NBSIR 75-718

Report of Fire Test on an AM General Metro Bus

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REPORT OF FIRE TESTS ON AN AM GENERAL METRO BUS

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The Center for Fire Research at the National Bureau of Standards has conducted a study of the fire safety of a bus supplied by the Washington D.C. Metropolitan Transit Authority. The objectives of the work were: (1) to determine the minimum ignition from source necessary to initiate a fire in the bus, and (2) to determine the means by which a fire, once started, is most likely to grow and spread.

A series of small-scale laboratory tests were run in addition to the three full-scale tests. Tests showed that accidental ignition by a cigarette or dropped match is unlikely. However, the seat can be ignited with one or two matches, if applied at the proper location, as by an arsonist. In full-scale tests, ignition of the seat occurs readily with the following ignition sources: (1) a small bag of paper trash on the seat, (2) a newspaper under the seat, or (3) if the contents of a can of lighter fluid is poured on the seat.

Fire growth and spread in the bus is primarily through involvement of the seat cushioning. Fire spreads from seat to seat with little direct involvement of other interior materials. In all three tests, between one and two minutes after the urethane ignited, dense smoke filled the bus space seriously reducing visibility. Spread of fire beyond the seat of origin is not necessary for the level of smoke to be formed.

Key words: AM General bus; arson; critical radiant flux; fire retardant; flammability; Flooring Radiant Panel Test; Metro; Motor Vehicle Safety Standard 302; urethane.

1. INTRODUCTION

Beginning in mid-December 1974, the Washington Metropolitan Transit Authority (Metro) experienced a series of bus fires involving their new fleet of AM General Buses.

Newspaper accounts of these fires indicated that ignition and subsequent flame spread within the bus interior occurred in a very short time period. The causes of these fires have never been determined, but the Fire Marshal of the District of Columbia has listed them as being of suspicious origin, possibly arson.

After the initial bus fire in December, arrangements were made to obtain a bus on which the National Bureau of Standards (NBS) could perform fire tests. On March 26, 1975, Metro delivered to NBS a bus that had been involved in a traffic accident, but with sufficient undamaged portion that testing could be carried out to determine: (1) the minimum heat source necessary to produce an ignition in the bus interior, and (2) the route by which the fire (smoke and flame) propagates from the point of initial ignition to the rest of the bus interior.

NBS conducted a program of laboratory and full-scale tests to develop this information. Small-scale laboratory tests describe the performance of the individual materials. Full-scale testing is needed to determine the performance of the complete assembly in a fire environment. The results of the small-scale tests were used to design the full-scale test sequence. NBS performed three full-scale tests on the bus supplied by Metro.

2. TEST RESULTS

2.1. Laboratory Tests

With the exception of Motor Vehicle Safety Standard 302 [1][1] which the National Highway Safety Administration requires be applied to all non-metallic interior materials, only the tests deemed appropriate for the particular application of the material in the bus were used.

The floor carpet was subjected to the Flooring Radiant Panel Test [2] as well as the test prescribed in the Standard for the Surface Flammability of Carpets and Rugs (DOC FF 1-70) [3]. Carpeting on the walls and ceiling was subjected to ASTM E-162 [4]. Smoke density measurements, using a smoke density chamber (NFPA-258T) [5] were conducted on the carpeting, seating materials and other interior components. In addition several special tests which are not published standards were performed on the seat assembly in order to determine the minimum energy level required for ignition. Results of the laboratory tests are listed in table 1.

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

Table 1. Summary of Small-Scale Test Results on Metrobus Components

Material	Test						
	MVSS 302	ASTM E-162	FF-1-70	Flooring Test (FRPT)	Smoke Density Chamber		Upholstery Test
					NFPA-258T	Horizontal	
	(in/min)	T_s		(W/cm^2)	D_m	D_m	
Floor Carpet	DNI[c]		pass	0.66	319	288	
Wall Carpet	DNI	181	pass				
Ceiling Carpet	DNI	51	pass		211	288	
Seat Cushion							DNI
- Fabric	3.74				67	125	
- Foam	1.35				83	205	
- Back	DNI						
Seat Back							DNI[b]
- Fabric	3.55						
- Foam 1[a]	1.92				111	98	
- Foam 2[b]	2.61				204	101	
Signs	8.05						
Wheel Housing	2.20				600	288	
Window Gasket						288	
Head Pad	0.96	940			374	288	

[a] Back panels composed of different types of foam.

[b] Seat assembly crevice test.

[c] DNI = does not ignite.

All synthetic materials found in the bus interior were chemically characterized. These data are listed in table 2.

2.1.1. Motor Vehicle Safety Standard (MVSS-302)

Motor Vehicle Safety Standard 302 is a test for horizontal burn rate. The standard requires that all materials used in the occupant compartment of a motor vehicle have a horizontal burn rate of less than 4 inches per minute. It can be seen from table 1 that the advertising signs were the only materials which failed to meet the minimum requirements set forth by MVSS-302. The other materials either did not ignite or flames spread across the surface at a rate of less than 4 inches per minute.

2.1.2. Radiant Panel Test (ASTM E-162)

This method measures flame spread and rate of energy release under a varying radiant flux ranging from 4 to 0.3 W/cm^2. The flame spread factor, F_s, calculated from the heat flux level and the flame spread velocity, and the rate of heat release of the burning sample, Q, are combined to yield a flammability index, I_s, defined as

$$I_s = F_s \cdot Q$$

The higher the index, the greater is the flammability. The values tabulated in table 1 represent the flammability indices found for the two carpet materials and the head pad at the rear of the bus.

There is no generally accepted level of performance, based on this test method since it is not a prescriptive standard. However, results for three materials are listed below in order to place the Metro bus data in context.

Flexible Polyether Urethane containing:	I_s
a fire retardant [6]	10
Plywood [7]	196
Nylon Carpet [7]	368

Table 2. Chemical Analysis of Metrobus Components[a]

Material	Basic Composition
Diffuser	Polystyrene
Poster	Styrene/butadiene coated with Ethylene-ethylaciylate copolymer
Seat Cushioning	Polyurethane (Polyether type)
Upholstery Fabric[b]	Nylon 6/6
Head Pad	
Cover material	Poly(vinyl chloride-acetate)
Foam material	Polyurethane
Carpeting	
Floor	Nylon 6/6
Wall	Nylon 6/6
Ceiling[b]	Acrylic Fiber and Polypropylene

[a] Comparable materials taken from another Metrobus; present materials currently being analyzed.

[b] May be flame retardant based on elemental analysis - x-ray fluorescence.

2.1.3. Standard for the Surface Flammability of Carpets and Rugs (Pill Test - DOC FF 1-70)

No carpets and rugs sold in the United States are permitted to spread a flame beyond a radius of 3 inches when exposed to a small ignition source (a methenamine pill). This standard is intended to eliminate carpets or rugs as an agent of flame spread from small ignition sources. All the carpeting found in the bus passed the "pill test."

2.1.4. NBS Flooring Radiant Panel Test (FRPT)

This test method exposes a specimen placed horizontally to a radiant energy load that varies across a 1 meter length from a maximum of 1.1 W/cm^2 to 0.1 W/cm^2. The specimen is ignited by a small flame at the high energy end. The distance of the sample from the end at which the burning flooring material extinguishes itself defines 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 critical radiant flux for the carpet specimen from the floor of the bus was found to be 0.66 W/cm^2. For comparison purposes, carpeting taken from several large fatal fires was also tested according to this method and found to have CRF's of less than 0.1 W/cm^2. A wood floor would have a CRF between 0.4 and 0.5, while vinyl floor materials have values greater than 1.1 W/cm^2. Thus, the Metrobus carpeting, by this test, is comparable to other conventional flooring materials.

2.1.5. Smoke Density Chamber (NFPA 258T)

This test method measures the smoke generation of solid specimens exposed to a radiant flux level of 2.5 W/cm^2. The smoke produced by the burning specimen in the chamber 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.

Two ignition modes are possible, flaming and nonflaming. All data presented here were taken under flaming ignition conditions in both vertical and horizontal positions. The data in table 1 are the maximum optical density, D_m, found for the various materials. D_m values measured on our apparatus can range from 0 to 600 units.

The values in the Metro bus materials ranged from a low 67 for the upholstery fabric to 354 for the wall carpet. In order to place these results into proper context, comparable results for other materials are listed below.

	D_m
Plywood [8]	45
Nylon (foam backing) Carpet [8]	270
Red Oak Flooring [8]	300
Glass Reinforced Polyester [8]	720

The values of D_m are useful primarily in ranking relative smoke production of the materials used, and in identifying likely sources of severe smoke production in a full-scale fire. The actual smoke levels produced when bus fire occurs, however, can only be determined in a full-scale test.

2.1.6. Upholstery Tests on Seats

A test method has recently been developed at NBS to determine the ignitability of upholstered furniture when exposed to a lighted cigarette. The test determines if an assembly ignites or does not ignite. It is performed on flat surfaces (i.e., seat cushions) and in any crevices in the entire assembly (i.e., junction of the back and seat cushions).

By this test, the seat assembly did not ignite, when in contact with a lighted cigarette. In a variation of the test, the cigarette was replaced by a methenamine pill, similar to those used in the carpet and rug test (DOC FF 1-70). The methenamine pill placed on the surface of the cushion did not ignite the seat assembly. However, placing the pill in the crevice between the seat back and bottom resulted in the ignition of the seat back.

Finally, ignition by matches was attempted. It was found that the seat would ignite with a single paper match held under the front seat edge. The fire grew and spread very slowly. Flaming matches dropped on the junction of the seat cushion and back did not ignite the seat assembly. However, if two matches were carefully placed in the crevice area, ignition of the seat assembly did occur.

2.2. Full-Scale Tests on the Bus

The Metro bus was modified by removing the entire forward compartment and building a wall just forward of the side exit door. This resulted in a total enclosed volume of approximately 25 m^3 (885 ft^3) which represents about one-half the total volume of a complete bus. Figure 1 shows the location of various ignition and ventilation points. Also, a smoke meter was permanently installed near the side exit door so that it would measure the light attenuation in a path from floor to ceiling. In addition, thermocouples were placed in several positions within the bus compartment.

In the first two tests, the fire was permitted to grow until it could be determined what path the fire was taking in spreading down the bus interior. Once this was determined, the fire was extinguished by a trained firefighter. The third test was permitted to progress to the point of window failure and then was extinguished.

All tests were photographed and taped by video camera. Other comments by NBS investigators were tape recorded.

2.2.1. Test Number 1

The ignition point was the center of a complete seat assembly. A bag comprising a total of 30 g (1 oz) of paper was placed in such a way that it rested on the junction between two adjacent seat cushions and touched both seat backs. A match was used to ignite the paper bag at the top. Data acquisition began with the ignition of the paper bag.

Ventilation within the bus was controlled by closing the side exit door and all of the windows except for one. The window was located on the opposite wall and to the rear of the ignition point. It was pushed back to give a 7.5 cm (3 inch) opening. Sometime during the latter part of the test, this window was unintentionally closed. The total test time was just over 8 minutes.

At the conclusion of the test, an inspection of the bus interior revealed that flames had spread to the adjacent seat behind the ignition point. It was also noted that the light diffusers above the windows had melted and fallen to the seats below; they did not appear to have burned in place. Advertising signs were not included in this test.

2.2.2. Test Number 2

The initial source of ignition in this test was .91 kg (2 lbs) of newspaper placed on the floor below a seat assembly. The newspaper was ignited in several places on its surface by a match. Data acquisition began with the ignition of the newspaper.

Ventilation in this test was accomplished by opening the forward-most window 4 cm (1-1/2 inches) on the same side as the ignition source. This window remained open throughout the test, which lasted 7 minutes.

For tests 2 and 3, a TV camera was placed in the wheel-well cover on the opposite wall so that it was looking up into the bus.

This test was conducted in the next-to-last row of seats. Normally a head pad is located just behind these seats. For this test, it was removed, leaving the metal back panel exposed. Advertising signs were placed over the light diffusers as they would be in actual operation.

By the conclusion of the test, the signs and diffusers had fallen to the seats below. The adjacent seat forward of the ignition point also ignited. This observation was made by the second camera and was later substantiated by the temperature data taken around that seat assembly.

2.2.3. Test Number 3

In this test, the ignition medium was 250 ml (8 l oz) of lighter fuel (roughly equivalent in energy content to 0.5 kg of paper) poured onto the seat cushion adjacent to the wall. A thermocouple was placed just above the seat cushion (0.3 cm) that had the lighter fuel on it. Ignition was achieved from the outside of the bus by electrically igniting a match held just above the ignition point. Data acquisition began aproximately 2 seconds before the actual ignition of the seat cushion.

Also, in this test, ventilation was controlled by a window previously set open to 7-1/2 cm (3 inches). The test lasted 10.5 minutes.

For this test, the rear end of the bus was completely furnished. Diffusers, signs, and head pads were all in place. Initial flame spread was due to falling material from the head pad that ignited other seat assemblies. The ignition point was completely destroyed in addition to the back seat and portions of the next forward seat. The window adjacent to the ignition point collapsed from its frame and fire damage spread to the next window pane and the rear window. The heat trapped in the bus also started to warp the other window panes.

3. DISCUSSION OF FULL-SCALE TEST RESULTS

3.1. Temperature Data

The temperature data obtained from all three tests at several locations throughout the bus were compared in order to determine: (1) the characteristics of the ignition source, (2) the effect of ignition source on fire spread and growth, and (3) the probable flow of heat in the compartment in relation to the open window.

Figure 2 is a comparison of temperatures above each ignition source. The rate of temperature rise (which is an indicator of the rate of heat release from the ignition source) is similar for test 1 and 2. The basic difference is the induction time that preceded any significant temperature rise. Test 1 had an induction time that was twice as long as test 2. The induction time for test 3 was too short to be measured accurately. It is evident from figure 2 that the initial heating rate was much higher in this test than the others.

There are several key times marked on the graphs (points A-D). The first represents the time when the foam became involved, based on visual observations. The second and third numbers represent the time when visibility into the bus fell to zero and the end of the test, respectively. Window failure occurred only in the last test and is marked on the plot for test 3.

Figures 3 and 4 present the aisle ceiling temperatures fore and aft of the ignition point. A comparison of the plots for test 1 indicates that there was a uniform buildup of heat at the ceiling until the test was terminated. It should be kept in mind that sometime during the test the ventilation window was inadvertently closed thereby eliminating any airflow bias.

Similar data from test 2 show a definite forward movement of heat. One of the forward windows was open 4 cm (1.5 inches) to provide ventilation to the combustion process.

The temperature profile for test 3 is very much different from the previous two tests. It indicates that burning had reached a quasi-steady state condition after about 3 minutes and in fact was probably oxygen limited.

3.2. Smoke Data

In addition to the temperature recordings, smoke density data in the form of percent transmission of polychromatic light was obtained at the top of the stairs by the exit door. These readings were taken in the vertical plane and, therefore, were not sensitive to smoke stratification.

Figure 5 is a plot of the percent of light transmission as a function of time from initial ignition to the conclusion of the test. The data indicate that almost total obscuration occurred between one and two minutes after the ignition of the urethane foam padding in the seat assembly. Also, the data indicate that the rate of increase in smoke density, once the foam had been ignited, was not appreciably different in the 3 tests. Zero visibility into the bus corresponds to a decrease in light transmission of about 90 to 95 percent of the original light level.

In comparing the smoke data from all three tests, the most critical event is the ignition of the foam padding in the seat assembly, since zero visibility occurs about a minute later. Referring to figure 5, the times to ignition of the foam for tests 1 and 2 were approximately 240 seconds and 160 seconds, respectively. For test 3, the time was too short to observe the ignition of the foam and it was arbitrarily set at 5 seconds. No data was obtained on the toxicity of the combustion gases or the effect of eye-irritation.

4. CONCLUSIONS

The interior furnishings of the bus all have burn rates below 4 inches per minute, in conformance with the Department of Transportation's Motor Vehicle Safety Standard 302. The results of other laboratory tests for the various materials are generally in line with what is typical for the class represented. Full-scale tests were necessary to determine the interaction of materials and their performance under actual fire conditions.

Based on the full-scale bus tests, the seats are the most probable source of hazard, given an ignition. The seats can be ignited with a source as small as a single paper safety match. Accidental ignition, for example via paper trash, may take a few minutes (2-1/2 and 4 min in the two tests run) to ignite the urethane foam on the seats.

Use of lighter fluid to simulate arson produced ignition of the urethane foam padding within a few seconds. Once the urethane seat padding catches fire a serious smoke hazard develops quickly. Within one to two minutes after the foam padding catches fire, visibility is nil within the bus. Evacuation of the bus would be imperative but would be made difficult because of the reduction in visibility. The fire from one seat, fully developed, is substantial and the heat is a hazard to occupants close by.

The vulnerability of the buses to accidental ignition and to arson can be reduced by removing the urethane padding, or preventing its ignition by use of a high-resistant fabric or by placing a barrier beneath the fabric. The level of fire safety of the passengers is determined in part by comparing the time required for safe evacuation with the time between the initial ignition and the ignition of the urethane paddings. The safety margin for escape, based on the above results, will not be very large. Clearly, the level of fire safety, in terms of passenger protection, will be improved in any case by removing or protecting the urethane padding.

5. REFERENCES

[1] Motor Vehicle Safety Standard - 302, National Highway Traffic Safety Administration, Federal Register, Vol. 36, No. 5, 70 (January 8, 1972).

[2] Hartzell, L. G., Development of a Radiant Panel Test for Flooring Materials, Nat. Bur. Stand. (U.S.), NBSIR 74-495 (May 1974).

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[4] Surface Flammability of Materials Using a Radiant Heat Energy Source, E-162, American Society for Testing and Materials. Philadelphia, Pa. (1967).

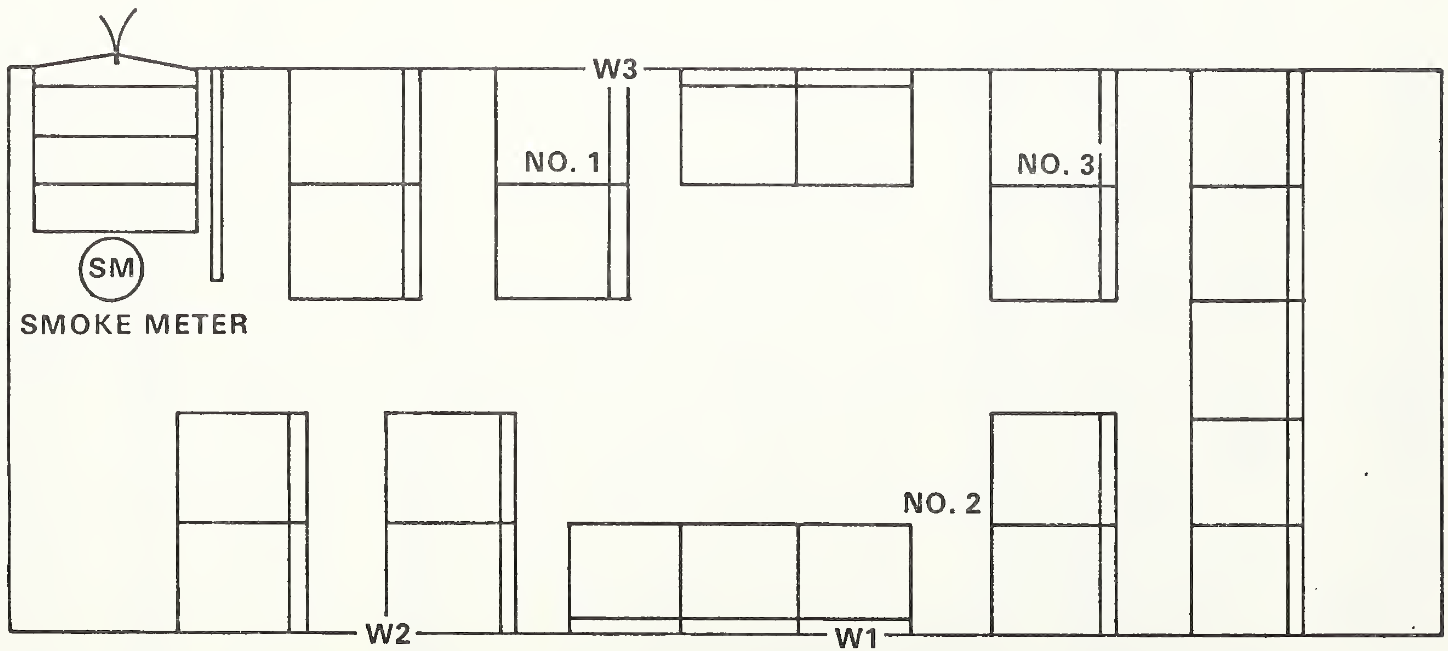
[5] Test Method For Measuring Smoke Generated by Solid Materials - 258T, National Fire Protection Association, 1974 NFPA Technical Committee Reports, Vol. IB, 1377-1424 (May 20, 1974).

[6] Robertson, A. F., Surface Flammability Measurements by the Radiant Panel Method, ASTM Symposium on Fire Test Methods, Special Technical Publications, No. 344-1962.

[7] Rose, A., Comparison of Flame-Spread Ratings by Radiant Panel, Tunnel Furnace, and Pittsburgh Corning Apparatus, National Research Council of Canada, NRC 10788 (June 1969).

[8] Lee, T. G., The Smoke Density Chamber Method for Evaluating the Potential Smoke Generation of Building Materials, Nat. Bur. Stand. (U.S.), Tech. Note 757 (Jan. 1973).

FIGURE 1 FLOOR PLAN OF METROBUS
SHOWING IGNITION POINTS AND WINDOW OPENINGS



IGNITION SOURCE
NO. 1 - TRASH BAG
NO. 2 - NEWSPAPER
NO. 3 - LIGHTER FUEL

WINDOW OPENING
W1 - 3.0 INCHES
W2 - 1.5 INCHES
W3 - 3.0 INCHES

FIGURE 2 TEMPERATURE PROFILE ABOVE IGNITION SOURCE

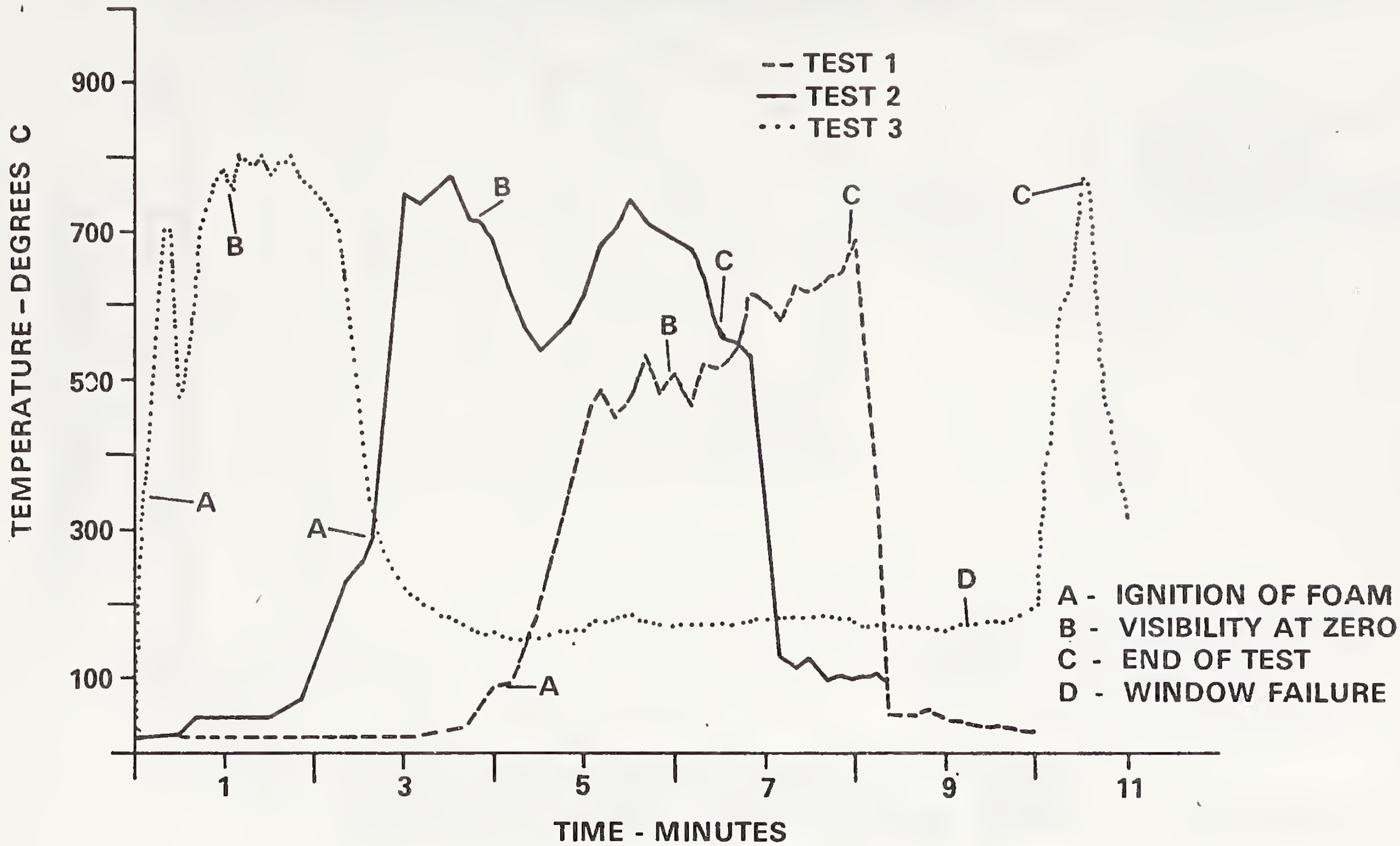


FIGURE 3 CEILING TEMPERATURE AISLE
3 FEET FORWARD OF IGNITION SOURCE

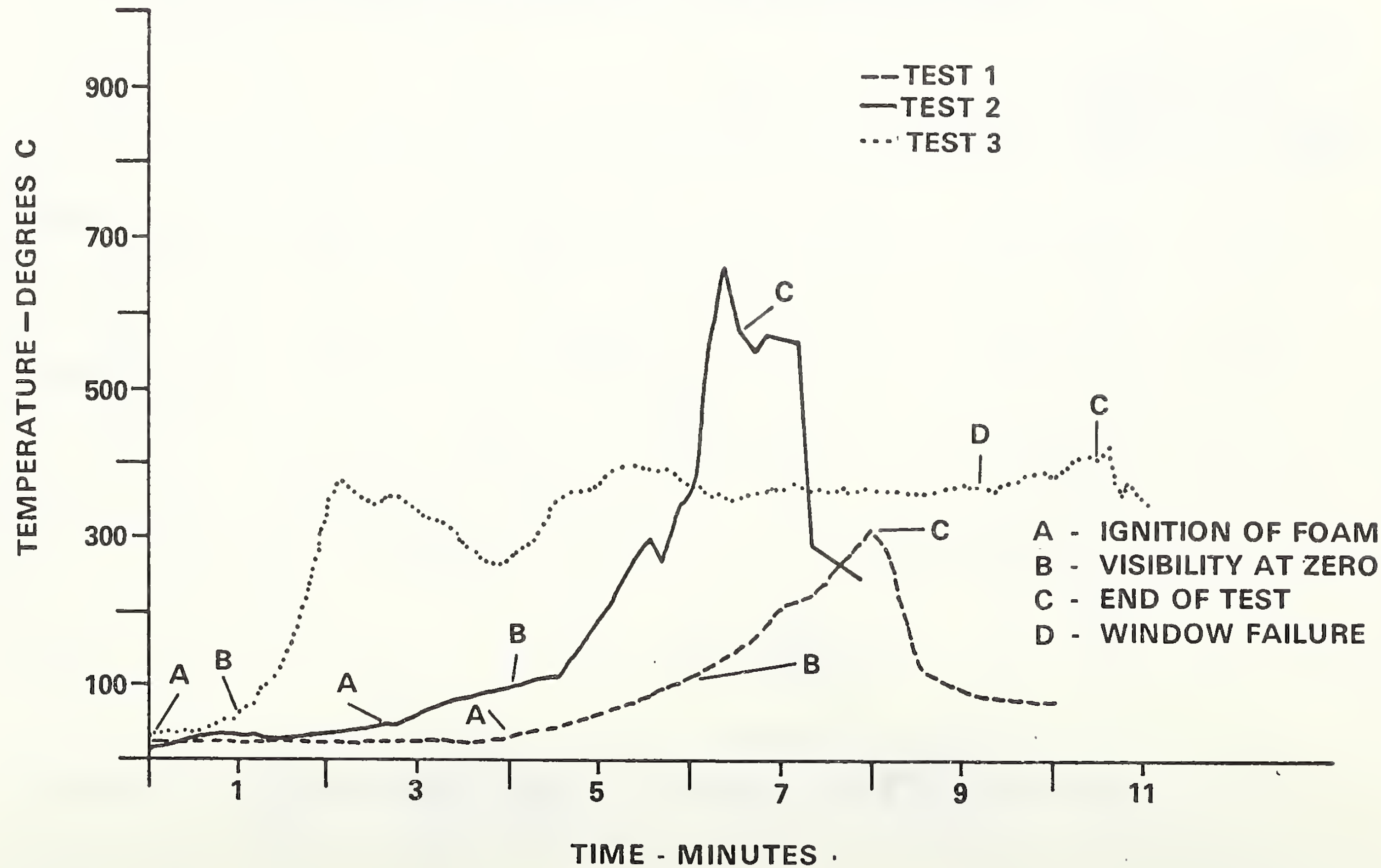


FIGURE 4 CEILING TEMPERATURE AISLE 2 FEET OF THE REAR OF IGNITION POINT

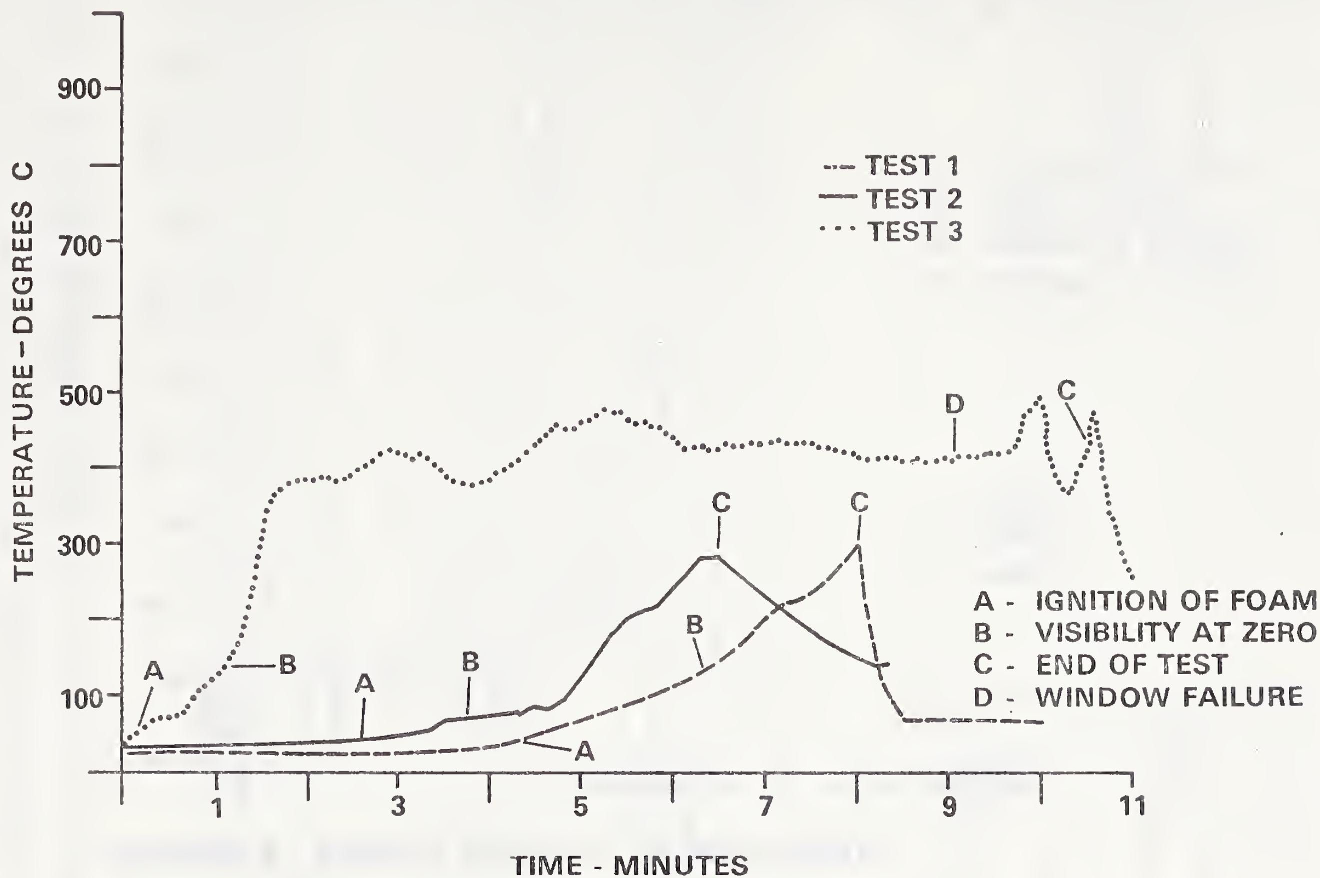
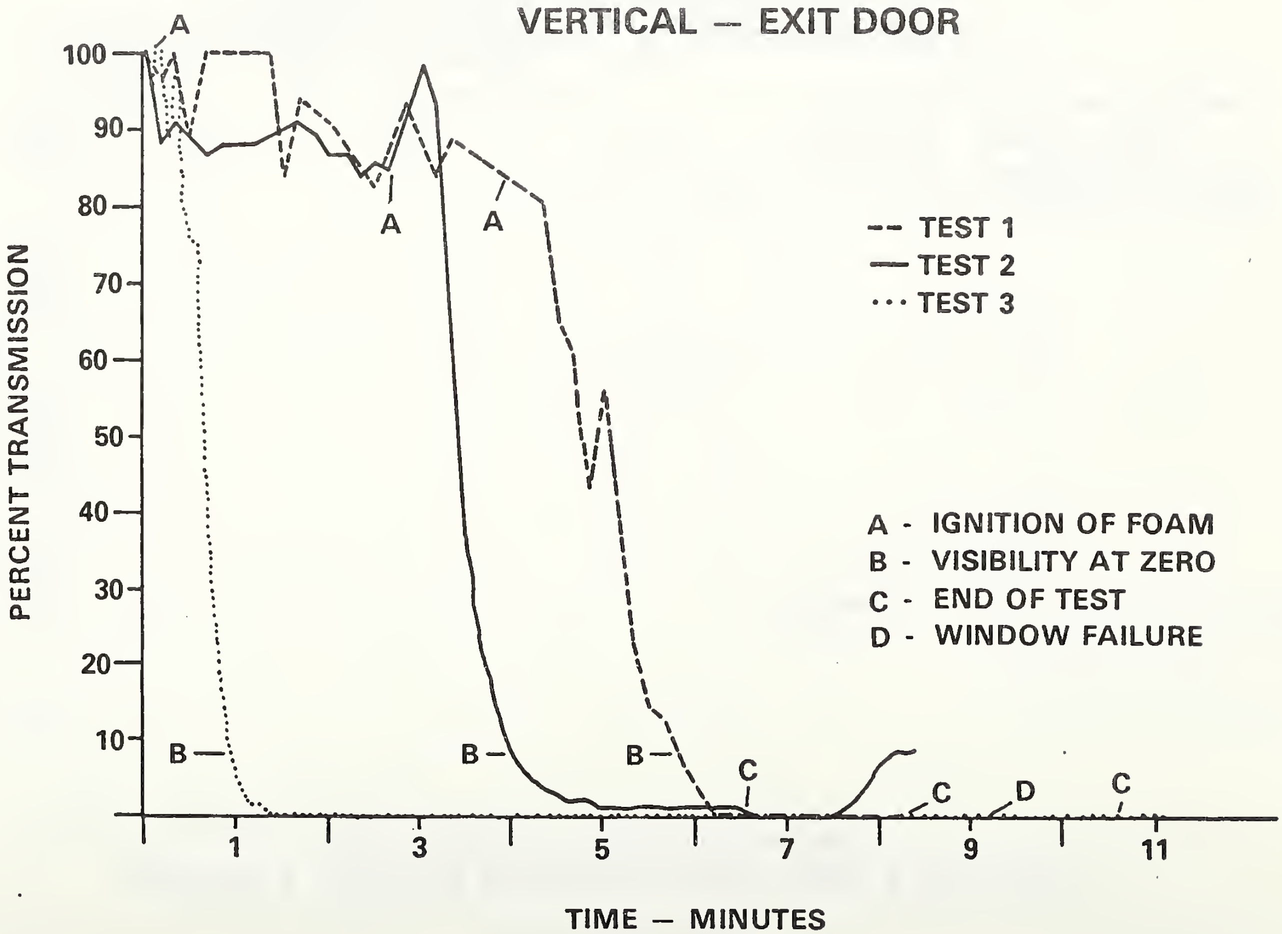


FIGURE 5 SMOKE DENSITY IN METROBUS

VERTICAL — EXIT DOOR



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15. SUPPLEMENTARY NOTES

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

The Center for Fire Research at the National Bureau of Standards has conducted a study of the fire safety of a bus supplied by the Washington D.C. Metropolitan Transit Authority. The objectives of the work were: (1) to determine the minimum ignition from source necessary to initiate a fire in the bus, and (2) to determine the means by which a fire, once started, is most likely to grow and spread.

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17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

AM General bus; arson; critical radiant flux; fire retardant; flammability; Flooring Radiant Panel Test; Metro; Motor Vehicle Safety Standard 302; urethane.

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