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DATA REPORT NO. 91

AIR TRANSPORT CABIN MOCKUP SMOKE STUDIES

PROJECT NO. 184-732-05X
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Purpose

Measure the smoke emission characteristics of burning aircraft seat foam padding inside a cabin from a visibility standpoint. Relate the Specific Optical Index (D_s) values calculated from the cabin smoke test data on the foams with that obtained with the standard NBS Smoke Density Chamber Apparatus as described in American Society for Testing Materials (ASTM) publication STP 422.

Background

During the past years, increasing attention by fire officials has been devoted to the problem of smoke caused by burning of interior materials as one of the major life hazards from fires within habitable enclosures. Following the experience of the B-727 Salt Lake City accident in November 1965, FAA in an effort to improve the survivability of passengers following a crash fire sponsored, a joint test program with the major airframe manufacturers under the direction of the Aerospace Industries Association (AIA) to study, develop, and recommend improved materials and safety systems for aircraft. Smoke, in addition to flammability, was recognized as an important element comprising the total aspect of fire protection, especially in its effect on reducing capability of the cabin for allowing rapid evacuation. Aside from the deleterious respiratory and toxicological effects of fumes, the physiological complications of which are extremely complex, interest in smoke has mainly centered on its effect on human vision. Smoke particulates in the air obscures exit signs, passageways, doors and windows, thus increasing the difficulty of passengers seeking escape from the fire.

A test program was initiated by FAA in 1966 with the National Bureau of Standards, Fire Research Section under a working agreement to conduct smoke tests on a large number of interior materials selected and supplied by NAFEC. As part of this program, toxic gases evolved during the burning of the materials in the smoke tests were identified and measured.

Description of the apparatus and results of the tests on some 140 representative cabin materials either in actual use or considered for possible future use are contained in FAA Report NA-68-36 (AD 675513), titled "Smoke and Gases Produced by Burning Aircraft Materials."

The NBS test method for measuring smoke consists of continuously recording, against exposure time to a known flame and radiant ignition source, the decrease in percent transmission of a vertical collimated beam of light extending from bottom to top of the chamber (3-foot optical path) as viewed by a sensor (Phototube 1P39) with response similar to that of the human eye. From this data, a Specific Optical Index designated by the symbol D_s (D_m for max) is calculated for each material specimen in the thickness appropriate to its use in aircraft interiors up to a maximum thickness of 1 inch for seat foams.

The formula used for calculating the Specific Optical Index for the foam materials burned in the cabin mockup and NBS chamber is given as follows:

$$D_s = V/LA\ (\log_{10} 100/T) = G\ (\log_{10} 100/(100-D)\ )$$

Where -

D_s = Specific Optical Index

T = Percent Light Transportation

D = Percent Smoke Density

V = Enclosure Volume

A = Exposed Area of Material Burned

L = Length of Light Path

G = V/LA = Geometrical Factor.

For the NBS chamber, V = 18 cubic feet, A = 0.0456 square foot, L = 3 feet, and G = 132.

For the cabin mockup the G factors were 320 (Figures 2 and 3), 385 (Figure 5), and 770 (Figures 4 and 6).

Since the D_s indices of the materials are based on unit dimensions of V, A, and L, these can presumably be extrapolated to predict the smoke density for any given size enclosure, area of material burned, and viewing distance through smoke by substituting the appropriate G factor in the formula. Of course, the accuracy to be expected is dependent on the degree of simulation in the test conditions between the two enclosures. It should be noted that this was not the case here, especially with reference to the ignition source. The main purpose of the tests being instead more to duplicate a typical foam fire than to conform to the NBS apparatus.

The NBS apparatus and test method for measuring smoke, since 1968, has undergone only minor changes up to the present time when the ASTM is considering making this test method a standard. About 2 years ago this apparatus became commercially available, and since that time it has been adopted by at least 60 laboratories. Extensive smoke data as a result have become available. These data are being used by FAA to prepare a Notice for Proposed Rule Making (NPRM) to limit the amount of smoke generated by burning materials. (Data Report No. 76, "Analysis of Industry Furnished Smoke Emission Data on New Cabin Interior Materials," January 1971). Other agencies, both public and private, have begun to specify maximum D_s values for materials.

Since it appears that the NBS test apparatus and method will be accepted as a standard by regulatory agencies for the certification of materials, the project effort concentrated on reaching this goal. However, past experience shows that every new test method introduced meets with opposition based on arguments that it is not needed; it is too costly; it is not reproducible; it is not applicable to some materials; and it is unrealistic of actual fire situations. Future tests are planned in answer to such criticisms or questions of the applicability of the NBS test method for smoke evaluation. A much more comprehensive effort in this direction, than presented herein, will be conducted by the Lockheed-California Company for FAA under contract (PRN 1-618 and PRN 2-821) by utilizing a 20-foot section of the L-1011 and a large number of materials.

Test Procedure

A description of the cabin mockup showing the locations of the smoke detectors with reference to position at which the foam pads were burned is presented in Figure 1. Each of the two smoke detectors consisted of a rigid tube with a light source at one end and a barrier-type photocell at the other end providing a 1-foot optical path. The tube was constructed in such a manner as to allow free passage of smoke from the convection of air through the tube, while preventing external light from the fire and windows from reaching the photocell. The tubes were supported horizontally by wires. A continuous type of recorder was used to obtain the smoke data.

Foam specimens were cut in the form of slabs 4 by 6 inches in crossection with lengths of from 5 to 12 inches. The weight of the foam used in the tests was either 2 or 4 ounces. Both the regular variety of urethane foam used in airplane seating as well as flame-retardant (FR) foam were used in the tests. Flammability and smoke data obtained in laboratory-scale tests on these foams are contained in FAA Reports NA-68-30 and NA-68-36. The foam specimens were burned inside a 12-inch-square steel pan 1 inch deep. For the flaming smoke tests, a

Bunsen burner flame of about 3 inches in length was directed against the side of the foam slab. The flame was held in contact with the foam for at least 1 minute or until it became self-flaming. For the smoldering smoke tests, the same burner was used, but with its flame directed against the bottom of the steel pan. Flame exposure was continued until all the foam was cooked.

An electric fan placed on the floor was used in an attempt to produce a more homogenous smoke mixture inside the cabin for averaging the readings without much effect. Smoke measurements were continued after the door was opened to determine how rapidly smoke would be expelled from the cabin.

Summary of Test Results

Smoke emission data plotted against time for a 4-ounce slab of regular urethane foam burning with open flames are shown in Figure 2. Very rapid flaming of the foam occurred within one minute of the application of the flame ignition source. Maximum smoke density registered by the top detector was 19 percent after 2.9 minutes and for the lower detector 27 percent after 3.6-minutes exposure. The Specific Optical Smoke Index numbers for this material listed under No. 128B (regular urethane) in FAA Report NA-68-36 was D_s = 41 (Max) under flaming combustion and D_s = 300 (Max) under smoldering combustion. Using the same formula given before and a G factor of 320, a D_s index value for the mockup cabin was calculated. The index values obtained for the mockup corresponding to 27-percent density was D_s = 44 (Max) and for 19-percent density D_s = 30 (Max). Considering the differences in the sizes of the two compartments (40 to 1), areas of the foam burned (30 to 1) and also the differences in the mounting and burning of the foam, the agreement is considered suprisingly close. Also, it should be noted that the NBS test method utilizes a vertical beam of light from bottom to top of the chamber to provide an average smoke index. Instead, in the mockup tests, the smoke was measured at two discrete levels. The smoke detector at midheight would be expected to more closely approximate the NBS test method by providing a better average reading.

Smoke emission data plotted for a 4-ounce slab of regular foam as in the previous test but under a smoldering condition of burning are shown in Figure 3. There was no flaming of the foam. The buildup of the smoke was much slower but reached a very much higher density than for the flaming condition. At about 55-percent smoke density, the lighted exit sign was barely visible from the outside looking through the opposite window. Maximum smoke density registered at 60 percent was the same at both detector locations. This corresponded to a calculated D_s = 128 (Max) for the mockup compared to a D_s = 300 (Max) for the NBS chamber.

Smoke emission data plotted for a 2-ounce slab of foam are shown in Figure 4. Since only half the quantity of foam was used compared to the previous test, maximum smoke density recorded was much less and occurred in half the time. The calculated Specific Optical Index values corresponding to maximum smoke densities of 41 and 36 percent were D_s = 147 (Max) for the top detector and D_s = 124 (Max) for the lower detector. These index numbers are in good agreement with those in Figure 3 for the 4-ounce slab of foam.

Smoke emission data plotted for a 4-ounce slab of FR urethane foam are shown in Figure 5. The Specific Optical Index numbers for this material listed under No. 128A (FR foam) in the report was D_s = 262 (Max) under flaming combustion and D_s = 286 (Max) under smoldering combustion. Unlike regular foam which is extremely flammable and produces low smoke, FR foam which is self-extinguishing produces very dense smoke regardless of how the foam is burned. It should be noted that new FR foams tested recently generate considerably less smoke (D_s = 100 to 200 (Max) than the older type foam used in the tests. Extremely dense smoke developed when the foam was cooked in the absence of flames (smoldering combustion). Smoke density reached 76 percent at the top detector level and 70 percent at the lower detector level. These readings correspond to an index of D_s = 238 (Max) and D_s = 200 (Max), respectively. These index values are in fairly good agreement with the D_s = 286 index for the NBS chamber.

Smoke emission data plotted for a 2-ounce slab of FR urethane foam are shown in Figure 6. Very dense smoke even with such a small quantity of foam was generated sufficient to block out the exit sign observed. The maximum smoke densities of 63 percent for top detector and 50 percent for the lower detector correspond to index values of D_s = 332 (Max) and D_s = 290 (Max), respectively. These index values are in close agreement with the D_s = 286 index for the NBS chamber and in fairly good agreement with those in Figure 5.

The major findings derived from the test program are as follows:

1. Extremely dense smoke can result from the burning of as little as 2 ounces of foam in a 640-cubic-foot enclosure sufficient to obliterate airplane cabin exit signs.

2. The test results were too limited and variable to establish a definite relationship between the Specific Optical Index values for seat foam obtained in the NBS Smoke Density Chamber with those obtained in the cabin mockup.

3. Considerable lag occurs between the smoke buildup near the ceiling and at a level 39 inches below the ceiling.

4. Stratification of smoke in the mockup continued during the entire test period from 16 to 30 minutes.

5. Evacuation of smoke from the mockup by opening the door is relatively slow.

A summary of the test conditions and results of the smoke tests on the urethane seat foam is presented in Table 1.

TABLE 1.--SUMMARY OF TEST RESULTS

Test	Urethane Foam			Type Combustion	Specific Optical Index - D_s (Max)			Maximum % Light Absorption	
						Mockup		Mockup	
	Type	Wt	Size		NBS Chamber	Ceiling	Midheight	Ceiling	Midheight
Fig. 2	Std	4 oz	12" x 6" x 4"	Flaming	41	30	44	19	27
Fig. 3	Std	4 oz	12" x 6" x 4"	Smoldering	300	128	128	60	60
Fig. 4	Std	2 oz	5" x 6" x 4"	Smoldering	300	147	123	41	36
Fig. 5	FR	4 oz	10" x 6" x 4"	Smoldering	286	238	200	76	70
Fig. 6	FR	2 oz	5" x 6" x 4"	Smoldering	286	332	290	63	50

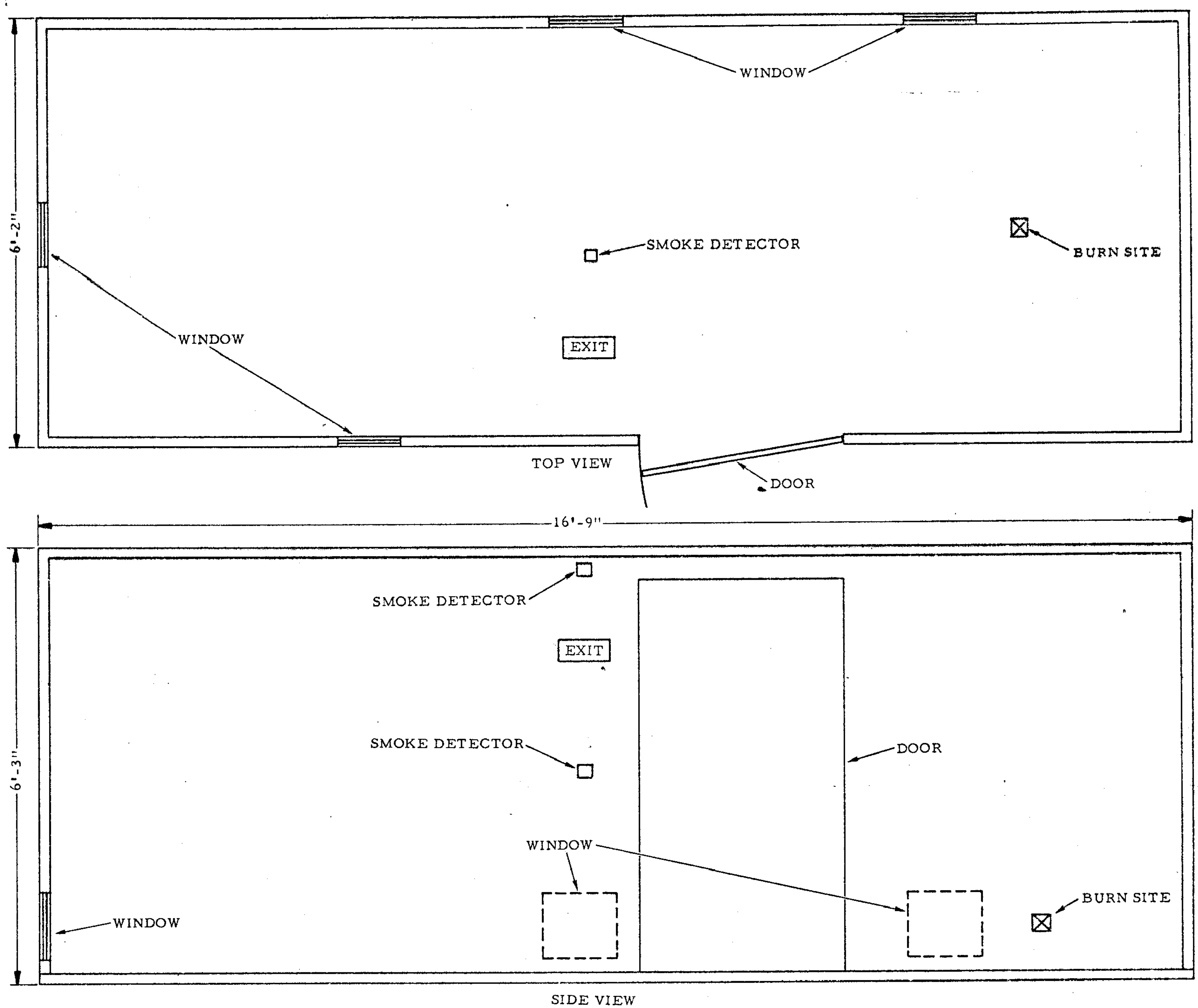

FIGURE 1 - SCHEMATIC OF CABIN MOCKUP

TEST CONDITIONS

FUEL LOAD
STANDARD FOAM (12" x 6" x 4" - 4 oz WEIGHT)

IGNITION SOURCE
3 INCH PROPANE FLAMES DIRECTED AGAINST SIDE OF FOAM PLACED IN PAN

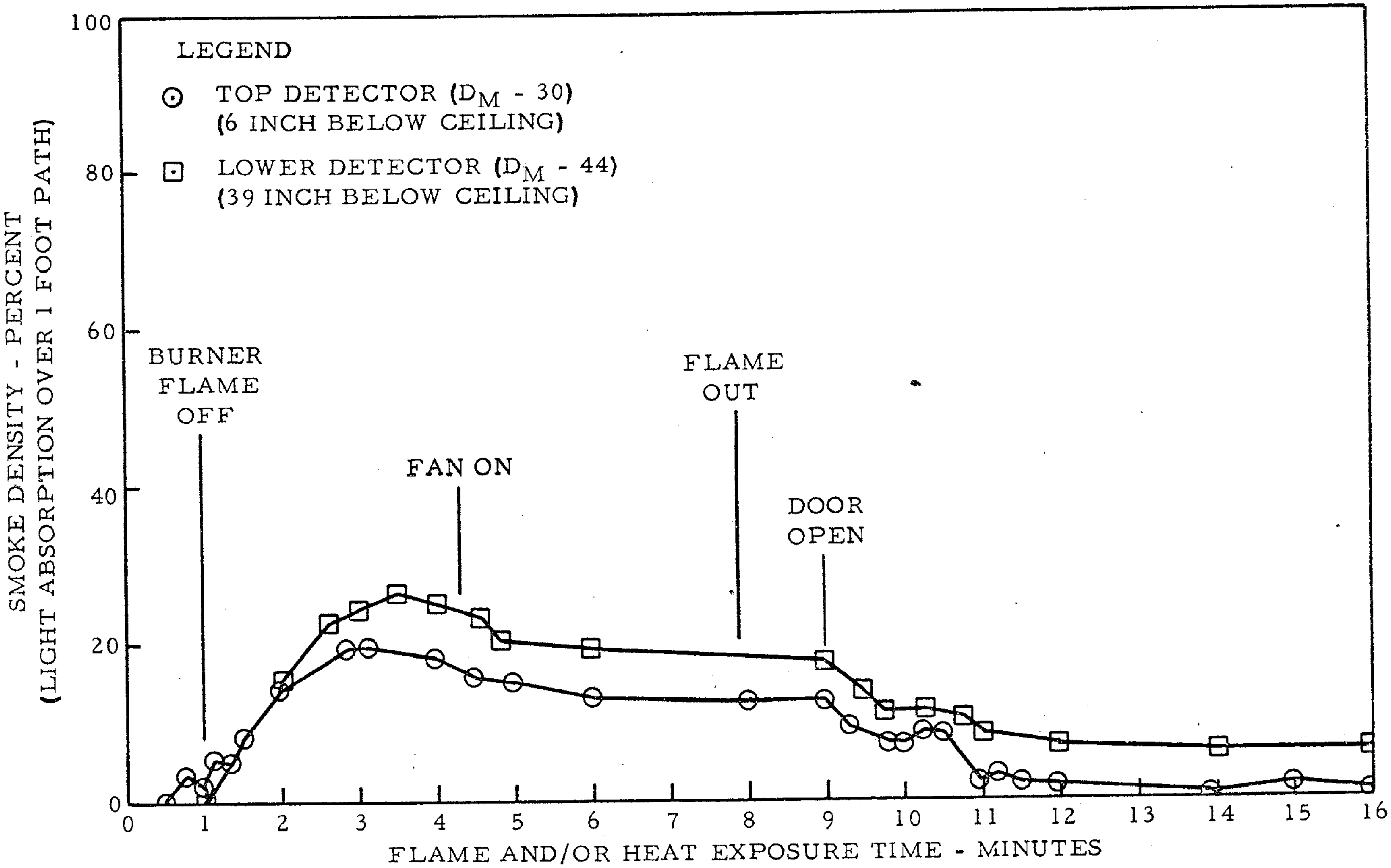

FIGURE 2 - SMOKE EMISSION OF FLAMING STANDARD URETHANE FOAM (4 OZ)

TEST CONDITIONS

FUEL LOAD
STANDARD FOAM (12" x 6" x 4" - 4 oz WEIGHT)

IGNITION SOURCE
1 1/2 INCH PROPANE FLAMES DIRECTED AGAINST UNDERSIDE OF PAN CONTAINING FOAM

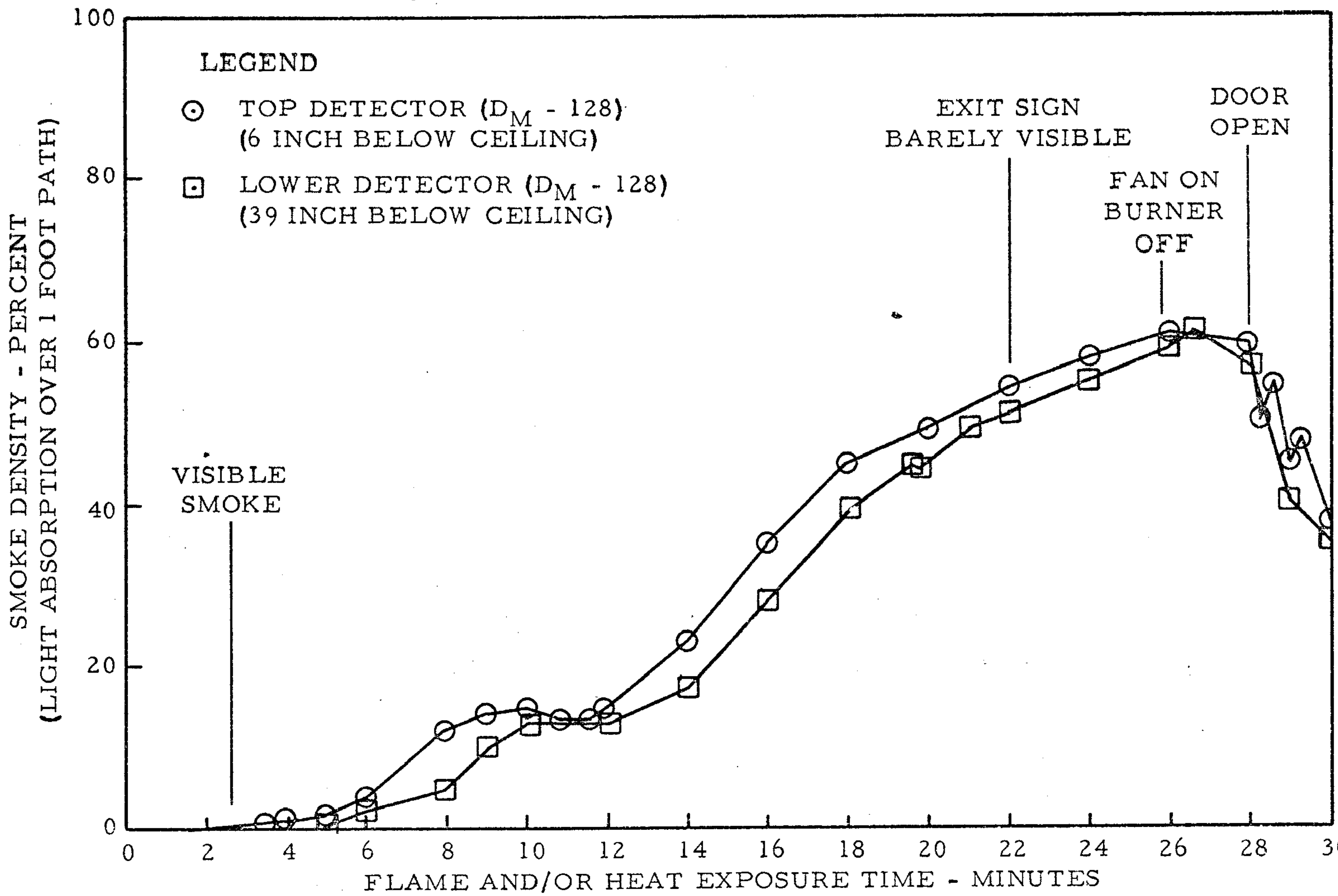

FIGURE 3 - SMOKE EMISSION OF SMOLDERING STANDARD URETHANE FOAM (4 OZ)

TEST CONDITIONS

FUEL LOAD
STANDARD FOAM (6" x 5" x 4" - 2 oz WEIGHT)
IGNITION SOURCE
1 1/2 INCH PROPANE FLAMES DIRECTED AGAINST
UNDERSIDE OF PAN CONTAINING FOAM

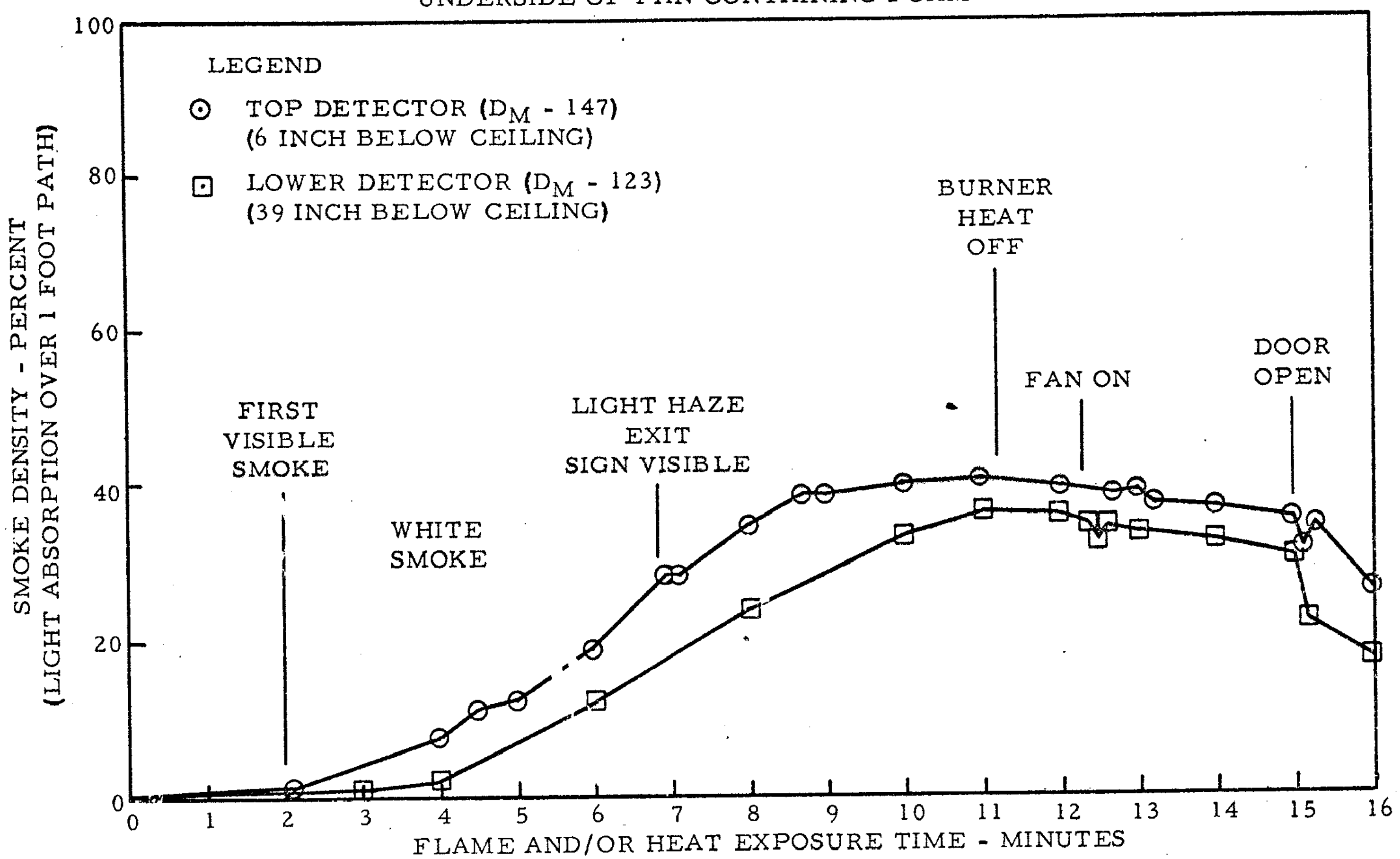

FIGURE 4 - SMOKE EMISSION OF SMOLERING STANDARD URETHANE FOAM (2 OZ)

TEST CONDITIONS

FUEL LOAD
FR FOAM (10" x 6" x 4" - 4 oz WEIGHT)
IGNITION SOURCE
1 1/2 INCH PROPANE FLAMES DIRECTED AGAINST UNDERSIDE OF PAN CONTAINING FOAM

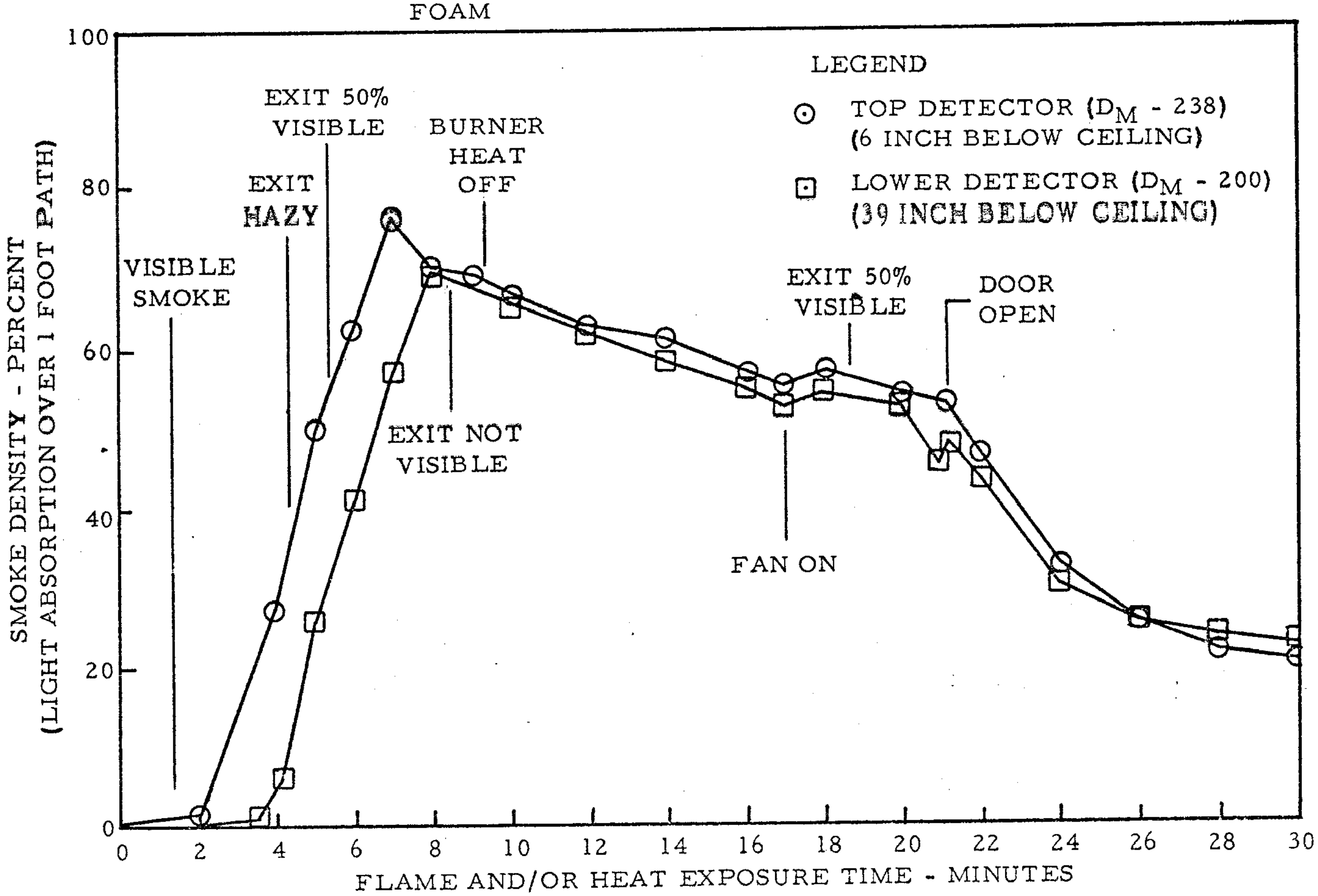

FIGURE 5 - SMOKE EMISSION OF SMOLDERING FLAME-RETARDANT (FR) URETHANE FOAM (4 OZ)

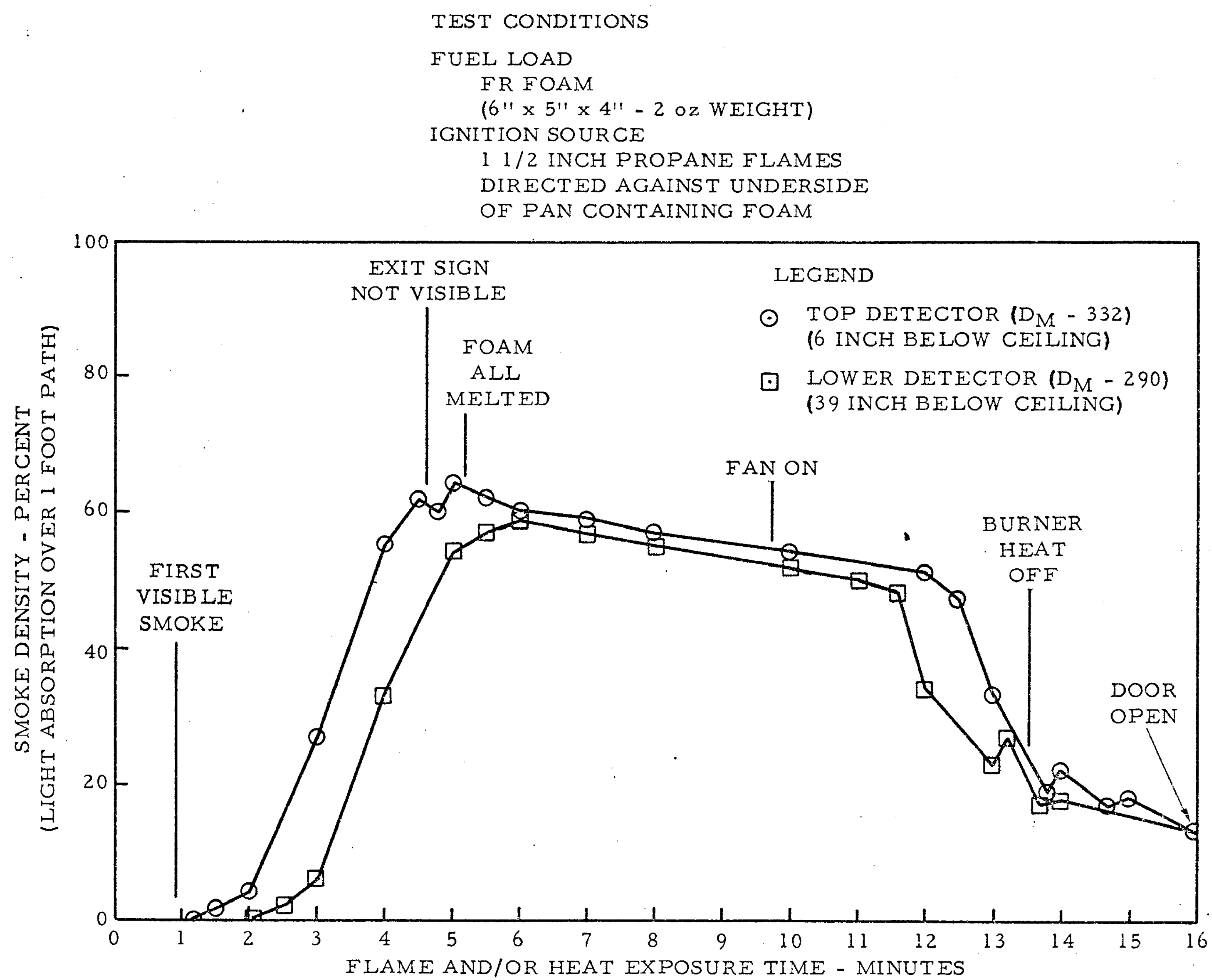

FIGURE 6 - SMOKE EMISSION OF SMOLDERING FLAME-RETARDANT (FR) URETHANE FOAM (2 OZ)