Fire Tests of Amtrak Passenger Rail Vehicle Interiors

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FIRE TESTS OF AMTRAK PASSENGER RAIL VEHICLE INTERIORS

Richard D. Peacock and Emil Braun

Abstract

A series of fire tests was conducted to assess the burning behavior of the interior of passenger rail vehicles. Three types of tests were performed: (1) small-scale laboratory tests to study the flammability and smoke generation characteristics of the individual materials, (2) full-scale calorimeter tests on the seats to determine the rate of heat release from burning seat assemblies, and (3) full-scale tests on mock-ups of the interior of the cars to investigate the potential for fire hazard in the fully furnished vehicles.

A comparison of the results of the selected small-scale laboratory tests with the full-scale mock-up tests shows that while the small-scale tests can be used to screen individual materials, the geometry of the full-scale vehicle interior, and the interaction of materials during the full-scale mock-up tests are critically important in predicting the potential for fire inside the vehicle.

Key words: calorimeters; flame spread; full scale tests; interior finishes; passenger vehicles; railroads; smoke; transportation.

1. INTRODUCTION

As part of an ongoing program to evaluate and improve the safety of rail transportation in the United States, the Federal Railroad Administration has sponsored studies at the Center for Fire Research to investigate the fire behavior of materials used in the interior furnishing of railroad passenger vehicles. A fire originating in the interior of a railroad passenger car may represent a serious hazard to the car occupants if there is a possibility of the rapid development of heat, smoke, or toxic combustion products, or if evacuation is difficult [1][1].

In general, a small number of fires appear to have originated in the interiors of railroad passenger cars. However, current design concepts incorporate an increased emphasis on the aesthetic impact of the interior with an attendant growth in the quantity of combustible materials. The relative increase in the ease of ignition of these materials compared to those used in earlier models of railroad passenger cars increases the likelihood of major fires in the interior of the car [1]. Thus, it is important that these new materials be evaluated in order to set reasonable guidelines to ensure an acceptable level of fire safety.

As in any transportation system, a complete fire safety analysis would include consideration of station design and placement, trackways, vehicle storage and maintenance areas, and emergency egress provisions, in addition to vehicle construction. This study is limited to the interior furnishing

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[1] Numbers in brackets refer to literature references listed at the end of this report.

materials that may be used in passenger rail vehicles, with the goal of assessing their potential fire and smoke hazards. The program was conducted in three parts:

- small-scale laboratory tests were performed on materials from the various components used on the interior of the cars;
- separate tests were conducted on full-size seat assemblies to compare their contribution to a developing fire; and
- eight fire tests were conducted on a mock-up car interior in order to determine the overall effects of an assembled system as compared to the fire performance characteristics of the individual components.

The work reported herein consists of a series of tests conducted to study the full-scale burning behavior of the materials used as furnishings for the interior of a passenger rail vehicle. Several different combinations of materials were included to exemplify some of the types that are currently used or that may be used in the future. Tests were conducted on:

- four different seat cushioning materials,
- two different carpets for both the walls or ceilings and the floor of the vehicles,
- two different window glazings, and
- three different window mask materials.

In addition to the full-scale tests, samples of the individual materials were evaluated using a number of standard laboratory-scale test methods designed to measure individual fire-related properties of the materials. Tests were included to evaluate:

- ignition and flame spread,
- smoke emission, and
- rate of heat release.

The study was designed to allow a comparison of the full-scale tests with the evaluation of the material properties as measured in the small-scale experiments. Areas of particular interest included:

- a comparison of large-scale and small-scale tests,
- a comparison of seating materials that may be used in the vehicles,
- the effects of changes in the geometry of the vehicle interior on the burning behavior,
- temperature levels and smoke or gas concentrations to which passengers may be exposed, and
- the adequacy of existing flammability guidelines.

Only the coach configuration of a vehicle was considered. No study was made of other car configurations, such as sleeper cars, dining cars, and club cars.

2. REVIEW OF PREVIOUS WORK

Few studies of the full-scale burning behavior of passenger rail car interiors have been conducted. Limited efforts to investigate other similar transportation vehicles are available. Considerable interest is evident in publications on individual materials and on test methods for individual components. The highlights of these efforts are detailed below.

Interest in improving the fire safety of passenger vehicles on railroads is certainly not new. From 1906 through 1928, the Pennsylvania Railroad undertook an ambitious program to replace their wooden passenger car fleet with all-steel passenger train cars due to a concern for safety and fire prevention [2]. A total of 5501 all-steel passenger train cars including baggage, mail, express, and dining cars were involved, representing an investment of approximately one hundred million dollars. More recently, emphasis on passenger comfort and aesthetic appeal have led to the increased use of synthetic materials [3]. Concern has been raised over the flammability of the materials in the end-use configuration even though they may be acceptable in small-scale tests [3]. According to a report by Arthur D. Little, Inc. for the U.S. Department of Transportation [4], the introduction of non-metallic materials in the vehicle interior can have a significant impact on the vehicle's fire hazard potential. While non-metallic materials have traditionally been found in seat cushioning and upholstery, their use in other system components such as coverings for floor, walls, and ceiling; window glazing and window or door gasketing; and non-structural storage compartments have increased the fire load within the vehicles. In addition to the flammability of the furnishing materials, the size, design, and structural integrity of the vehicle are all factors in determining the ultimate hazard to the passengers due to a fire.

In addition to the interior furnishing materials, limited ventilation and difficult egress compound the potential hazard in inter-city rail transportation. Ventilation in a rail car is typically 17,000 ℓ/s (600 cfm) of fresh makeup air. Exhaust is through leakage and, thus during evacuation, through the same exits used by escaping passengers [4].

Thus, while the interior furnishings of the vehicle are only a part of the total hazard, they provide a key location for purposeful ignition and provide a significant fuel load for a developing fire within a vehicle.

2.1 Fire Accidents

The Federal Railroad Administration compiles data on accidents, injuries and deaths involving railway equipment. The results seem to indicate that there are relatively few reported cases of fires on inter-city passenger trains. For passenger and freight train accidents involving more than $2,900 in damages to railroad on-track equipment, signals, track, track structures, and roadbed, the following data are available for 1978 [5]:

Type	No. of Accidents	Damage ($)	Average Damage/ Accident ($)	Damage/ Million Train Miles ($)	Accidents/ Million Train Miles
Collisions	1476	33,630,565	22,772	44,724	1.96
Derailments	8763	250,266,525	28,551	332,819	11.66
Grade Crossing	286	8,684,617	30,359		
Fire or Violent Rupture	301	7,472,338	24,824	27,999	1.38
Other	451	4,897,382	10,859		
Total	11,277	304,951,427	27,033	405,540	15.00

Thus, accidental fires account for only three percent of all accidents in 1978, with the average damage per accident comparable to derailments, collisions, and grade crossings. Fire is grouped with "Other" types of accidents for damage per million train miles and accidents per million train miles. The "Other" category is significantly smaller than collisions or derailments.

A similar group for casualties in 1978 by type of person injured for all trains is shown below. In this case, fire accidents are also not listed separately. They are included in the "Other" category:

Train Accidents	Total No. Accidents	Accidents w/Injuries	Injuries			
			Employees	Passengers	Other	Total
Collisions	1476	1464	264	702	4	970
Derailments	8763	8753	342	98	185	625
Grade Crossing	286	225	89	16	130	235
Other	752	748	45	25	11	81
Total	11,277	11,190	740	841	330	1,911

Train Accidents	Total No. Accidents	Accidents w/Fatalities	Fatalities			
			Employee	Passenger	Other	Total
Collisions	1476	12	16	-	-	16
Derailments	8763	10	10	4	27	41
Grade Crossing	286	61	1	-	77	78
Other	752	4	2	-	2	4
Total	11,277	87	29	4	106	139

The "Other" category, which includes fire accidents, accounted for three percent of all passenger injuries and no passenger fatalities.

2.2 Current Flammability Guidelines

The British Railways [6] and the National Academy of Sciences [7] have provided general guidelines for the use of flammable materials in railway transit vehicles. The British Railways Board quite simply specifies that new materials must not present a greater risk than existing materials. The National Academy of Sciences recommends the use of only those polymeric materials that by testing and comparison, are judged to be the most fire retardant and that have the lowest smoke and toxic gas emission rates. Further they recommend these be used sparingly, consistent with comfort and serviceability.

In 1973, the Urban Mass Transportation Administration (UMTA) initiated a program to improve the fire safety of transit vehicles. As a part of this program, the Transportation Systems Center developed "Guidelines for Flammability and Smoke Emission Specifications" for materials used in transportation vehicles [8]. Table 1 illustrates the guidelines. Six laboratory scale tests are recommended to evaluate the burning behavior and smoke emission characteristics of the materials used for seating, interior panels, flooring, insulation, and other miscellaneous materials [9-14]:

Materials	Tests Used to Evaluate Flammability and Smoke Emission
Seating (cushion, frame, shroud, upholstery)	ASTM D 3675, NFPA 258, ASTM E 162, FAR 25.853
Panels (wall, ceiling, partition, windscreen, HVAC ducting, window, light diffuser)	ASTM E 162, NFPA 258
Flooring (structural, covering)	ASTM E 119, NFPA 253
Insulation (thermal, acoustic, elastomers)	ASTM E 162, NFPA 258
Miscellaneous (exterior shell, component box covers)	ASTM E 162, NFPA 258

2.3 Laboratory Scale Tests

Rakaczky [15] provides a survey of available literature on fire and flammability characteristics of materials which could be used in rail passenger cars. Limited information was available for materials that related specifically to railroad passenger vehicles. Most of the literature reviewed related to transportation was concerned primarily with aircraft, with a few reports dealing with buses or automobiles. Many reports dealt with the flammability properties of upholstered furniture. From all these sources, he reviews what he considers the most important flammability areas:

- ignition related properties or ignitability,
- flame spread or flame propagation,
- smoke emission,
- heat release, and
- the production of toxic gases (combustion or **pyrolysis** products).

Information on flammability tests used in the specifications for other rail transportation systems is available from a number of sources, In tests to evaluate the small scale burning behavior of materials used in a bus and subway system, Braun [16-18] presents a screening of materials by several test methods, The test results are shown in table 2. Of particular interest in this study are the results of tests on the seat assemblies and interior lining materials:

	Test Method			
	Flame Spread Tests		Floor Covering Test	Smoke Generation Test
Material	**FAR 25.853** Flame Time (s)	ASTM E 162 ASTM D 3675 Flame Spread Index, I_s	NFPA 253 Critical Radiant Flux, (kW/m^2)	**NFPA 258** Maximum Optical Density, D_m
Seat Cushions	0–9			205-678
Floor Carpeting		8	6–11	319-694
Wall Covering		51–181		211–710

These and other small-scale test results will be reviewed in greater detail below in discussions of the individual test methods,

2.3.1 Ignition Resistance Test, Federal Aviation Regulation *FAR-25.853*

This standard, issued by the Federal Aviation Administration, defines both a test procedure and acceptance criteria for small-scale fire performance of interior materials used in transport category airplanes [12]. The test procedure outlined in this standard is a vertical test with a 38 mm (1.5 in) flame applied for either 12 s or 60 s (determined by the end use of the material) to the lower edge of a 51 mm (2 in) wide by 305 mm (12 in) long specimen. The test records the flame time, burn length, and flaming time of dripping materials, The test criteria require that specimens self-extinguish with a burn length not exceeding 150 to 200 mm (6 to 8 in) (depending again upon the end use of the material), a flame time not exceeding 15 s after removal of the burner, and flaming on the floor of the cabinet not to exceed 3 to 5 s (end use dependent). From table 2 results of tests of materials used in other transit systems are detailed below [16-19]:

Results of Tests of Other Transit System Materials by FAR 25.853

Material	Burn Time (s)	Burn Length (mm/in)	Drip
Floor Carpeting [16-17]	3.5	64/2.5	-
Seat Cushion Fabric [19]	60	58-127/2.3-5.0	n.d.
Seat Cushion Foams [18]	0-9	33-76/1.3-3.0	-
Interior Wall Panel [16-17]	0	64/2.5	-

n.d. = none detected

- = data not recorded

2.3.2 Flame Spread Test, ASTM E 162

This method measures flame spread and energy release of (6 by 18 in) specimens exposed to a varying radiant flux ranging from 40 kW/m^2 down to 3 kW/m^2 [9]. The flame spread factor, F_s, calculated from the flame spread velocity, and the heat evolution factor of the burning sample, Q, are combined to yield a flammability index, I_s, defined as

$$I_s = F_s * Q$$

The higher the index, the greater is the flammability. There is, however, no generally accepted level of performance based upon this test method since it is not a prescriptive standard. Again, from table 2, results of tests of materials from other transit systems are detailed below [16-18]:

Results of Test of Other Transit System Materials by ASTM E 162

Material	Flammability Index, I_s
Floor Carpeting [17]	8
Wall Carpeting [16]	181
Ceiling Carpeting [16]	51
Interior Wall Lining [17]	51

2.3.3 Floor Covering Test, NFPA 253-1978

This test, the Standard Method of Test for Critical Radiant Flux of Floor Covering Systems Using a Radiant Heat Energy Source, NFPA 253-1978, exposes a specimen placed horizontally to a radiant energy source that varies across a one meter length from a maximum of 11 kW/m^2 down to 1 kW/m^2 [14]. After ignition by a small flame at the high energy end, the distance is determined at which the burning flooring material extinguishes itself. This point defines the critical radiant flux (CRF) necessary to support continued flame spread. The higher the CRF, the better is the fire safety of the carpeting. Carpeting taken from several large fatal fires in which the carpeting was determined to be the means of fire spread, tested according to this method, was found to have CRF's of less than 1 kW/m^2. A wood floor would have a CRF of between 4 and 5 kW/m2, while vinyl flooring systems have values greater than 11 kW/m^2. Acceptance criteria of 2.5 kW/m2 for residential and commercial occupancies and of 5 kW/m^2 for health care facilities have been suggested [20-23]. Carpeting tested from other transit systems meets both of these criteria:

Results of Tests of Other Transit Systems Materials by NFPA 253-1978

Material	Critical Radiant Flux (kW/m^2)
Floor Carpeting [16]	6.6
Floor Carpeting [17]	> 11

2.3.4 Smoke Emission Test, NFPA 258-1976

The smoke density chamber, NFPA 258-1976, measures the smoke generation of solid specimens exposed to a radiant flux level of 25 kW/m^2 [10]. The smoke produced by the burning specimen is measured by a light source-photometer combination. The maximum attenuation of the light beam by the smoke is a measure of the optical density or "quantity of smoke" that a material will generate under the given conditions of the test. The maximum optical density, D_m, is useful primarily in ranking relative smoke production of materials, or in identifying likely sources of severe smoke production in a large-scale fire. The results of smoke generation tests of materials used on other transit systems are shown in table 2 and detailed below [16-19]:

Results of Tests of Other Transit System Materials by **NFPA** 258-1976

Material	Overall	D_s 90 s	D_s 4 min
Floor Carpeting [17,18]	319-694	-	-
Ceiling Carpeting	211	-	-
Seat Cushion Fabrics [17]	67-83	-	-
Seat Cushion Fabrics [19]	-	10-64	33-127
Seat Cushion Foam [17,18]	111-678	-	-
Interior Wall Lining [17]	710	-	-

- = no data reported

2.3.5 Heat Release Rate Tests

The rate of heat release for materials provides a measure of the contribution by the material to the growth of a fire. Unfortunately, no established standard test method to measure the rate of heat release existed at the time this report was written. Several tests have been proposed and are in the process of adoption by standards organizations.

Smith [24-26] has proposed one test method that allows measurement of rate of heat, smoke, and toxic gas release of materials. The apparatus measures release rate, on a flow through system, of a material exposed to various heat flux exposures. Release rates are determined by measuring temperature, and smoke and toxic gas concentrations leaving a chamber containing the sample. Smith has also proposed criteria and methodology for testing of materials used in transit systems. Spieth and Trabold [19], and Jenkins [27] have reported on tests with this apparatus on seating materials for transit systems:

Results of Tests of Seat Cushion Assemblies by a
Modified OSU Calorimeter

Material	Heat Release	
	Peak (kW/m^2)	Total at 10 min (kW-min/m^2)
Nylon/Vinyl Upholstery Polyurethane Foam	100	569
Wool/Nylon Upholstery Polyamide Foam		213
Wool/Nylon Upholstery Neoprene Sponge	58	115

Note: Seat cushion assemblies consisted of foam, backing and upholstery. Data are from references [19] and [27].

Babrauskas [28] describes the development of a bench-scale apparatus for measuring rates of heat release of flat materials by use of the oxygen consumption principle. Huggett [29], in an examination of a wide variety of materials, concluded that the heat of combustion released per kg of oxygen consumed is nearly a constant number. Thus, in theory, to measure the rate of heat released by a specimen, it should be necessary only to measure the total mass flow of oxygen in the combustion products and to compare that to the initial inflow of oxygen [28]. The apparatus developed by Babrauskas utilizes this technique. The design includes an open construction with a horizontal or vertical specimen exposed to a temperature controlled electrical radiant heating element capable of irradiance levels from zero to over 100 kW/m^2. He reports repeatability to within 5% for both gases and solid fuels.

2.4 Large Scale Tests

Due to the effort and expense involved, few large scale studies of the burning behavior of passenger rail vehicles have been performed. In an early test, Hawthorne [6] reported on tests in a full-scale mock-up of a passenger coach compartment. The construction of the mock-up consisted of glass fiber reinforced polyester wall lining (two layers with urethane foam sandwiched between) with wooden frame, horsehair cushioned seating. He concluded that while the spread of fire was not as rapid as anticipated, the assembly presented a greater fire hazard than an all steel vehicle. For several ignition sources, ranging from paper beneath a seat to diesel fuel on the walls, he reported an easy to extinguish fire. The double-skinned structure of the wall lining was effective in restricting the spread of fire through the compartments in his tests [13]. Little burning of the urethane foam sandwich was noted.

However, in more recent studies [16,27], entire transit vehicles have been destroyed by fires originating near a foam sandwich. In the January 1977 Trans-Bay Tube fire on the BART subway system in San Francisco, California, most of the foam within an aluminum/urethane foam/aluminum sandwiched floor assembly was consumed.

The fire hazard of fully furnished intra-city commuter buses was studied by Braun [17]. He concludes that while all materials used in the interior furnishing of the bus have burn rates below 102 mm/min (4 in/min), in conformance with the Department **of** Transportation's Motor Vehicle Safety Standard No. 302 [30], fires of significant size can develop in short periods of time with the vehicle. The seats were found to be the most probable source of hazard in the tests. The urethane foam seats were ignited within four minutes with paper trash and within a few seconds with the use of lighter fluid simulating purposeful ignition. Near zero visibility was noted within one to two minutes. Air temperature levels above the seat where ignition occurs exceeded 700°C at points up to 0.9 m (3 ft) away.

A series of fire tests was conducted for the Washington Metropolitan Area Transit Authority to assess the potential for fire hazard in newly delivered subway cars [18]. The results of laboratory-scale tests were found inadequate for this assessment. Full-scale tests on mock-ups of the interior showed that the potential for hazard arose primarily from the seat padding (urethane foam) and from the plastic wall lining (a polyvinyl chloride-acrylic construction). Average ceiling temperatures for the tests involving urethane cushions ranged from 138 to 288°C. By comparison, temperatures during tests of the polychloroprene seat assemblies reached only 55 to 92°C. Gas concentrations were also measured during the tests:

Summary of CO, CO_2 and O_2 Concentrations
During Mock-up Tests of a Subway Car Interior

Seat Material	Time of Peak Reading (min)	CO Maximum (%)	CO_2 Maximum (%)	O_2 Minimum (%)
Urethane	9 - 18	0.7 - 2.5	1.9 - 6.6	14.0 - 19.1
Polychloroprene	8 - 9	0.4 - 0.5	0.7 - 0.8	19.1 - 20.1

Note: Readings are at ceiling level

A toxicological evaluation of the combustion products was also performed [31].

During tests to study the ignition of bus seats, Barecki [32] concluded that a vinyl upholstery/polychloroprene foam seat assembly sustained little damage from a fire ignited on the seat from paper trash. A vinyl covered urethane foam seat ignited readily and burned completely during the same series of tests. Temperature levels of 120 to 540°C were noted above the ignition source.

3. FULL-SCALE MOCK-UP TESTS

3.1 Experimental Configuration

All of the full-scale tests were conducted in a test enclosure to mock-up a portion of the interior of an Amtrak passenger coach. A cutaway view of the interior of an actual car is shown in figure 1. The mock-up consisted of floor, wall, and ceiling panels plus two double seat assemblies. The configuration of the test enclosure and test sample are shown in figure 2. The 2.4 m wide x 3.6 m long x 2.4 m high (8 ft x 12 ft x 8 ft) enclosure was constructed of steel studding with a covering of perforated steel sheet on the walls and ceiling. Wall and ceiling carpeting were glued directly to the perforated steel sheet. The baggage rack, lined with the same carpeting used for the walls and ceiling, extended to the rear of the second seat assembly in tests 1-3 and the entire length of the mock-up in tests 4-8. Window glazing and window masks were provided similar to those used in the full size vehicles. The only opening to the mock-up was an open doorway 0.76 m (2-1/2 ft) wide by 2.04 m (6-2/3 ft) high. Ambient conditions during the tests were a temperature of 20 to 25°C and a relative humidity of approximately 40 percent.

3.2 Instrumentation

The test enclosure was instrumented to measure environmental conditions throughout the tests. Instrumentation, shown in tables 3 to 5 and figures 3 to 5, consisted of thermocouples for gas temperature measurement within the mock-up and in the doorway, heat flux meters at floor level, velocity probes in the doorway, gas sampling probes in the doorway to measure CO, CO_2 and O_2 levels, and smoke meters to measure optical density in the doorway. Additional instrumentation in the exhaust stack allowed determination of total smoke production and rate of heat release from the fires. All instrument data were automatically recorded at regular intervals on a high-speed digital data acquisition system. Data obtained included:

Temperature measurements. Chromel-alumel thermocouples 0.51 mm, 0.25 mm, 0.13 mm, and 0.05 mm (20 mil, 10 mil, 5 mil, and 2 mil) in diameter were located in three vertical strings within the room and in one vertical string in the center of the doorway.

Heat flux measurements. Gardon-foil type water-cooled heat flux meters were used to measure heat flux incident near the center of the floor of the mock-up enclosure.

Velocity measurements. Bidirectional, low-velocity probes were located in the doorway to measure the flow both in and out of the test enclosure, as well as in the exhaust stack. This type of probe was developed by Heskestad [33] for obtaining low-velocity measurements under fire conditions. McCaffrey and Heskestad [34] have provided calibration techniques for these probes. The probes used were 12.7 mm (1/2 inch) in diameter, with construction details as given in the above references. The basic equation for determining velocity is:

$$u = \frac{\sqrt{2\Delta P/\rho}}{C(Re)}$$

where ΔP is the measured differential pressure, ρ is the gas density (obtained from temperature readings adjacent to the probe and the ideal gas law), u is the gas velocity, and $C(Re)$ is a constant dependent upon the Reynolds number. For low velocities, the constant can be taken as $C(Re) = 1.08$, according to the recommendations of McCaffrey and Heskestad [34].

Gas concentration measurements. Concentrations of CO, CO_2, and O_2 were measured at three locations in the doorway and in the exhaust stack. Gas analysis for CO and CO_2 were made with non-dispersive infra-red analyzers. Oxygen measurements were made with paramagnetic analyzers. The sampling lines were fitted with a series of traps to remove particulates and water in the samples to protect the instrumentation.

Smoke density measurements. Smoke density was measured by light attenuation at three locations in the doorway during tests 1 through 4. An additional measurement within the exhaust stack was made during all tests. The meters were constructed following the design of Bukowski [35].

Rate of heat release measurement. Temperature, velocity, and oxygen concentration measurements in the exhaust stack allow calculation of the total rate of heat release [36]. The rate of heat release can be calculated as

$$\dot{Q} = \frac{\Delta O_2 \cdot h \cdot v \cdot A \cdot T_a}{T}$$

where $\dot{Q}$ is the rate of heat release in kW, ΔO_2 is the oxygen depletion expressed as a mole fraction, h is the heat of combustion of fuel per unit volume of oxygen consumed at standard temperature and pressure (kJ/m^3), v is the outflow gas velocity in m/s, A is the area of the opening in m^2, T_a is the ambient gas temperature in K and T is the outflow gas temperature in K. Several corrections and adjustments for carbon monoxide concentration, water vapor, or the specific fuel burned may effect the calculation [37].

3.3 Test Program

All tests were conducted in the test room described above. For each test, 50 double sheets (1.06 kg) of newspaper (100 sheets (2.12 kg) for tests 6 and 8) were placed on the rear window seat and ignited with a single book of matches. Tests 1 through 4 were conducted with fully furnished mock-up vehicles. Table 6 gives details of the tests. For tests 5 through 8, only the wall and floor carpeting was installed, with newspaper ignition on a non-combustible seat assembly.

Test 1: The mock-up was furnished with products typically found in Amtrak Amfleet I coaches. The walls and ceiling were lined with acrylic carpeting glued to a perforated sheet steel base material. The underside of the baggage rack also was covered with the same acrylic carpeting. The floor was covered with nylon carpeting over a polyurethane underlayment. The window mask was glass-reinforced plastic and the window glazing was double-paned glass. The seat frames were steel with the shrouds, back shells, and food trays made of 10 percent glass-filled polycarbonate; the arm rests were self-skinning polyurethane. The seat upholstery material was a 90/10 wool/nylon blend with a synthetic latex backing and vinyl trim. The seat cushions were a combination of FAR 25.853 grade ("standard" transit grade) polyurethane and fire retardant polyurethane; the headrests contained a small amount of FR-polychloroprene and polyvinyl chloride stiffeners. The foam cushions were covered with muslin.

Test 2: The mock-up was furnished with products found in a typical "Amfleet II" configuration. The walls and ceiling were lined with modacrylic carpeting glued to the perforated sheet steel base material. The baggage rack was also covered with the same modacrylic carpeting. The floor was covered with nylon carpeting over a polyurethane underlayment. The window mask was a molded isophthalic polyester resin containing aluminum trihydrate filler and 1-inch chopped strand glass reinforcement. The window glazing was polycarbonate. The seat frames were steel with the shrouds, back shells, and food trays made of 10 percent glass fiber-filled polycarbonate. The arm rests were molded polychloroprene, and the seat upholstery material was a 90/10 wool/nylon blend with a synthetic backing. For test 2, the seat foam was polychloroprene.

Test 3: Like test 2, the mock-up was furnished with products found in a typical "Amfleet II" configuration. All materials were the same, except the seat foam was high-performance polyurethane.

Test 4: The mock-up was furnished with products representing a combination of "Amfleet I" and "Amfleet II" configurations. The walls and ceiling were lined with an acrylic/modacrylic blend carpeting glued to the perforated sheet steel base material. The baggage rack, extending the full length of the mock-up, was covered with the same carpeting. The floor was covered with a nylon carpeting over a polyurethane underlayment. The window mask was a molded polyvinyl chloride/acrylic copolymer in a low smoke and fire retarded formulation. The window glazing was polycarbonate. The seat frames were steel with the shrouds, back shells, and food trays made of 10 percent glass fiber-filled polycarbonate. The arm rests were self-skinning polyurethane, and the seat upholstery material was a 90/10 wool/nylon blend with a synthetic backing. Seat foam was a low-smoke formulation polychloroprene.

Tests 5-8: The mock-up was furnished with carpeting lining the floor, walls, ceiling, and luggage rack. A glass window glazing was mounted on the wall near the ignition seat. A non-combustible seat frame of steel and calcium silicate board supported the newspaper for ignition. The tests were conducted to isolate the carpeting as a single variable without the interaction of other materials. The tests were as follows:

Tests 5-8

Test	Wall/Ceiling/Luggage Carpeting	Ignition Source (sheets of newspaper)
5	Acrylic/Modacrylic Blend	50
6	Acrylic/Modacrylic Blend	100
7	Modacrylic	50
8	Modacrylic	100

3.4 Full-scale Mock-up Test Results

Temperature levels reached during the four fully furnished mockup tests are presented in figures 6 through 9. In these figures, average temperatures near the ceiling (thermocouples 150 mm (6 in) from the ceiling) and at approximately passenger head level (thermocouples 760 mm (2.5 ft) from ceiling) are shown for the tests of fully furnished mock-ups (tests 1 to *4).* For all tests, peak temperatures and time to reach peak levels are tabulated in table 7. Temperature profiles in the interior of the mock-up from floor to ceiling are presented in figures 10 through 13.

Smoke levels in the doorway and in the exhaust stack are presented in figures 14 through 17 for the four fully furnished mock-up tests. Peak smoke levels and time to reach peak levels are presented in table 8 for all tests.

Measured concentrations of O_2, CO_2, and CO for the four fully furnished mock-up tests are shown in figures 18 through 21. Maximum levels of CO_2 and CO and minimum concentration of O_2 are tabulated in table 9 along with time required to reach the maximum or minimum levels.

The rate of heat released from the burning, fully furnished mock-up assemblies, calculated from the oxygen depletion in the exhaust stack is presented in figures 22 through 25. Peak rate of heat release and time to reach the peak rate are shown in table 10 for all tests.

3.5 Discussion of Full-scale Mock-up Tests

3.5.1 Hazard Levels

Babrauskas has presented an analysis of the hazard to humans due to burning mattresses [38] and to burning furniture items [39]. Quintiere et al. [40] provide an analysis of hazard due to toxic gases. From these, hazard limits can be developed for the current test series. The hazard to humans exposed to a fire environment can be considered a combination of individual elements such as:

- high temperatures and heat fluxes,
- visibility obscuration by smoke, and
- toxic gases.

Appropriate levels of hazard for temperature and heat flux should be separated into two regimes - a level which would produce unacceptable levels of pain requiring evacuation and a second higher level indicative of impending full room involvement or flashover. For human exposure, a range of threshold levels leading to pain or burn is available [38]. Simms and Hinkley [41] and Derksen, Monahan, and Delhery [42] have suggested limits of 1.2 kW/m^2. Dinman [43] and Parker and West [44] concluded a higher level of 2.5 kW/m^2 should be considered a pain threshold for extended exposure. The latter value corresponds to a radiating black body at a temperature of 183°C; the former to one at 110°C [41,42]. For the higher criterion of impending full room involvement, a number of studies of room fires have suggested conditions for flashover as gas temperatures greater than 500 to 600°C and heat flux levels greater than about 20 kW/m^2 [45-55]. A review of these efforts is presented in reference [56].

Babrauskas [38] has suggested a limit of

$$k = 1.2 \ m^{-1}$$

for smoke obscuration, where k is the extinction coefficient. His choice was based upon studies by Jin [57-59] on visibility in a smoke filled environment. Jin concludes an approximate relationship of

$$kV = 2,$$

where V is the visibility in meters. Proposed limits on k, based on walking speed in a smoke filled environment being at least that of a blindfolded subject in a smoke free environment, were suggested as $k = 1.2 \ m^{-1}$ for "non-irritating" smoke and $k = 0.5 \ m^{-1}$ for "irritating" smoke [57-59]. For this study, two levels of hazard limits are presented - the limit proposed by Babrauskas of $k = 1.2 \ m^{-1}$ and a lower threshold of $k = 0.2 \ m^{-1}$ corresponding to the maximum level insuring visibility from the center of the car to the car ends in a 24 m (80 ft) car.

Concentrations of carbon dioxide and carbon monoxide were measured in the doorway during all the tests. While these are not the only products of pyrolysis and combustion, carbon monoxide is one of the primary toxicants generated in fires, and CO_2/CO ratios can be used as an indication of the completeness of combustion. As very high levels of CO_2 are also toxic, these concentrations can be used to indicate when tenability conditions are reached. Based upon tabulations by Kimmerle [60] and Pryor and Yuill [61], a limit of 10 percent for CO_2 is appropriate as a level which produces general discomfort and labored breathing. Kimmerle [60] and Levin et al [62] have studied the levels of CO necessary to cause a 50% lethality in laboratory animals. From Kimmerle:

Carbon Monoxide Levels Necessary to Cause a 50% Lethality in Laboratory Animals

Exposure Time (min)	CO Level (%)	CO Dose (%-min)
10	0.88	8.8
20	0.61	12.2
30	0.55	16.5
60	0.47	28.0

Source: Reference [60]

Levin et al [62] present results for a 30 minute exposure similar to Kimmerle's with a level of 0.5% CO to cause a 50% lethality. However, since the CO dose levels necessary to cause adverse effects changes so drastically depending upon the time of exposure (from 8.8%-min to 28%-min for a 50% lethality), a simpler criterion based. on the CO level is sufficient. Since the maximum time available for escape or rescue during **all** four fully furnished mock-up tests would be 10 minutes or less, a level of 0.8% is appropriate. In summary, the tenability limits used in the evaluation of the full scale mock-up tests were:

Tenability Criteria for Mock-up Test Evaluation

Criteria	Acceptable Tenability Limit	
Gas Temperature	$< 183°C$ $< 600°C$	(pain threshold) (full room involvement)
Smoke Obscuration	$k < 0.2 m^{-1}$ $k < 1.2 m^{-1}$	(full car visibility) (unacceptable mobility)
Gas Concentrations		
CO_2	$< 10\%$	
CO dose	$< 0.8\%$	
O_2	$> 9\%$	

3.5.2 Gas Temperatures and Heat Release Rate

Peak gas temperatures during the eight mock-up tests ranged from 114 to 825°C (237 to 1517°F) near the ceiling and from 29 to 768°C (84 to 1414°F) at 1.5 m (5 ft) from the floor, the approximate passenger head height. During two tests, critical temperatures were reached at both levels. During test 1, a fully furnished mock-up with non-fire retarded polyurethane cushioning on the ignition seat, temperature levels of 183°C (361°F) were reached in 315 s and 411 s at ceiling level and at passenger height, respectively. The higher critical temperature of 600°C (1112°F), indicating full room involvement, was reached at 468 s and 478 s. Similar data from test 4, a fully furnished mock-up with seating cushions of a low-smoke formulation polychloroprene, different wall carpeting, ceiling carpeting, window mask, window glazing, and luggage rack than test 1, showed a time of 200 s to reach 183°C (361°F) and of 270 s to reach 600°C (1112°F) at ceiling level. The fire was extinguished prior to attainment of critical temperatures at the passenger level. From these data and figures 6 and 10, it is apparent that the growth of the fires is slow at first, requiring 315 s and 200 s to reach 183°C, and growing rapidly after these times to peak temperatures at 478 s and 275 s. This change from a slowly growing fire to a more rapidly growing one corresponded visually to the ignition of the carpeting covering the underside of the luggage rack,

The rate of heat released from the burning mock–up interiors shows similar results. From figures 22 and 25, peak rates of heat release of 4.4 MW during test 1 and 1.6 MW during test 4 are reached rapidly after a long initial period of low heat output. Peak rate of heat release ranged from a low of 40 kW to a high of 4.4 MW during the eight mock–up tests.

Thus, an ignition source that provides enough heat for a sufficient period of time to ignite the carpeting beneath the luggage rack is likely to lead to a serious fire. During test 1, the non–fire retarded polyurethane cushioning and polyurethane armrest provided the necessary ignition energy. During test 4, the extension of the luggage rack to the full length of the mock–up allowed a larger percentage of the heat to be trapped beneath the luggage rack leading to ignition by the newspaper, upholstery fabric and more importantly, the polyurethane armrest, The lower rate of heat released from the seat assemblies and the shortened luggage rack in tests 2 and 3 prevented the attainment of untenable thermal conditions.

3.5.3 Smoke Levels

Peak smoke levels in the doorway during tests 1 to 4 previously were shown in figures 14 to 17 and table 8. Times to reach an extinction coefficient of 0.2 m^{-1} and 1.2 m^{-1} were also shown in table 8. During all tests, visibility was reduced below the level necessary to see the end of the car (from the center of the car) quickly, with times to reach 0.2 m^{-1} from 40 s to 134 s at the top of the door. At passenger height, times to reach 0.2 m^{-1} were considerably longer, 215 s to 2613 s. The higher critical value of 1.2 m^{-1}, indicating a severe decrease in mobility and thus hampering evacuation, occurred at passenger height only during two tests. During test 1, this level was reached in 486 s and during test 4, in 225 s.

Like the gas temperature data, the smoke data show a rapid change in tests where full room involvement was attained. For tests 1 and 4, only 10 to 25 s elapsed between the time to reach 0.2 m^{-1} and the time to reach 1.2 m^{-1}.

3.5.4 Gas Concentrations

Maximum concentrations of CO_2 measured at the top of the doorway and at passenger height ranged from 0.9 to 13.4% and 0.4 to 10.9%, respectively. For CO, peak levels ranged from 0.1 to 3.9% and 0.1 to 3.1%. Minimum O_2 concentrations ranged from 20.1 to 1.1%. Critical levels of O_2, CO_2, and CO were reached only in tests 1 and 4:

Time to Reach Critical Gas Concentrations at Ceiling Level During Tests 1 and 4

Test	Time to Reach 9% O_2 (s)	Time to Reach 10% CO_2 (s)	Time to Reach 0.8% CO (s)
1	503	503	450
4	295	n.r.	270

Peak gas concentrations and critical levels of the gases measured were reached at times corresponding to full room involvement for tests 1 and 4. The rapidly changing environment within the room at these times leads to unacceptable conditions at passenger level with little delay:

Time to Reach Critical Gas Concentrations at
Passenger Level During Tests I and 4

Test	Time to Reach 9% O_2 (s)	Time to Reach 10% CO_2 (s)	Time to Reach 0.8% CO (s)
1	510	510	482
4	n.r.	n.r.	275

For all other tests, none of the criteria were exceeded.

4. SEATING CALORIMETER TESTS

In order to ascertain the full-scale burning behavior of the seating materials without the interaction of other materials or of changes in test room geometry, full-size, upholstered specimens of the seat cushions and seat backs were tested in a full scale calorimeter to measure the rate of heat released from the burning seats. Details of the apparatus and test procedure are presented in reference [63]. Briefly, the full size specimen is burned beneath a hood collection system designed to contain all the combustion products of the burning item. Rates of heat release are measured using the oxygen consumption principle [28,29,37]. Figure 26 shows the design of the calorimeter.

For the present tests, fully upholstered specimens of the seat cushions and seat backs used in each of the four fully-furnished mock-up tests were placed on a non-combustible seat frame simulating the configuration in a rail car. Ignition was accomplished with the same ignition source used for the mock-up tests -- 50 sheets of newspaper (approximately 1.06 kg). Figure 27 shows the rate of heat release of the newspaper ignition source measured in the furniture calorimeter using a non-combustible seat assembly. The peak rate of heat release for the burning newspaper was 55 kW at 100 s after ignition.

The rate of heat release for the four seat cushion assemblies is also shown in figure 27. Initial peaks from the burning newspaper are evident in all tests with an average time to this first peak of 100 s, identical to the peak observed for the burning newspaper alone. After this initial peak, the burning behavior of the upholstered seats varied markedly. For the four specimens tested, peak rates of heat release (after the initial newspaper peak) were:

Peak Rate of Heat Release of Seating
Measured in the Furniture Calorimeter

Seating Foam	Used in Mock-up Test	Heat Release (kW)	Peak Rate of Time to Peak (s)
Polyurethane	1	139	470
FR polychloroprene	2	45	630
FR polyurethane	3	30	310
Low smoke polychloroprene	4	31	780

5. LABORATORY SCALE TEST RESULTS

The purpose of laboratory scale tests is to provide the researcher/developer and the purchaser a means for selecting materials based on performance. In fire safety, the problem is compounded by the fact that system design can have a significant effect on the fire performance of a single component. A material developer typically relies on single parameter tests to determine relative fire performance of one material against another, because he is not in a position to specify the end use environment. The responsibility of integrating fire performance and system design rest on the system design engineer. He must exercise a great deal of caution in using single parameter test methods as a means for predicting large scale fire performance. To assist the transit design engineer in developing a reasonably fire safe vehicle, the Department of Transportation has developed and published for comment, "Recommended Fire Safety Practices for Rail Transit Materials Selection" [64].

As previously cited, six test methods are recommended for the evaluation of component materials used in transit vehicles. The recommended test procedures and performance criteria for each functional component were summarized in table 1. A subset of the recommended test procedures applicable to the current testing program is tabulated in table 11 along with the performance criteria for each functional group.

Four of these six test methods were used to evaluate the fire performance of component materials used in the large scale tests. In addition, all of the materials were tested to determine the rate of heat release according to the method and apparatus developed by Babrauskas [28]. Component materials involved the coverings for the wall, ceiling and floor, as well as seat cushions, window masks, and window glazing. The following materials were not evaluated in any laboratory scale tests: arm rests, non-metallic firepans and trays, seat shroud, and upholstery fabric.

Table 12 describes the materials and their functional use in the interior of the large scale test. The test procedures used to evaluate each material are also indicated in table 12.

5.1 Smoke Measurements

The smoke density chamber, NFPA 258-1976, measures the decrease in light transmission due to the smoke produced from a vertically mounted solid specimen exposed to a heat source. The data reported here involved the use of a 25 kW/m^2 radiant heat source and a small burner flame system. The fraction of light transmission (T) is used to compute the specific optical density, D_s, which is defined as

$$D_s = \frac{V}{AL} \log (1/T)$$

where V = chamber volume

L = light beam path length

A = surface area of the specimen

D_m is used to designate the maximum value attained by D_s. The test method defines $D_{m,corr}$ as the difference between D_m and D_c, the specific optical density for a ventilated chamber at the end of a test exposure.

At least three replicates of each sample were tested. Figures 28 to 32 show the specific optical density, D_s, as a function of time for an individual specimen. These figures represent the data obtained from the individual specimen having the highest D_s value at 1.5 minutes from test initiation. Each figure shows the data from one functional group. Figure 28 shows that the window masks designated FRP II, produced less smoke at a lower rate than either of the other two materials.

The seat cushion materials, figure 29, fall into two groups. There is little practical difference within each group. The original polyurethane foam and polychloroprene foam produced large quantities of smoke in a short period of time. The FR-polyurethane and the low smoke polychloroprene produced significantly smaller amounts of smoke over a longer period of time.

Two glazing materials were used in the large-scale tests, a 3 mm thick polycarbonate sheet and a laminated plate glass of comparable thickness. Only the polycarbonate glazing was tested by NFPA 258. Figure 30 shows the results of those tests. The polycarbonate glazing required a long exposure to the heat source before significant quantities of smoke were produced.

Figures 31 and 32 illustrate the test results for all carpet samples. Figure 31 represents those carpets that were intended for use on the walls, ceilings, and underside of the overhead luggage rack. These samples were tested without an underlayment. Carpet D produced more smoke more rapidly than carpets G and B.

The samples designated as floor covering materials were tested with a polyurethane foam underlayment. Carpet F appears to be a significantly better carpet, figure 32. Only one carpet was tested with and without an underlayment, carpet B. Figure 33 shows that the influence of the underlayment on the smoke production characteristics of carpet B is only apparent late in the test.

Table 13 summarizes the results of NFPA 258. Data are tabulated for the average $D_{m,corr}$ as well as the D_s values for 1.5 minutes and 4.0 minutes as recommended in the DOT guidelines. Within a functional group, the materials are listed according to a decreasing D_s (1.5). It can be seen that the D_s (1.5) and D_s (4.0) produce similar rankings. In two cases, FRPI/PVC-acrylic and polyurethane/low smoke polychloroprene, the $D_{m,corr}$ values do not correlate with the D_s rankings.

DOT recommended D_s values for all materials and applications are:

D_s (1.5) $\lesssim$ 100,
D_s (4.0) $\lesssim$ 200.

With the exception of the wall covering, each functional area had acceptable materials, All carpet samples intended for use on the wall or ceiling of the interior of a transit vehicle failed to meet DOT smoke production levels at 4 minutes. Only carpet F, intended for floor covering, had a D_s (4.0) less than 200. With the exception of carpet D, all carpet samples had D_m values within a small range, 230 to 300. Carpet D had a D_m value of 470.

5.2 Flame Spread Tests

ASTM E 162 and D 3675 measure the ability of a material to resist flame spread and heat evolution under the influence of an external radiant flux. Both test methods yield a flame spread index, I_s, that is the product of a flame spread factor and a heat evolution factor. The test methods are functionally identical. Minor differences exist in the manner in which specimens are prepared for testing. ASTM D 3675 is intended for the evaluation of flexible cellular materials that have a tendency to shrink and fall out of the specimen holder. Specimen preparation, therefore, requires the use of a sheet of 2.5 mm 20 gage hexagonal steel wire mesh over the exposed face of the specimen. In all other aspects, the two test methods are identical.

Three replicates of each material were tested to determine a flame spread index. The results of these tests are tabulated in table 14. The seat cushions were tested according to ASTM D 3675, while the other materials were tested following ASTM E 162 specifications. DOT recommended performance criteria for each functional group are also listed. It can be seen that each functional group has at least one material that meets the criterion.

Significant differences existed between all of the carpet samples tested. Carpet B had the worst performance, I_s = 270, while carpet D failed to ignite at all. Carpet D was the only wall covering material which met the DOT criterion. In terms of performance, the two fiberglass reinforced plastic window masks barely met the criterion, while the vinyl chloride/acrylic copolymer was far superior as a window mask material.

5.3 Critical Radiant Flux

NFPA 253 exposes a specimen placed horizontally to a radiant energy gradient that varies along a 1-meter length from 11 kW/m^2 to 1 kW/m^2. The specimen is ignited by a small flame at the high energy end. The distance burned to the point at which the flooring material extinguishes itself determines the critical radiant flux (CRF) necessary to support continued flame propagation. The higher the CRF, the better is the fire safety of the carpet.

The DOT recommended guidelines stipulate that floor coverings must have a CRF greater than or equal to 5 kW/m2. This is equivalent to performance requirements placed on floor coverings used in corridors and exitways of health care facilities.

Two carpet samples were tested to determine their CRF rating. Carpet B was used in large-scale tests 2, 3, 4, 5, and 6, while carpet F was used in tests 1, 7, and 8. Each carpet was tested with the underlayment used in the large scale test, i.e., polyurethane foam. Carpet F performed very well. It had a CRF of > 11 kW/m^2. Carpet B had a CRF of 5.5 kW/m^2. Both samples meet or exceed DOT recommendations.

5.4 Rate of Heat Release

Two measurement techniques exist for the determination of the rate of heat release. One method measures sensible heat in the exhaust gas, while the other method utilizes the oxygen consumption principle. Smith [24-26,65] employed the former method to calculate a fire hazard load value for a furnished enclosure. The primary parameter was the total heat release at 3 minutes at a fixed external incident heat flux. Measurements were made over a range of incident heat flux levels - 11 kW/m^2 to 34 kW/m^2. The actual data used depended on the end use of the material. Smith selected heat release rate data at the upper exposure limit for ceiling and wall materials and lower level exposure data for the evaluation of flooring materials.

Using the oxygen consumption principle, Krasny and Babrauskas [66] demonstrated the difficulties encountered in attempting one-to-one correlations between bench scale and large-scale tests. While they were able to correlate horizontal flame spread on upholstery furniture mockups with the time to 100 kW heat release rate in a full size furniture calorimeter, it was necessary to compare maximum heat release rates in the furniture calorimeter with cone calorimeter total heat release at 3 minutes normalized by the total weight of the sample before equivalent material ranking could be achieved.

The cone calorimeter [28] was used to evaluate the component materials used in the large-scale mockups. Three replicates of each material were tested at an incident flux level of 25 kW/m^2. This is at the mid-range of Smith's data and comparable to the incident flux level used by Krasny and Babrauskas. The 3 minute values used by Smith and Krasny proved unsatisfactory because at 25 kW/m^2 the rate of heat release for some samples was bimodal with the broader peak biasing the three minute average. Therefore, a fire hazard load value similar to Smith's could not be determined for all materials.

The maximum rate of heat release per unit surface area, Q_p, was used as an initial measure of material flammability. Table 15 summarizes the results obtained from the cone calorimeter. Within functional groups the data are listed according to decreasing Q_p. Also listed in table 15 are the time at which the peak value was recorded, an approximate ignition delay time and the total heat released at Q_p.

The ignition delay time was determined from the output data rather than actual observations and, therefore, are only approximate. The lowest Q_p was observed for the low smoke polychloroprene sample, 27 kW/m^2, and the highest was the polyurethane foam cushion, 600 kW/m^2. One set of composite tests was conducted to determine the effect of an upholstery material on the rate of heat release. The polychloroprene was covered with samples from the upholstery material used in the large scale test. It was found that while the polychloroprene alone released heat at a low rate, 32 kW/m^2, the inclusion of a cover fabric raised this to 280 kW/m^2. In addition, Q_p occurred much sooner, 32 seconds versus 264 seconds, for the covered foam cushion. However, the total heat released, Q_T, by the covered foam cushion was less than the exposed foam, 2.2 MJ/m^2 for covered foam and 3.2 MJ/m^2 for exposed foam. An interesting feature of the covered foam tests demonstrated a bi-modal burning behavior, figure 34. First, the cover fabric burned with the rate of heat release decaying to nearly zero before the foam began to contribute to the rate of heat release.

The carpet samples had higher heat release rates than most of the other component materials. Carpet F had the lowest Q_p, but it had the highest total heat released. At 25 kW/m^2, carpet F was the most resistant to ignition with only the fiberglass reinforced plastic materials having a longer ignition delay time.

The polycarbonate glazing material would not ignite at 25 kW/m^2 external incident flux. Tests at 50 kW/m^2 produced the following results:

$\dot{Q}_p = 480\ kW/m^2$ at 153 seconds

$Q_T = 9.7\ MJ/m^2$

Ignition = 123 seconds

60 DISCUSSION OF LARGE-SCALE AND SMALL-SCALE TESTS

Table 16 presents the results of the laboratory-scale tests arranged according to the use in each full-scale mock-up test. Only the materials from mock-up test 4 met the flame spread guidelines. None of the sets of materials from the four fully furnished mock-up tests met the smoke emission guidelines recommended by DOT. Since no recommended limits have been proposed for a rate of heat release measurement, no notation is made in table 12 of acceptable rate of heat release values. Figure 35 graphically presents the small-scale flame spread and smoke emission measurements. While the multiple acceptable limits under ASTM E 162 have been omitted for simplicity, all materials within the dashed line box in figure 35 are considered acceptable under DOT guidelines.

6.1 Small-Scale Tests Versus Large-Scale Tests

As a more detailed comparison of the laboratory-scale tests and the full-scale mock-up tests, figures 36 to 39 show the laboratory-scale test results plotted against selected full-scale test data. Results of smoke density measurements in the laboratory-scale test are compared with peak smoke extinction coefficient (figure 36) and with time to reach the critical smoke extinction coefficient of $1.2 m^{-1}$ (figure 37). For the flame spread measurements, the peak rate of heat release measured during the mock-up tests are compared with test results from ASTM E 162 (figure 38) and with peak rate of heat release measured by the cone calorimeter (figure 39). Results similar to figures 38 and 39 could be obtained using gas temperature as a measure of fire growth during the mock-up tests rather than rate of heat release.

All four figures (36 to 39) lead to similar trends comparing laboratory-scale and full scale measurements. First, consider only mock-up tests 1 through 3. The small-scale tests correctly predict that mock-up test 1 should be more severe than tests 2 or 3. Smoke measurements and flame spread measurements exhibit this trend. However, test 4 is not as easily predicted. Small-scale flame spread measurements would indicate that the materials in test 4 should behave equivalent to or better than tests 2 and 3. Clearly, this was not observed in test 4. Laboratory-scale smoke measurements would lead to the conclusion that test 4 would behave similarly to test 3, not test 1 as observed in the mock-up tests. Thus, small-scale tests appear to adequately predict the effect of changes of materials within the same geometry (as in tests 1 through 3), but cannot be used to predict full-scale performance of materials in different geometries (test 4).

6.2 Adequacy of Existing Materials

As previously stated, no set of materials used in any of the four fully furnished mock-up tests completely met the DOT guidelines for flammability and smoke emission. Smoke emission characteristics were typically further from acceptable limits than flame spread characteristics. Carpeting used as wall covering or floor covering was the only material in which none of the samples tested exhibited acceptable smoke emission characteristics.

Of the materials evaluated in the small scale and large scale tests, the most promising combinations of materials were:

- Window Mask -- FRPII or PVC-Acrylic
- Glazing -- glass
- Seat Cushions -- Low smoke polychloroprene or FR polyurethane
- Wall Carpeting -- None acceptable, Carpet G (modacrylic carpet) best of those tested
- Floor Carpeting -- Carpet F (nylon carpet)

7. SUMMARY AND CONCLUSIONS

A series of tests was conducted to assess the large-scale burning behavior of materials used as furnishings for the interior of passenger rail coach vehicles. Eight full-scale mock-up tests (four of these fully furnished) were complemented with tests on the full seat assemblies and with small-scale laboratory tests on individual materials from the various components used on the interior of the cars.

The four fully furnished mock-up tests could be divided into two groups -- those in which full room involvement was obtained (tests 1 and 4) and those in which few, if any hazardous conditions were noted (tests 2 and 3). This distinct grouping was evidenced by peak gas temperatures (649°C to 825°C in tests 4 and 1; 114°C to 118°C in tests 2 and 3), smoke levels (17.3 m^{-1} to 19.9 m^{-1} in tests 4 and 1, 5.6 to 8.3 in tests 3 and 2), and gas concentrations (CO concentration of 3.6 to 3.9 percent in tests 4 and 1, 0.2 to 0.4 percent in tests 2 and 3).

Results of the small-scale laboratory tests on individual materials were found to be able to predict trends in full-scale fire performance for a given full scale geometry. However, when the geometry of the full scale test room was changed, the chosen small-scale tests failed to predict the effect of these changes. Thus, a possible vehicle interior evaluation protocol is evident:

- A small number (1 or 2) full size tests to determine a set of acceptable materials for the geometry of the full vehicle;
- A series of small-scale tests to evaluate alternative materials. Materials which are equal or better in all tests to those tested in the full-size vehicle could be substituted without further full-scale testing.

Of course, changes in the physical layout of the vehicle interior (i.e., the geometry of the vehicle interior) would necessitate additional full-size tests.

Some specific recommendations can be made based upon the results of these tests:

1) The extension of the full-carpeted luggage rack to the full length of the vehicle in test 4 made ignition of the luggage rack carpeting easier. FRA and Amtrak should study alternatives to the current luggage rack design to eliminate the combustible covering and to prevent (potentially hot) gases from being trapped beneath the luggage rack,

2) Padded armrests should be eliminated from the seat assemblies to retard spread of fire from one seat to the next,

3) Particular attention should be paid to insure the material used as a wall covering (carpeting or window mask) adjacent to seating will resist ignition and subsequent spread of fire,

The tests reported herein represent only a limited number of tests on a limited number of materials. Other materials or other combinations of materials may lead to different test results. The larger volume of an entire rail car (as opposed to the mock-up) would change the time response of the total system, To insure acceptable behavior in the full size vehicle, additional full vehicle tests, preferably in a full car, should be performed, Instrumentation for these tests would be similar to that used in the mock-up tests — temperature measurements within the vehicle from floor to ceiling and smoke density measurements and gas concentration measurements at several locations within the vehicle. At least two tests should be performed on the best combination of materials -- one with all openings closed and one with evacuation exits opened at a selected time during the test. These two tests would allow evaluation of the positive or negative effects of vehicle evacuation and determination of conditions at the exits as the fire develops.

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TABLE 1.
Recommendations For Testing The Flammability And Smoke Emission Characteristics Of Transit Vehicle Materials

Category	Function of Material	Test Procedure	Performance Criteria
Seating	Cushion[a,b,e]	ASTM D 3675	$I_s^h \leq 25$
		NFPA 258	D_s (1.5) $\leq$ 100; D_s (4.0) $\leq$ 200
	Frame[a,e]	ASTM E 162	$I_s \leq 35$
		NFPA 258	D_s (1.5) $\leq$ 100; D_s (4.0) $\leq$ 200
	Shroud[a,e]	ASTM E 162	$I_s \leq 35$
		NFPA 258	D_s (1.5) $\leq$ 100; D_s (4.0) $\leq$ 200
	Upholstery[a,b,c,e]	FAR 25853	Flame Time $\leq$ 10 sec; burn length $\leq$ 6 inch
		NFPA 258	D_s (4.0) $\leq$ 250 coated
			D_s (4.0) $\leq$ 100 uncoated
Panels	Wall[a,e]	ASTM E 162	$I_s \leq 35$
		NFPA 258	D_s (1.5) $\leq$ 100; D_s (4.0) $\leq$ 200
	Ceiling[a,e]	ASTM E 162	$I_s \leq 35$
		NFPA 258	D_s (1.5) $\leq$ 100; D_s (4.0) $\leq$ 200
	Partition[a,e]	ASTM E 162	$I_s \leq 35$
		NFPA 258	D_s (1.5) $\leq$ 100; D_s (4.0) $\leq$ 200
	Windscreen[a,e]	ASTM E 162	$I_s \leq 35$
		NFPA 258	D_s (1.5) $\leq$ 100; D_s (4.0) $\leq$ 200
	HVAC Ducting[a,e]	ASTM E 162	$I_s \leq 35$
		NFPA 258	D_s (4.0) $\leq$ 100
	Window[d,e]	ASTM E 162	$I_s \leq 100$
		NFPA 258	D_s (1.5) $\leq$ 100; D_s (4.0) $\leq$ 200
	Light Diffuser[e]	ASTM E 162	$I_s \leq 100$
		NFPA 258	D_s (1.5) $\leq$ 100; D_s (4.0) $\leq$ 200
Flooring	Struttural[f]	ASTM E 119	Pass
	Covering[g]	NFPA 253	C.R.F. $\geq$ 0.5 w/cm^2
Insulation	Thermal[a,b,e]	ASTM E 162	$I_s \leq 25$
		NFPA 258	D_s (4.0) $\leq$ 100
	Acoustic[a,b,e]	ASTM E 162	$I_s \leq 25$
		NFPA 258	D_s (4.0) $\leq$ 100
	Elastomers[a]	ASTM C 542	Pass
Miscellaneous	Exterior Shell[a,e]	ASTM E 162	$I_s \leq 35$
		NFPA 258	D_s (1.5) $\leq$ 100; D_s (4.0) $\leq$ 200
	Component Box Covers[a,e]	ASTM E 162	$I_s \leq 35$
		NFPA 258	D_s (1.5) $\leq$ 100; D_s (4.0) $\leq$ 200

Notes to Table 1

a) Materials tested for surface flammability should not exhibit any flaming running, or flaming dripping.

b) Flammability and smoke emission characteristics should be demonstrated to be permanent by washing, if appropriate, according to FED-STD-191A Textile Test Method 5830.

c) Flammability and smoke emission characteristics should be demonstrated to be permanent by dry-cleaning, if appropriate, according to AATCC-86, Materials that cannot be washed or dry cleaned should so be labeled and should meet the applicable performance criteria after being cleaned as recommended by the manufacturer.

d) For double window glazing, the interior glazing should meet the materials requirements specified herein, the exterior glazing need not meet those requirements.

e) **NFPA-258** maximum test limits for smoke emission (specified optical density) should be measured in either the flaming or non-flaming mode, depending on which mode generates the most smoke,

f) Structural flooring assemblies should meet the performance criteria during a nominal test period determined by the transit property. The nominal test period should be twice the maximum expected period of time, under normal circumstances, for a vehicle to come to a complete, safe stop from maximum speed, plus the time necessary to evacuate all passengers from a vehicle to a safe area. The nominal test period should not be less than 15 minutes. Only one specimen need be tested,

g) Carpeting should be tested in accordance with **NFPA-253** with its padding, if the padding is used in actual installation.

h) Symbols and abbreviations for acceptable performance criteria are described in detail in the individual test methods, Text of report summarizes test methods,

TABLE 2.
Summary Of Selected Small-Scale Test
Results On Transit Vehicle Components

Material	MUSS 302 (mm/s)	FAR 25.853		ASTM E-162 (I_s)	NFPA 253 (kW/m^2)	NFPA 258 (Dm)	Reference[a]
		Burn Length (mm)	Flame Time (sec)				
Wall Capetings	DNI[b]			181			[17]
	DNI			51		211	[17]
Floor Coverings	DNI	64	3.5	8	6.6	319	[17]
					11	694	[18]
Seat Cushion Foams							
Polyurethane		33	9			632	[18]
Polychloroprene		76	0			678	[18]
Foam 1[c]	0.57					83	[17]
Foam 2[c]	0.82					111	[17]
Foam 3[c]	1.11					204	[17]
Interior Walls							
PVC-Acrylic Copolymer		64	0	51		710	[17]

Notes:
a - see section 9 for reference
b - DNI = did not ignite
c - mixture of different foams, composition not specified

TABLE 3.
Instrumentation For Mock-up Test 1

Doorway Gas Temperature	100,170,510,850,900,1300,1780 mm from top of doorway
Interior Gas Temperature	
South Wall	30,50,80,100,150,760,1370,2130 mm
East Wall	30,50,80,100,150,760 mm
West Wall	30,50,80,100,150,760 mm measured from ceiling
Exhaust Stack Gas Temperature	nine positions dividing cross section (for velocity calculations)
Smoke Optical Density Doorway	
Doorway	170,510,850 mm measured from top of doorway
Exhaust Stack	one position measured at centerline of velocity/temperature grid
Gas Concentration - CO, Co_2,O_2	
Doorway	170,510,850 mm measured from top of doorway
Exhaust Stack	one position measured at centerline of velocity/temperature grid
Exhaust Stack Gas Velocity	five positions dividing cross section
Heat Flux	center of room at floor level

TABLE 4.
Instrumentation For Mock-up Tests 2-4

Measurement	Locations
Doorway Gas Temperature	100,170,850,1300,1930 mm measured from top of doorway
Interior Gas Temperature	
South Wall	150,760,1370,2130 mm
East Wall	150,760,1370 mm
West Wall	150,760,1370 mm measured from ceiling
Exhaust Stack Gas Temperature	nine positions dividing cross section (for velocity calculations)
Smoke Optical Density	
Doorway	170,510,850 mm measured from top of doorway
Exhaust Stack	one position measured at centerline of velocity/temperature grid
Gas Concentration - CO, CO_2, O_2	
Doorway	170,510,850 mm measured from top of doorway
Exhaust Stack	one position measured at centerline of velocity/temperature grid
Exhaust Stack Gas Velocity	five positions dividing cross section
Heat Flux	center of room at floor level

TABLE 5.
Instrumentation For Mock-up Tests 5-8

Measurement	Locations
Doorway Gas Temperature	200,510,810,1120,1730 mm measured from top of doorway
Interior Gas Temperature	
East Wall	150,300,610,910,1220,1520,1830,2130 mm
Center	150,300,610,910,1220,1520,1830,2130 mm measured from ceiling
Exhaust Stack Gas Temperature	nine positions dividing cross section (for velocity calculations)
Smoke Optical Density	
Exhaust Stack	one position measured at centerline of velocity/temperature grid
Gas Concentration - CO, CO_2, O_2	
Doorway	168,510 mm measured from top of doorway
Exhaust Stack	one position measured at centerline of velocity/temperature grid
Exhaust Stack Gas Velocity	five positions dividing cross section
Heat Flux	center of room at floor level

TABLE 6.
Materials And Test Conditions For Full-Scale Mock-up Tests

MATERIALS	Test 1	Test 2	Test 3	Test 4
Carpeting Wall Ceiling Baggage Rack	Acrylic "G"	→	→	Acrylic/Modacrylic D
Floor	Nylon "F"	Nylon "B"	→	→
Window Mask	FRPI	FRPII	→	Vinyl Chloride Acrylic Copolymer
Window Glazing	Glass	Polycarbonate	→	→
Seat Assembly				
Armrest	PU[a]	PCP	→	→
Side Shroud Back Shell Food Tray	Glass-Filled Polycarbonate	→	→	→
Cushions Headrest	PU	PCP	FR-PU	LS-PCP
Upholstery	90/10 Wool Nylon, Vinyl, Muslin Undercover	→	→	→
TEST CONDITIONS				
Temperature (^{o}C)	24	23	27	24
Relative Humdity (% RH)	45	42	40	43

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[a] PU = Polyurethane, PCP = Polychloroprene, FR-PU = FR-Polyurethane, LS-PCP = Low Smoke Polychloroprene, FRP = Glass Fiber Reinforced Polyester

Table 7.
Gas Temperature Levels During Mock-up Tests With Time To Reach Critical Temperatures

Test	Peak Temperature (°C)	Time to Reach Peak (s)	Time to Reach 183°C/361°F (s)	Time to Reach 600°C/1112°F (s)
		At Ceiling		
1	825	478	315	468
2	114	674	n.r.[a]	n.r.
3	118	120	n.r.	n.r.
4	649	275	200	270
5	113	200	n.r.	n.r.
6	171	100	n.r.	n.r.
7	123	100	n.r.	n.r.
8	149	120	n.r.	n.r.
		At Passenger Height		
1	768	493	411	478
2	86	687	n.r.	n.r.
3	82	140	n.r.	n.r.
4	542	270	n.r.	n.r.
5	29	200	n.r.	n.r.
6	36	120	n.r.	n.r.
7	32	100	n.r.	n.r.
8	38	140	n.r.	n.r.

a - n.r. = not reached

TABLE 8.
Smoke Levels During Mock-up Tests With Time To Reach Critical Smoke Levels

Test	Peak Extinction Coefficient (m^{-1})	Time to Reach Peak (s)	Time to Reach 1.2 m^{-1} (s)	Time to Reach 0.2 m^{-1} (s)
		At Top of Door		
1	19e9	532	212	99
2	8.3	604	318	134
3	5.6	1990	356	89
4	17e3	295	90	40
5				
6				
7				
8				
		At Passenger Height		
1	13e1	500	486	471
2	0.5	795	n.r.[a]	407
3	0e3	2613	n.r.	2613
4	16e4	290	225	215
5	-[b]	-	-	-
6	-	-	-	-
7	-	-	-	-
8	-	-	-	-

Notes:

a - n.r. = not reached

b - smoke levels not measured during tests 5 through 8

TABLE 9.

Peak Gas Concentrations And Time To Reach Critical Gas Concentrations During Mock-Up Tests

Test	Minimum Oxygen Concentration (%)	Time to Reach Minimum (s)	Time to Reach 9%-O_2 (s)	Peak CO_2 Concentration (%)	Time to Reach Peak (s)	Time to Reach 10% CO_2 (s)	Peak CO Concentration (%)	Time to Reach Peak (s)	Time to Reach 0.8% CO (s)
At Top of Door									
1	1.1	521	503	13.4	517	503	3.9	510	450
2	19.7	712	n.r.[a]	0.9	242	n.r.	0.2	674	n.r.
3	19.6	184	n.r.	1.0	152	n.r.	0.4	1278	n.r.
4	7.4	300	295	7.9	300	n.r.	3.6	300	276
5	19.8	200	n.r.	1.1	200	n.r.	0.1	440	n.r.
6	18.7	110	n.r.	2.2	110	n.r.	0.2	130	n.r.
7	19.4	120	n.r.	1.6	110	n.r.	0.1	400	n.r.
8	20.1	200	n.r.	1.8	130	n.r.	0.3	410	n.r.
At Passenger Height									
1	5.6	521	510	10.9	517	510	3.1	507	482
2	20.6	165	n.r.	0.5	159	n.r.	0.1	490	n.r.
3	20.7	159	n.r.	0.4	120	n.r.	0.2	1341	n.r.
4	12.8	300	n.r.	5.2	295	n.r.	2.3	300	275
5	20.5	210	n.r.	0.5	200	n.r.	0.2	330	n.r.
6	19.6	170	n.r.	1.3	160	n.r.		-	-
7	20.1	150	n.r.	0.8	130	n.r.	0.2	180	n.r.
8	20.1	200	n.r.	0.9	190	n.r.	0.3	210	n.r.

[a] n.r. = not reached

TABLE 10.
Peak Rate of Heat Release Through Exhaust Stack During Mock-up Tests

Test	Peak Rate of Heat Release (kW)	Time to Peak (s)
1	4400	515
2	70	763
3	40	140
4	1600	302
5	60	230
6	170	140
7	80	120
8	90	140

TABLE 11.
Test Procedures And Evaluation Criteria For Small-scale Testing Of Amtrak Furnishings

Material	Test Procedure	Performance Criteria
Window Mask	ASTM E 162	$I_s \leq 35$
	NFPA 258	D_s (1.5) $\leq$ 100, D_s (4.0) $\leq$ 200
Window Glazing	ASTM E 162	$I_s \leq 100$
	NFPA 258	D_s (1.5) $\leq$ 100, D_s (4.0) $\leq$ 200
Wall Covering	ASTM E 162	$I_s \leq 35$
	NFPA 258	D_s (1.5) $\leq$ 100, D_s (4.0) $\leq$ 200
Floor Covering	NFPA 253	CRF $\geq$ 5 kW/m^2
Seat Cushions	ASTM D 3675	$I_s \leq 25$
	NFPA 258	D_s (1.5) $\leq$ 100, D_s(4.0) $\leq$ 200

TABLE 12
Small-scale Tests Conducted On Amtrak Materials

Test Methods

Application	Material Description	Density kg/m^3	ASTM D-3675	ASTM E-162	NFPA 258	NFPA 253	RHR Cone
Window Mask				X	X		X
	Fiberglass reinforced plastic (I)	1.8×10^3					
	Fiberglass reinforced plastic (II)	1.6×10^3					
	Vinyl Chloride Acrylic Copolymer	1.4×10^3					
Glazing				X	X		X
	Polycarbonate	2.61×10^3					
Wall Covering				X	X		X
	Carpet D (Acrylic/Modacrylic)	3.9×10^2					
	Carpet G (Acrylic)	3.7×10^2					
	Carpet B (Nylon)	3.9×10^2					
Seat Cushions			X		X		X
	Polyurethane	6.2×10^1					
	FR-Polyurethane	7.7×10^1					
	Polycloroprene	8.0×10^1					
	Low smoke polycloroprene	1.5×10^2					
Floor Covering						X	X
	Carpet F (Nylon)	3.8×10^2					

TABLE 13.
NFPA 258 Optical Density Test Results for Amtrak Interior Furnishing Components Under Flaming Exposure Conditions

Application	Material	D_s (1.5)	D_s (4.0)	$D_{m.corr}$
Window Mask				
	FRP I	110	320	270
	Vinyl Chloride Acrylic Copolymer *	45	170	330
	FRP II *	0	41	170
Glazing				
	Polycarbonate *	2	64	350
Seat Cushions				
	Polyurethane	320	620	620
	Polychloroprene	260	410	410
	FR-polyurethane*	87	170	160
	Low Smoke Polychloroprene*	68	140	310
Wall Covering				
	Carpet D	200	460	470
	Carpet G	69	250	250
	Carpet B	8	250	230
Floor Covering with underlayment				
	Carpet B	6	260	300
	Carpet F *	0	170	280

* meets criteria in DOT guidelines

TABLE 14.
ASTM E-162 Flame Spread Test Results On Amtrak Interior Finishing Materials

Application	Material	I_s	DOT Guidelines
Window Mask			$I_s \leq 35$
	FRPI *	34	
	FRPII *	35	
	Vinyl Chloride Acrylic Copolymer *	3	
Glazing			$I_s \leq 100$
	Polycarbonate *	54	
Wall Covering			$I_s \leq 35$
	Carpet B	270	
	Carpet F	150	
	Carpet G	80	
	Carpet D *	DNI	
Seat Cushions[a]			$I_s \leq 25$
	Polyurethane	960	
	FR-Polyurethane*	< 5	
	Polychloroprene*	< 5	
	Low Smoke Polychloroprene*	< 5	

[a] ASTM D-3675-76 standard test method was followed for flexible cellular materials.

* meets criteria in DOT guidelines

TABLE 15.

Characterization Of Amtrak Materials By The Cone Calorimeter, Average Value For Three Replicates Tested At 25 kW/m^2

Application	Material	Peak Heat Release Rate (kW/m^2)	Time (sec)	Ignition Delay Time (sec)	Total Heat Release (MJ/m^2)
Window Mask					
	FRPI	370	157	137	6.1
	FRPII	230	280	237	8.9
	Vinyl Chloride Acrylic Copolymer	200	99	90	1.6
Floor and Walls					
	Carpet G	410	57	48	3.1
	Carpet B	380	141	95	13
	Carpet F	350	228	117	21
Seat Cushions					
	Polyurethane	600	49	10	12
	FR-Polyurethane	210	139	16	8.9
	Polychloroprene	32	264	-	3.2
	Low Smoke Poly-chloroprene	27	434	-	10

TABLE 160
Results Of Small-scale Test Evaluation Of Materials Used In Fully Furnished Mock-up Tests

		Flame Spread		Smoke Emission (NFPA 258)		Heat Release Rate (Cone Calorimeter)
Mock-up Test	Material	ASTM E162 I_s	NFPA 253 CRF (kW/m^2)	D_s @ 1.5 min	D_s @ 4 min	Peak Rate (kW/m^2)
1	Window Mask	34*		110	320	370
	Glazing	0*		0	0	-
	Seat Cushions	960		320	620	600
	Wall Covering	80*		69	250	410
	Floor Covering		>11*	0	170*	350
2	Window Mask	35*		0	41*	230
	Glazing	54*		2	64*	-
	Seat Cushions	<5*		260	410	32
	Wall Covering	80		69	250	410
	Floor Covering		5.5*	8	250	380
3	Window Mask	35*		0	41*	230
	Glazing	54*		2	64*	-
	Seat Cushions	<5*		87	170*	210
	Wall Covering	80		69	250	410
	Floor Covering		5.5*	8	250	380
4	Window Mask	3*		45	170*	200
	Glazing	54*		2	64*	-
	Seat Cushions	<5*		68	140*	27
	Wall Covering	<5*		201	460	-
	Floor Covering		5.5*	8	250	380

* meets criteria in DOT guidelines

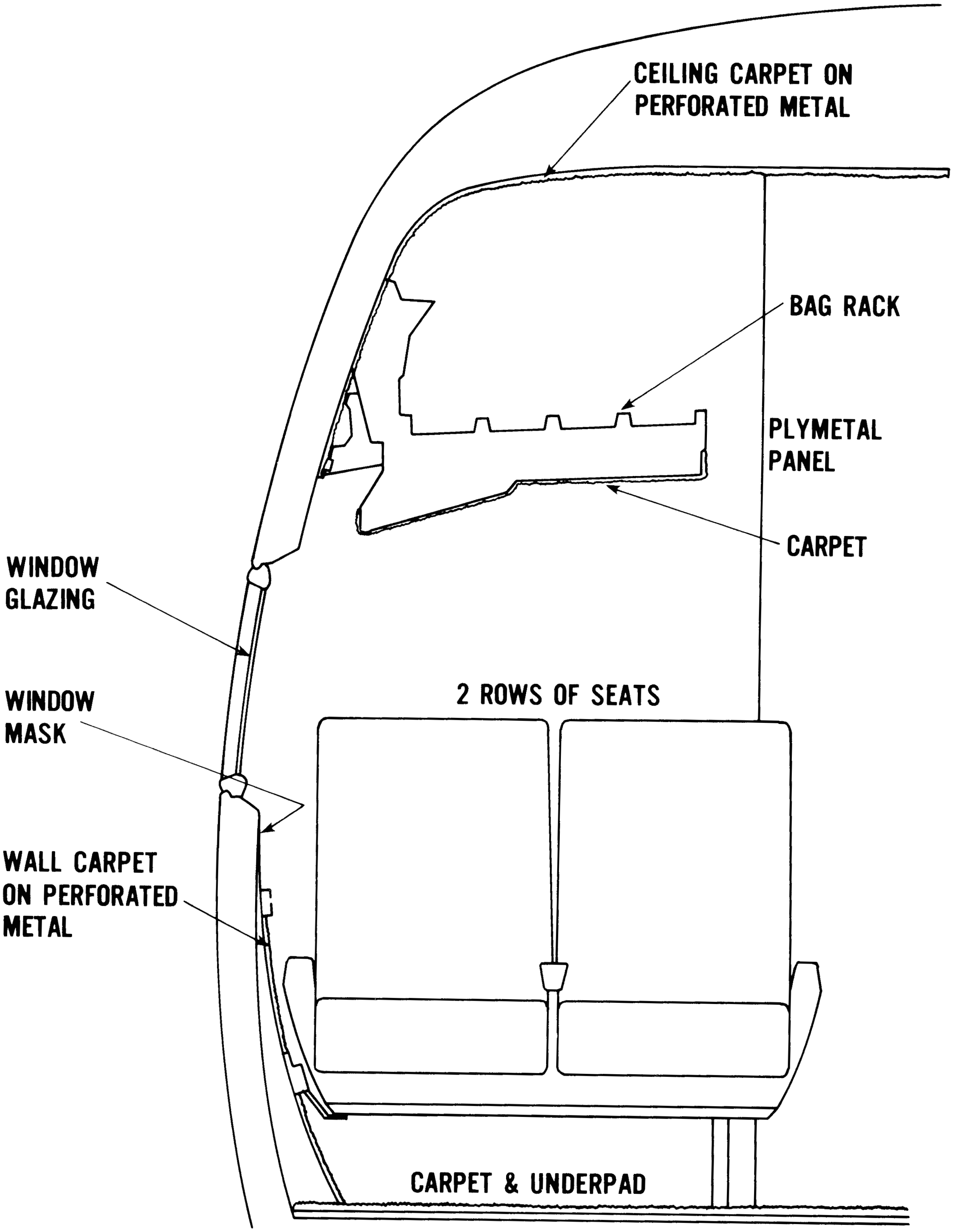

Figure 1. Cutaway view of Amtrak Passenger car interior

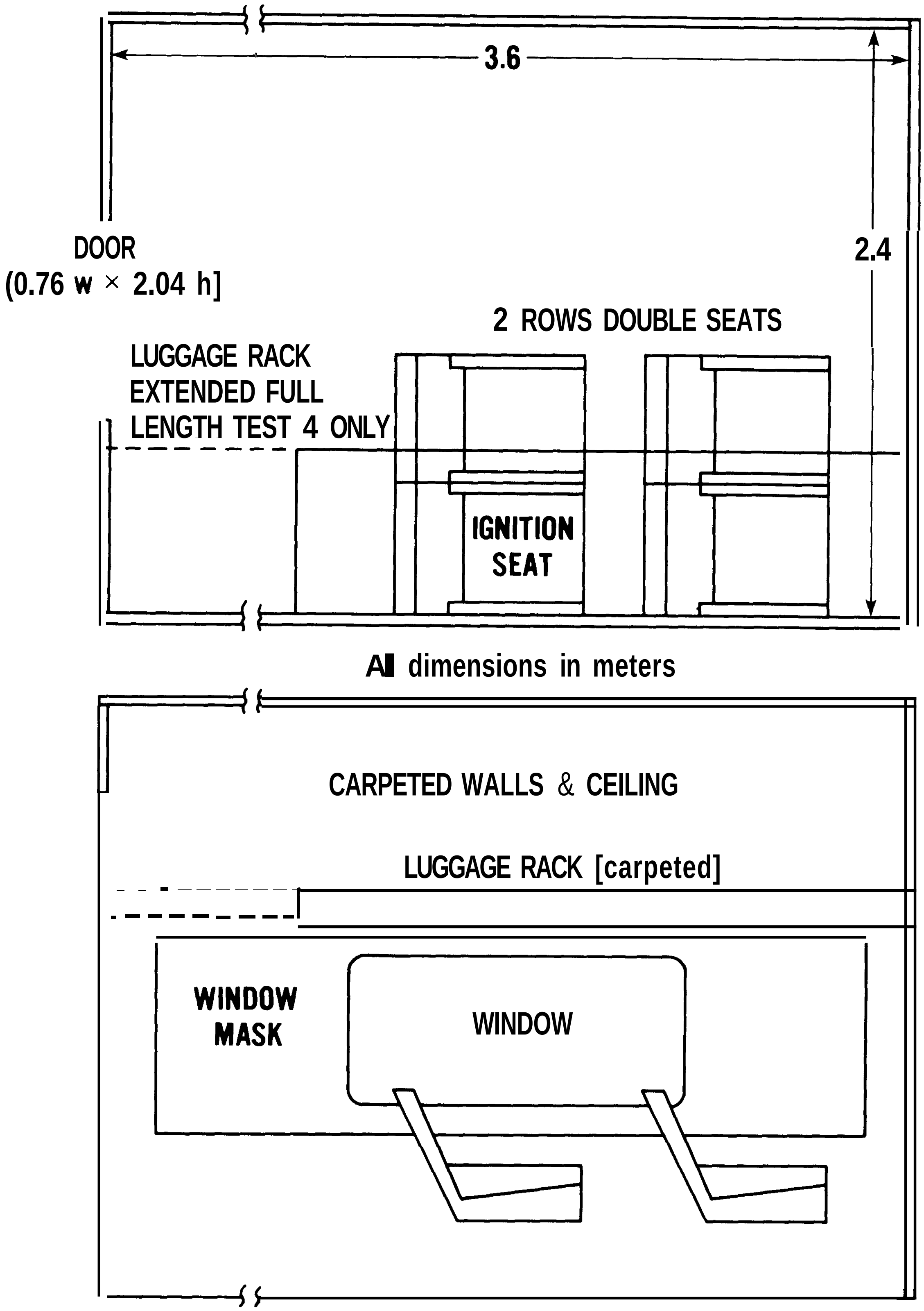

Figure 2. Mock–up test room configuration

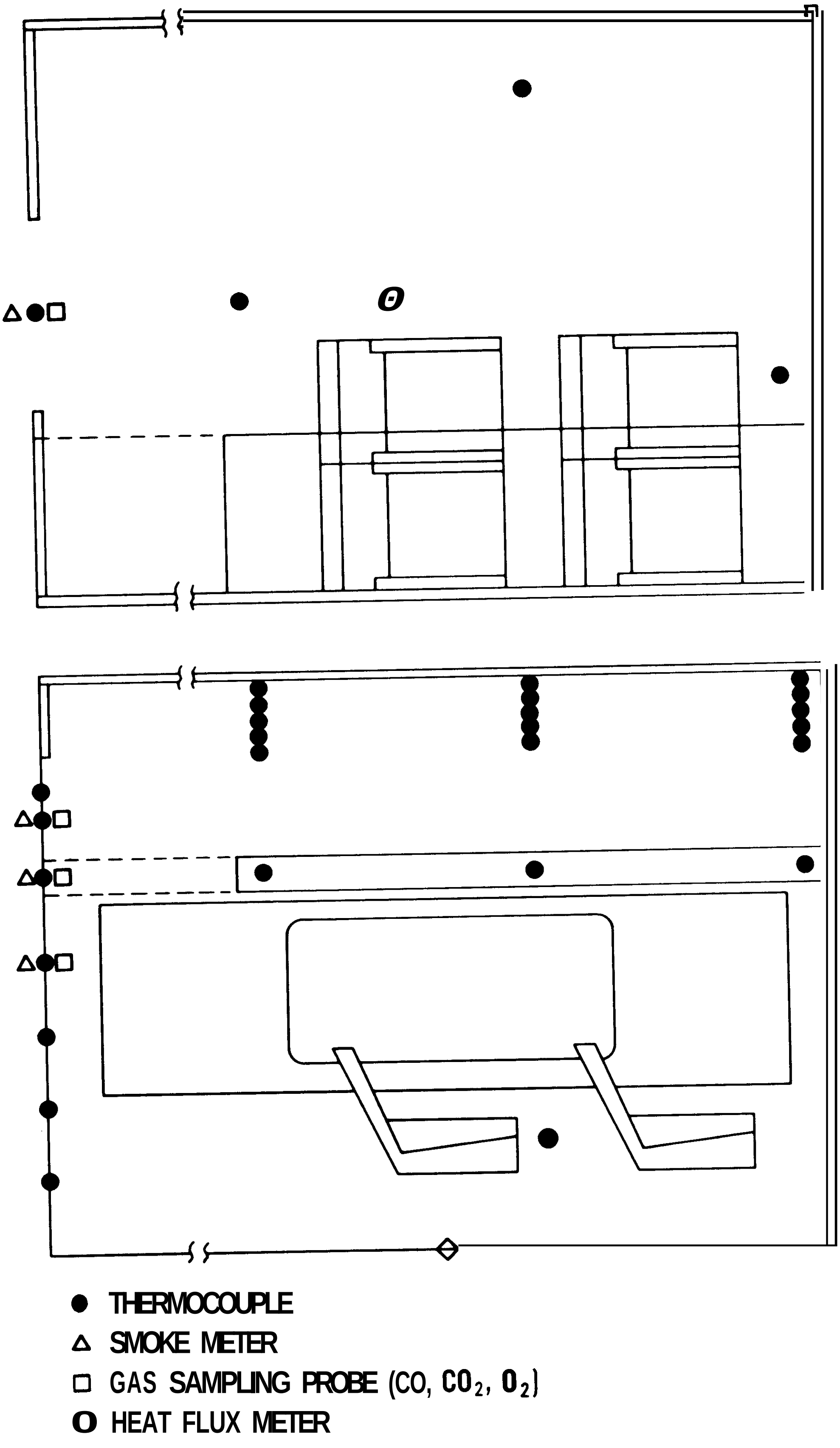

Figure 3. Instrumentation for full-scale mock-up test 1

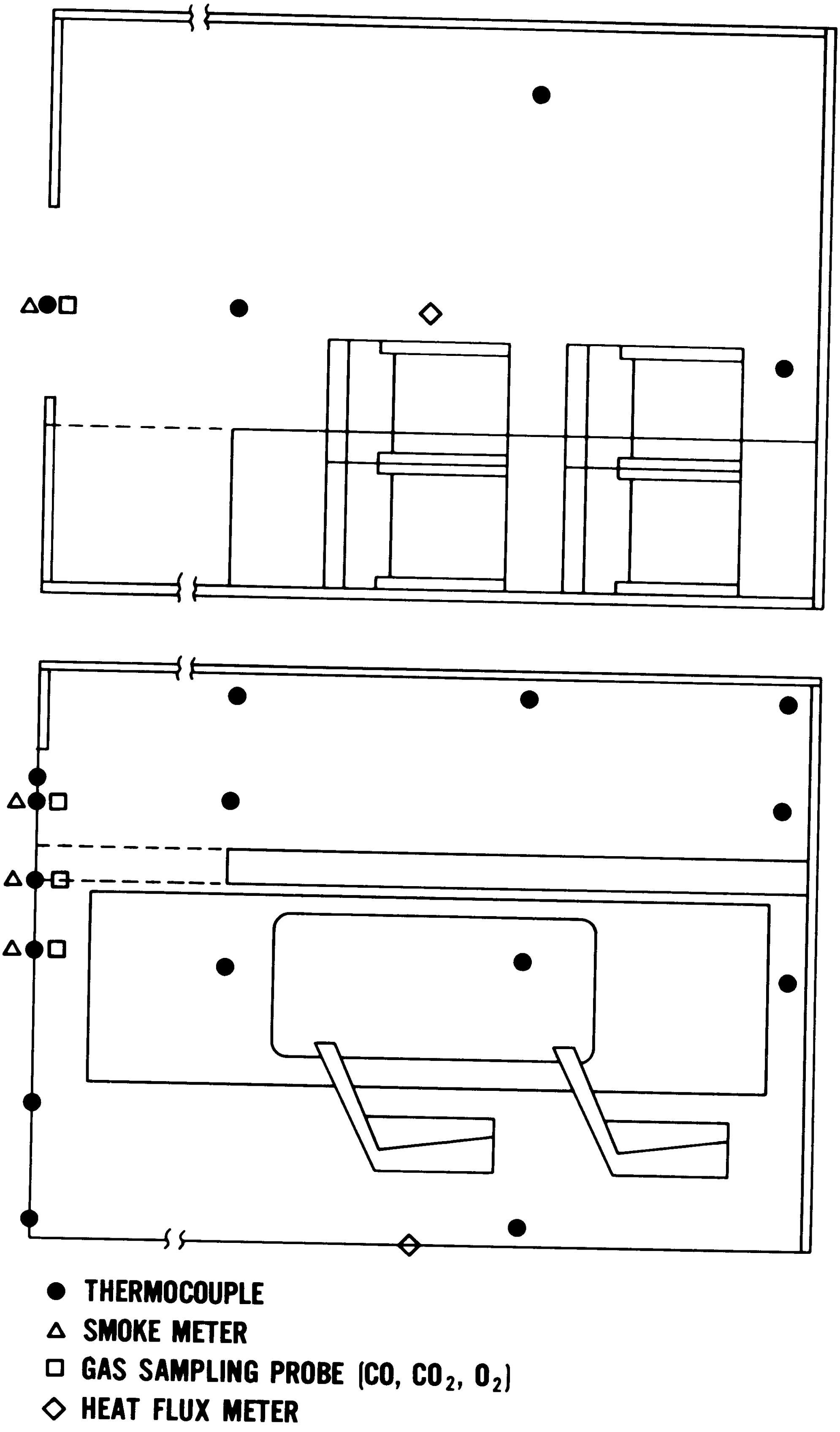

Figure 4. Instrumentation for full-scale mock-up tests 2 through 4

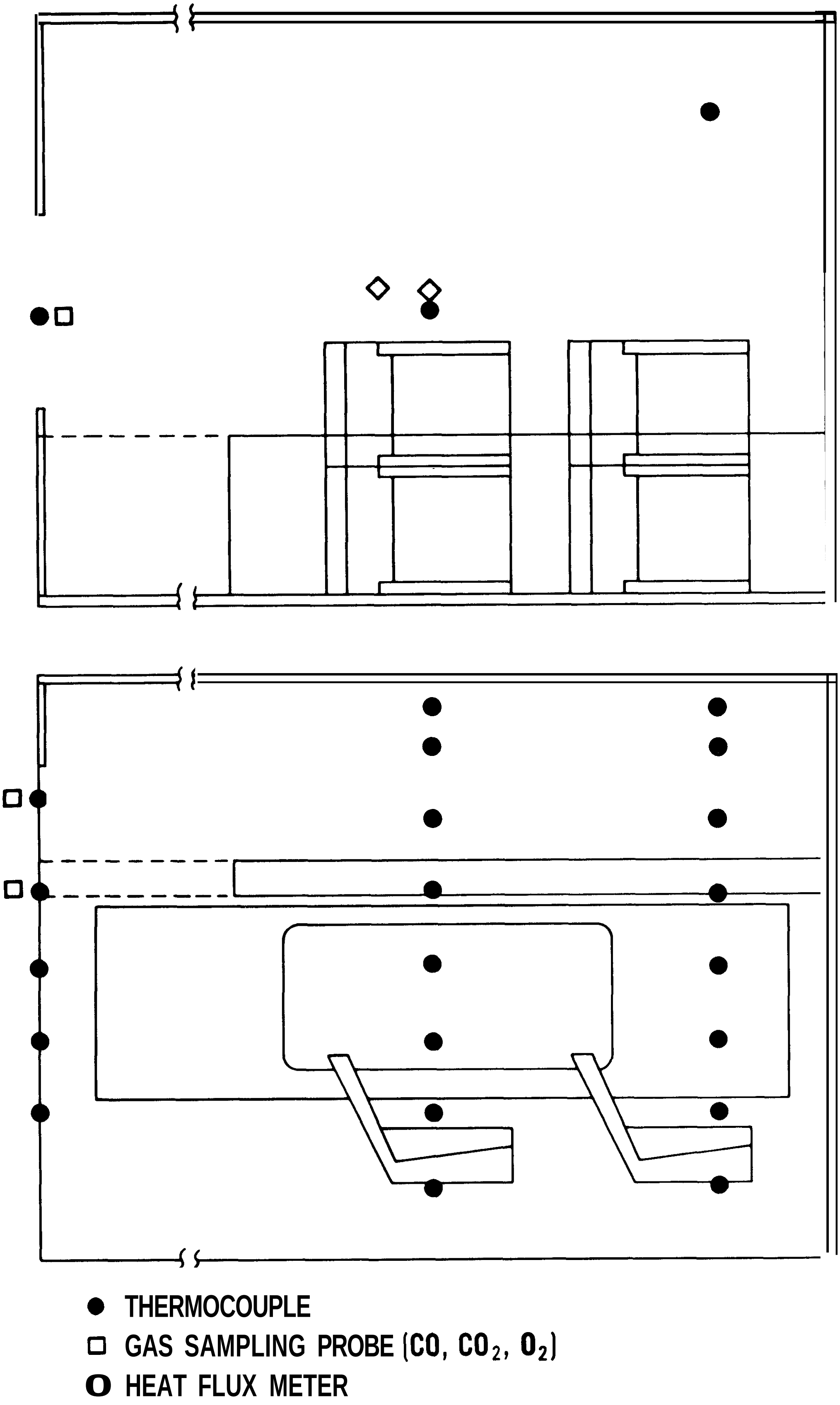

Figure 5. **Instrumentation** for **full-scale mock-up tests 5 through 8**

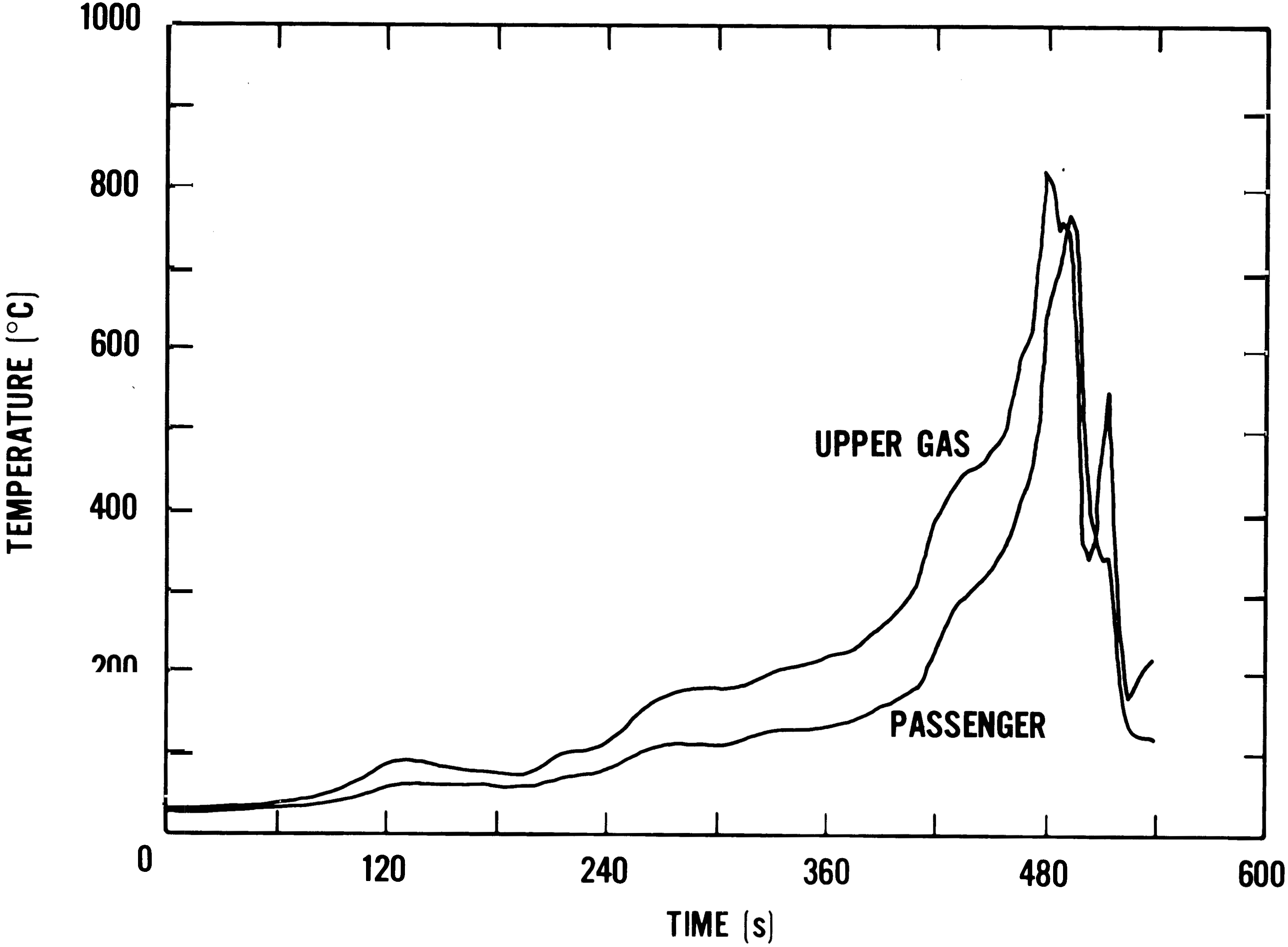

Figure 6. Temperatures measured at ceiling level and at passenger level during full-scale mock-up test 1

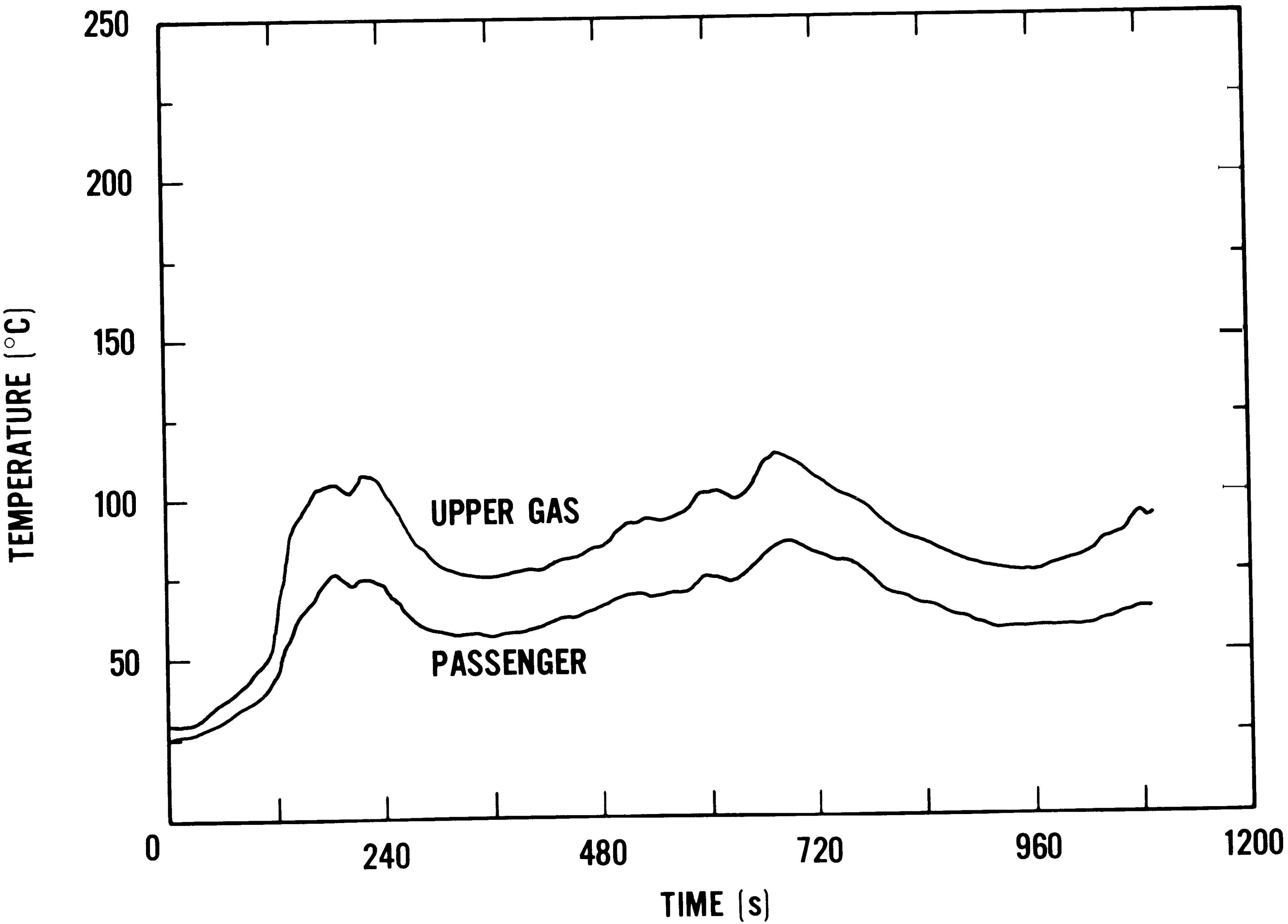

Figure 7. Temperatures measured at ceiling level and at passenger level during full-scale mock-up test 2

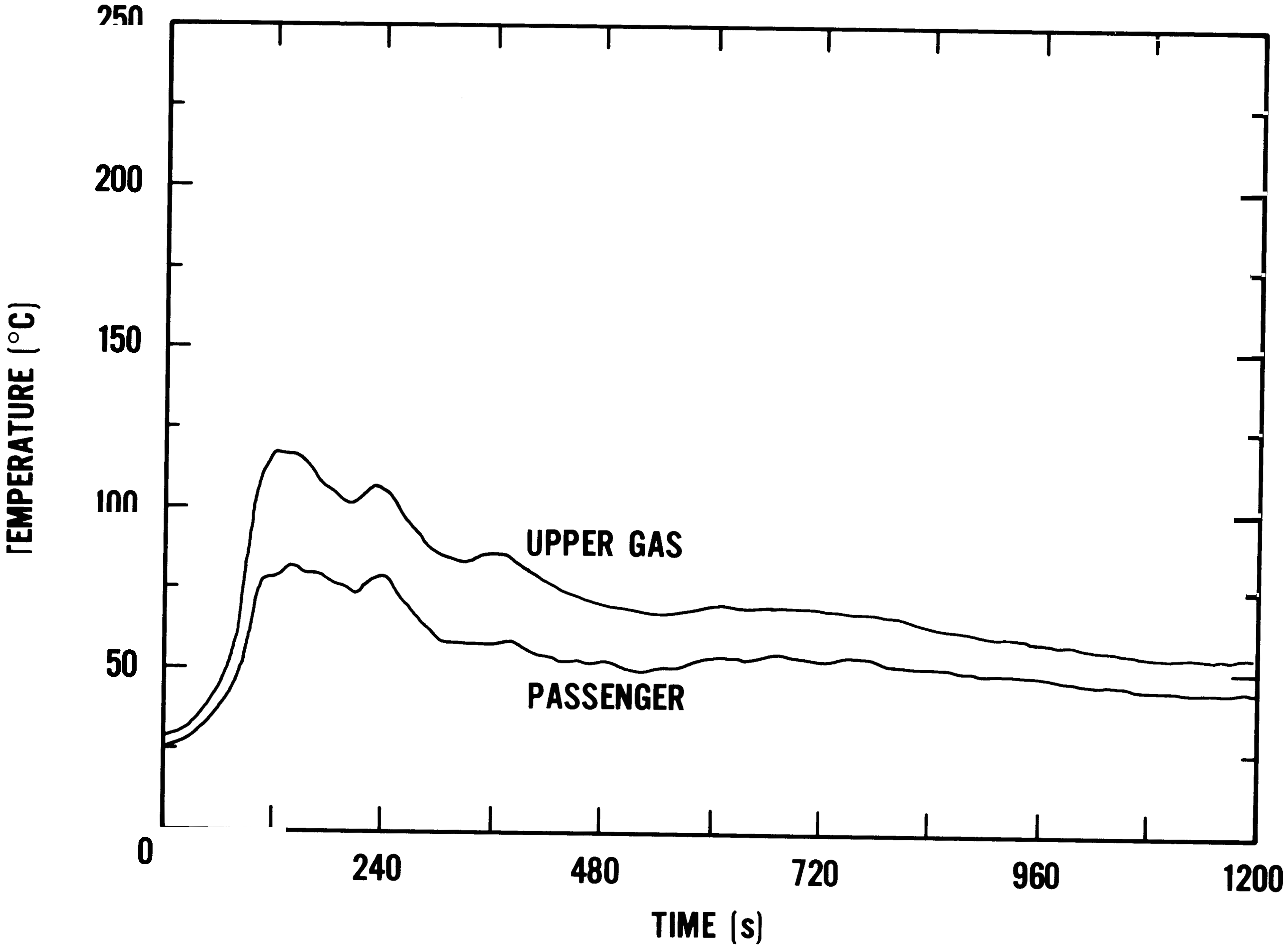

Figure 8. Temperatures measured at ceiling level and at passenger level during full-scale mock-up test 3

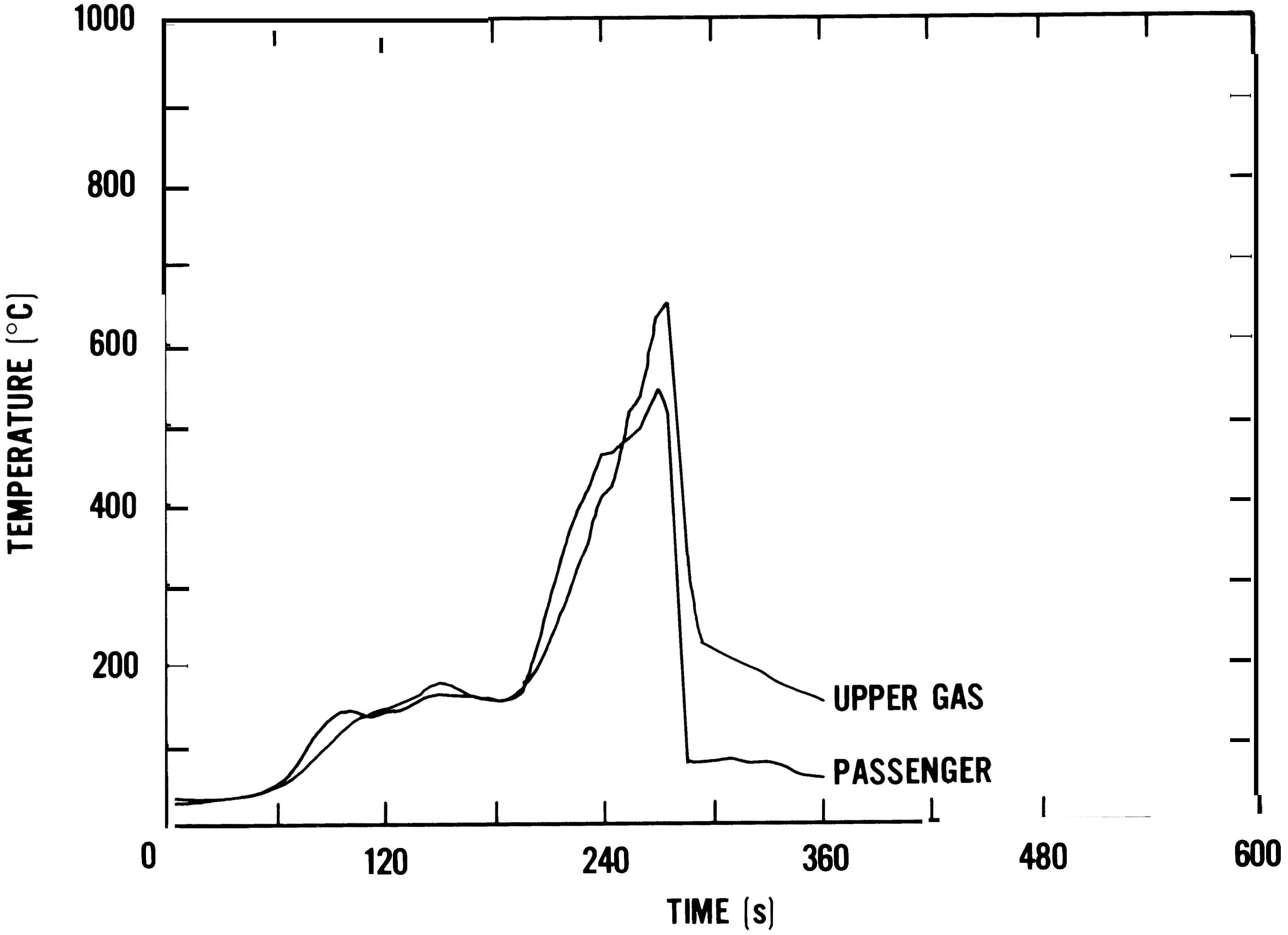

Figure 9. Temperatures measured at ceiling level and at passenger level during full-scale mock-up test 4

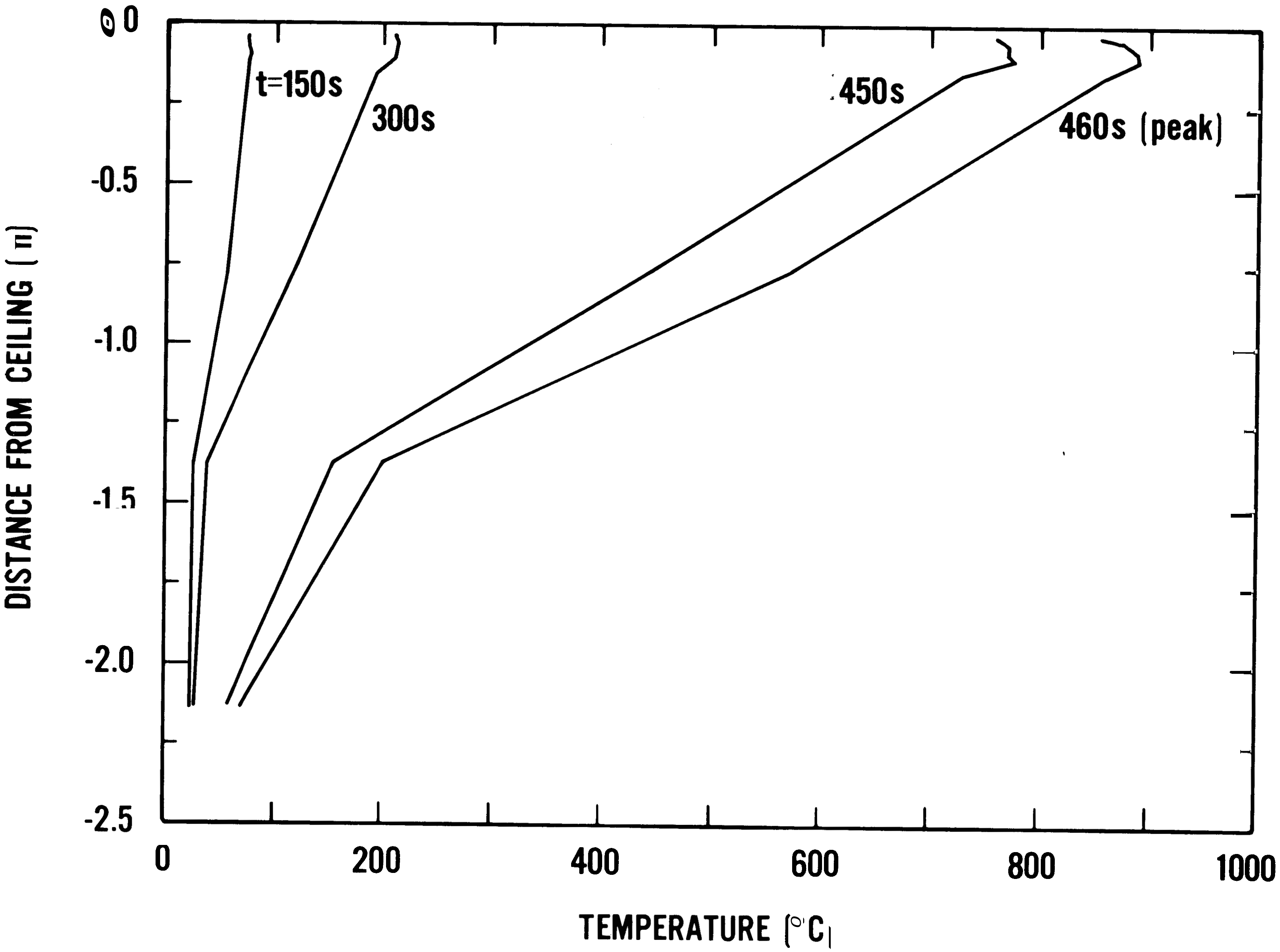

Figure 10. Temperature profiles from floor to ceiling during full-scale mock-up test 1

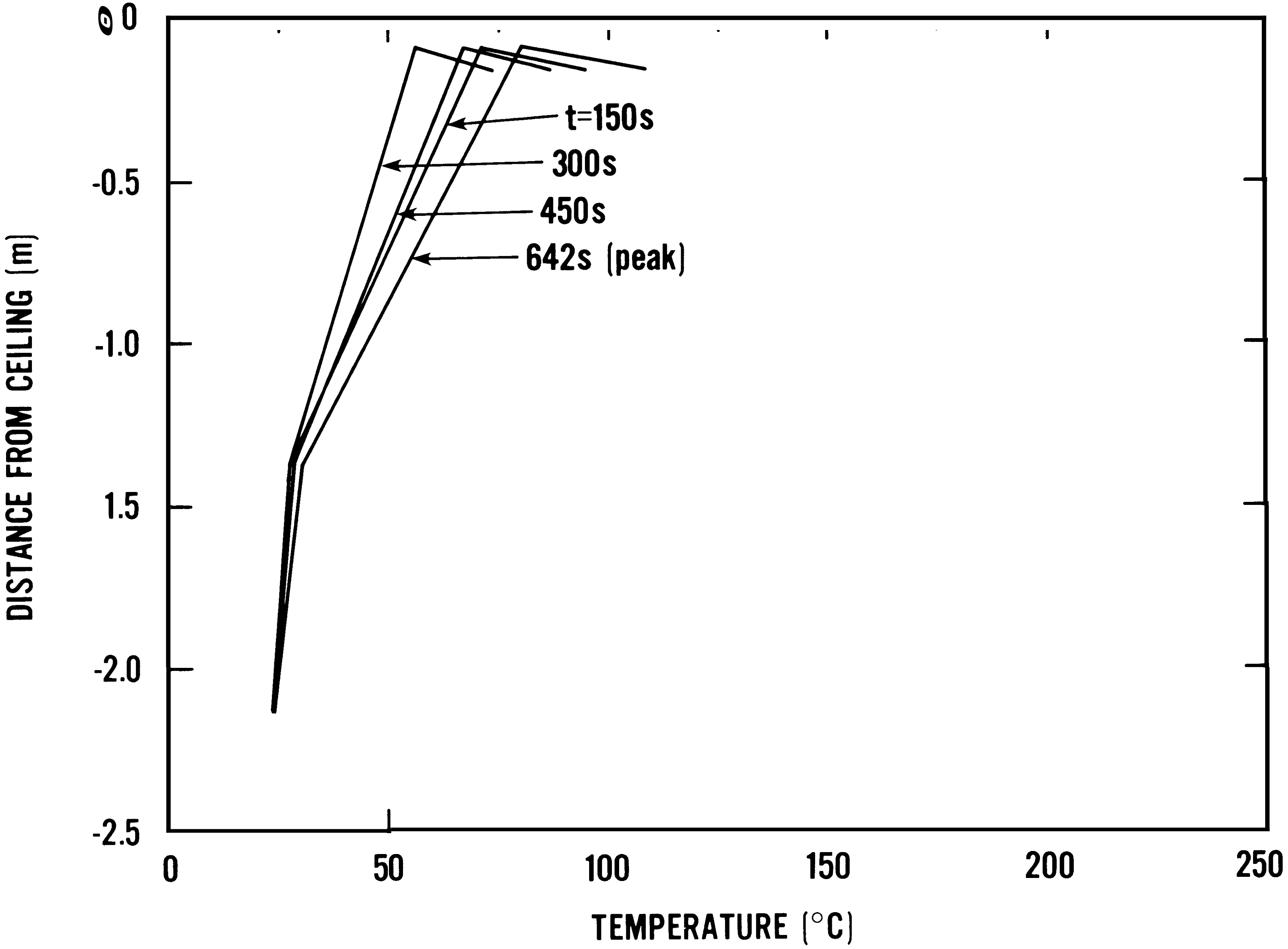

Figure 11. Temperature profiles from floor to ceiling during full-scale mock-up test 2

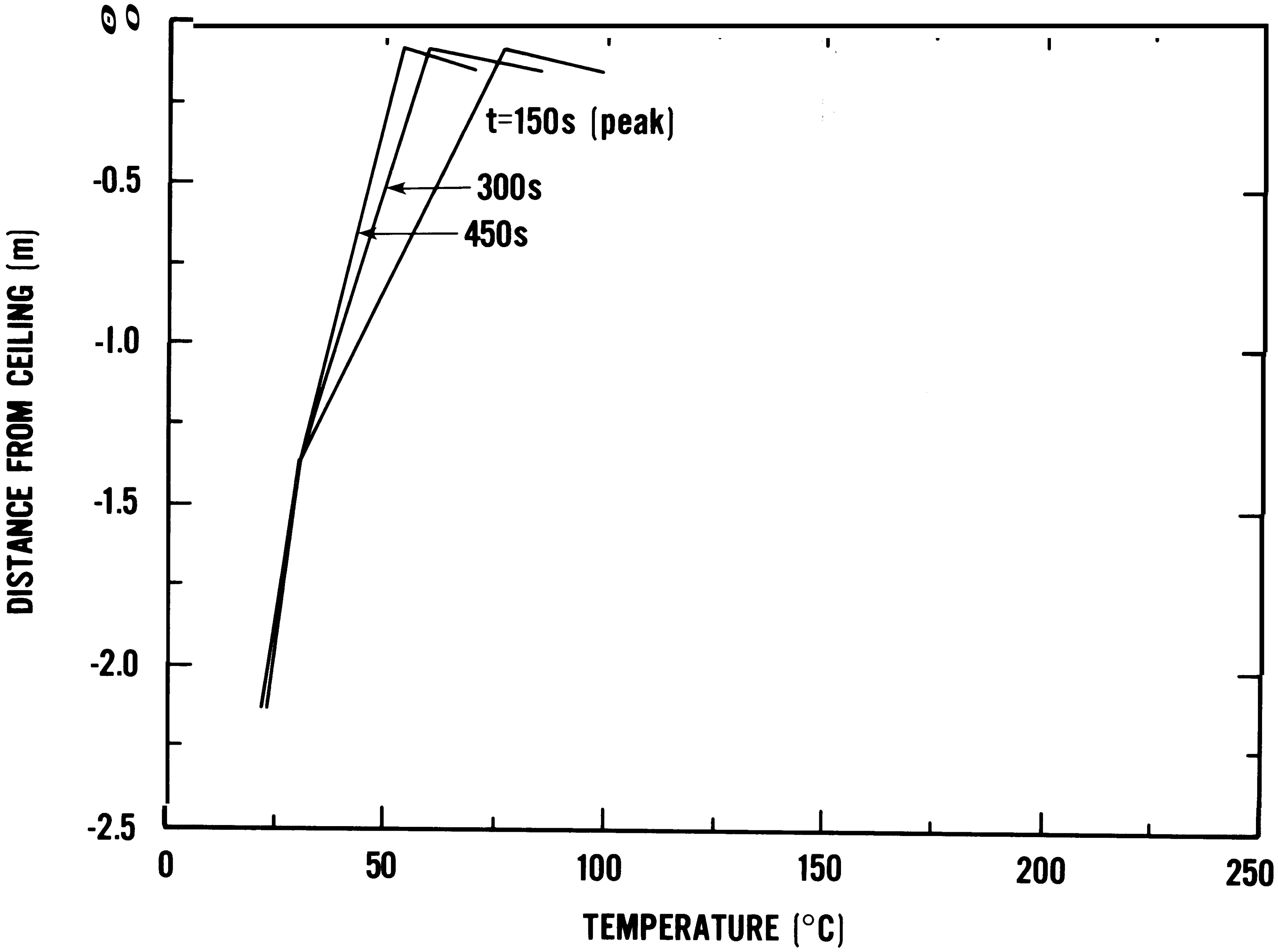

Figure 12. Temperature profiles from floor to ceiling during full-scale mock-up test 3

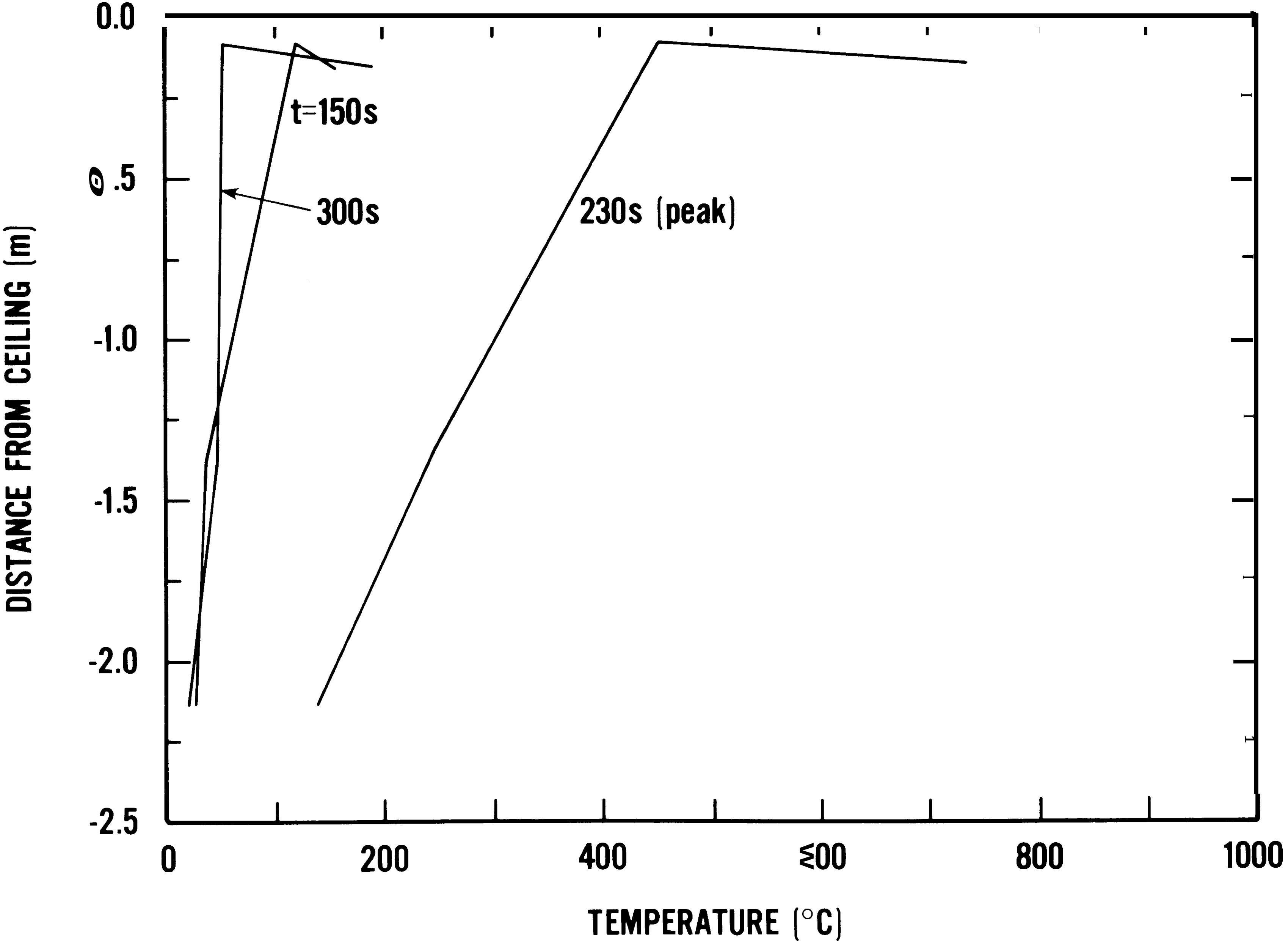

Figure 13. Temperature profiles from floor to ceiling during full-scale mock-up test 4

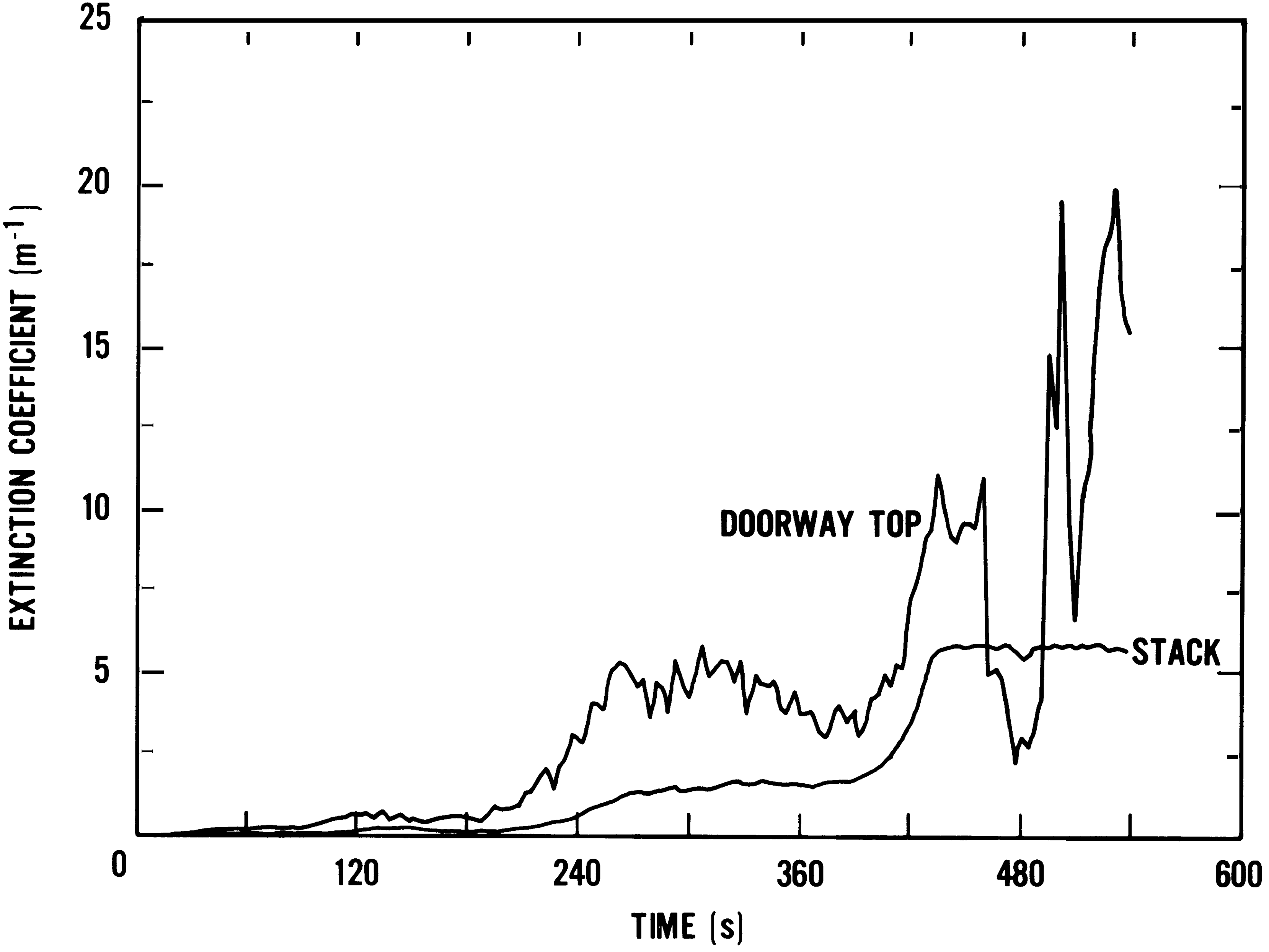

Figure 14. Smoke obscuration measured at ceiling level and in exhaust stack during full-scale mock-up test 1

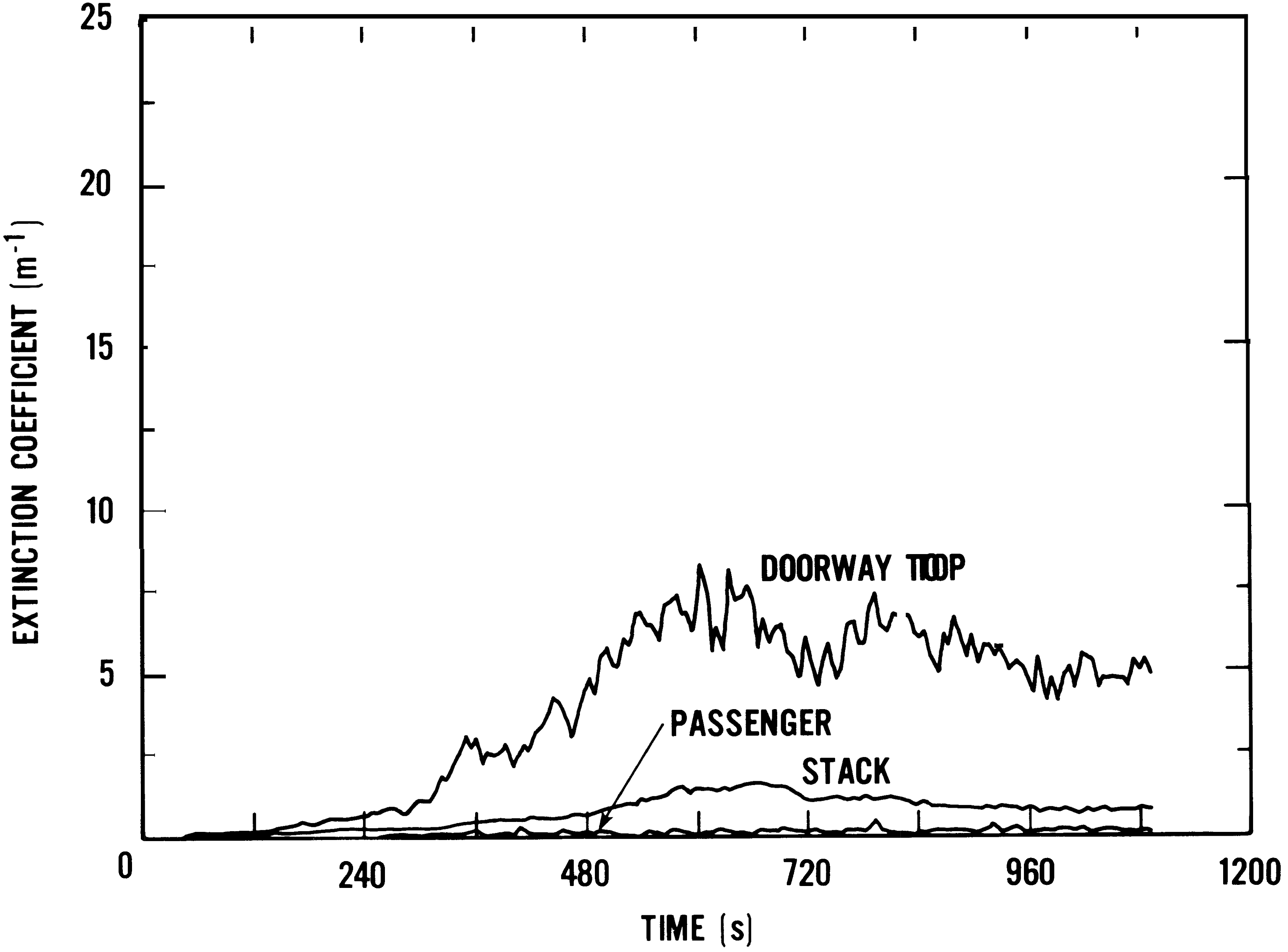

Figure 15 Smoke obscuration measured at ceiling level, passenger level, and in exhaust stack during full-scale mock-up test 2

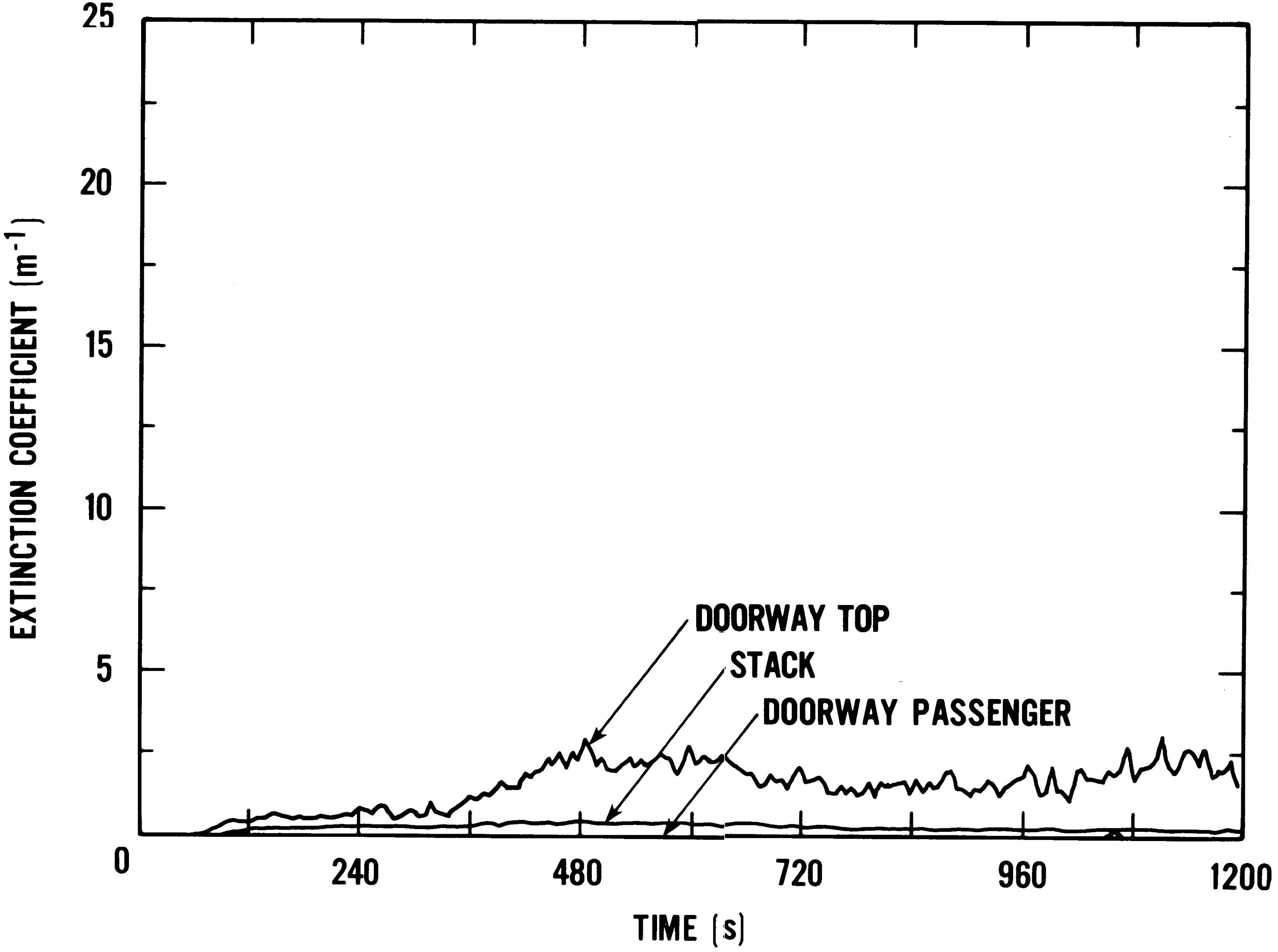

Figure 16. Smoke obscuration measured at ceiling level, passenger level, and in exhaust stack during full-scale mock-up test 3

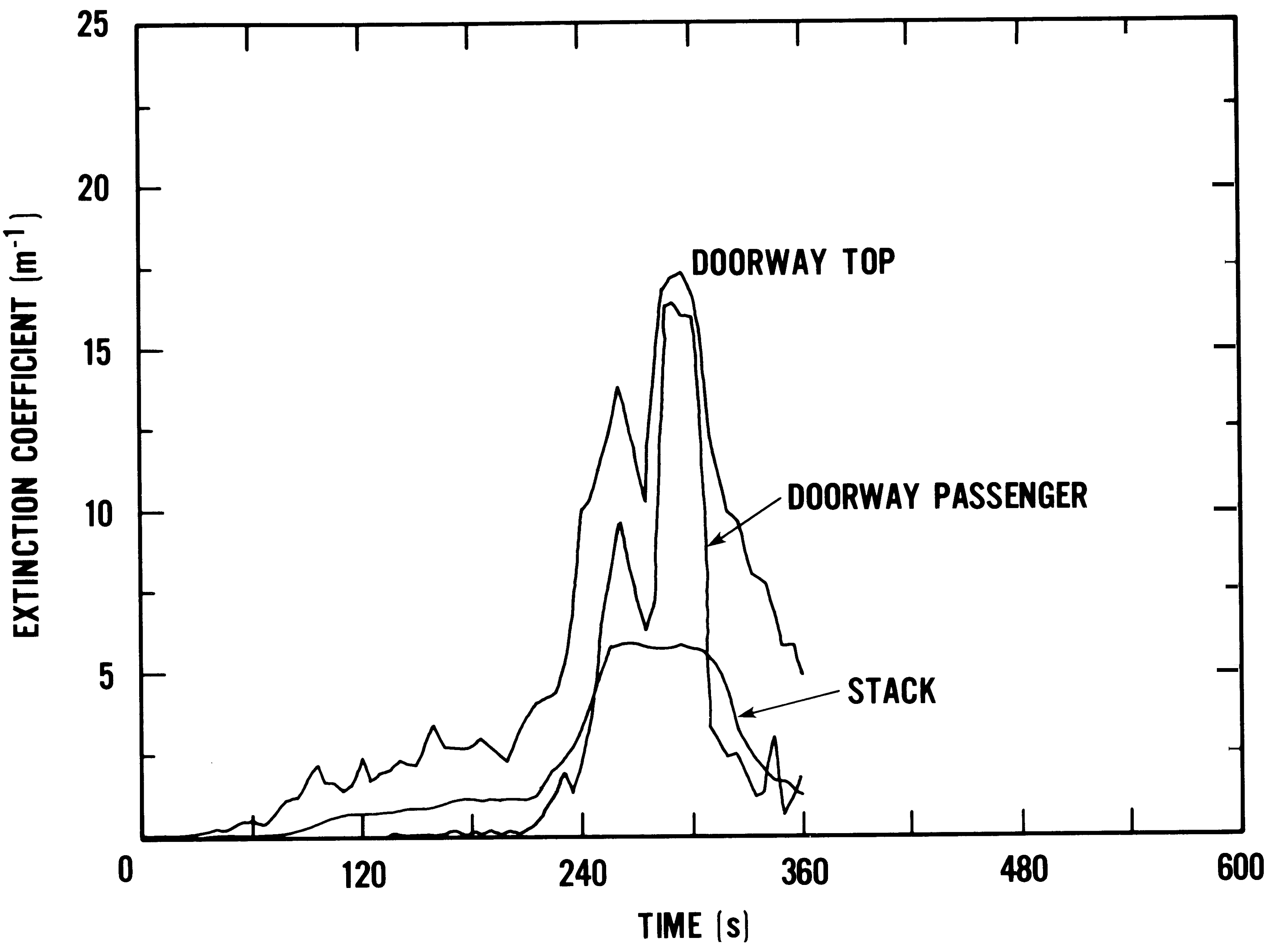

Figure 17. Smoke obscuration measured at ceiling level, passenger level, and in exhaust stack during full-scale mock-up test 4

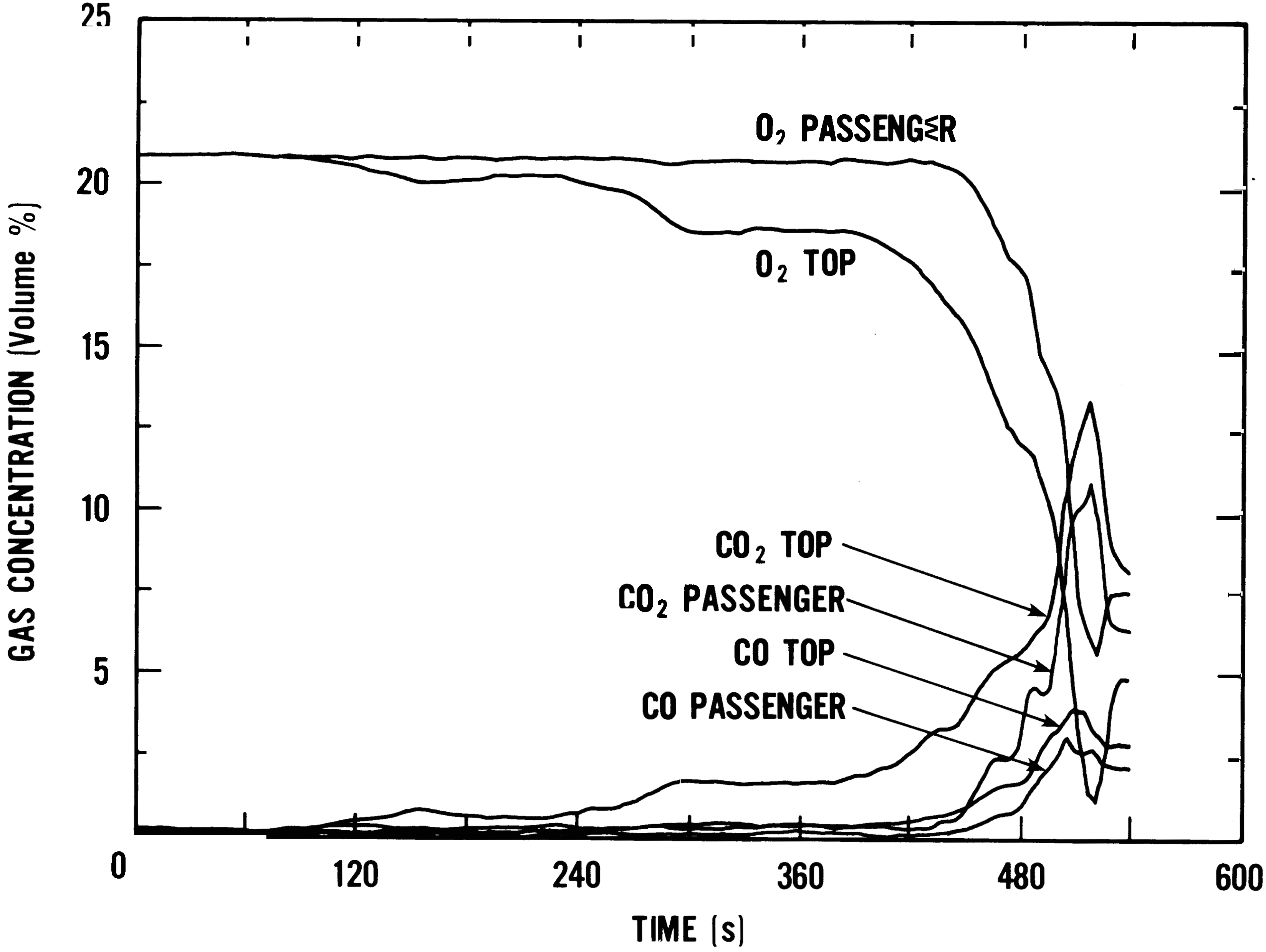

Figure 18. Concentrations of oxygen, carbon monoxide, and carbon dioxide measured at ceiling level and at passenger level during full-scale mock-up test 1

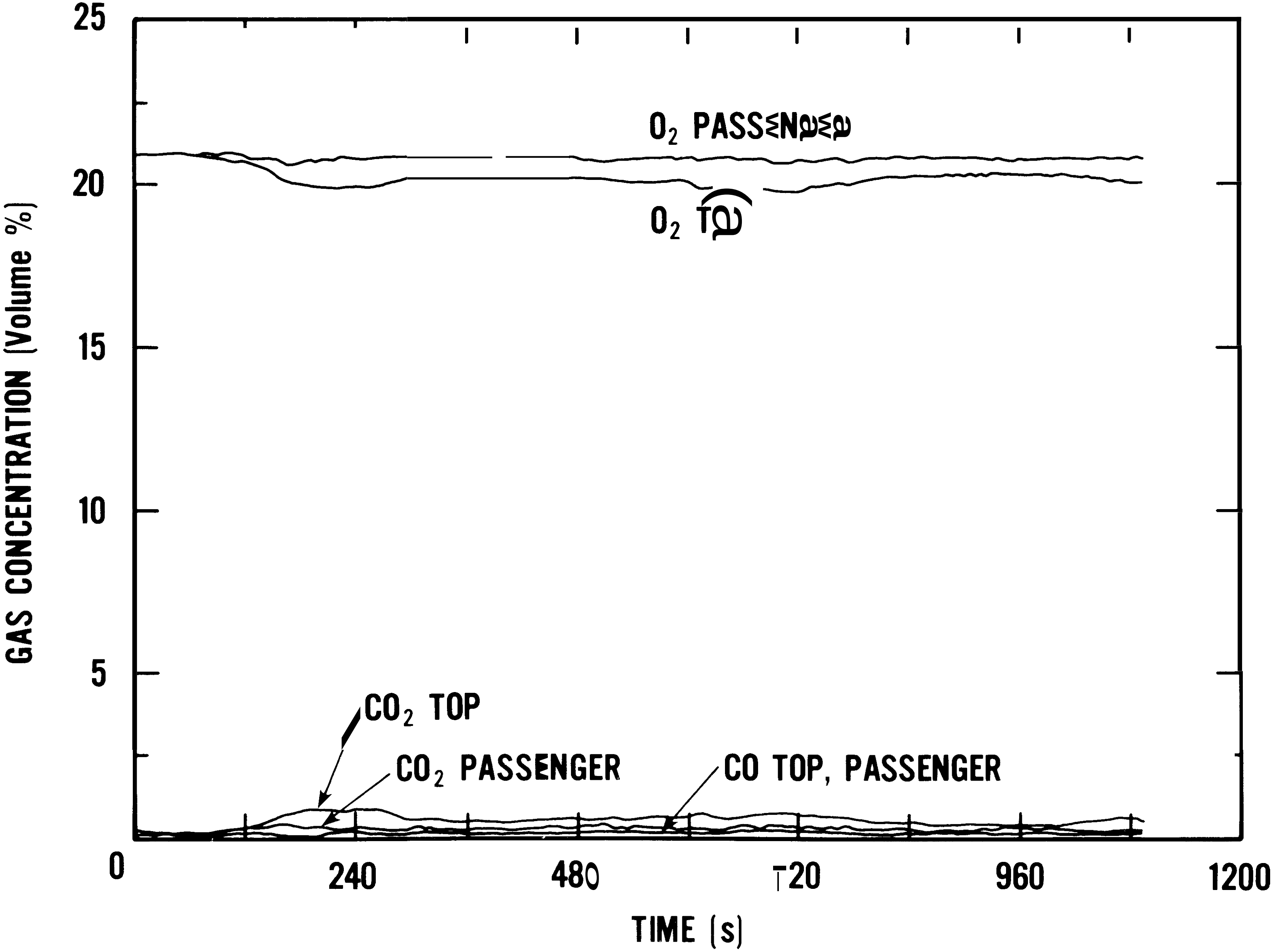

Figure 19. Concentrations of oxygen, carbon monoxide, and carbon dioxide measured at ceiling level and at passenger level during full-scale mock-up test 2

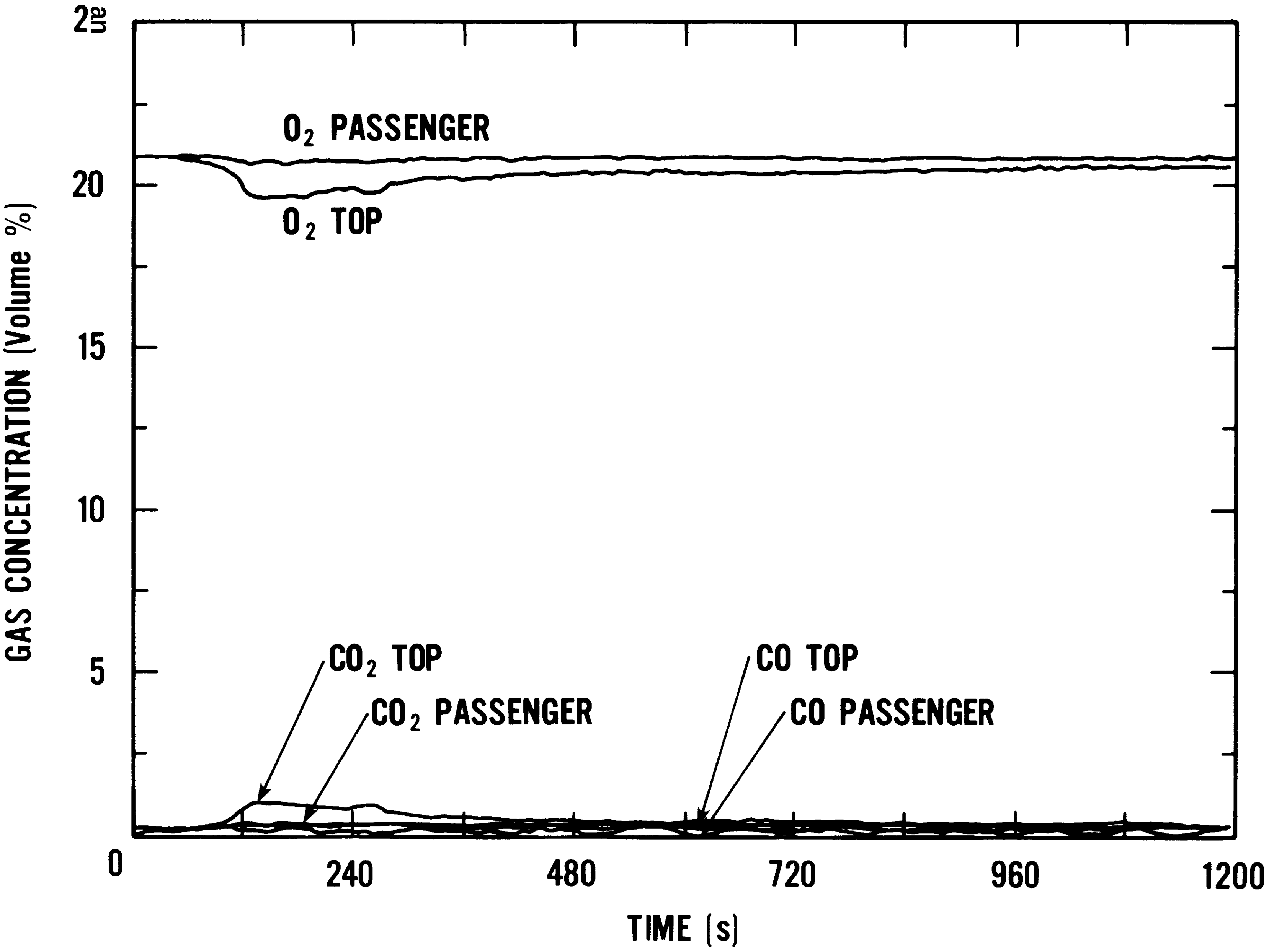

Figure 20. Concentrations of oxygen, carbon monoxide, and carbon dioxide measured at ceiling level and at passenger level during full-scale mock-up test 3

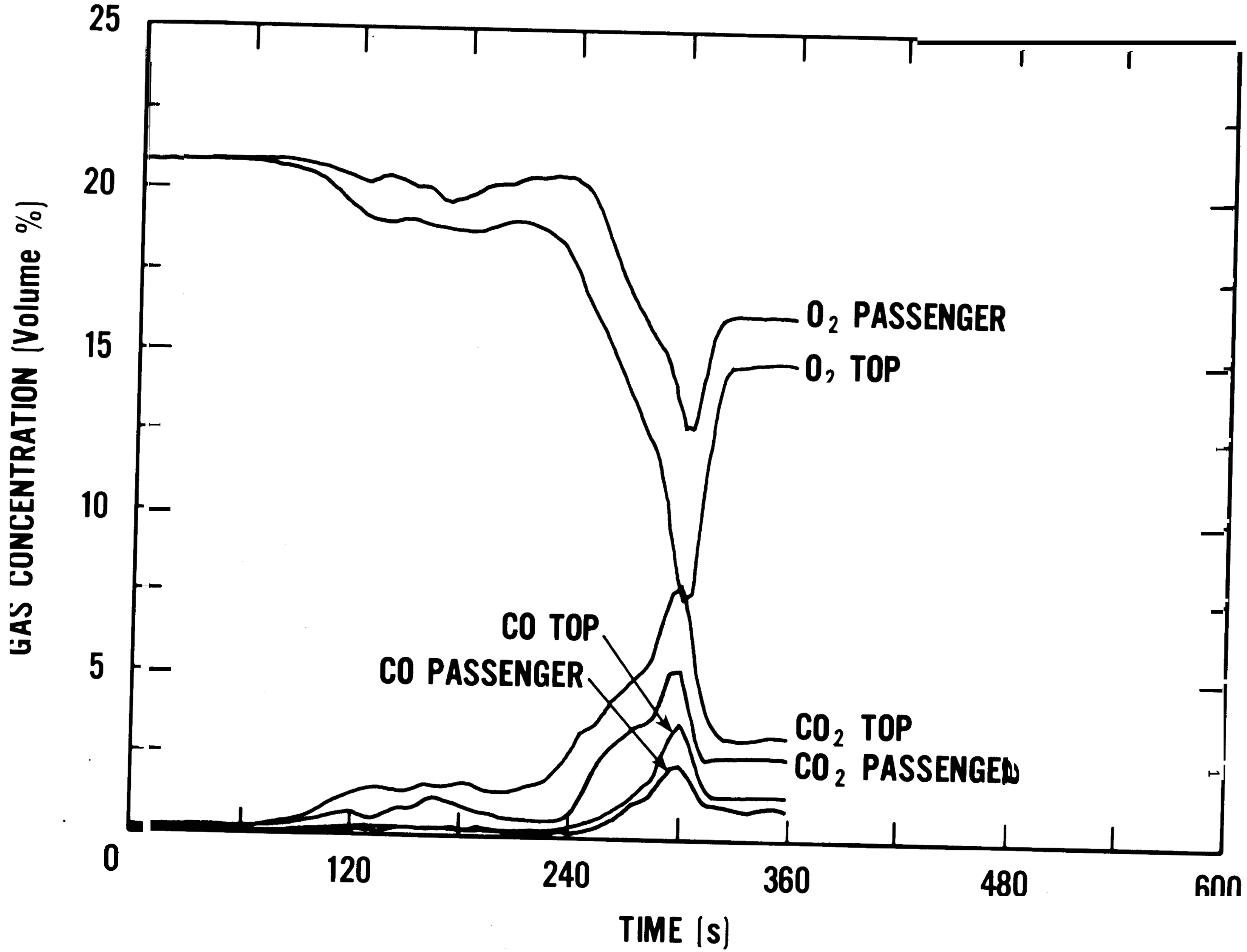

Figure 21. Concentrations of oxygen, carbon monoxide, and carbon dioxide measured at ceiling level and at passenger level during full-scale mock-up test 4

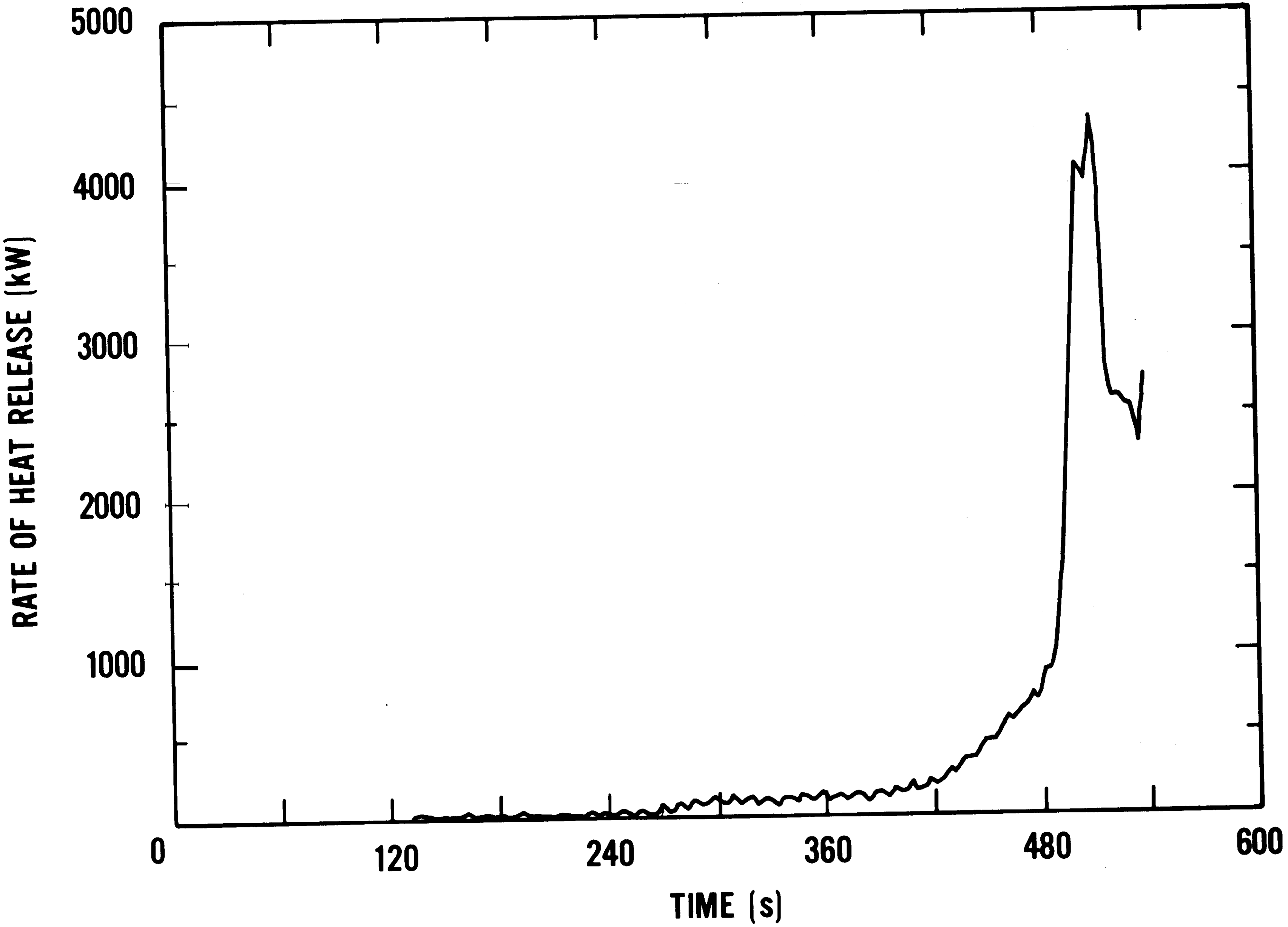

Figure 22. Rate of Heat release measured in exhaust stack during full-scale mock-up test 1

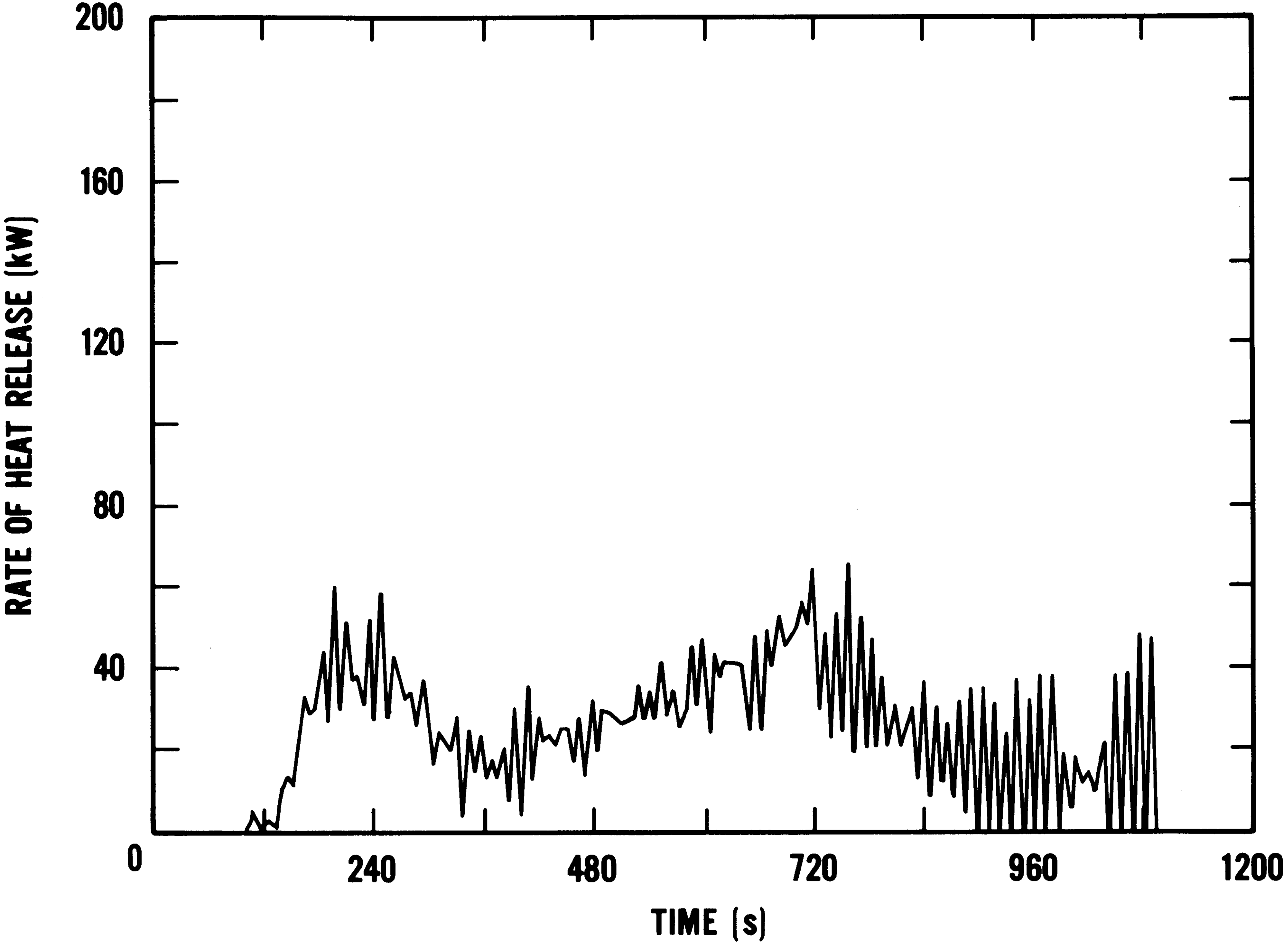

Figure 23. Rate of heat release measured in exhaust stack during full-scale mock-up test 2

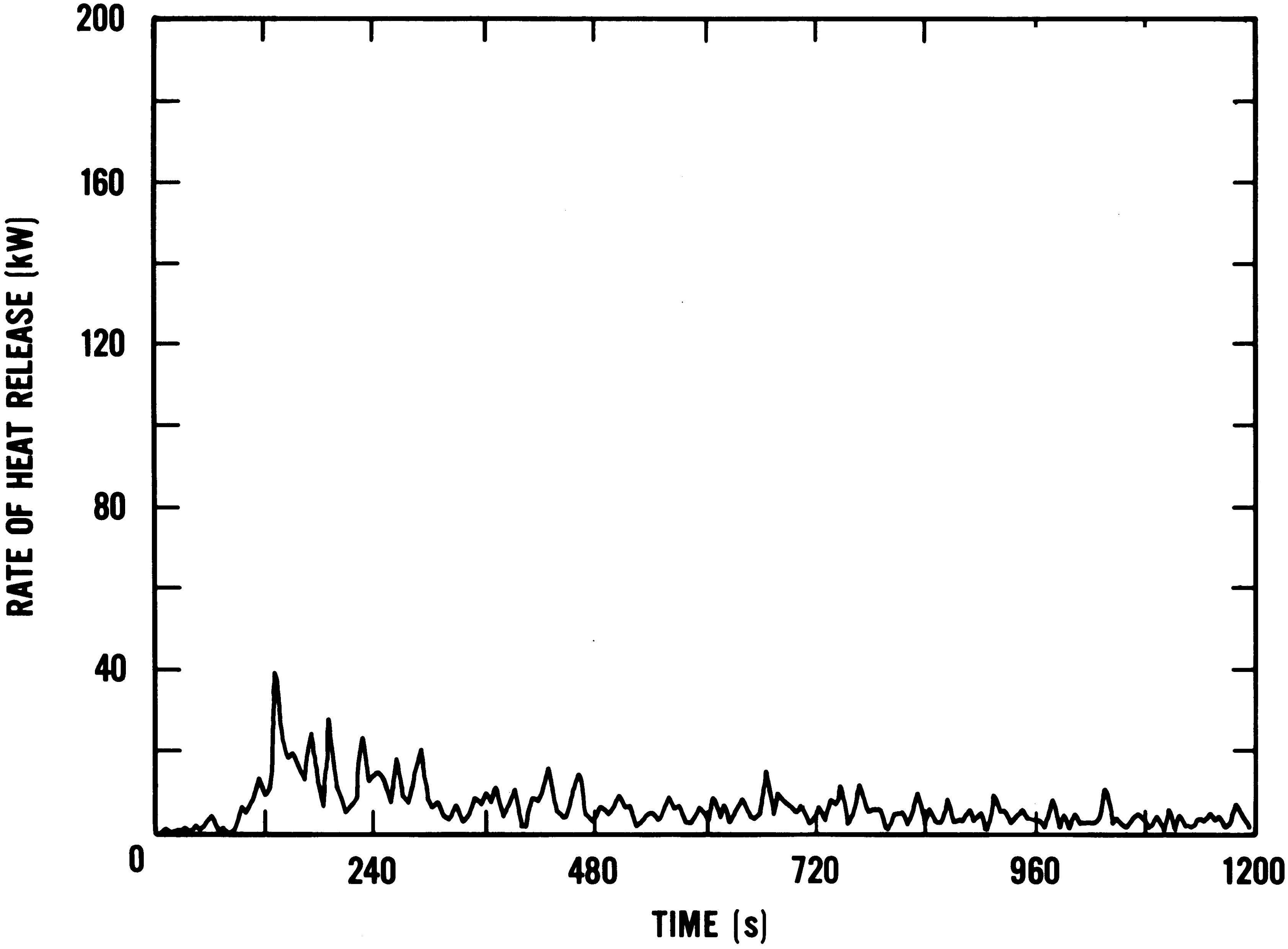

Figure 24. Rate of heat release measured in exhaust stack during full-scale mock-up test 3

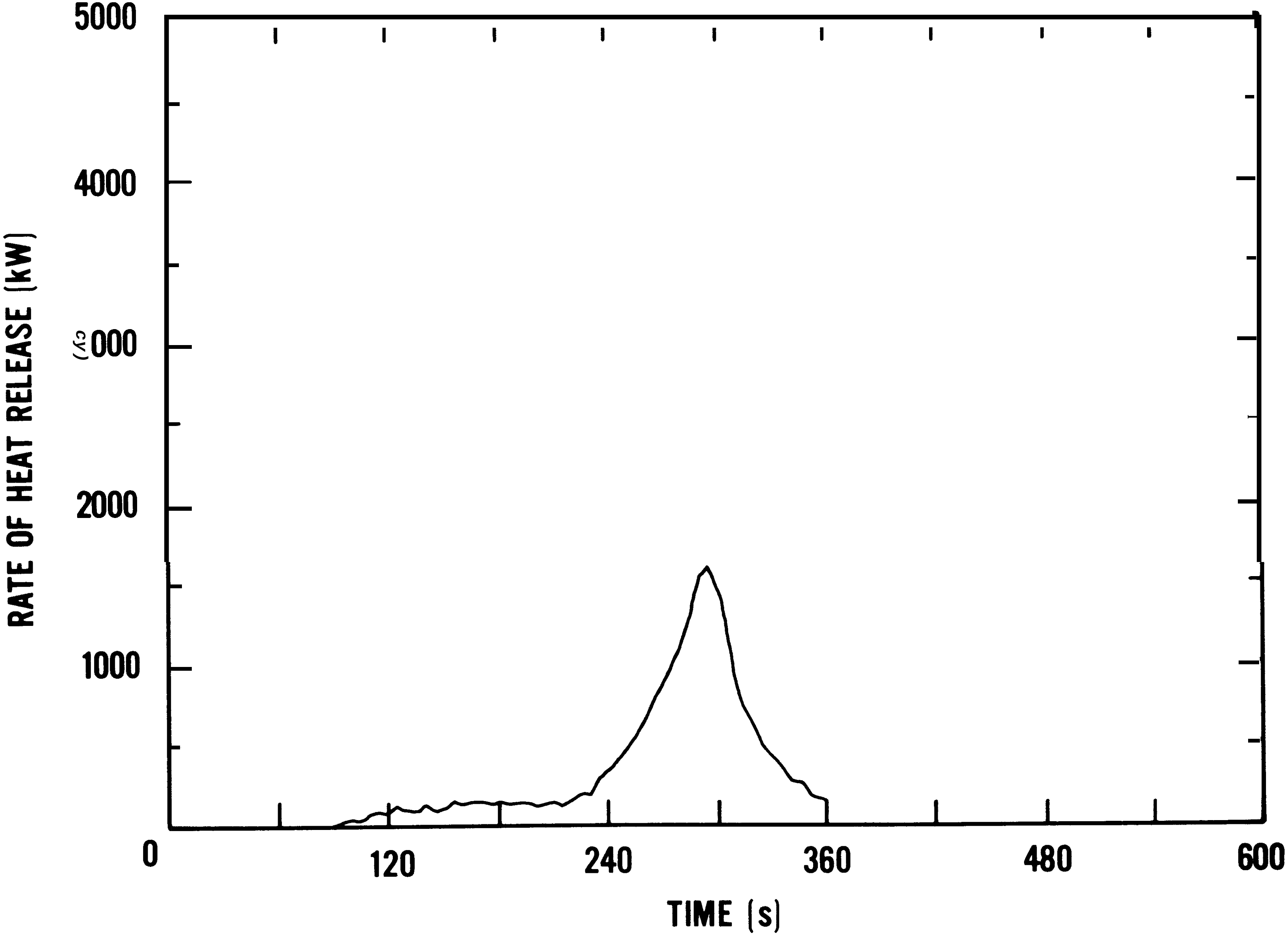

Figure 25. Rate of heat release measured in exhaust stack during full-scale mock-up test 4

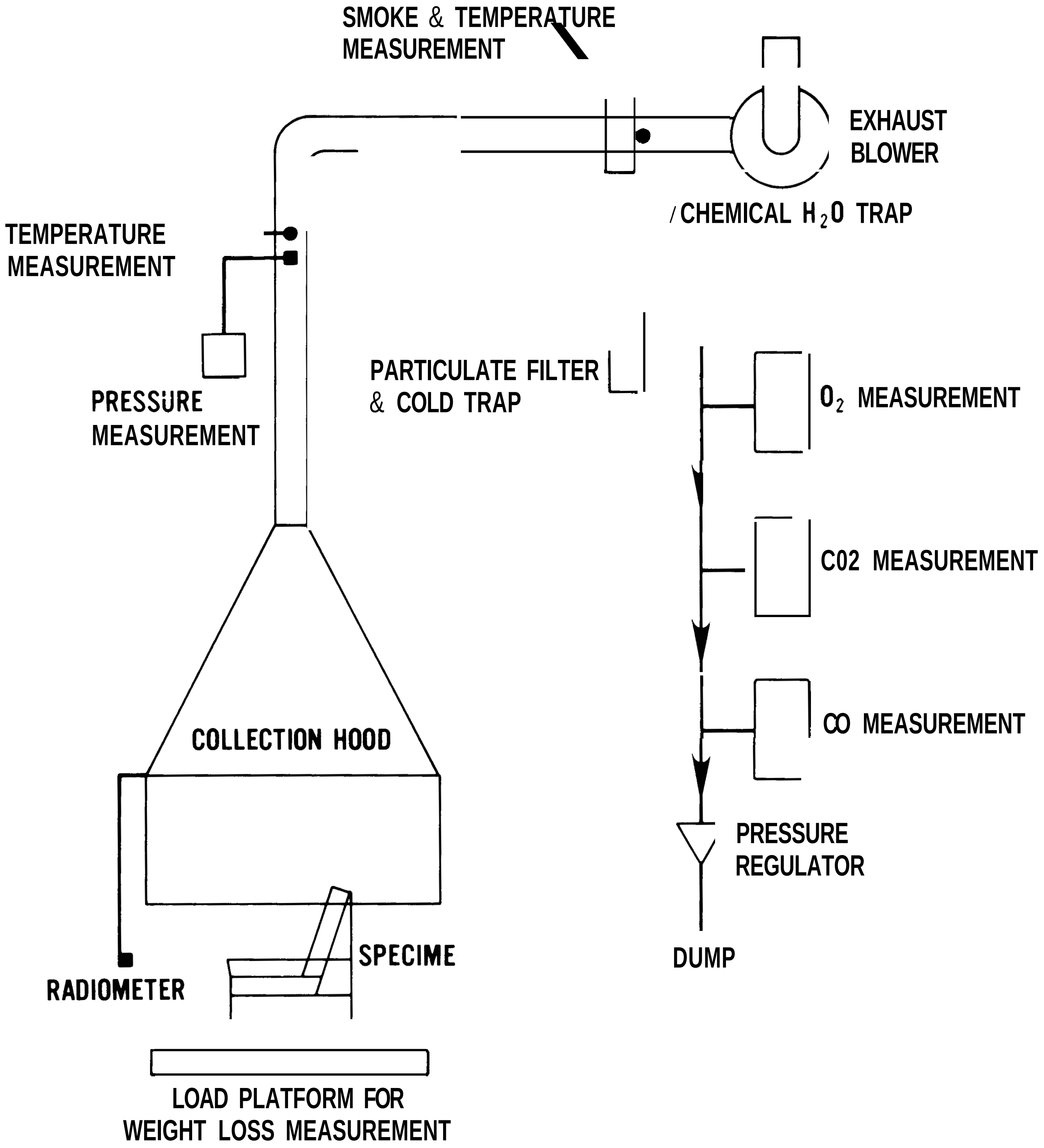

Figure 26. Schematic layout of full-scale furniture calorimeter

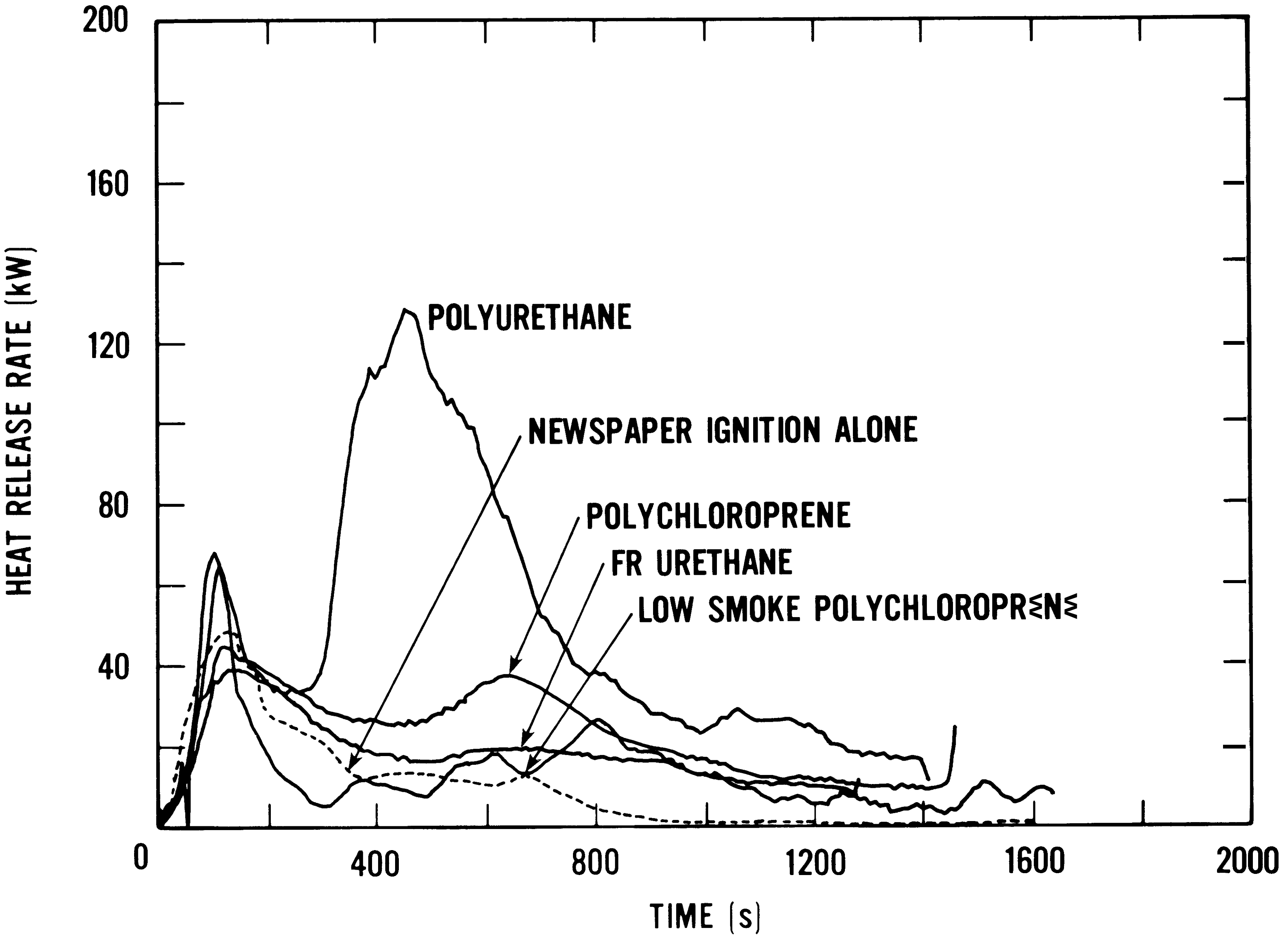

Figure 27. Rate of heat release of seat cushion assemblies measured in the furniture calorimeter

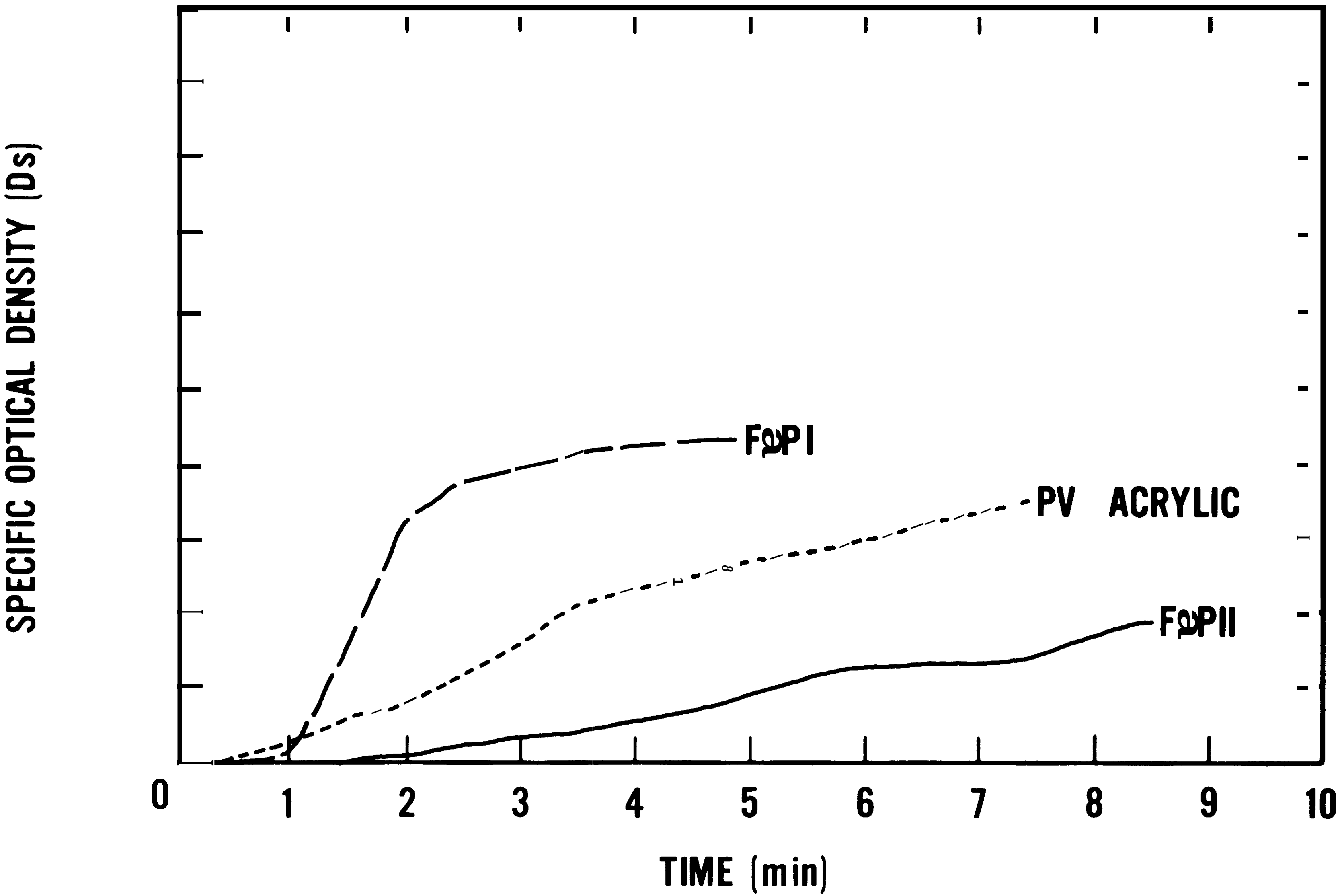

Figure 28. Specific optical density measured by the NFPA 258 test method for window masks used in the full-scale mock-up tests

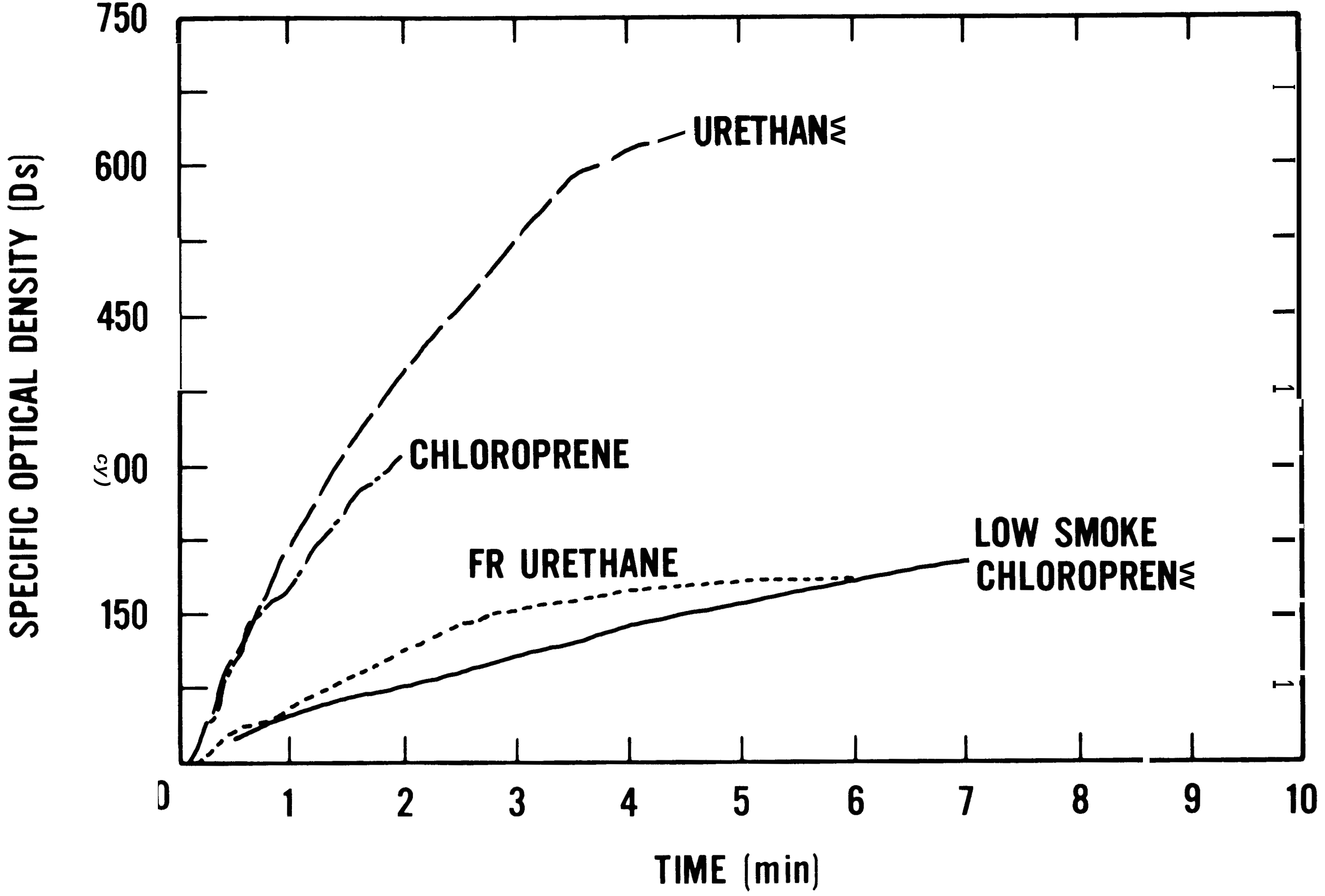

Figure 29. Specific optical density measured in the NFPA 258 test method for seat cushion materials used in the full-scale mock-up tests.

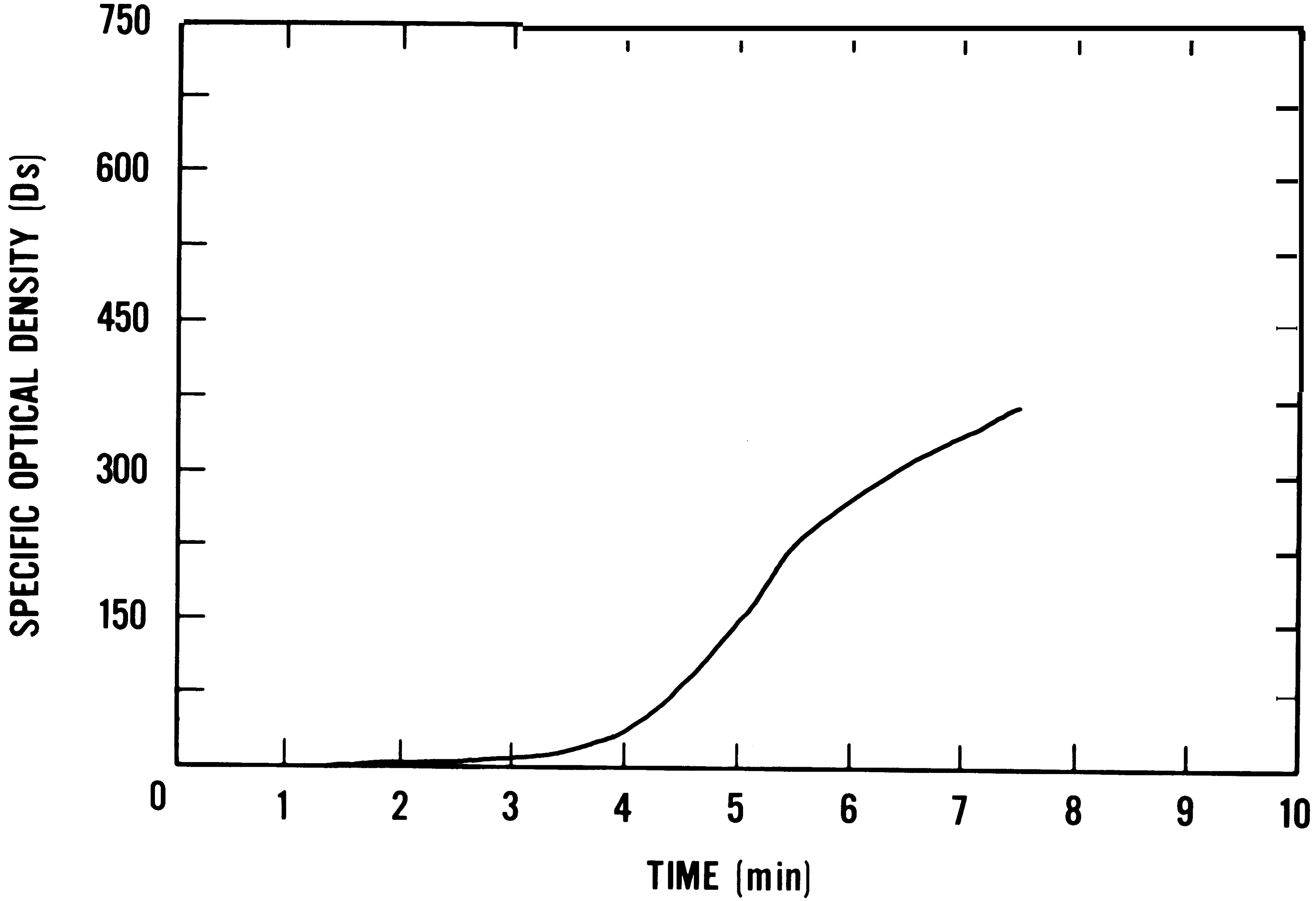

Figure 30. Specific optical density measured by the NFPA 258 test method for polycarbonate window glazing used in the full-scale mock-up tests

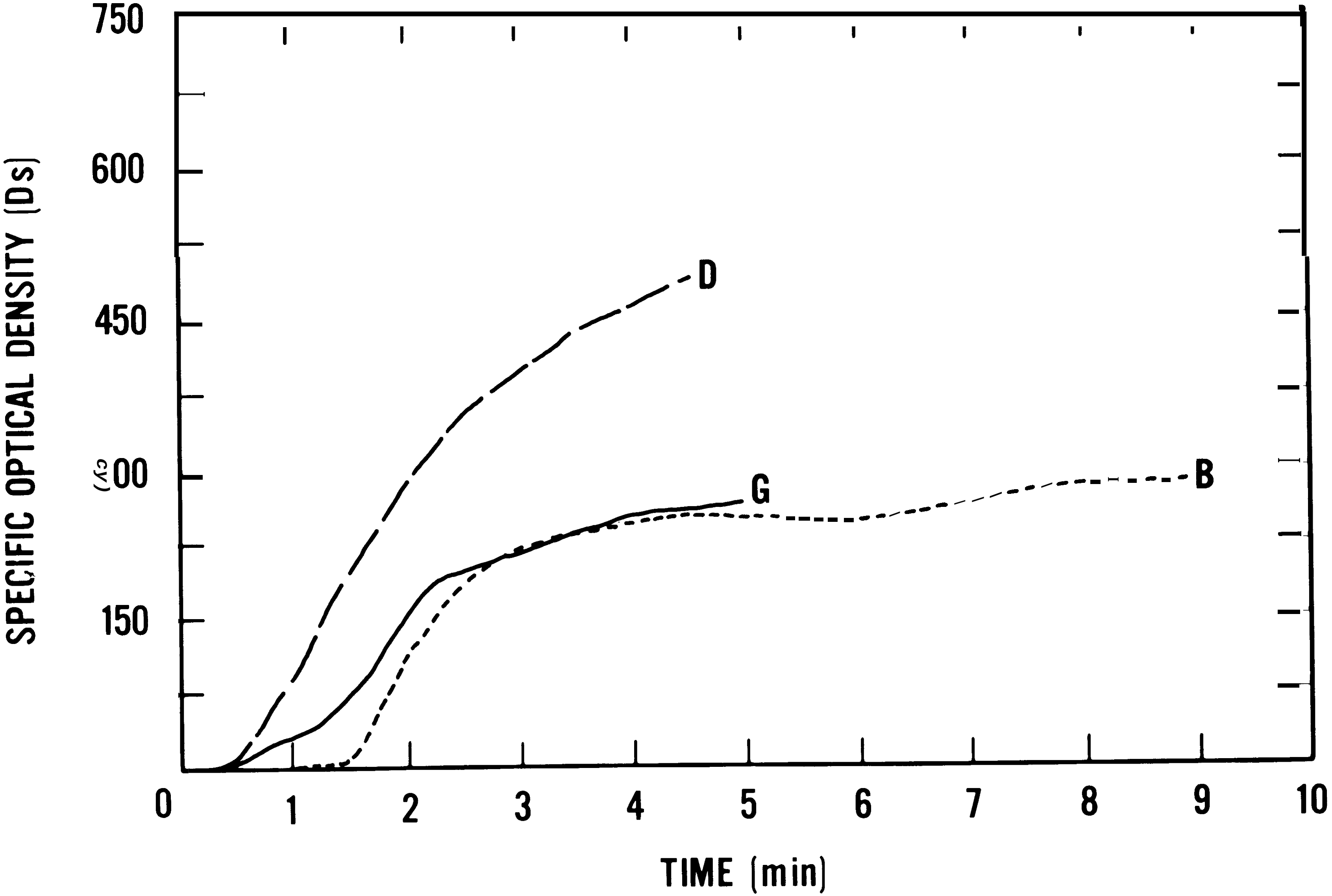

Figure 31. Specific optical density measured by the NFPA 258 test method for wall lining materials used in the full-scale mock-up tests

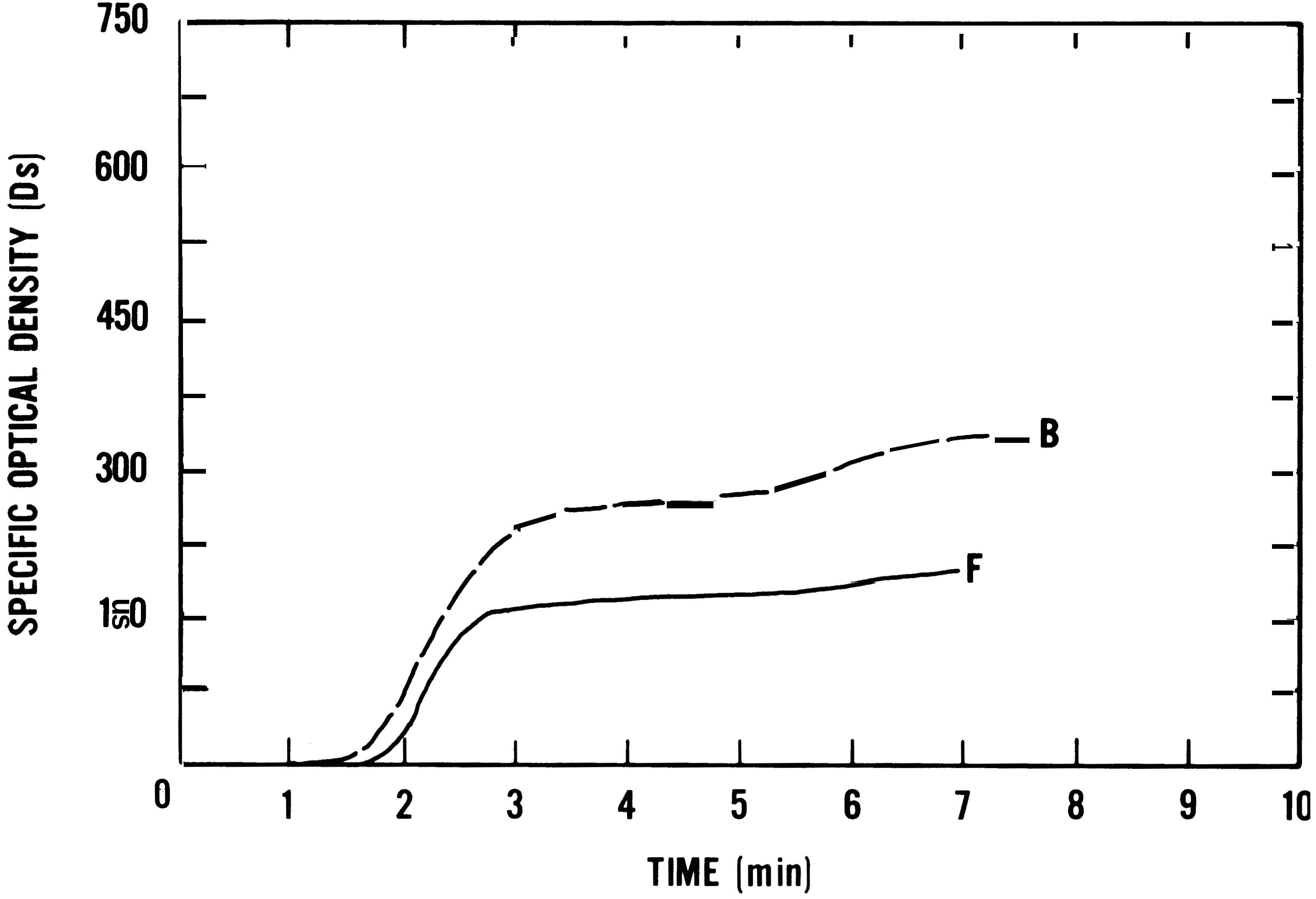

Figure 32. Specific optical density measured by the NFPA 258 test method for floor covering materials used in the full-scale mock-up tests

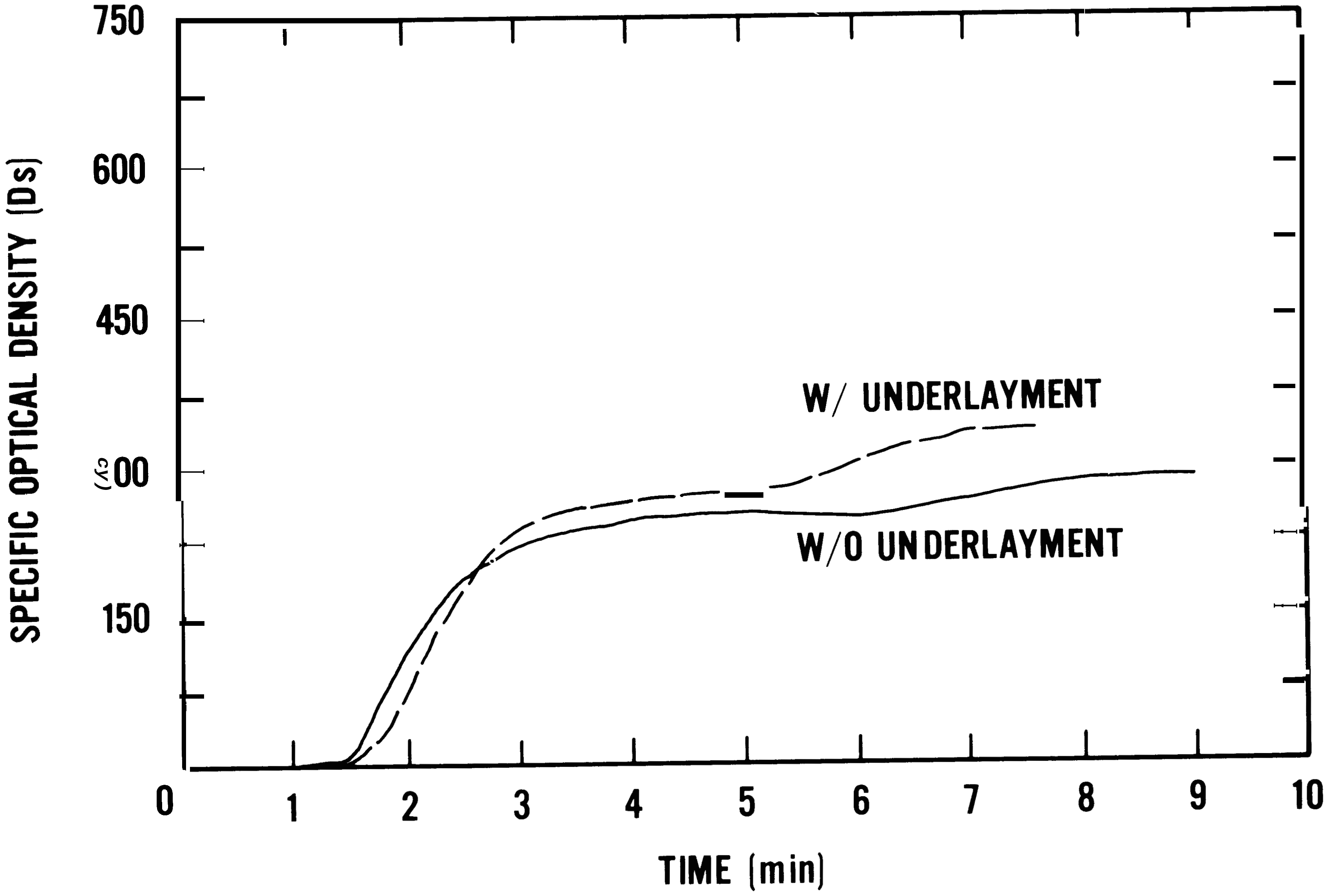

Figure 33 Influence of an underlayment on the laboratory-scale smoke production of carpet B

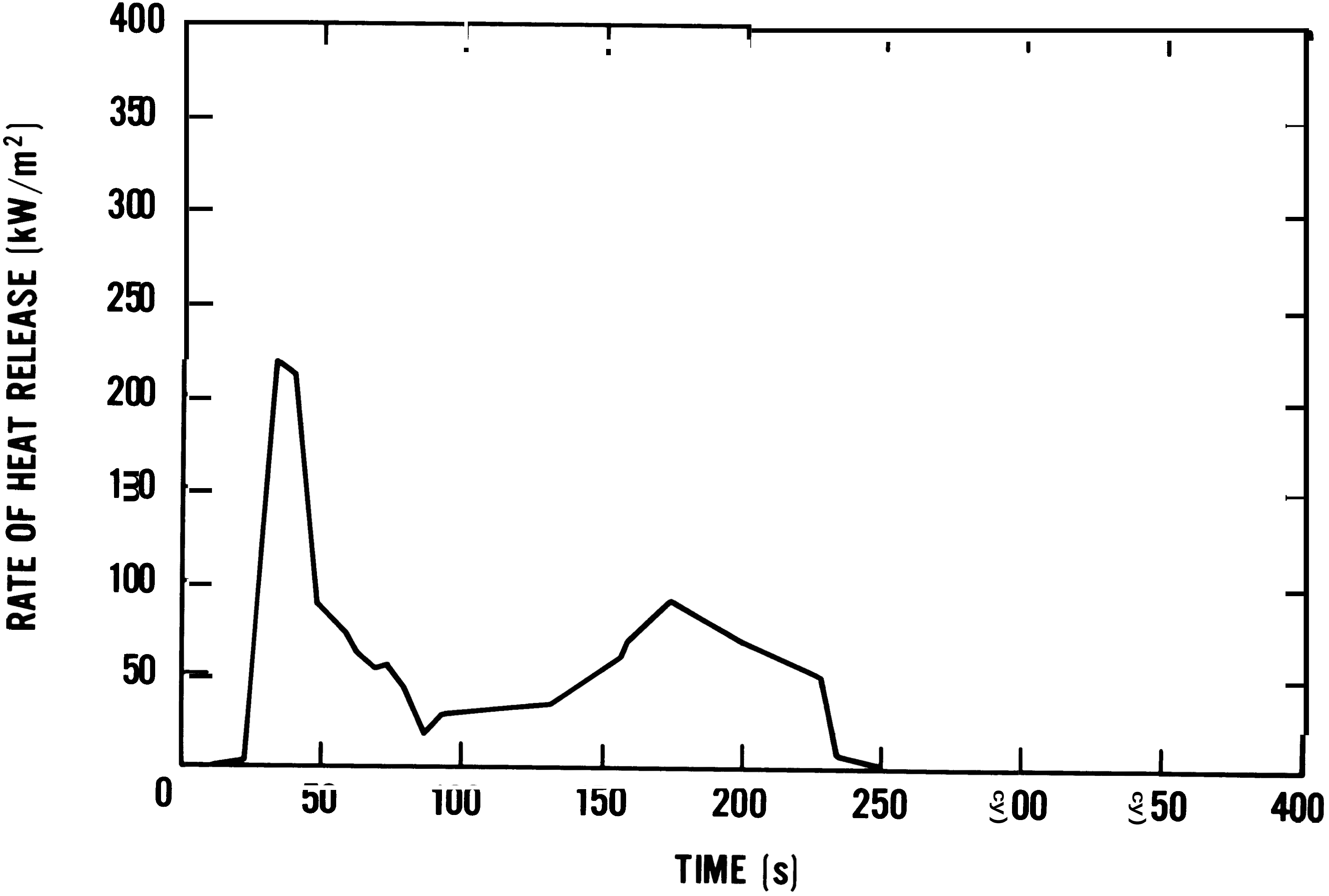

Figure 34. Bi-modal burning behavior of covered seat cushioning measured in the cone calorimeter

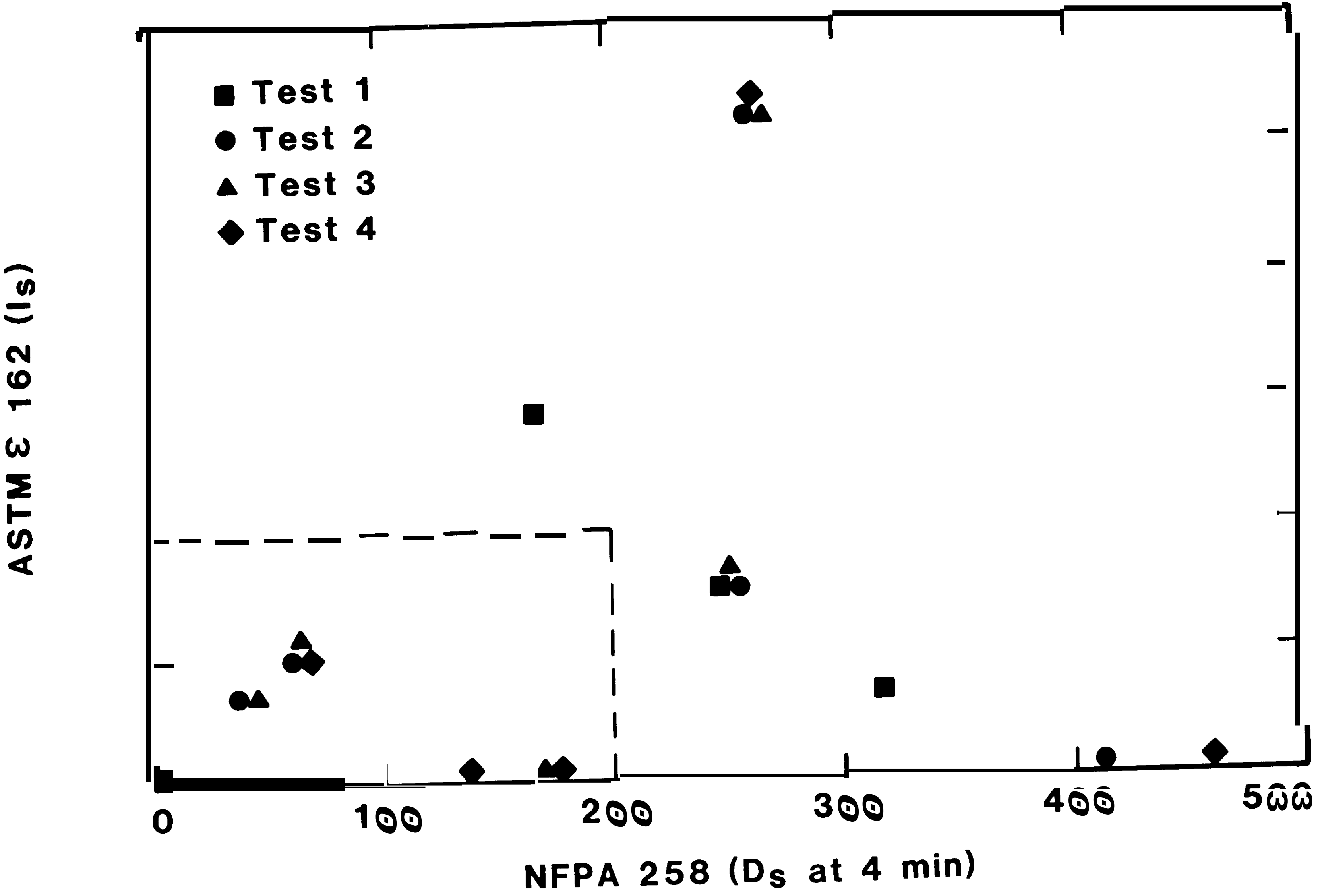

Figure 35. Small scale test results for all materials used in fully furnished Amtrak mock-up tests

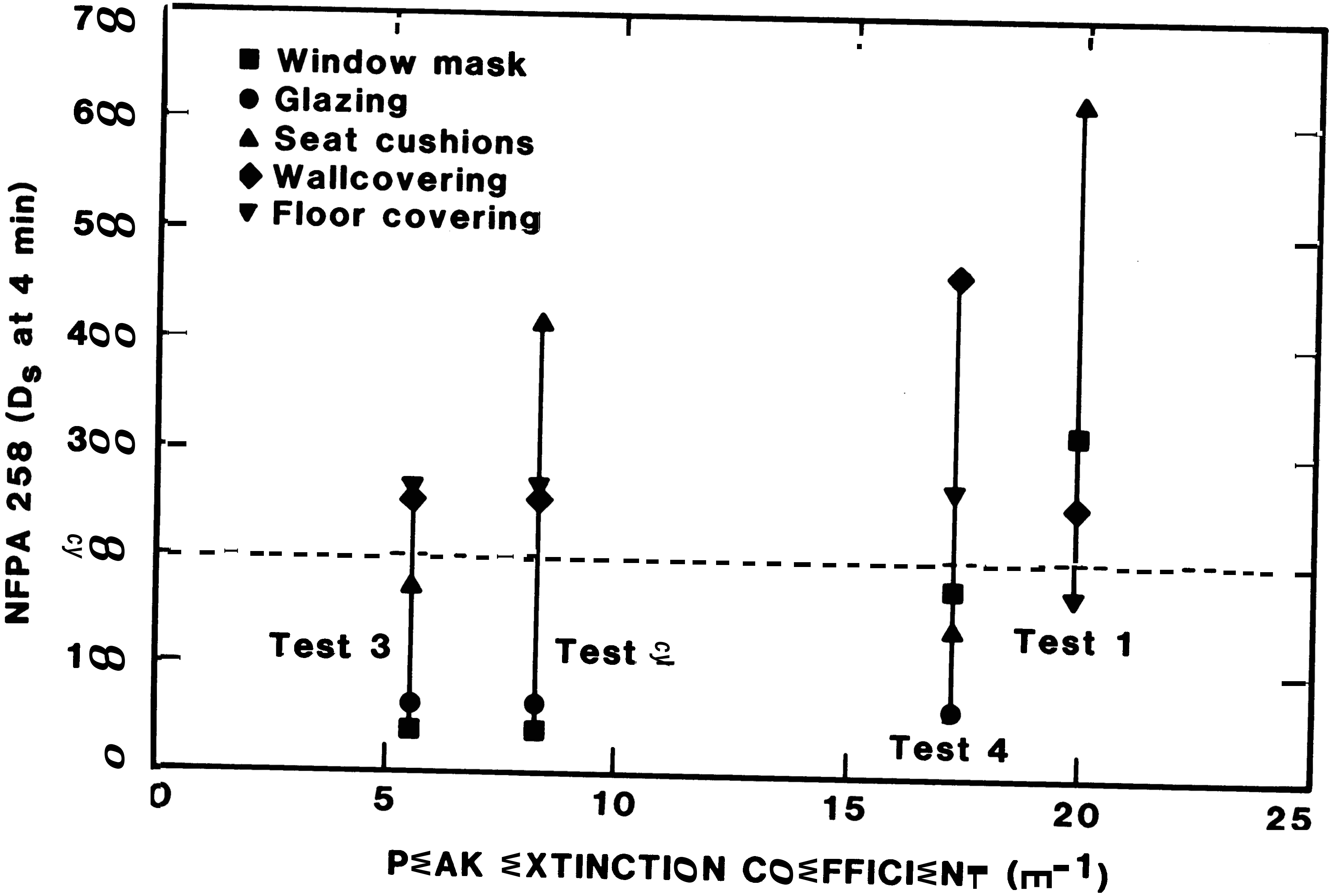

Figure 36. A comparison of small scale smoke measurement with peak smoke levels measured during fully furnished Amtrak mock-up tests

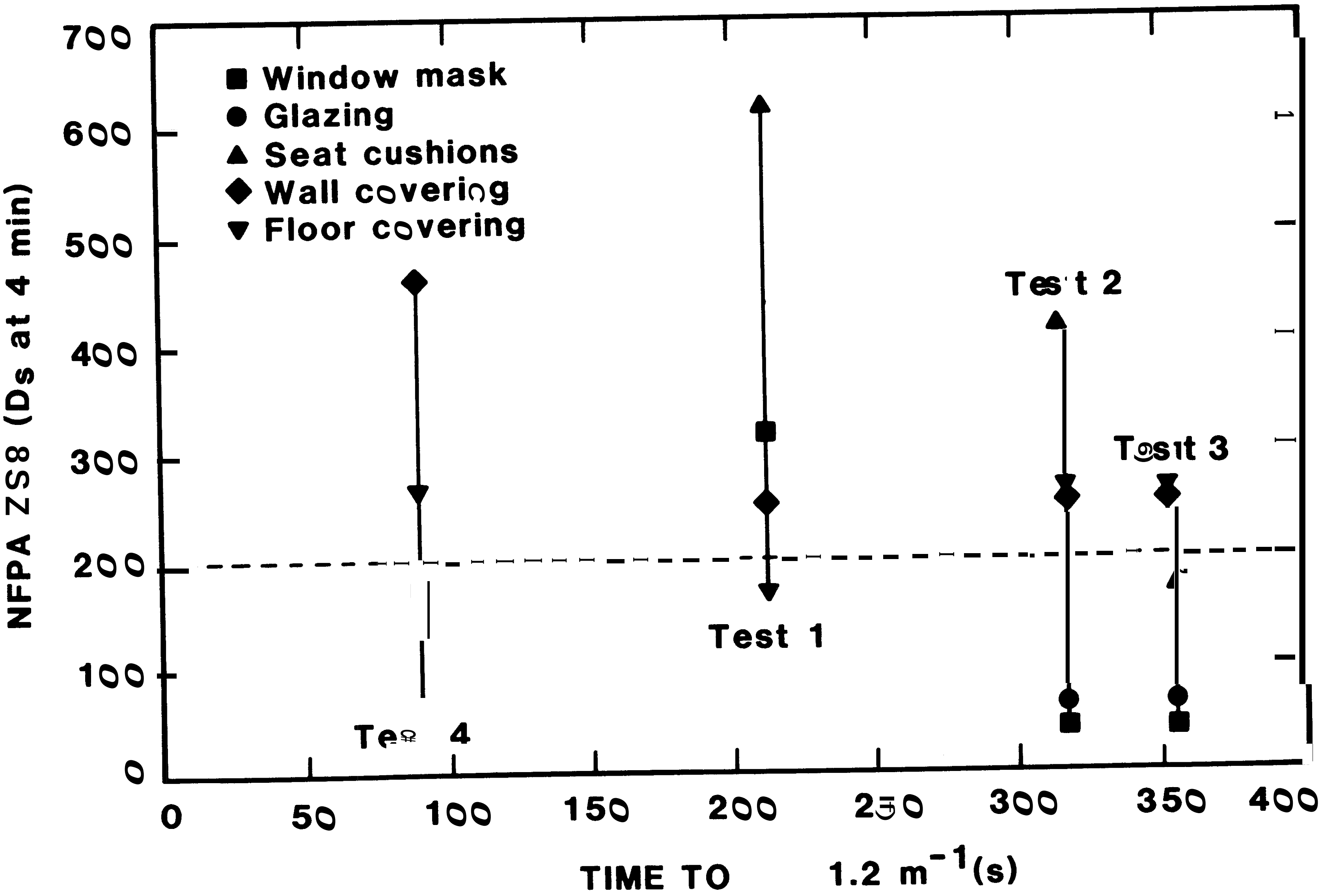

Figure 37. A comparison of small scale smoke measurements with time to reach critical smoke levels measured during fully furnished Amtrak mock-up tests

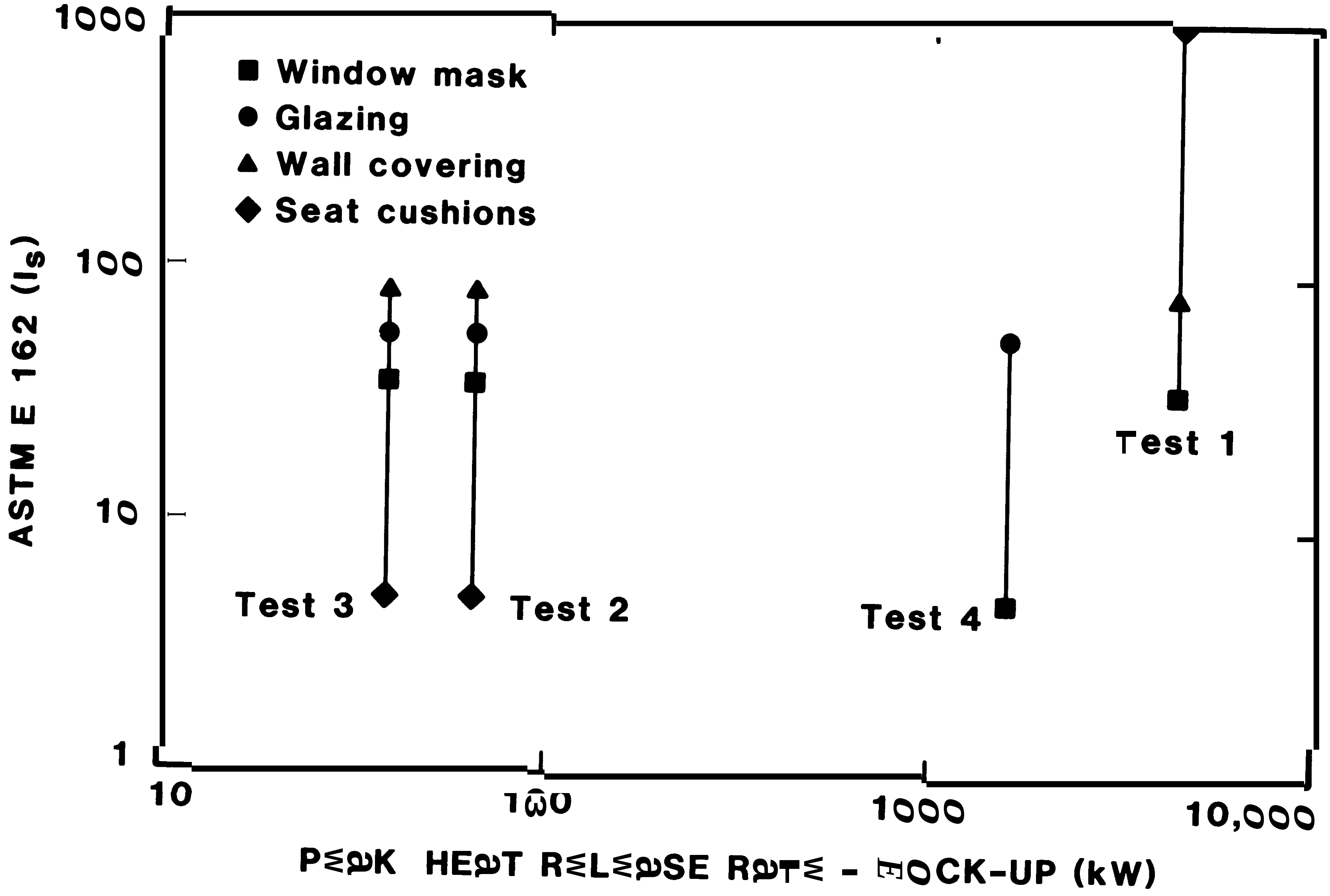

Figure 38. A comparison of small scale rate of heat release measured by ASTM E162 with peak heat release rate measured during fully furnished Amtrak mock-up tests

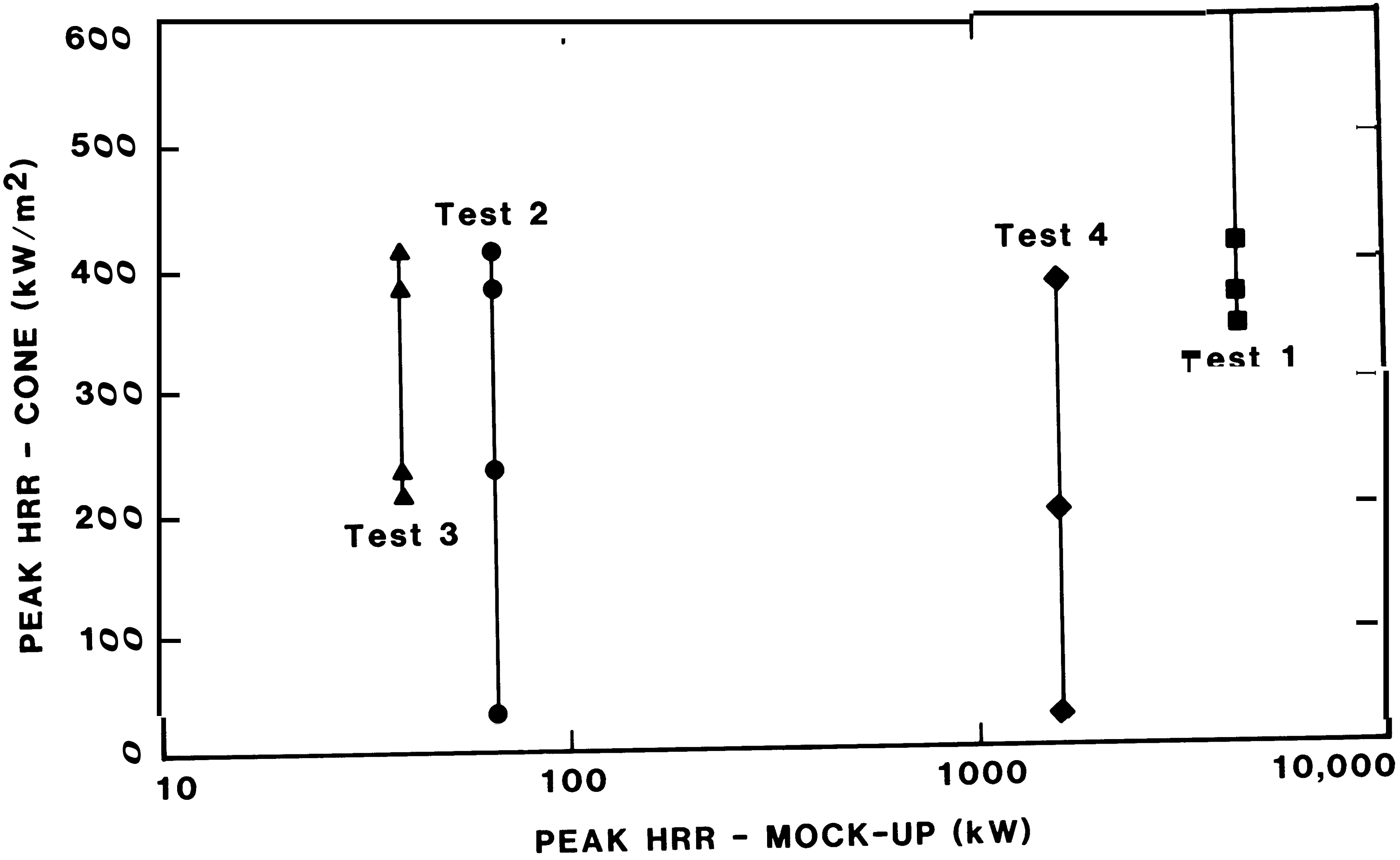

Figure 39. A comparison of small scale rate of heat release measured by the cone calorimeter with peak heat release rate measured during fully furnished Amtrak mock-up tests

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R. D. Peacock and E. Braun

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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)*

A series of fire tests was conducted to assess the burning behavior of the interior of passenger rail vehicles. Three types of tests were performed: (1) small–scale laboratory tests to study the flammability and smoke generation characteristics of the individual materials, (2) full–scale calorimeter tests on the seats to determine the rate of heat release from burning seat assemblies, and (3) full–scale tests on mock–ups of the interior of the cars to investigate the potential for fire hazard in the fully furnished vehicles.

A comparison of the results of the selected small–scale laboratory tests with the full–scale mock-up tests shows that while the small–scale tests can be used to screen individual materials, the geometry of the full–scale vehicle interior, and the interaction of materials during the full–scale mock-up tests are critically important in predicting the potential for fire inside the vehicle.

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

calorimeters; flame spread; full scale tests; interior finishes; passenger vehicles; railroads; smoke; transportation.

13. AVAILABILITY

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