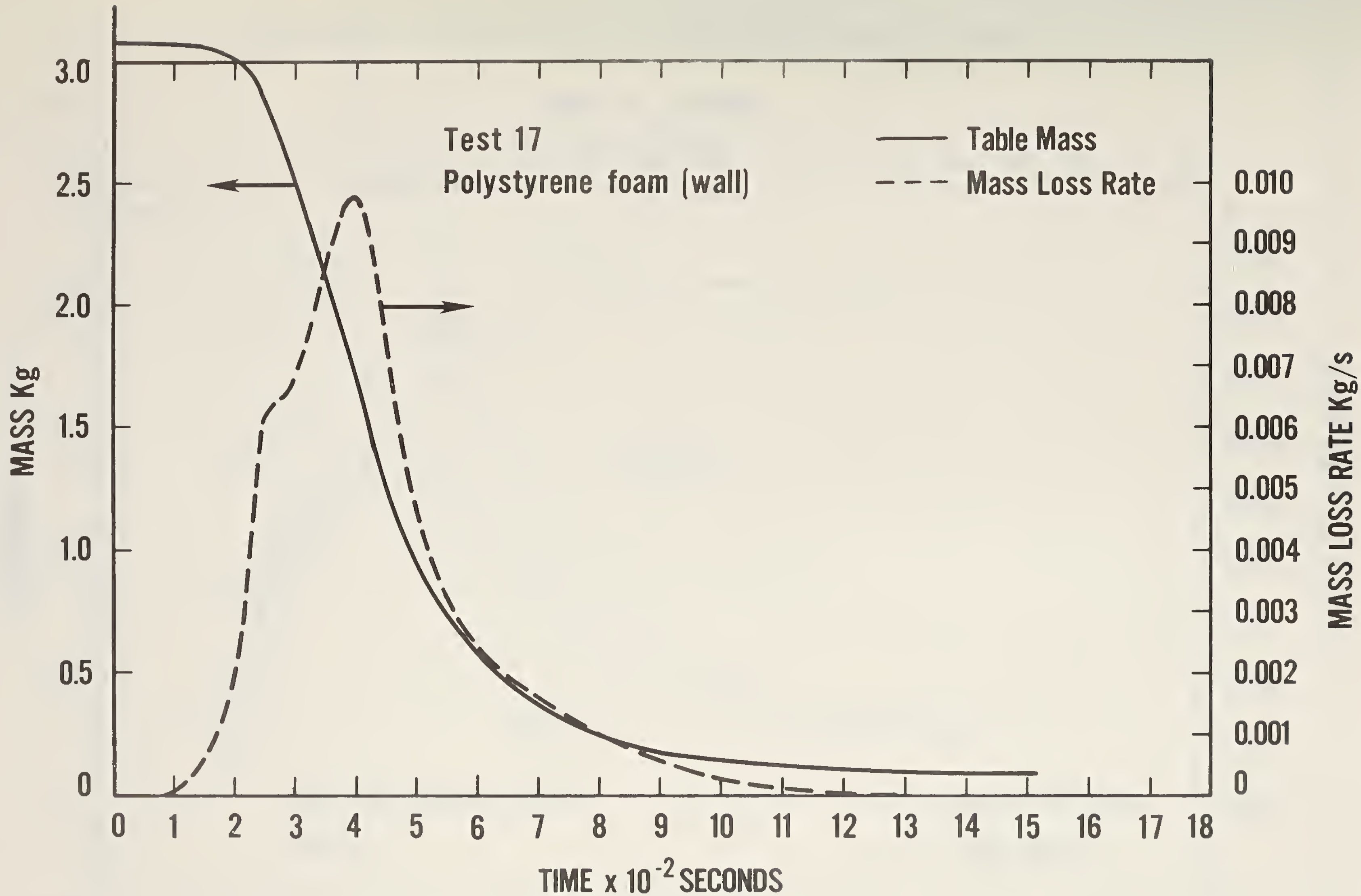


Figure 36. Table mass and mass loss rate for test 17

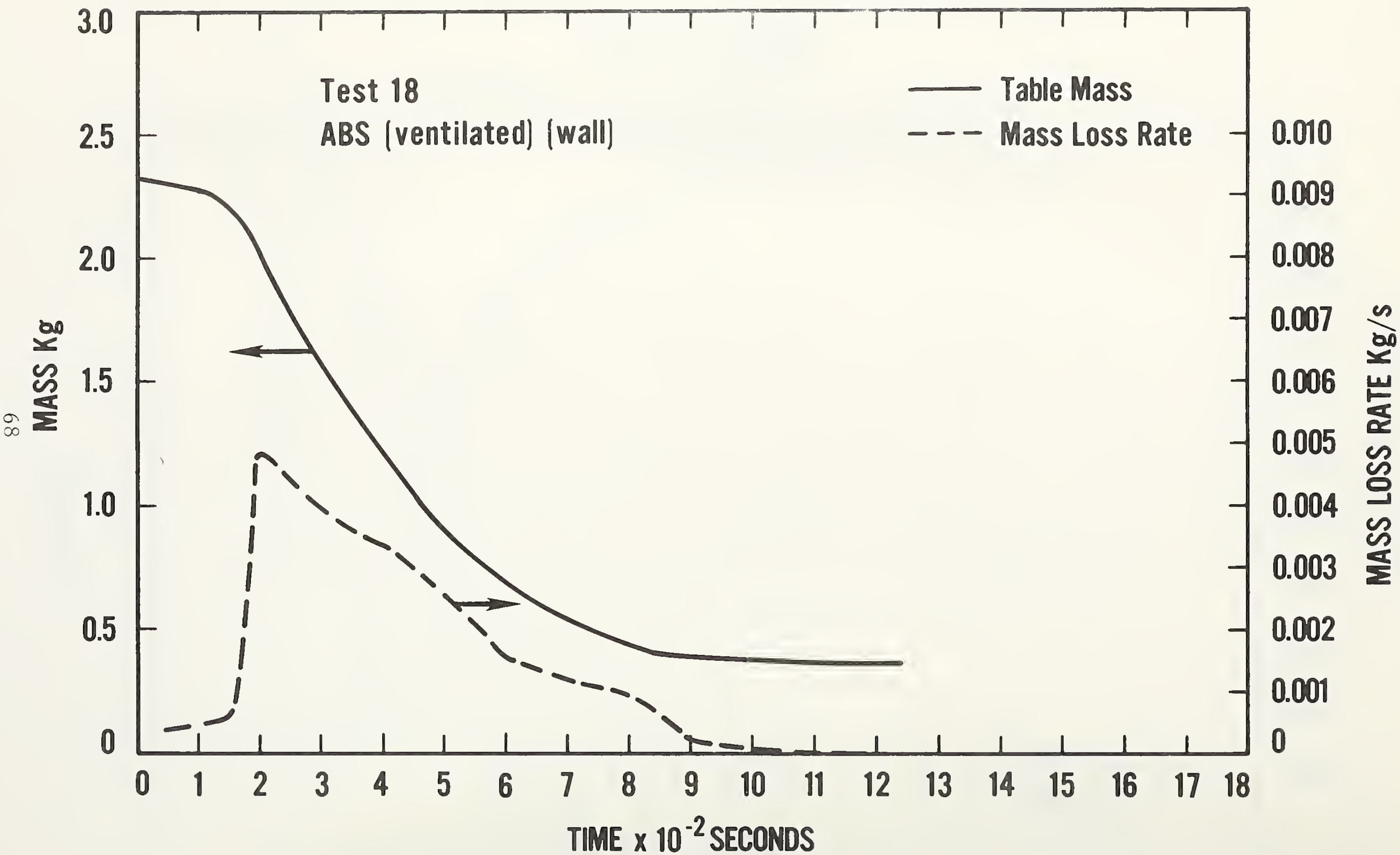


Figure 37. Table mass and mass loss rate for test 18

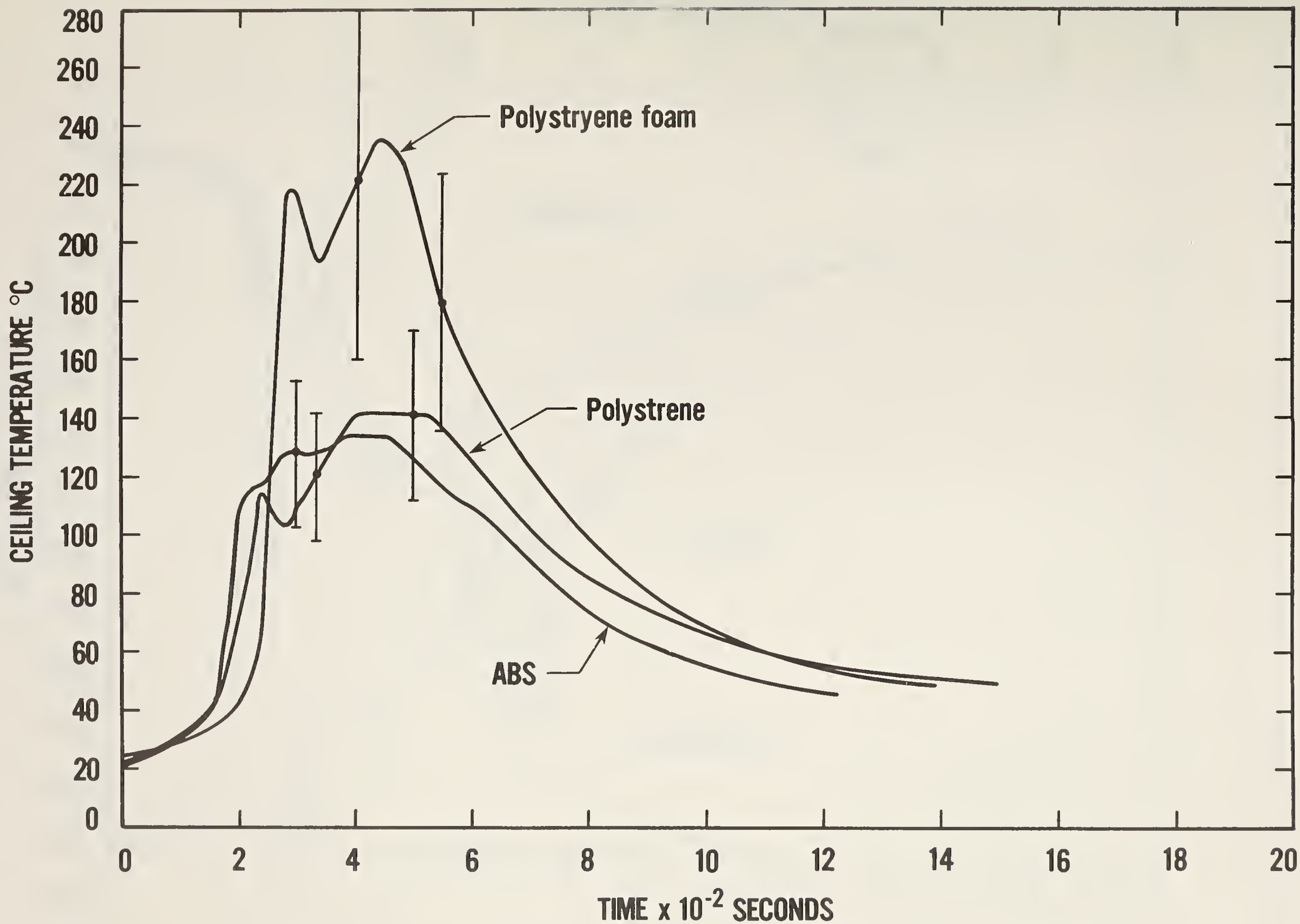


Figure 38. Average ceiling temperature for wall tests

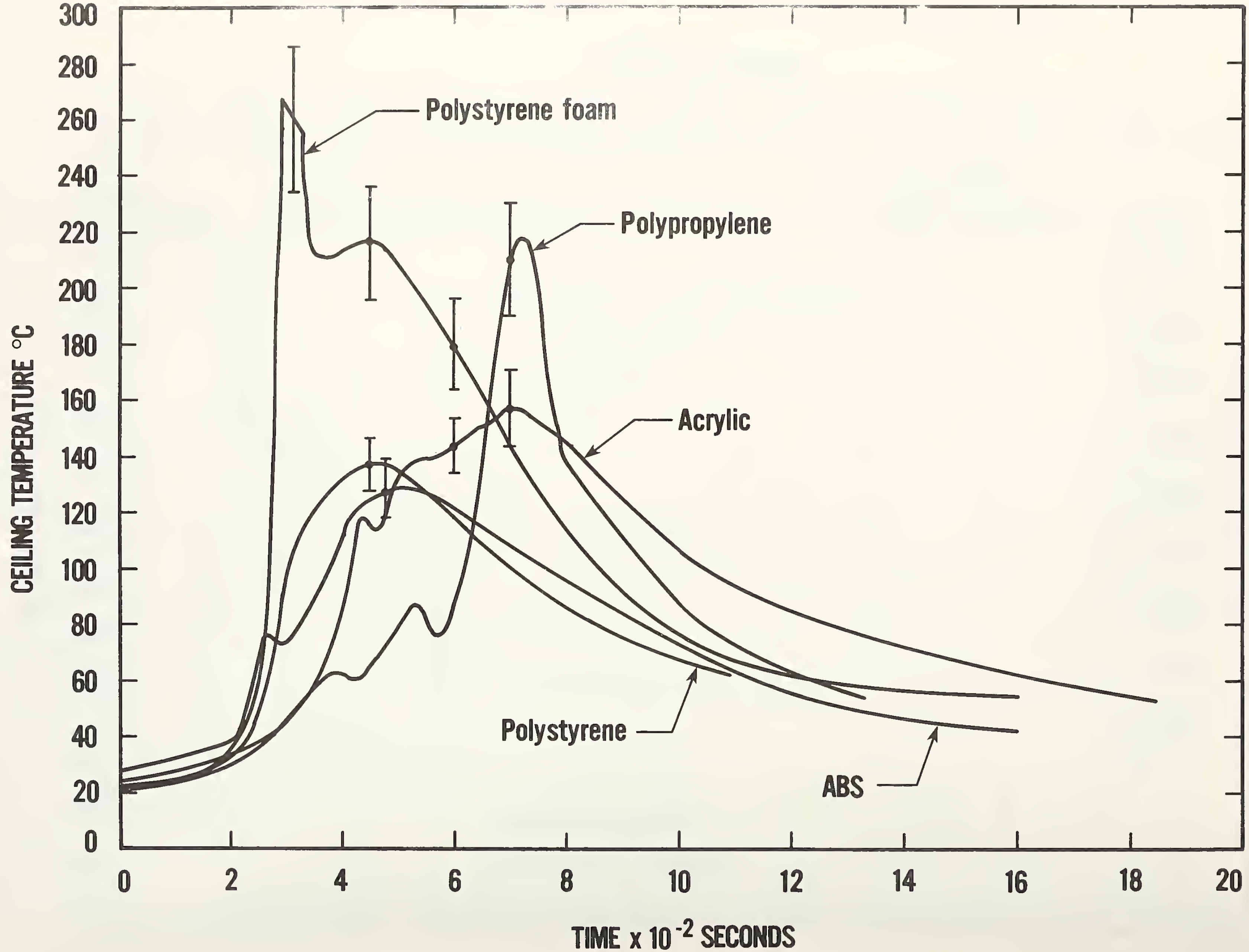


Figure 39. Average ceiling temperature for corner tests

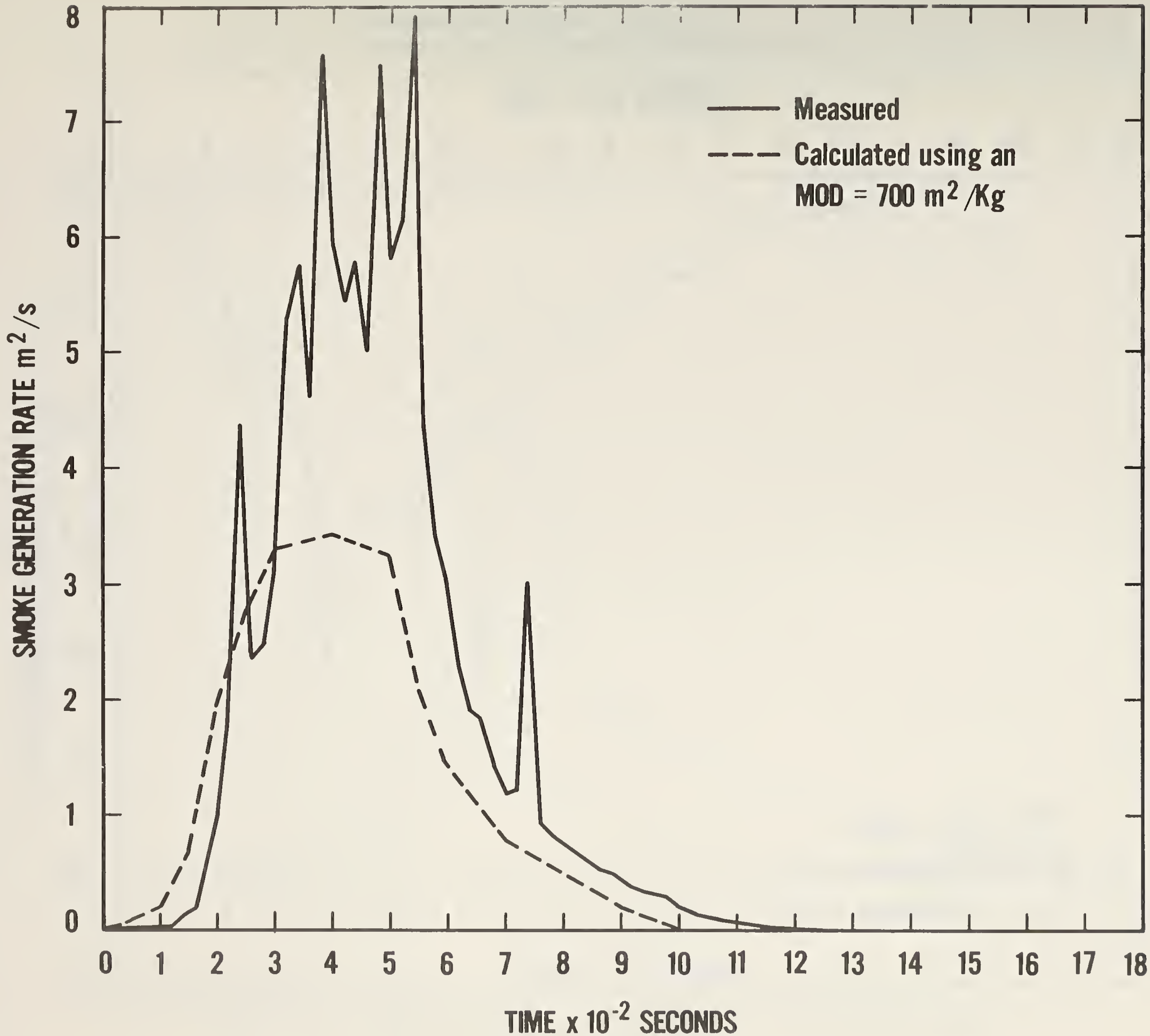


Figure 40. Comparison of calculated and measured smoke generation rates, test 7

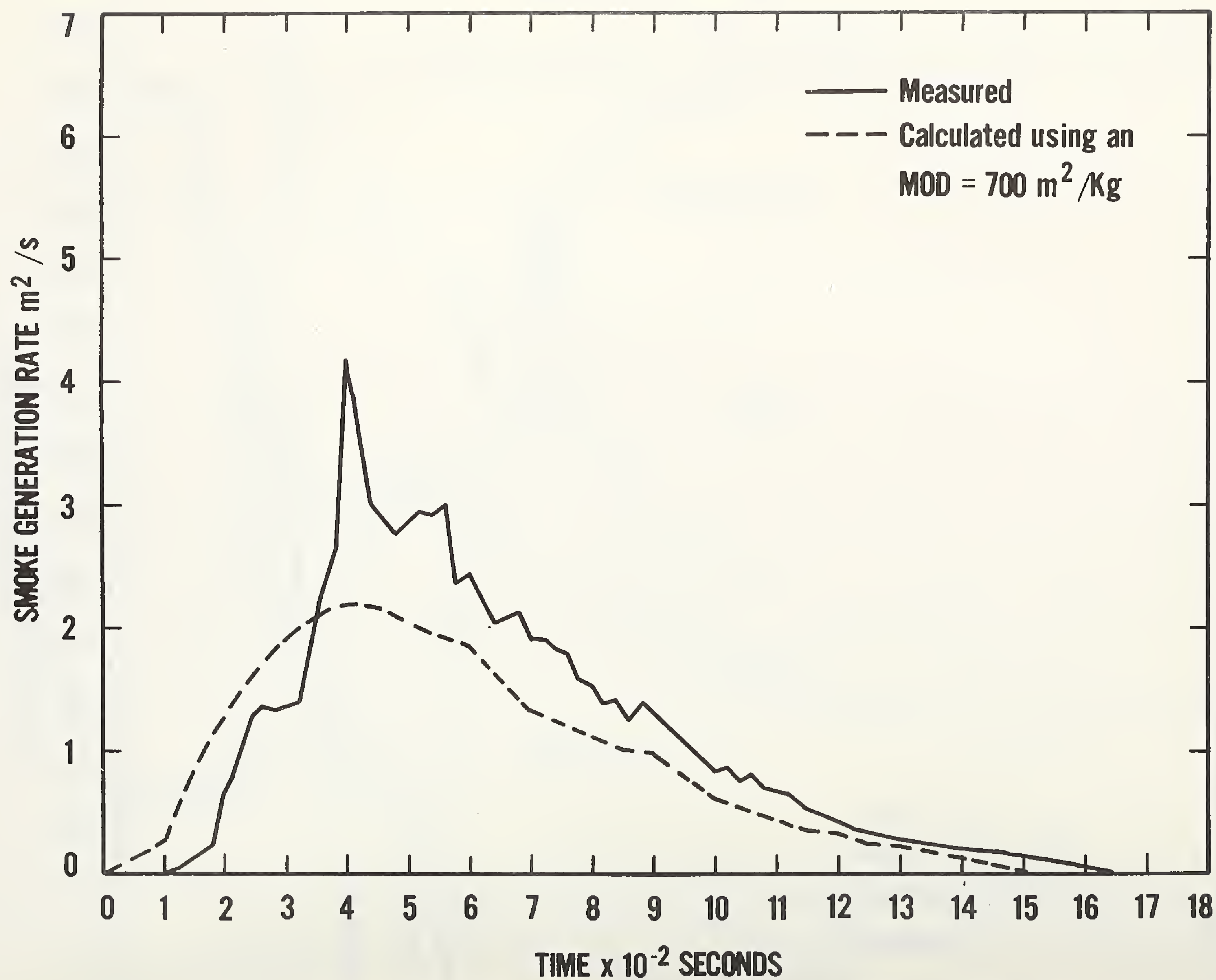


Figure 41. Comparison of calculated and measured smoke generation rates, test 8

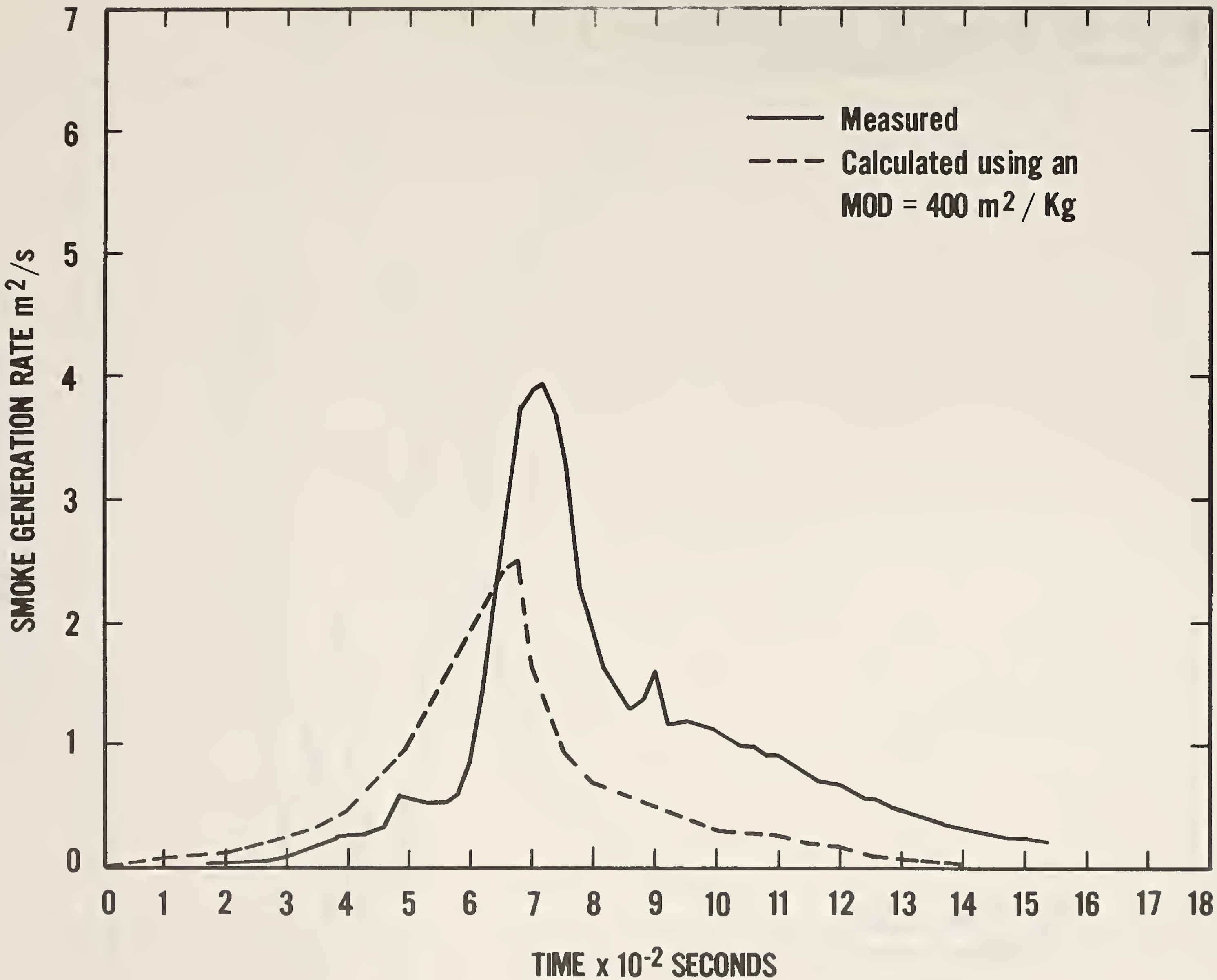


Figure 42. Comparison of calculated and measured smoke generation rates, test 11

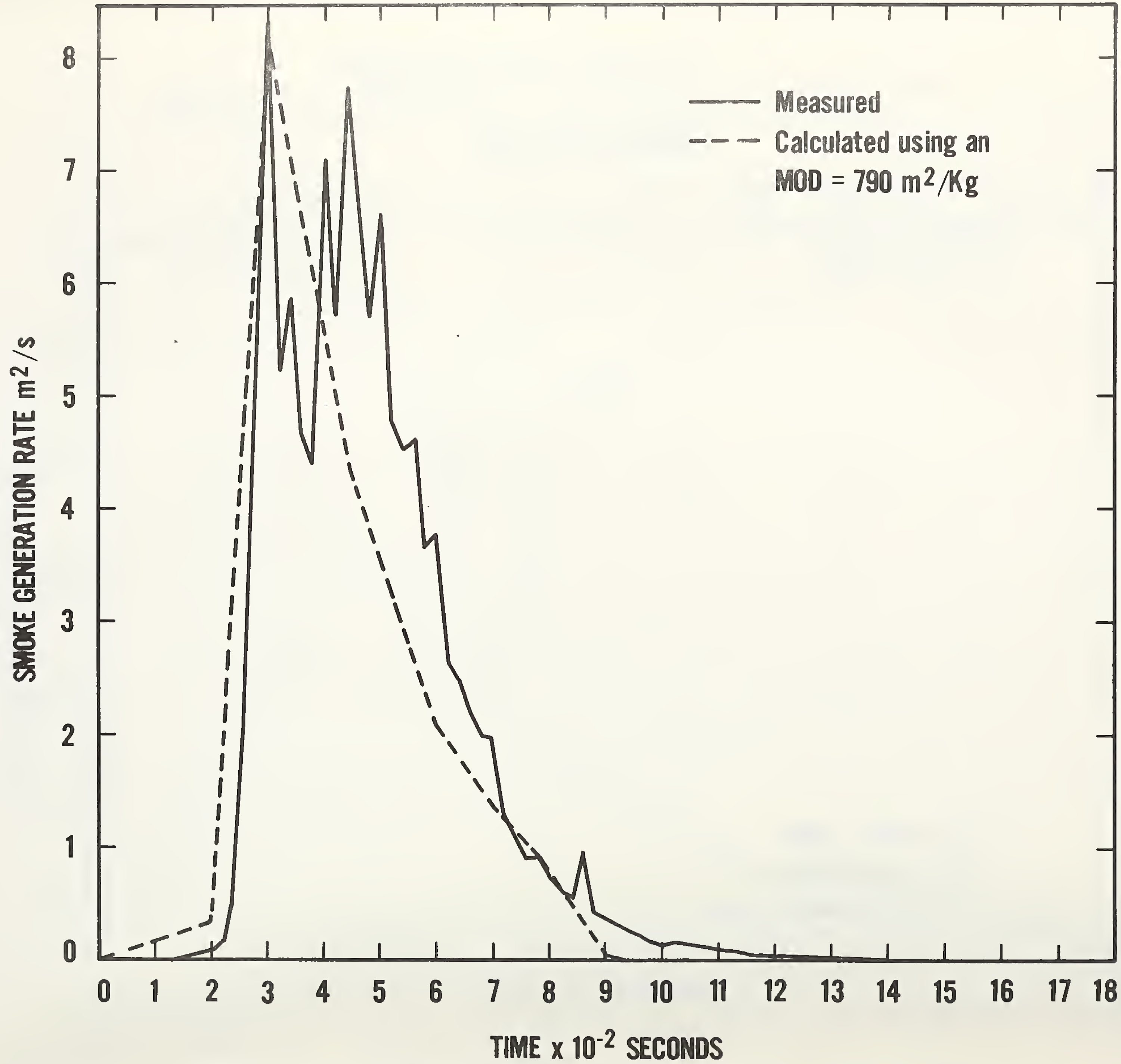


Figure 43. Comparison of calculated and measured smoke generation rates, test 16

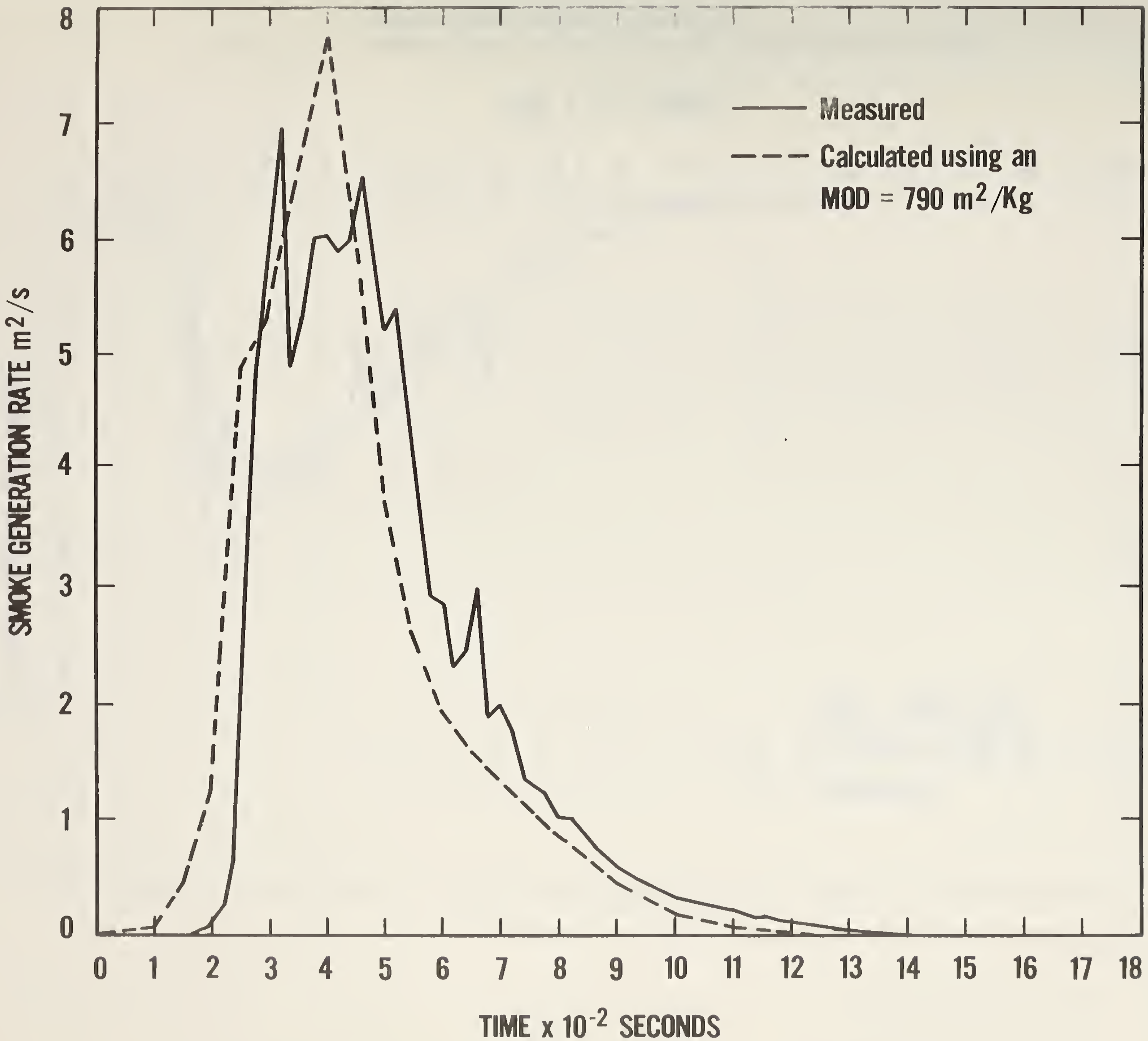


Figure 44. Comparison of calculated and measured smoke generation rates, test 17

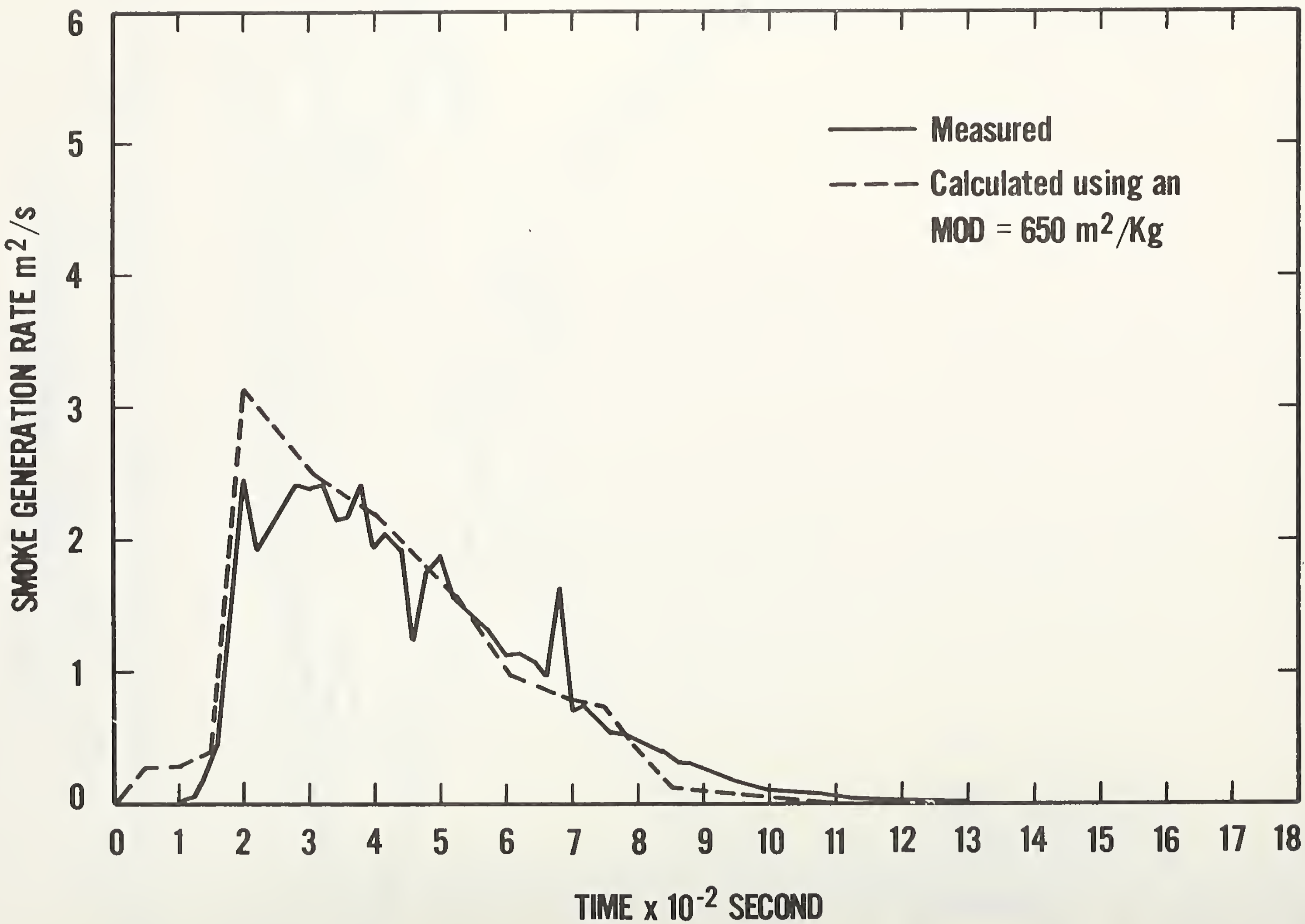


Figure 45. Comparison of calculated and measured smoke generation rates, test 18

Table 1

Parsons Table Tests

Test #	Date	Material	Shape *	Position in Room	Animal Evaluation	Video Tape
1	12-23-74	Wood	-	Middle		
2	12-23-74	Particle Board	A	Middle		Yes
3	12-23-74	Polystyrene	A	Middle		Yes
4	12-24-74	Polystyrene	A	Middle		Yes
5	12-30-74	Polystyrene	A	SE Corner		Yes
6	12-31-74	Polystyrene	A	SE Corner		Yes
7	1-21-75	Polystyrene	A	E Wall	Yes	Yes
8	1-21-75	Polystyrene	A	E Wall		Yes
9	1-22-75	Polypropylene ABS	B	E Wall	Yes	
10	1-23-75	ABS	A	E Wall	Yes	
11	1-23-75	Polypropylene	A	SE Corner	Yes	
12	1-24-75	Polypropylene	A	SE Corner	Yes	Yes
13	1-27-75	Polypropylene PVC	B	SE Corner	Yes	Yes
14	1-27-75	ABS	A	SE Corner		Yes
15	1-28-75	Acrylic	A	SE Corner	Yes	Yes
16	1-28-75	Polystyrene Foam	D	SE Corner		Yes
17	1-30-75	Polystyrene Foam	D	E Wall		Yes
18	1-30-75	ABS	A	E Wall		Yes

* See Figure 1

Table 2

Instrumentation - Data Channel Numbers

Data Channel #	Description
1	Thermocouple - center of burn room 0.03m down from ceiling
2	Thermocouple - center of burn room 1.07m down from ceiling
3	Thermocouple - center of burn room 1.52m down from ceiling
4	Thermocouple - center of burn room 2.13m down from ceiling
5	Thermocouple - southeast corner of burn room 0.30m down from ceiling
6	Thermocouple - southeast corner of burn room 0.91m down from ceiling
7	Thermocouple - southeast corner of burn room 1.37m down from ceiling
8	Thermocouple - southeast corner of burn room 2.13m down from ceiling
9	Thermocouple - southeast corner of burn room 0.30m down from ceiling
10	Thermocouple - northeast corner of burn room 0.91m down from ceiling
11	Thermocouple - northeast corner of burn room 1.52m down from ceiling
12	Thermocouple - northeast corner of burn room 2.13m down from ceiling
13	Thermocouple - northwest corner of burn room 0.30m down from ceiling
14	Thermocouple - northwest corner of burn room 0.76m down from ceiling
15	Thermocouple - northwest corner of burn room 1.52m down from ceiling
16	Thermocouple - northwest corner of burn room 1.83m down from ceiling
17	Thermocouple - southwest corner of burn room 0.30m down from ceiling
18	Thermocouple - southwest corner of burn room 0.91m down from ceiling
19	Thermocouple - southwest corner of burn room 1.52m down from ceiling
20	Thermocouple - southwest corner of burn room 2.13m down from ceiling
21	Thermocouple - 0.91m from E. wall and S. wall in burn room 0.076m from ceiling
22	Thermocouple - 0.91m from E. wall and S. wall in burn room 0.102m from ceiling
23	Thermocouple - 0.91m from E. wall and S. wall in burn room 0.30m from ceiling
24	Thermocouple - 0.91m from E. wall and S. wall in burn room 0.61m from ceiling
25	Thermocouple - 0.91m from E. wall and S. wall in burn room 0.91m from ceiling
26	Thermocouple - 0.91m from E. wall and S. wall in burn room 1.22m from ceiling
27	Thermocouple - 0.91m from E. wall and S. wall in burn room 1.52m from ceiling
28	Thermocouple - 0.91m from E. wall and S. wall in burn room 1.83m from ceiling
29	Thermocouple - 0.91m from E. wall and S. wall in burn room 2.44m from ceiling
30	Thermocouple - northeast corner of burn room 0.30m down from ceiling
31	Thermocouple - northwest corner of burn room 0.30m down from ceiling
32	Thermocouple - northwest corner of burn room 1.22m down from ceiling
33	Thermocouple - northwest corner of burn room 2.13m down from ceiling
34	Thermocouple - southwest corner of burn room 0.30m down from ceiling
35	Thermocouple - on S. wall of burn room 1.83m down and 1.22m from west wall
36	Thermocouple - on S. wall of burn room 0.61m down and 2.44m from west wall
37	Thermocouple - on E. wall of burn room 1.83m down and 1.22m from S. wall
38	Thermocouple - back up for #37 on outside surface of wall
39	Thermocouple - on E. wall of burn room 0.61m down and 1.22m from S. wall
40	Thermocouple - opposite #39 on outside surface of wall
41	Thermocouple - on N. wall of burn room 1.83m down and 1.22m from E. wall
42	Thermocouple - opposite #41 on outside surface of wall
43	Thermocouple - on N. wall of burn room 0.61m down and 1.07m from W. wall
44	Thermocouple - opposite #43 on outside surface of wall
45	Thermocouple - on center line of burn room ceiling 0.30m from E. wall
46	Thermocouple - on center line of burn room ceiling 1.83m from E. wall

Table 2 (Cont'd)

Data Channel #	Description
47	Thermocouple - opposite #46 on outside surface of ceiling
48	Thermocouple - on center line of burn room ceiling 2.74m from E. wall
49	Thermocouple - opposite #48 on outside surface of ceiling
50	Thermocouple - on center line of burn room ceiling 3.35m from E. wall
51	Thermocouple - on burn room ceiling 0.91m from W. wall and S. wall
52	Thermocouple - on burn room ceiling 0.91m from E. wall and S. wall
53	Thermocouple - on burn room ceiling 0.91m from E. wall and N. wall
54	Thermocouple - opposite #53 on outside surface of ceiling
55	Thermocouple - on burn room ceiling 0.91m from W. wall and N. wall
56	Thermocouple - center of burn room doorway 0.089m down from top of door
57	Thermocouple - center of burn room doorway 0.127m down from top of door
58	Thermocouple - center of burn room doorway 0.30m down from top of door
59	Thermocouple - center of burn room doorway 0.61m down from top of door
60	Thermocouple - center of burn room doorway 0.91m down from top of door
61	Thermocouple - center of burn room doorway 1.22m down from top of door
62	Thermocouple - center of burn room doorway 1.52m down from top of door
63	Thermocouple - center of burn room doorway 1.68m down from top of door
64	Thermocouple - halfway from center of doorway to its S. side 0.127m down from top
65	Thermocouple - halfway from center of doorway to its S. side 1.52m down from top
66	Thermocouple - center of adjacent room 0.30m down from ceiling
67	Thermocouple - center of adjacent room 0.91m down from ceiling
68	Thermocouple - center of adjacent room 1.52m down from ceiling
69	Thermocouple - center of adjacent room 2.13m down from ceiling
70	Thermocouple - center of adjacent room doorway 0.30m down from top of door
71	Thermocouple - center of adjacent room doorway 0.91m down from top of door
72	Thermocouple - center of adjacent room doorway 1.52m down from top of door
73	Thermocouple - center of adjacent room doorway 2.13m down from top of door
74	Thermocouple - on burn room floor 0.91m from east and south walls
75	Thermocouple - on burn room floor 1.07m from north and east walls
76	Thermocouple - on burn room floor in northwest corner
77	Thermocouple - on burn room floor in southwest corner
78	Thermocouple - on burn room floor on door centerline 0.61m from east wall
79	Thermocouple - on burn room floor on door centerline 2.59m from east wall
80	Thermocouple - on burn room floor on door centerline 3.05m from east wall
81	Thermocouple - opposite #45 on outside surface of ceiling
82	Thermocouple - quick response next to thermocouple #48
83	Thermocouple - on top doorway velocity impact probe
84	Thermocouple - on 2nd from top doorway velocity impact probe
85	Thermocouple - on 3rd from top doorway velocity impact probe
86	Thermocouple - on 4th from top doorway velocity impact probe
87	Thermocouple - on 5th from top doorway velocity impact probe
88	Thermocouple - on 6th from top doorway velocity impact probe
00	Pitot tube exhaust stack
101	Smokemeter in exhaust stack
102	CO_2 in stack
103	CO_2 in stack
104	O_2 in stack
105	CO in adjacent room 1.52m from floor
106	CO_2 in adjacent room 1.52m from floor
107	O_2 in adjacent room 1.52m from floor
108	load cell
109	open
110	Horizontal smokemeter burn room doorway 0.61m from ceiling
111	Horizontal smokemeter burn room doorway 1.22m from ceiling
112	Horizontal smokemeter burn room doorway 1.83m from ceiling

Table 2 (Cont'd)

Data Channel #	Description
113	Velocity impact probe burn room doorway 0.127m from top of door
114	Velocity impact probe burn room doorway 0.30m from top of door
115	Velocity impact probe burn room doorway 0.66m from top of door
116	Velocity impact probe burn room doorway 1.07m from top of door
117	Velocity impact probe burn room doorway 1.37m from top of door
118	Velocity impact probe burn room doorway 1.91m from top of door
119	Radiometer in adjacent room 0.91m from burn room door on room center line 0.91m up from floor
120	Radiometer in burn room on W. wall 1.83m up and 0.61m from S. wall
121	Heat flux meter in burn room on W. wall 1.83m up and 0.61m from S. wall
122	Heat flux meter in burn room on ceiling 0.61m from door on door centerline
123	Radiometer on burn room ceiling in the center
124	Heat flux meter on burn room ceiling in the center
125	Radiometer on burn room cieling 0.91m from the door on the door centerline
126	Heat flux meter on burn room ceiling 0.91m from the door on the door centerline
128	Horizontal smokemeter in burn room doorway 0.30m from ceiling
129	Vertical smokemeter in doorway
130	Smokemeter at animals - 0.91m for ceiling and 0.61m from adjacent room door
131	Time

Table 3

Test Event Times (Estimated from Video Tapes)

Test #	Materials	Sustained IGN	First Drip	Major Melting and Drip	Table Fell into Screen	Table Collapsed
1	Wood	NONE	-	-	-	-
2	P.B.	NONE	-	-	-	-
3	P.S.	70	120	130	220(a)	400
4	P.S.	35	75	240	310	360
5	P.S.	25	100	240	265	290
6	P.S.	(b)	85	225	225	270
7	P.S.	35	100	180	215	250
8	P.S.	45	90	185	240	250
9	PP-ABS	(c)	c	c	c	c
10	ABS	(c)	c	c	c	c
11	PP	(c)	c	c	c	c
12	PP	110	90	330	510	540
13	PP-PVC	45	135	185	220	290
14	ABS	115	175	260	295	315
15	Acr.	(b)	250	395	(3)	430
16	P.S.F.	70	100	250	310	315
17	P.S.F.	50	155	260	275	295
18	ABS	(b)(d)	80(d)	155(d)	185(d)	200(d)

(a) No screen used in this test; table fell off platform
(b) Unable to detect time
(c) No video tape available
(d) Video started sometime after ignition of heptane
(e) Table collapsed directly to the platform

P.B. Particle Board
P.S. Polystyrene
PP-AB Polypropylene - ABS
ABS ABS
PP Polypropylene
PP-PVC Polypropylene - PVC
Acr Acrylic
PSF Polystyrene Foam

Table 4

Description of Parsons Tables[a]

Materials	Part (each)	Size, m[b]	Weight, kg	Thickness, mm	Outside Surface Area sq. m.
Acrylonitrile	Top (1)	.406 x .406	--	4.8	0.1652
Butadiene styrene	Leg (4)	.057 x .057 x .349[b]	--	4.8	0.1600
ABS	Lip (4)	.064 x .406	--	4.8	0.1032
TOTAL		.406 x .406 x .406	2.36		0.4284
Polypropylene Molded in the same mold as ABS					
TOTAL			1.82		0.4284
Polystyrene Molded in the same mold as ABS					
TOTAL			2.22		0.4284
Acrylic	Top (1)	.438 x .457		5.6	0.2
	Leg (4)	.057 x .057 x .349[b]		5.6	
	Lip (2)	.064 x .457		5.6	
	Lip (2)	.064 x .457		5.6	
TOTAL		.413 x .438 x .457	2.95		0.4632
Tube Table #1					
Polypropylene	Tops (1)	.457 x .457	1.0		0.2090
ABS	Legs (4)	.051 x .356[c]	1.09		
ABS	Crosspipes (8)	.051 dia x .0406[c]			
Polypro-pylene	Corner Pieces (8)		0.54		
Polypropylene	Caps (8)				
TOTAL		.483 x .503 x .508	2.63		0.5897

[a]Data by D.W. Schmulling 1/75

[b]Right angle corner

[c]Pipe shape

Table 4 (Cont'd)

Materials	Part (each)	Size, m[b]	Weight, kg	Thickness, mm	Outside Surface Area sq. m.
Tube Table #2					
Polyproplylene	Top (1)	.457 x .457	1.0		0.2090
PVC	Legs (2)	.051" dia. x .356[c]	1.27		
PVC	Crosspipes (8)	.051" dia. x .356[c]			
Polypro-pylene	Corner Pieces (8)		0.54		
TOTAL		.483 x .508 x .508	2.81		0.5897
Butcher Block	Top (1)	.508 x .603		13.	0.3064
Particle Board with		.102 x .102 x .349[d]		13.	
Vinyl Overlay	Lip (2)	.146 x .508		13.	
	Lip (2)	.146 x .603		13.	
TOTAL		.495 x .508 x .603	12.17		0.9316
"Brunch" No. 1					
Particle Board	Top (1)	.019 x .457 x .457	2.86		0.2090
Solid Wood	Leg (4)	.051 x .051 x .368	2.04		
	Lip (4)	.041 x .041 x .356	1.82		
	Braces (4)	angle wedges	0.32		
TOTAL		.381 x .457 x .457	7.04		0.4490
"Brunch" No. 2					
Particle Board with	Top (1)[b]	.019 x .394 x .394		19.	0.1548
High Pressure Overlay	Leg (4)	.057 x .057 x .394		19.	0.1806
on Total Exterior	Lip (4)	.019 x .057 x .286		19.	0.645
TOTAL		.394 x .394 x .394	4.77		0.3999

[b]Right angle corner

[c]Pipe shape

[d]Hollow

Table 5

Breden's Mass Optical Density Numbers for Table Materials

Parsons Table Material	MOD (m^2/kg)
ABS	520
Acrylic	100
Polypropylene	400
Polystyrene	785
Polystyrene foam	790

Table 6

Comparison of Breden's MOD Values with those from a Retesting of Materials

Material	Breden	MOD Retest m^2/kg	
ABS	520	650[3]	540[5]
Acrylic	100	65[1]	70[5]
Polypropylene	400	400[2]	440[5]
Polystyrene	785	700[4]	690[5]
Polystyrene Foam	790	(6)	(6)

[1]Average plateau value from figure 8
[2]Average plateau value from figure 9
[3]Average plateau value from figure 10
[4]Average plateau value from figure 11
[5]Values based on ratio of slopes method
[6]No material available to retest

MOD retest data collected by Robin Breese

Table 7a

Flame Spread Index (I_s) for Parsons Table Materials

Number	Material	I_s (duplicate)		I_s Avg.
1	Particle Board with Vinyl Overlay	80,	80	80
2	Particle Board Underside	114,	147	131
3	Table Type A* Particle Board Underside	122,	84	103
4	Polystyrene Impact Grade Pigmented White	147,	192	170
5	Polypropylene Impact Grade Pigmented White	358,	309	334
6	ABS Pigmented White	328,	255	292
7	Acrylic Clear	390,	324	357

Table 7b

Ranking of Table Materials Based on Flame Spread Index

1.	Particle Board with Vinly Overlay	80	(1)
3.	Table Type A, Particle Board	103	(1)
2.	Particle Board	131	(1)
4.	Polystyrene	170	(2)
6.	ABS	292	(3)
5.	Polypropylene	334	(3)
7.	Acrylic	357	(3)

Least significant difference between any two average values at the 95% confidence level is 82.

Table 8a

Flame Spread Factor (F_s) for Parsons Table Materials

Number	Material	F_s (duplicate)	F_s Avg.
1	Particle Board Vinyl Overlay	5.7, 4.7	5.2
2	Particle Board Underside	5.0, 6.85	5.9
3	Table Type A* Particle Board Underside	5.3, 5.0	5.2
4	Polystyrene Impact Grade Pigmented White	6.8, 6.5	6.7
5	Polypropylene Impact Grade Pigmented White	15.3, 13.6	14.5
6	ABS Pigmented White	6.7, 6.0	6.4
7	Acrylic Clear	6.1, 5.4	5.8

Table 8b

Ranking of Table Materials based on Flame Spread Factor

3	Type A* Particle Board	5.2	(1)
1	Particle Board with Vinyl Overlay	5.2	(1)
7	Acrylic	5.8	(1)
2	Particle Board	5.9	(1)
6	ABS	6.4	(1)
4	Polystyrene	6.7	(1)
5	Polypropylene	14.5	(2)

Least significant difference between any two average values at the 95% confidence level is 1.85.

Table 9a

Heat Release Factor (Q) for Parsons Table Materials

Number	Material	Q (duplicate)		Q_s Avg.
1	Particle Board Vinyl Overlay	14.1,	17.0	15.6
2	Particle Board Underside	22.9,	21.4	22.2
3	Table Type A* Particle Board Underside	23.0,	16.8	19.9
4	Polystyrene Impact Grade Pigmented White	21.6,	29.6	25.6
5	Polypropylene Impact Grade Pigmented White	23.4,	22.7	23.1
6	ABS Pigmented White	48.9,	42.5	45.7
7	Acrylic Clear	63.9,	60.0	62.0

Table 9b

Ranking of Table Materials based on Heat Release Rate Factor

1	Particle Board Vinyl Overlay	15.6	
3	Type A* Particle Board	19.9	(1)
2	Particle Board	22.2	
5	Polypropylene	23.1	(2)
4	Polystyrene	25.6	
6	ABS	45.7	(3)
7	Acrylic	62.0	(4)

Least significant difference between any two average values at the 95% confidence level is 8.24.

Table 10a

Time Difference Between First Drip and Table Collapse
(Based on Video Tape Estimates)

Test #	Material	Location	Time, sec First Drip	Time, sec Table Collapse	Time, sec Time Difference
3	Polystyrene	Middle	120	400	280
4	Polystyrene	Middle	75	360	285
5	Polystyrene	Corner	100	290	190
6	Polystyrene	Corner	85	270	185
7	Polystyrene	Wall	100	250	150
8	Polystyrene	Wall	90	250	160
12	Polypropylene	Corner	90	540	450
13	Polypropylene-PVC	Corner	135	290	155
14	ABS	Corner	175	315	135
15	Acrylic	Corner	250	430	180
16	Polystyrene Foam	Corner	100	315	215
17	Polystyrene Foam	Wall	155	295	140
[illegible]	ABS	Wall	80	200	120

Table 10b

Ranking of Time Differences from Table 10a for Wall and Corner Tests

Wall		Corner	
Polystyrene	155 sec	Polypropylene	450 sec
Polystyrene Foam	140 sec	Polystyrene Foam	215 sec
ABS	120 sec	Polystyrene	187 sec
		Acrylic	180 sec
		ABS	135 sec

Table 11

Key Parameters of Ceiling Temperature Curves

Test #	Area Under Curve[1]	Start Time[2] Seconds	Peak Time[3] Difference Seconds	Peak Temp.[4] Difference °C	End Time[5] Seconds
6	24,000	260	240	67	800
7	41,940	200	240	101	720
8	31,560	220	220	59	980
10	35,900	180	260	79	740
11	33,600	400	300	145	840
12	34,320	380	340	174	760
13	27,860	200	420	53	980
14	32,440	280	200	74	820
15	35,480	380	300	87	1160
16	72,060	260	40	206	960
17	64,840	240	200	170	840
18	29,760	180	200	68	720

(1) Area Under Curve - Area between the time-temperature curve and the line at 40°C plus initial ambient temperature.

(2) Start Time - Test time for the first temperature excussion above 40°C plus the initial ambient temperature.

(3) Peak Time Difference - Test time to the peak minus start time.

(4) Peak Temperature Difference - Peak temperature minus the quantity 40°C plus the initial ambient temperature.

(5) End Time - Time of last temperature excussion above 40°C plus the initial ambient temperature.

Table 12

Variability of Key Parameters for Wall and Corner Tests

	Coefficient of Variation (percent)*	
	Wall	Corner
Area Under Curve	20.0	1.5
Start Time	6.7	3.6
Peak Time Difference	6.2	8.8
Peak Temperature Difference	37.1	12.9
End Time - Start Time	26.5	10.3

*Values based on two tests.

Table 13

Comparison of Smoke Chamber* and Room Fire Test Plateau MOD Values for Various Materials

Test No.	Material	MOD m^2/kg Table Fire	Smoke Chamber	Ratio
7	Polystyrene	1000	785	1.34
8	Polystyrene	800	785	1.02
11	Polypropylene	670+	400	1.68
16	Polystyrene Foam	820	790	1.04
17	Polystyrene Foam	800	790	1.01
18	ABS	540	520	1.04

* Data furnished by Breden

+ Value may be unrealistically high as the top smoke meter in the doorway indicated significantly lower than 100% light transmission at the end of the test.

Table 14

Comparison of Calculated and Measured Total Smoke Production from the Table Fires

Test #	Material	Table Mass	$OD\text{-}m^2$ Table Fire Smoke Production	$OD\text{-}m^2$ Calculated Smoke Production	Ratio
7	Polystyrene	2.3 kg	2.4×10^3	1.8×10^3	1.3
8	Polystyrene	2.3 kg	1.8×10^3	1.8×10^3	1.0
11	Polypropylene+	1.8 kg	1.3×10^3	0.72×10^3	1.8
16	Polystyrene Foam	3.0 kg	2.4×10^3	2.3×10^3	1.04
17	Polystyrene Foam	3.1 kg	2.4×10^3	2.5×10^3	0.96
18	ABS	2.4 kg	1.1×10^3	1.2×10^3	0.92

+See footnote table 11.

APPENDIX A

Room Gas and Ceiling Temperatures

Time	Test time in seconds
GAS 1 - GAS 7	Gas temperatures in °C from channel numbers 5, 6, 9, 10, 13, 14 and 17 respectively. Locations are shown in figures 4, 5, and 8.
AV GAS	The average value of the gas temperature measure at a given time.
CL 1 - CL 6	Ceiling temperatures in °C from channel numbers 45, 46, 51, 52 and 55 respectively. Locations are shown in figures 4, 5, and 8.
AV CL	Is the average value of the ceiling temperature at a given time.

NOTE: Data reproduced in Analysis of Data from Room Fire Test of Parsons Tables and Comparison with Laboratory Test Methods for Flame Spread and Smoke Generation, Volume II.

APPENDIX B

Doorway Gas Velocity, Table Mass and Light Transmittance Data

Time	Test time in seconds, channel 131
Mass	Table mass in kilograms, channel 108
VEL 1 - VEL 6	Are doorway gas velocities from data channels 113, 114, 115, 116, 117, 118, respectively. Locations are shown in figures 4, 5, and 8. Positive values represent gas flow out of the test room, negative values are inflow.
Smoke 1 - Smoke 4	Are doorway smoke meter transmittance data in units of percent of full transmittance, channels 128, 110, 111, 112 respectively.

NOTE: *Negative smoke transmittance value replaced by 0.0001
[]Extraneous reading replaced by average of reading before and after

NOTE: Data reproduced in Analysis of Data from Room Fire Test of Parsons Tables and Comparison with Laboratory Test Methods for Flame Spread and Smoke Generation, Volume II.

APPENDIX C

Room Fire MOD Values

Time	Test time in seconds
Mass Loss	Table weight loss up to a given time in units of kilograms
OD Flow	Flow rate of smoke out of the test room at a given time in units of m^2/s
Total OD	Total flow of smoke out the doorway throughout the test in units of m^2
MOD	Mass optical density number in units of m^2/kg

NOTE: Data reproduced in Analysis of Data from Room Fire Test of Parsons Tables and Comparison with Laboratory Test Methods for Flame Spread and Smoke Generation, Volume II.

NBS-114A (REV. 2-80)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET (See instructions)	1. PUBLICATION OR REPORT NO. NBSIR 81-2400	2. Performing Organ. Report No.	3. Publication Date November 1981

4. TITLE AND SUBTITLE

ANALYSIS OF DATA FROM ROOM FIRE TEST OF PARSONS TABLES AND COMPARISON WITH LABORATORY TEST METHODS FOR FLAME SPREAD AND SMOKE GENERATION, VOLUME I

5. AUTHOR(S)

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6. PERFORMING ORGANIZATION (If joint or other than NBS, see instructions)

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

7. Contract/Grant No.

8. Type of Report & Period Covered

Final

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (Street, City, State, ZIP)

10. SUPPLEMENTARY NOTES

[ ] Document describes a computer program; SF-185, FIPS Software Summary, is attached.

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

Data from a series of 18 room fire tests in which a Parsons table was the only combustible item were analyzed. Selected data from the tests were compared to laboratory fire test data from the ASTM E162 surface flammability test, and a modified smoke density test.

The flame spread index from the ASTM E162 test was not shown to be an dependable indicator of either the time for table fire involvement or room fire intensity. Results from the National Bureau of Standards smoke chamber using an MOD (mass optical density) method for data reduction were able to predict the smoke production rate and total smoke production from the table fires to within 34 percent and in several cases within 5 percent.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

ASTM E162; fire tests; flame spread; tables; plastics; smoke chamber.

13. AVAILABILITY

[X] Unlimited
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[X] Order From National Technical Information Service (NTIS), Springfield, VA. 22161

14. NO. OF PRINTED PAGES

102

15. Price

$11.00

USCOMM-DC 6043-P80

NBSIR 81-2400 VOLUME II