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USE OF THE NBS SMOKE CHAMBER FOR RATING THE SMOKE BEHAVIOR OF MATERIALS AND ITS LIMITATIONS FOR PREDICTING THE VISIBILITY DURING A CABIN FIRE

by

Constantine Sarkos

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Federal Aviation Administration
National Aviation Facilities Experimental Center
Atlantic City, New Jersey 08405

ABSTRACT

The National Bureau of Standards (NBS) Smoke Chamber is shown to be the most appropriate laboratory test method available for predicting a material's relative performance with respect to the smoke it will produce in an aircraft cabin fire. The advantages and limitations of this method are described and a hypothetical method of relating NBS Smoke Chamber data to human visibility in a cabin is presented.

INTRODUCTION

Purpose

A request was received from Flight Standards Service (FS), AFS-120, to qualify the selection of the NBS Smoke Chamber, compare the NBS Smoke Chamber with other test methods and to discuss the relationship between NBS Smoke Chamber test data and human visibility under actual fire conditions (Appendix A). This report is a response to this specific request.

Background

In the event of a survivable passenger transport crash with an ensuing fuel-spill fire developing and ultimately igniting cabin interior materials, the smoke produced by the burning materials will accumulate within the cabin. It is generally recognized that of all the hazards associated with a fire, the smoke or toxic gases present the most immediate threat to passenger survivability. The smoke hazard considered in this report is primarily associated with liquid and solid aerosols produced by burning cabin materials having the following possible detrimental effects on passengers:

1. Obscuration of vision resulting in disorientation and inability to escape from the airplane.

2. Psychological threat to those effected possibly leading to a panic situation.

3. Ingestion can cause coating and blockage of the various respiratory channels and passageways with resulting severe edema, spasms and incapacitation.

4. Physiological effects from irritant and toxic gases which invariably accompany smoke.

In 1969, the Federal Aviation Administration (FAA) issued an Advanced Notice of Proposed Rule Making (ANPRM) advising the public of an intent to limit the allowable smoke emission from burning cabin materials. The purpose of the ANPRM was to increase aircraft cabin fire safety by ruling out the use of those materials producing the greatest amount of smoke when becoming involved in a fire. The elimination of such materials would be advantageous, both from the standpoint of improved visibility and a reduction in irritant and toxic gases and particulates produced during a fire. Unfortunately, the magnitude of these added benefits has not been measured.

NAFEC endorsed the NBS Smoke Chamber, which had been used previously to measure the smoke optical density of 140 aircraft interior materials (reference 1). It was believed at that time - and is still now - that the NBS Smoke Chamber was the best laboratory test apparatus for this purpose (see detailed discussions later in report). An agreement was reached by FAA and the Aerospace Industries Association (AIA) in 1969 whereby many typical cabin materials would be tested by Lockheed, Boeing and Douglas and the data delivered to National Aviation Facilities Experimental Center (NAFEC) for analysis. Smoke level limits based on this data bank were proposed by the NAFEC Project Manager in October 1970 (reference 2) with primary consideration being given to the availability of materials so as not to impose a design hardship on the airframe manufacturers. Over two-thirds of the 250 materials tested in the NBS Smoke Chamber, with a substantial number in each of the nine materials categories, passed the proposed limits, which were higher than desired but still provided a substantial improvement by eliminating the smokier materials such as the thick thermoplastic sheets of ABS, acrylics and vinyls. It was not possible to forecast and consider in the determination of reasonable limits any development and marketing of new materials possibly motivated by an ANPRM.

DISCUSSION

Selection of the NBS Smoke Chamber for Measuring Smoke Generated by Burning Materials

The NBS Smoke Chamber was developed in 1966 by NBS because there was no meaningful and accurate test method suitable for measuring a wide range of smoke concentrations. The most popular test method at that time was the XP2 test chamber developed by the Rohm and Haas Company (reference 3). Examination of the XP2 chamber by NBS revealed many deficiencies which were eliminated in the design of a new chamber constructed at NBS. The major considerations included in the NBS Smoke Chamber, but found lacking in the XP2 chamber, are as follows (reference 4):

1. A vertical (average), rather than horizontal (spot), photometer was used to measure total smoke and avoid differences due to smoke stratification, thus assuring a higher degree of reproducibility for all types of materials;

2. An electrically-heated radiant heat source and a small auxilliary pilot flame were used to provide close control of the specimen heat exposure conditions, which was not attainable with the XP2 chamber, where the specimen is tested unrealistically by being completely immersed in flames;

3. The chamber was closed to prevent smoke loss;

4. The chamber was of greater capacity to permit burning of larger size specimens; and

5. A photometer and recorder with sufficient resolution to permit measurement of the maximum quantity of smoke emitted by any common material.

One of the earliest applications of the NBS Smoke Chamber was for the measurement of smoke produced by aircraft cabin interior materials (reference 1). The complete theory, construction details and the test method procedures are given in references 4 and 5. The NBS Smoke Chamber is an 18-foot^3 closed cabinet in which a 3-inch-square specimen is supported vertically in a holder and exposed to one of two conditions, designated as "flaming" or "nonflaming" (smouldering). The specimen is tested in the thickness normally used for its application. As the specimen is subjected to the fire exposure conditions, smoke accumulates within the chamber as the test specimen is consumed. The percentage of light transmission through the smoke is continuously measured with a photometer. The final data format is usually a plot of specific optical density against test time.

The Pros of the NBS Smoke Chamber

1. The NBS Smoke Chamber is the most widely-used laboratory test method for measuring the smoke generated by burning materials. It has gained acceptance and usage in the United States and throughout the world.

2. The chamber is commercially available. It can be purchased from the American Instrument Company (Aminco) at a reasonable cost of $5,500. As of January 1, 1974, Aminco will have delivered 106 chambers and estimates a minimum of 130 to 140 chambers sold by 1975 (Appendix C). A users list as of November 21, 1973, is shown in Appendix B (does not include a small number of home-built chambers).

3. Independent test laboratories offer a service which measures the smoke generated by materials tested in the NBS Smoke Chamber. The following laboratories have reported that they can provide this service for the public: Aminco; Underwriters' Laboratories, Inc.; Southwest Research Institute and U. S. Testing Company.

4. All three transport aircraft manufacturers currently use the NBS Smoke Chamber to measure the smoke production from cabin materials. If all other material selection considerations are reasonably close when comparing several candidate materials, the manufacturer generally selects the material that produces the least amount of smoke.

5. Considerable data obtained with the NBS Smoke Chamber is available on current and candidate cabin materials. References 1 and 2 alone describe about 400 tests. It can be safely estimated that the transport manufacturers have tested upwards of 1,000 materials using the NBS Smoke Chamber. If the NBS Smoke Chamber were replaced by another test method in the proposed FAA smoke regulations, then all the data obtained to date with the NBS Smoke Chamber would be inapplicable since no correlation exists between any two smoke test methods.

6. The NBS Smoke Chamber has been demonstrated to exhibit good repeatability which surpasses that of many American Society for Testing and Materials (ASTM) standard fire test methods. A round-robin evaluation of the chamber was conducted and included 10 material-condition combinations and 18 laboratories (reference 5). The round-robin was designed to examine the reproducibility of the test method for materials with a <u>wide range of properties</u> in terms of composition, thickness, reaction to heat and flame, and production of smoke. It included a cross section of laboratories - some were research oriented while others were test oriented; some were new at measuring smoke while others were experienced. The results, therefore, reflected a conservative

estimate of the precision of the test method. A statistical analysis of the results indicated that the median coefficient of variation of reproducibility was 7.2 percent under nonflaming exposure and 13 percent under flaming exposure. The computation of reproducibility includes within-laboratory repeatability and between-laboratory reproducibility.

7. A ruggedness (sensitivity) evaluation conducted on the NBS Smoke Chamber demonstrated no potential critical requirements on the test procedure. Tests were performed under extreme deviations from the following test conditions: irradiance; maximum chamber pressure; conditioned relative humidity; chamber wall temperature; lamp voltage; propane flow rate; horizontal displacement of specimen holder; photometer window temperature; condition of wall surface; zero adjustment of photometer; operator procedures and specimen foil wrapper leakage area. It was reported in reference 6 that "for the selected conditions and ranges, the 'ruggedness' test did not indicate any unexpected sensitivity in the measurement of maximum specific optical density, and there is no need to change the existing proscribed tolerances on irradiance, chamber wall temperature, etc."

8. The NBS Smoke Chamber is being considered for adoption by the National Fire Protection Association (NFPA) and the ASTM. Within the last several months, the NFPA Committee on Fire Tests has drafted a document "Recommended Practice on Measurement of Smoke Production from Building, Furnishings and Construction Materials," which is expected to be voted upon in the near future. In 1970, the NBS Smoke Chamber Test Method was submitted to ASTM for consideration and possible promulgation as a "voluntary standard." It has not yet been officially accepted by ASTM. The ASTM Subcommittee E-05.02, Smoke and Combustion Products, under whose auspices the chamber is, has two task groups working to (a) evaluate other smoke test methods and (b) identify the interactions in the round-robin test series which have prevented statistical acceptance of the method. However, the concensus opinion of many experienced fire test professionals that the author has conversed with is that (a) the NBS Smoke Chamber is now the best laboratory test method for rating and comparing the smoke produced by different materials and (b) the opposition to the round-robin is unjustified since ASTM in the past has accepted fire test methods with poorer reproducibility than the NBS Smoke Chamber. In the opinion of the author, the ASTM opposition stems from committee (manufacturers') representatives whose products generate copious amounts of smoke when tested in the NBS Smoke Chamber under smouldering conditions and they are thus opposed to its adoption as a standard.

9. Several governmental and civic organizations already have smoke regulations specifying compliance tests using the NBS Smoke Chamber. These include the (a) U. S. Department of Housing and Urban Development "Operation Breakthrough" for construction materials, (b) General Services Administration (GSA) for plastic office partitions, (c) Port of New York Authority (PONYA) for carpeting used in their facilities, and (d) Department of Defense (DOD) for hospital and ambulance litter pads.

10. The following NBS Smoke Chamber design features account for its high degree of relevency and reproducibility:

a. The test specimen consists of the solid material or assembly in the thickness used during its application. The smoke density produced by a material of given thickness cannot be extrapolated to predict the smoke density at any other thickness, although a material will ultimately produce more smoke the greater the thickness. The importance of specimen thickness is illustrated in Figure 1 plotted from data in reference 4. The deviation from a linear relationship between D_m (maximum specific optical density) and thickness results from the decreasing pyrolysis rate from the unburned material which becomes more insulated as the char layer increases and the increasing rate of smoke settling and condensation as high smoke concentrations develop. Thus, the most meaningful approach for assessing the smoke hazard from different materials is to burn them at their usage thickness; a comparison of different materials each tested at the same thickness will give misleading results; the smoke density of a material at one thickness cannot be used to predict the smoke density at another thickness.

b. The test specimen is subjected to each of two fire exposure conditions: flaming combustion with supporting radiant heating and nonflaming radiant heat-induced pyrolysis. These conditions were derived after recognizing that the more flammable materials (untreated) which include some plastics (acrylics) but are more representative of the cellulosics like paper, wood and cotton, generate much more smoke when smouldering instead of flaming. Cabin materials which meet the self-extinguishing requirements of FAR 25, however, almost invariably produce more smoke when burned in the flaming condition. Thus, these two conditions were selected as representative of the two extremes of fire involvement of the product.

c. The smoke chamber is completely sealed so that all smoke produced during the test is retained. Other test methods do not have this feature and allow undetermined amounts of smoke to escape, making a comparison of the smoke yield of different materials subject to error.

d. The amount of smoke is measured with a photometer consisting of a light source at the floor of the chamber and a photodetector at the ceiling. The fraction of light transmitted (T) across a 3-foot distance is measured and is used to compute the optical density (D), which is defined as

$$D = \log \frac{1}{T}$$

Optical density is the single measurement most characteristic of the "concentration of smoke."

e. Results are expressed in terms of specific optical density (D_s), and represents the optical density measured over unit path length (L) within a chamber of unit volume (V) produced from a burning material of unit surface area (A). Thus,

$$D_s = D \frac{V}{AL}$$

The specific optical density is a dimensionless property of a material tested but must be recognized as relating to the specimen in the thickness tested. It can be used in providing a means for computing the hypothetical smoke density which will be produced by the same product (with equivalent thickness tested) for other fire involvement areas in other enclosure volumes on the assumption of a uniform smoke/air mixture. (The limitations of the application of this scaling will be discussed in detail later in the report.)

f. The photometer provides a <u>continuous</u> recording of the concentration of smoke accumulating within the chamber. This can be contrasted to test methods which rely upon the deposition of liquid and solid smoke particles on a filter, which only provides an indication of the ultimate total weight of smoke.

g. The photometer light beam is oriented vertically rather than horizontally in order to minimize measurement differences due to smoke stratification. It has been observed that stratification can be quite significant during the first few minutes of the test, especially for lightweight smokes (reference 4). An "averaging out" of stratification effects is necessary since the proposed smoke density limits for rule making are specified at 90 seconds and 4 minutes; i.e., near the beginning of the test when the stratification is significant.

h. The photometric scale used to measure smoke by this test method is similar to the optical density scale for human vision (reference 5).

i. Provision was made to insure that thermoplastics which melted and fell away from direct exposure to the pilot flame were collected in a trough and forced to burn. This assesses the fire hazard of thermoplastics that melt and drip when burned. The trough provision probably exposes the thermoplastic to the worst of fire exposure conditions likely to be experienced.

j. The light beam window on the floor of the chamber has an electrical heater to minimize smoke condensation. Absence of this feature will allow soot deposits and cause unrepresentatively high smoke density readings.

k. The NBS Smoke Chamber has sufficient resolution to continuously measure the quantity of smoke released until the maximum amount is accumulated for all common aircraft cabin materials. This is primarily accomplished using a recorder whose sensitivity can be increased five decades during the course of a test. Thus, with the recorder set to its most sensitive range, the transmitted light will be recorded on a scale from zero to 0.001 percent.

l. The volume of the chamber (18 feet^3) was selected to provide adequate air for complete combustion of the test specimen. Based on the combustion of a 1/4-inch-thick hardboard specimen of unity specific gravity, the chamber volume provides a 20 to 1 air-fuel ratio, on a weight basis (about four times the air requirement for complete oxidation of the fuel). The air-fuel ratio for the lighter plastics would be even greater.

m. Only the frontside surface of the material or composite is exposed to the smouldering or flaming heating, thus providing an assessment of material response similar to a "real fire" exposure condition and also, a measure of the effectiveness of surface treatments.

n. During the initial development of the chamber, significant variations in smoke production resulted depending on the way the specimen was backed (reference 4). This was caused by the smoke passing through the material and escaping out through the rear surface. In order to eliminate this variable, the rear, edge and nonexposed frontal surfaces of the specimen are covered with aluminum foil wrapper. A 1/2-inch-thick asbestos board is placed behind the foil-wrapped specimen which fits snuggly within the holder.

o. A few measurements confirmed the fact that significant variations in smoke production were caused by changes in moisture content of the specimen (reference 4). In order to standardize experimental conditions, dried specimens are conditioned to equilibrium with air at 73 $\pm 5^{\circ}$F and a relative humidity of 50 $\pm$5 percent.

p. The pilot flame is applied continuously during the exposure period for specimens tested in the flaming combustion condition. This test procedure was established after experiments with short duration pilot flame exposure exhibited considerable variability in the time of cessation of specimen burning, resulting in large differences in smoke production (reference 4).

<u>The Cons of the NBS Smoke Chamber</u>

1. The two heat exposure test conditions used in the NBS Smoke Chamber are (a) an irradiance flux of 2.5 watts/cm^2 (2.2 Btu/ft^2 sec) and (b) a like exposure with the addition of six propane-air flame - lets impinging across the lower edge of the exposed specimen area. Selection of these conditions was based primarily upon two considerations. First, it was experimentally observed that many organic materials release copious amounts of smoke during smouldering combustion, with the smoke level increasing the greater the irradiance, and that the smoke decreases when the material bursts into flames (see Figure 2 obtained from reference 4). An irradiance level of 2.5 watts/cm^2 was determined to be sufficiently close to the self-ignition point of most untreated organic materials so that test results attained with this exposure condition are indicative of the greatest potential smoke hazard from a material. Secondly, it was also recognized that in addition to radiant heat, a material is usually exposed to flames in a real fire situation. Thus, the derivation of the two test exposure conditions "selected as representative of two extremes of fire involvement of the product" (reference 7). In the event of an accidental cabin fire, a

selected area of material is not exposed to a constant flame and/or radiant heat intensity as in the NBS Smoke Chamber or any other fire test method for that matter, but instead, to a continuously increasing level of flame and/or heat intensity - the exact variation with time being dependent upon (a) the physical and chemical properties of the material, (b) fire intensity, (c) ventilation conditions, (d) material attitude, and (e) distance of the material from the initial ignition source. During the selection of the chamber test exposure conditions, only minor consideration was given to probable or characteristic cabin fire intensity levels primarily because they are not known from experience. Each survivable crash fire accident is different from the other. To reasonably recreate the fire scenario, fire spread and heat intensity throughout the cabin with time based on the visible remnants of a burned-out cabin is impossible. The answer is, of course, to determine these conditions by testing under full-scale conditions. Such tests have been conducted in the past, but have usually been "one-shot affairs." What is required is a series of tests in a fuselage furnished with representative materials passing present FAA flammability regulations with varying controllable conditions of fire intensity and ventilation.

Other Smoke Measurement Test Methods

ASTM Subcommittee E5.02, Smoke and Combustion Products, has a task group reviewing smoke test methods. They have determined that there are eight popular smoke test methods being used. Three of these methods - Ringleman Chart, ISO method and electrostatic precipitator - are presently judged to be either inapplicable or not fully developed. The remaining four methods, excluding the NBS Smoke Chamber, are discussed below. Neither of the seven test methods offers a better approach than the NBS Smoke Chamber for estimating visibility in a smoke-filled cabin, simply because they were not and could not be designed for that purpose.

XP-2 Chamber: This apparatus consists of a 12 x 12-inch metal box 30 inches high. An exit sign is mounted on the back. The specimen to be tested, usually 1 x 1 x 1/4-inch, is placed on a supporting metal screen. A propane flame is used to burn the specimen. Smoke is measured with a horizontal photometer.

The pros of the XP-2 Chamber are as follows:

1. A principle feature is that procedural changes and the exploration of variables can be made quickly and economically.

2. The test apparatus is available commercially.

3. The exit sign provides a measure for visually or photographically observing smoke development.

4. There are about 75 chambers in existence.

5. The apparatus is relatively cheap, costing about one-fourth the price of the NBS Smoke Chamber.

6. The equipment is portable and requires about one-half the work space of the NBS Smoke Chamber.

The cons of the XP-2 Chamber are as follows:

1. The XP-2 Chamber does not have a sensitive photometer system and recorder to provide the resolution needed to continuously measure up to the maximum level the quantity of smoke produced by many cabin materials. Thus, once the concentration of smoke reduces the light transmission to 1-2 percent, the apparatus is saturated and cannot measure further reductions in light transmission as the smoke concentration increases, whereas, the NBS Smoke Chamber can accurately measure below 0.001 percent light transmission and thus, the maximum smoke concentrations of almost all cabin materials.

2. Obscuration produced by smoke is measured horizontally and since smoke stratifies (especially during the first several minutes of the test), it is likely that the obscuration measured is not a true measure of the amount of smoke filling the chamber. Since the proposed FAA smoke rule specifies limitations on the smoke level relatively early into the test at 90 seconds when the stratification is still significant, a vertical photometer similar to that used in the NBS Smoke Chamber is imperative to indicate a realistic assessment of the smokiness of a material.

3. Any test apparatus utilizing a horizontal photometer will produce data dependent upon the smoke stratification and thus, the arbitrary distance of the photometer from the ceiling of the smoke chamber. The data in turn can be expected to be highly nonreproducible

because of the influence on the degree of stratification of inadvertent small deviations in the test procedure. Additional variations in smoke have been reported to result from difficulties in maintaining an exact position of the sample on the sample holder and from variations in the wire screen used to support the specimen (reference 8).

4. Optical density is the measurement most characteristic of the concentration of smoke. However, the smoke level in the XP-2 Chamber is reported in terms of light transmission. Furthermore, the sample size used in the XP-2 Chamber has varied considerably, and it is recognized that the smoke level is strongly influenced by the sample size. The NBS Smoke Chamber test procedure eliminates these problems by testing materials in the thickness they are used and reporting the data in terms of specific optical density, which is the optical density per unit area of material, per unit volume of enclosure, per unit light transmission viewing distance. Thus, for a given material and usage thickness, the specific optical density determined using the NBS Smoke Chamber is ideally independent of the specimen area. Limited tests have verified the independence of specific optical density on area for surface area to volume ratios at least up to 15 (reference 4).

5. The XP-2 Chamber is not completely closed, thus making the data in some cases dependent upon the arbitrary uncontrolled ventilation.

6. The flaming exposure condition gives no indication of the potential high, dangerous smoke levels that may be produced during smouldering combustion. This deficiency was recognized during the initial design of the NBS Smoke Chamber and corrected by the provision of two separate test conditions, smouldering and flaming, for the evaluation of the smoke produced from material combustion.

7. The specimen is unrealistically subjected to complete immersion in flames during the test. Since the hazard of smoke is most important during the early stages of a fire when the combustion is primarily a surface phenomena, a more meaningful test would only involve heat exposure of the frontal surface, as accomplished in the NBS Smoke Chamber. Complete flame immersion can be expected to be highly inprobable especially for assemblies, composites and solids with surface treatments.

8. Wide differences in smoke data obtained in the XP-2 Chamber have been reported due to variations in the fire exposure conditions (reference 8). In the NBS Smoke Chamber, close control of the fire exposure is obtained by employing an electrically-heated furnace and small pilot flamelets.

9. A serious disadvantage of the XP-2 Chamber is the condensation of soot on the windows of the light source and the photoelectric cell. When the smoke has been completely evacuated from the chamber after the completion of a test, the condensed soot may cause as much as 80 percent reduction in the light reaching the photocell. An electric heater located below the glass window on the floor of the NBS Smoke Chamber prevents any significant soot condensation during the test.

E 84 Tunnel: This test method was originally developed by Underwriters' Laboratories and consists of a long, enclosed, box-like furnace. The 20-inch by 25-foot sample is positioned at the top of the tunnel. Gas burners provide a 4.5-foot-long exposure flame with an induced airflow of 240 ft/min and a heat input of 5,000 Btu/min. Flame spread is observed through windows, temperatures measured with thermocouples and smoke is measured with a photometer located in the exhaust stack. The smoke density rating is determined by comparing the area under the smoke curve with that obtained with red oak flooring calibration material.

The primary purpose of the E 84 test method is to develop a surface flame spread rating, while the capability for smoke measurement appears to have been an afterthought for the purpose of obtaining very rough and approximate indications of smoke, as evidenced by the somewhat arbitrary location of photometers (reference 9). This standard has been adopted widely in building codes throughout the country for the control of flammability of interior finishes, but should not be considered as a smoke test method by the FAA primarily for the following reasons:

1. As previously stated, there is no technical basis for arguing that the E 84 test method would better predict smoke generation of cabin materials in a real aircraft fire than the NBS Smoke Chamber.

2. The large amount of smoke data already obtained with the NBS Smoke Chamber on cabin materials would be wasted if another standard of measurement is adopted.

3. The apparatus is very expensive, requires a large facility and high costs are incurred when conducting a test. The cost of the tunnel 4 years ago was estimated at $40,000 (reference 8). None of the three major airframe manufacturers own E 84 tunnels. About 15 to 20 tunnels are in operation in the United States and Canada with independent laboratories charging $350 to test one material.

4. The E 84 tunnel can give misleading test results for thermoplastic and cellular foam materials, which are used in substantial quantities in commercial transport aircraft. In May 1973, the Federal Trade Commission (FTC) issued a complaint which focused - amongst many other things - on the E 84 tunnel as that standard applies to "plastic products in the construction or furnishing of homes, buildings or other structures." The FTC has taken the position that the E 84 tunnel, as applied to these materials only, is inaccurate and should be immediately withdrawn.

5. The E 84 test method for the measurement of smoke is far less reproducible than the NBS Smoke Chamber. Results from a recent interlaboratory evaluation of the E 84 test method (reference 9) indicate a between-laboratory mean coefficient of variation (reproducibility) for smoke developed of 57 percent (ranged from 34 to 85 percent) compared to the NBS Smoke Chamber values of 7.2 percent for smouldering (ranged from 2.9 to 27 percent) and 13 percent for flaming (ranged from 3.8 to 34 percent) exposures (reference 5). It was concluded in reference 9 that the reproducibility of measurement of smoke report ed in the round-robin was "not acceptable" and that alternative methods for smoke measurement are available.

The remaining two smoke test methods are included for the sake of completeness, are far less popular than either the NBS Smoke Chamber, XP-2 Chamber or E 84 tunnel and are thus only briefly discussed. The arguments against the XP-2 Chamber and E 84 tunnel concerning relevency to aircraft cabin fire, lack of correlation with the NBS Smoke Chamber (or any other method), disqualification of data already obtained with the NBS Smoke Chamber due to the use of a new standard, and economic penalties to industry are also applicable.

<u>E 286 8-Foot Tunnel Test:</u> The 8-foot tunnel furnace was developed by the Forest Products Laboratory as a research and development tool. Using a test specimen size of 13-3/4 by 96 inches, it will provide data on smoke development as well as flame spread and heat contribution.

Smoke is measured using a photometer in the exhaust stack and reported in a manner similar to the E 84 tunnel test method. The primary heat source for the test specimen is a radiant stainless steel plate and a small pilot ignition flame. Test results reflect the importance of the selected heat exposure conditions on the absolute magnitude of the smoke production. Fire retardant materials usually yield high smoke index values under nonflaming exposure compared to red oak which flames under these conditions. This differs in the 25-foot tunnel where both red oak and fire retardant materials flame when exposed to the large test flame, usually resulting in low smoke index values for fire retardant materials. A round-robin conducted 10 years ago demonstrated reproducibility less than that of the NBS Smoke Chamber. The mean coefficient of variation of reproducibility was 28 percent, with values obtained in the range extending from 11 to 124 percent.

Ohio State Facility: This apparatus was recently developed in 1972 to provide for the simultaneous measurement of the rate-of-release of heat, smoke and toxic gases from the front face of the tested specimen (reference 10). It basically consists of a box-like chamber, exhaust stack with photometer, radiant heat panel, pilot ignition flame, radiation reflector for testing materials horizontally, air supply and air distribution plate. In appearance, the Ohio State Facility is similar to the NBS Radiant Panel Test (ASTM E 162), but is also enclosed in a chamber. The capability exists for testing with the specimen horizontal or vertical and varying the radiant heat flux (these changes have been easily incorporated into the NBS Smoke Chamber by some experimentalists). Conceptually, the apparatus is attractive because it offers one test method for determining the flammability, smoke and toxic gas hazards from a burning material. Being a new test method with only one facility being operational and four additional being built, it has the disadvantage of not yet fully undergoing an objective appraisal of its operational characteristics and reproducibility.

The Relationship of NBS Test Data to Actual Human Visibility in Full-Scale Cabin Conditions

The inability of laboratory fire tests to predict the performance of a material in a "real fire" has been stated by Yuill to be a "credibility gap" (reference 11). To evaluate the concept of applying simple scaling laws to translate NBS Smoke Chamber laboratory data to "real fire" material performance, the assumptions inherent in this calculation requires examination. This is best achieved by dividing the problem into two parts: (1) scaling from small laboratory to large actual fire dimensions for identical heat exposure conditions; and (2) accounting for the differences between the conditions of fire exposure within the NBS Smoke Chamber and a "real fire" situation.

Scaling from Laboratory to Full-Scale Dimensions for Equivalent Fire Exposure Conditions: The assumptions which must be made in order to perform this calculation can be determined by deriving the relationship for specific optical density.

When a beam of light passes through a uniform volume of smoke, the intensity of the beam is attenuated by scattering, and the decrease in intensity obeys Bouguer's exponential law (reference 4).

$$I/I_o = \exp(-KL) \tag{1}$$

The initial intensity is I_o, the intensity after the light has travelled the distance L is I, and K is an attenuation coefficient. Rearrangement of terms yields the usual logarithmic form.

$$KL/2.303 = \log(I_o/I) \tag{2}$$

For the characterization of a given smoke, it is assumed that the attenuation coefficient K is proportional to smoke particle density; i.e.,

$$K = K_1 \; m/V \tag{3}$$

where m is the mass of smoke, V is the volume of enclosure and K_1 is a constant independent of smoke concentration or volume. Optical density is defined as:

$$D = \log(Io/I) \tag{4}$$

Therefore, it also follows from equations 2 and 3 that

$$D = \log(Io/I) = KL/2.303 = K_1 \, mL/2.303V \tag{5}$$

Thus, the specific optical density for burning of material of surface area A has been defined as

$$D_s = DV/AL \tag{6}$$

since by substituting equation 5 into equation 6 gives

$$D_s = K_I m/2.303A \tag{7}$$

If K_I is indeed a constant, and if the amount of smoke is proportional to the burning area "A" producing the smoke (i.e., m/A is a constant), then D_s is a constant for a given material and a given burning condition. The possible extension of measured values of D_s for other burning areas, larger enclosure volumes, and longer light path lengths (for the same fire exposure conditions) is logical. However, the validity of these calculations depends upon the validity of the four major assumptions which are discussed below.

1. Smoke is uniformly distributed throughout the volume of interest. Stratification has been measured to be significant in the NBS Smoke Chamber during the first several minutes of the test, with better mixing and a close approach to a uniform smoke distribution as the quantity of smoke increased (reference 4). This behavior can be expected to be more pronounced in a large enclosure, since natural convection is the driving force for the transport of smoke throughout the enclosure, particularly during the early stages of the fire when the rate of heat release is small.

2. The amount of smoke produced is proportional to the exposed area. Perhaps the greatest uncertainty second to the distribution of smoke is the application of equation 6 with respect to the sample area A. The availability of oxygen controlling the burning rate of material will vary over the sample area, probably decreasing from bottom to top, and the variation will be more pronounced for large samples compared to the nominal 3 by 3-inch sample. Also, heat transfer "edge effects" will somewhat govern the temperature of the exposed face of the test specimen. These "edge effects" will be more significant for the smaller specimens, tending to decrease the surface temperature.

3. The optical density is proportional to the concentration of smoke. The validity of this assumption was verified by Gross, et al (reference 4) for a large number of smokes produced by synthetic and natural materials at least up to specific optical densities of 600.

4. Settling, deposition or agglomeration of smoke during its generation are independent of specimen size, or volume and shape of enclosure. Gross, et al (reference 4) observed that the settling,

deposition and agglomeration of smoke was dependent on optical density, for values less than 0.15 per foot, during dilution tests from the chamber volume of 18 feet^3 to a total volume of 72 feet^3. Deviations at greater volume ratios can be expected at least for dilute smokes.

The invariability of the optical density relationship (equation 6) in a wide-bodied jet cabin was studied recently by Lockheed under an FAA contract (reference 12). Tests were conducted in a L-1011 cabin mockup, 2774 feet^3 in volume, using test specimen areas of 1, 4 and 9 feet^2, and compared with results obtained with identical materials tested in the NBS Smoke Chamber. Figure 3 is a representative comparison of D_s between the cabin mockup and NBS Smoke Chamber, exhibiting a consistent time lag between the mockup and chamber. Notwithstanding the difficulties encountered in appropriately and practicably duplicating the radiant heater and pilot flame on a large scale (reference 12), the lag time is believed to be primarily caused by the nonuniformity (stratification) of the smoke as observed and measured during the test. Relatively good agreement was obtained for the maximum specific optical density (D_m) compared between the mockup and chamber. A comparison of D_m (reference 12) for the mockup and chamber is shown in Figure 4. Practically all of the data points (29) lag within $\pm$100 percent of the perfect agreement line. Of the three data points showing exceptionally poor agreement, two specimens were polycarbonate materials that melted during the mockup testing and were thus only partially instead of completely pyrolyzed as during the chamber test. The remaining data point for an aluminum facing, Nomex core flooring specimen, can be discounted because testing of this material produced anamolous behavior. Plus and minus 100 percent was judged relatively good upon consideration of the large volume (154 to 1) and area (22, 87 and 195 to 1) ratios between mockup and chamber. The agreement between mockup and chamber data at maximum specific optical density is believed to be due to a consequence of the approximate realization in each test of the four major assumptions necessary to validate the invariability of the specific optical density relationship (equation 6).

Fire Exposure Conditions in the NBS Smoke Chamber and During a Cabin Fire: The fire exposure conditions in the NBS Smoke Chamber - radiant heat level (2.2 Btu/ft^2-sec) and size of burner flames (50 cm^3/min of propane and 500 cm^3/min of air) - represent two of an infinite number of possible conditions. Changes in exposure conditions will necessarily change the test results.

In order to use the specific optical density measured in the NBS Smoke Chamber to predict the smoke produced as a function of time under "real" or actual cabin fire conditions, there must be a predictable relationship between fire exposure conditions in the chamber and in the cabin. Unfortunately, no work has ever been done to determine this relationship for cabin fires.

The most definitive work is that of Christian and Waterman (reference 13) who measured smoke produced by different interior finish materials in full-scale room and corridor fires and compared the results with measurements made by various laboratory smoke test methods. Their data indicated that of the methods studied, the E 84 tunnel best represents the smoke produced by a fire spreading across a material, while the NBS Smoke Chamber best represents the results when the entire surface of the material is completely exposed to fire.

Cabin materials can be expected to exhibit varying degrees of behavior characterized as being dominated by flame spread and/or fire exposure, depending upon the severity and location of the ignition source, materials orientation and interaction, physical and chemical properties of the materials, and draft conditions. The unpredictability and importance of ambient wind in cabin crash fires was demonstrated in full-scale tests conducted by both the FAA (reference 14) and Aerospace Industries Association of America (AIA), reference 15. In both series of tests, which consisted of fuel-pool fires adjacent to an opening in the fuselage, cabin interior involvement with the fire was minimal or nonexistent when the ambient wind condition was calm or blowing the flames away from the fuselage; however, when the wind directed the pool-fire flames through the opening, the portion of the cabin adjacent to the opening became completely involved in fire.

The work performed for FAA by Lockheed (reference 12) is a start in trying to understand the smoking behavior of interior materials during a cabin fire. However, additional work is necessary before we can predict with some degree of confidence the smoke level of different materials involved in a cabin fire. Because of the wide variations in the possible characteristics of cabin fires, the full-scale fire should be representative of the most severe exposure condition which does not incapacitate passengers. This will probably require a series of full-scale tests with varying conditions of ventilation, volume and fuel. Tests with severe fire conditions are then necessary to determine the relationship between fire exposure conditions in the chamber and in the cabin, with due consideration also being given to material flame spread rate as a function of orientation and position in the cabin. Until these above full-scale tests are performed (it is not clear whether they will be completely interpretive and useful in conjunction with any laboratory smoke test to predict a material's smoke behavior during a real fire), the selection of materials for smoke regulations should be based on a comparative basis using the best test method which is the NBS Smoke Chamber, with the allowable limits based on consideration of available state-of-the-art material smoke performance.

Hypothetical Calculation of Smoke Produced in a Cabin Using NBS Smoke Chamber Data

In spite of all the uncertainties previously discussed in using any laboratory smoke date for accurately predicting the visibility during a cabin fire, the NBS Smoke Chamber provides data in a form that can readily be used to perform this calculation. It has three major measurement and procedural characteristics (numbers 2 and 3 are unique) which are important in this respect:

1. Measurement is made of optical density which is the relevant property of smoke related to visibility.

2. Photometer and recorder resolution permits the continuous measurement of the quantity of smoke produced including the maximum amount.

3. Smoke density data is recorded in terms of specific optical density, a mathematical form which easily allows for the extension from chamber dimensions to any other exposed area, enclosure volume or light path length.

In order to predict the visibility during a cabin fire, information must be obtained and used relating the optical density of smoke to visibility. This is readily available in the literature and Figure 5 shows data from reference 16 representing the visual threshold response for various types of smokes for several observers situated outside a room viewing through a window a backlighted sign.

The following examples show how smoke data obtained with the NBS Smoke Chamber may be used to estimate the visibility in a hypothetical situation. Assume the cabin section to be that of an L-1011 wide-bodied jet with a volume of 15,000 $feet^3$. Also, the fire is assumed to be confined to the ceiling area for the sake of simplicity. The ceiling material is the typical paneling used in wide-bodied jets composed of a Nomex honeycomb core and resin-impregnated fiberglas skins. Figure 6 reproduces a plot of D_s versus time for this ceiling panel obtained by AIA (Run No. 0412) using the NBS Smoke Chamber and constitutes one of the over 250 test runs analyzed by Marcy (reference 2). The optical density is calculated by rearranging equation 6 to give

$$D/L = D_s A/V \qquad (8)$$

and the visibility then calculated from equation 8 and Figure 5.

The loss in cabin visibility for ceiling burning areas assumed to be 30 and 60 $feet^2$ is shown in Figure 7. The visibility drops off abruptly and levels off as the smoke production begins to peak. Obviously, the greater the area of burning material (or smaller the volume of enclosure), the poorer the visibility. Also included in Figure 7 are dashed lines recording the assumed linear movement of passengers from their seat to the nearest exit (it was further assumed that the greatest possible distance from an exit is 30 feet). Thus, if the area of burning ceiling is 30 $feet^2$, passengers initially located 30 feet from an exit will lose sight of the exit sign at 0.3 mins or after they have vacated 6 feet from their seats. If the area is 60 $feet^2$, these people will lose visibility at 0.13 mins (moved 2.5 feet), while passengers initially 20 feet from the exit will lose their visibility at 0.21 mins, after only moving 4.2 feet from their seats. By drawing tangents to the visibility curves parallel to the movement line, the maximum initial distance of a passenger from the nearest exit for safe evacuation can be determined - for A = 30 $feet^2$, this value is 26.5 feet and for A = 60 $feet^2$, it is 18 feet. In spite of the simplicity of the calculations, the results are somewhat frightening. They predict that if 60 $feet^2$ of ceiling panel (slightly failing the proposed FAA smoke limits) become immediately immersed in flames, then about 40 percent of the passengers (assuming uniform passenger seating distance from nearest exit) will lose sight of the nearest exit sign during their attempted evacuation.

Additional calculations were conducted to determine the effect of flame spread on the results. Figure 8 compares the visibility (1) assuming a burning area of 150 $feet^2$ and (2) assuming a 150-$foot^2$ area becomes completely immersed in flames linearly with time at 1.5 minutes. The latter calculation was performed numerically by accounting for an incremental 10-foot^2 increase in burning area every 0.1 minute. The difference in visibility loss between the two assumed burning conditions is significant, reflecting the necessity of estimating the flame spread rate in cabin fires when this is an important characteristic. For complete flame immersion, passengers beyond 11 feet from an exit will ultimately lose sight of the exit sign, while if the flame spread rate is approximated, only passengers beyond 22.5 feet will encounter loss of vision.

The preceding simple calculations demonstrate how NBS Smoke Chamber data can be used to predict the loss of visibility during a cabin fire. At the present time, no realistic quantitative consideration can be given to the following significant factors during the first critical 90 seconds of a cabin fire: smoke stratification settling, agglomeration and condensation; fire and ambient wind-induced cabin ventilation; material flame spread as affected by orientation and location; and a predictable relationship between fire exposure conditions in the chamber and in a real cabin fire, with a predictable relationship for the change in smoke generation resulting from differences in exposure conditions. Thus, a rational approach has not been developed yet to assess the safety benefits of various D_s limits against the cost of furnishing airplanes with different categories of smoke-producing materials. Selection of materials can only be made now on a comparative basis. The loss in visibility predicted by these calculations is significantly dependent upon the assumed area of burning material; however, it is quite clear that under specific fire exposure and cabin environmental conditions, a relatively small area of material passing proposed FAA specific optical density limits can generate copious amounts of smoke in a cabin fire, reducing passenger visibility and impeding their safe evacuation from the aircraft.

SUMMARY AND CONCLUSIONS

The development of the NBS Smoke Chamber evolved from deficiencies in the XP-2 Chamber, primarily consisting of poor resolution, uncontrollable and unrepresentative fire exposure conditions and an impractical horizontal photometer for measuring smoke density. The NBS Smoke Chamber has since become the most popular world-wide laboratory test method for measuring smoke from burning materials, being commercially available, considered by ASTM and NFPA for adoption as a standard, specified by several regulatory bodies in smoke rules, and used almost exclusively by the airframe manufacturers and cabin material suppliers. By comparing the smoke level of 250 cabin materials, NAFEC proposed FAA regulatory smoke limits with primary consideration given to the availability of materials so as not to impose a design hardship on the airframe manufacturers.

Like any other laboratory fire test method, data obtained with the NBS Smoke Chamber cannot be extended to describe material performance in a "real fire," primarily because a "real fire" is usually a never-defined condition that varies from one fire to the next, and also because a particular "real fire" is always a dynamic condition. The specific problems and necessary assumptions inherent in scaling calculations include that (1) the distribution of smoke be uniform; (2) the settling, deposition or agglomeration of smoke during its generation are independent of material size, or volume, wall area and shape of enclosure; and (3) the NBS Smoke Chamber exposure conditions simulate the unique, dynamic cabin fire. Several simple and ideal hypothetical calculations demonstrate the drastic potential loss of passenger visibility during a small cabin fire.

The NBS Smoke Chamber provides relevant and useful results, good repeatability and sufficient resolution to continuously measure the smoke generated by most materials. However, a rational approach for deriving regulatory smoke limits by scaling NBS Smoke Chamber data to the cabin fire environment is discounted because of the numerous assumptions necessary to perform such a calculation, and a smoke regulation based on comparative material performance in the NBS Smoke Chamber is recommended. NBS Smoke Chamber data can be readily scaled to hypothetical cabin parameters to give the user an approximate estimate of the visibility during a cabin fire.

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4. Gross, D.; Loftus, J. J.; and Robertson, A. F.; "Method of Measuring Smoke from Burning Materials," American Society for Testing and Materials, Special Technical Publication 422, 1967.

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Prepared by:

Constantine Sarkos
Activity Manager

Reviewed by:

George B. Geyer
Program Area Leader

Approved by:

Charles M. Middlesworth
Chief, Propulsion & Fire Protection Br.

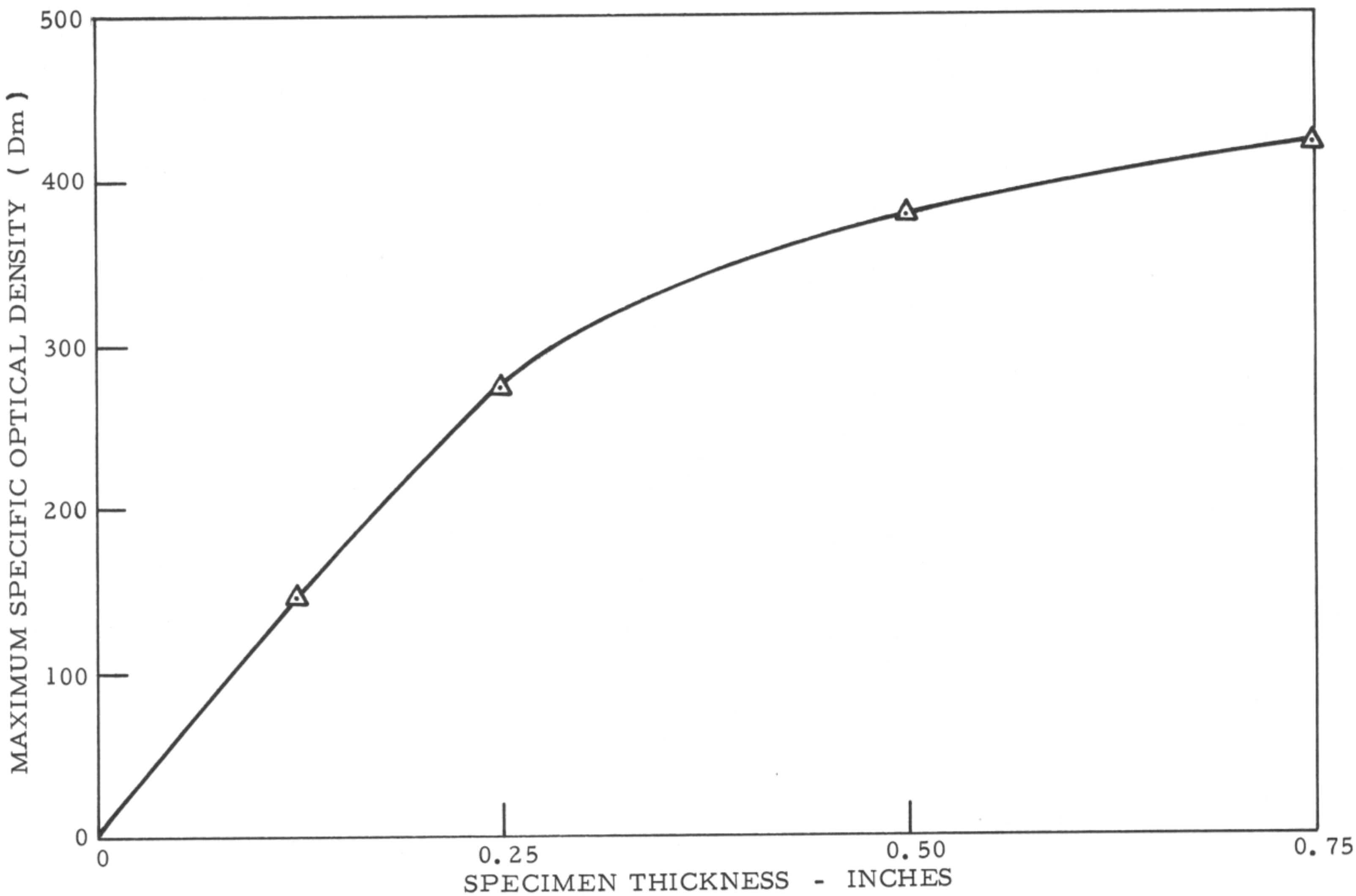

FIGURE 1. NBS SMOKE CHAMBER SMOKE MEASUREMENTS UNDER NONFLAMING EXPOSURE ON CLEAR SPRUCE AS A FUNCTION OF SPECIMEN THICKNESS (REF. 4)

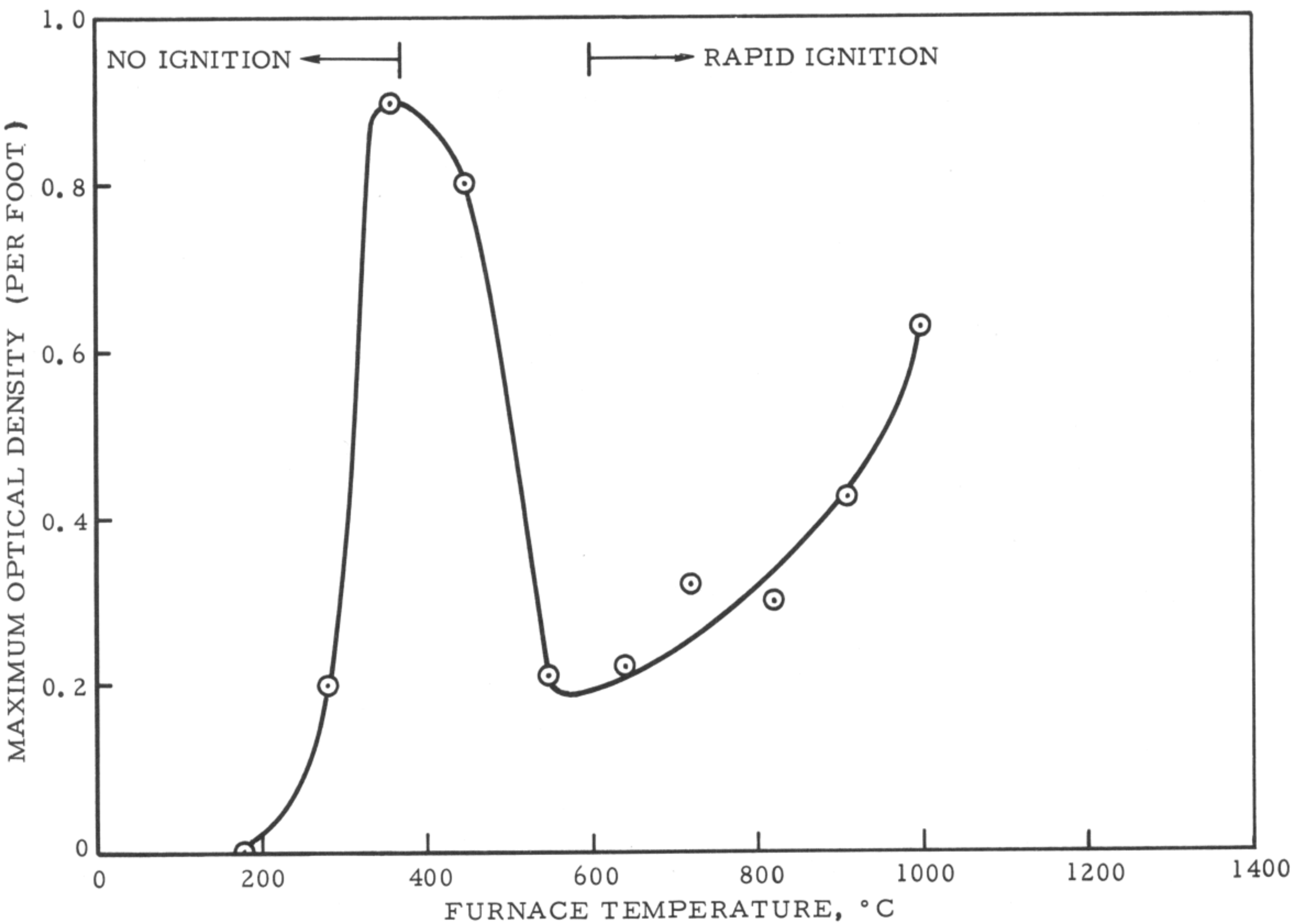

FIGURE 2. VARIATION IN MAXIMUM SMOKE ACCUMULATION CAUSED BY CHANGING THE RADIANT HEAT EXPOSURE USING AN ELECTRICALLY HEATED FURNACE (REF. 4)

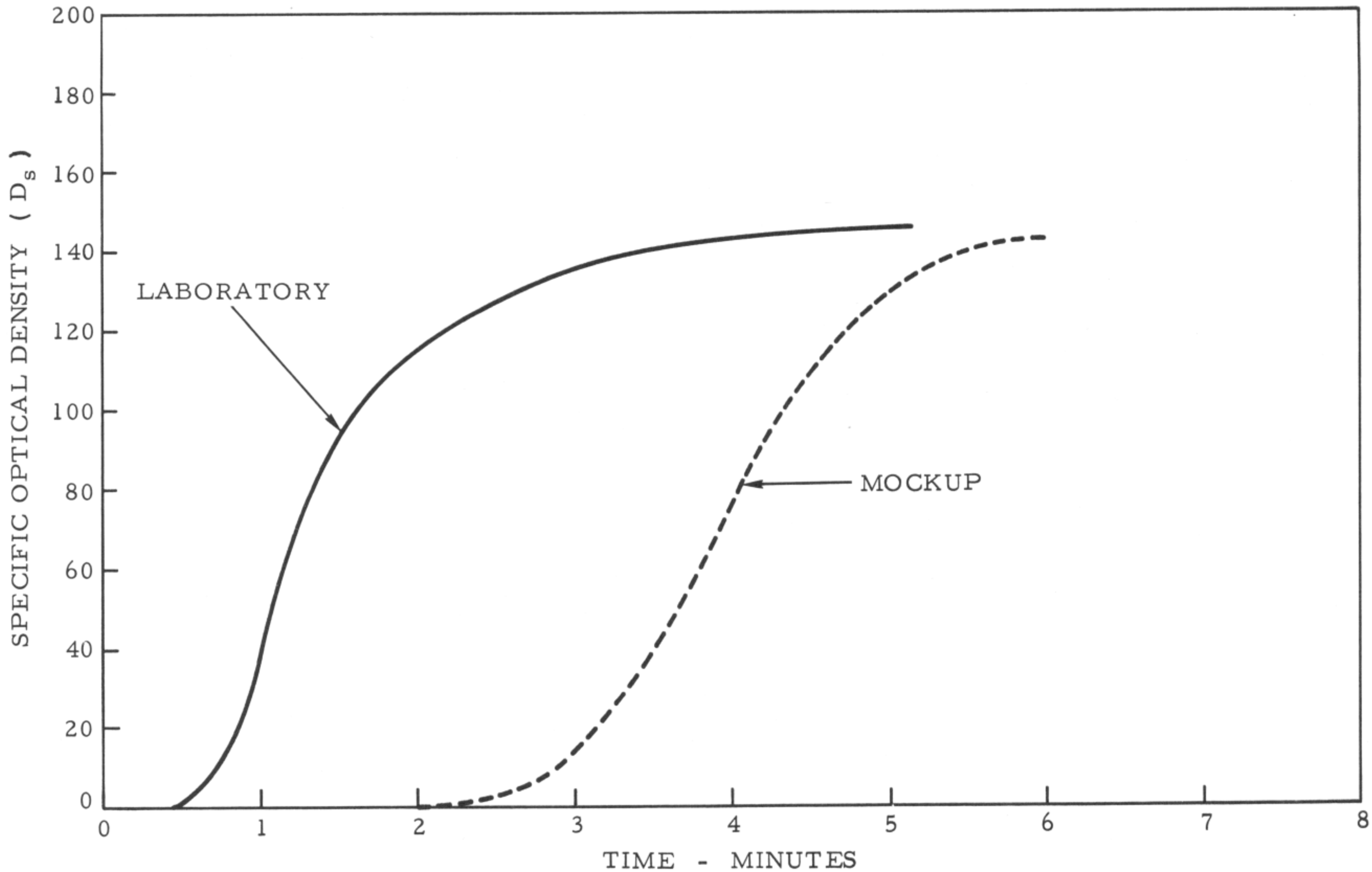

FIGURE 3. COMPARISON OF SMOKE ACCUMULATION FOR STRUCTURAL FLOORING IN THE NBS SMOKE CHAMBER AND A L-1011 CABIN MOCKUP (REF 12)

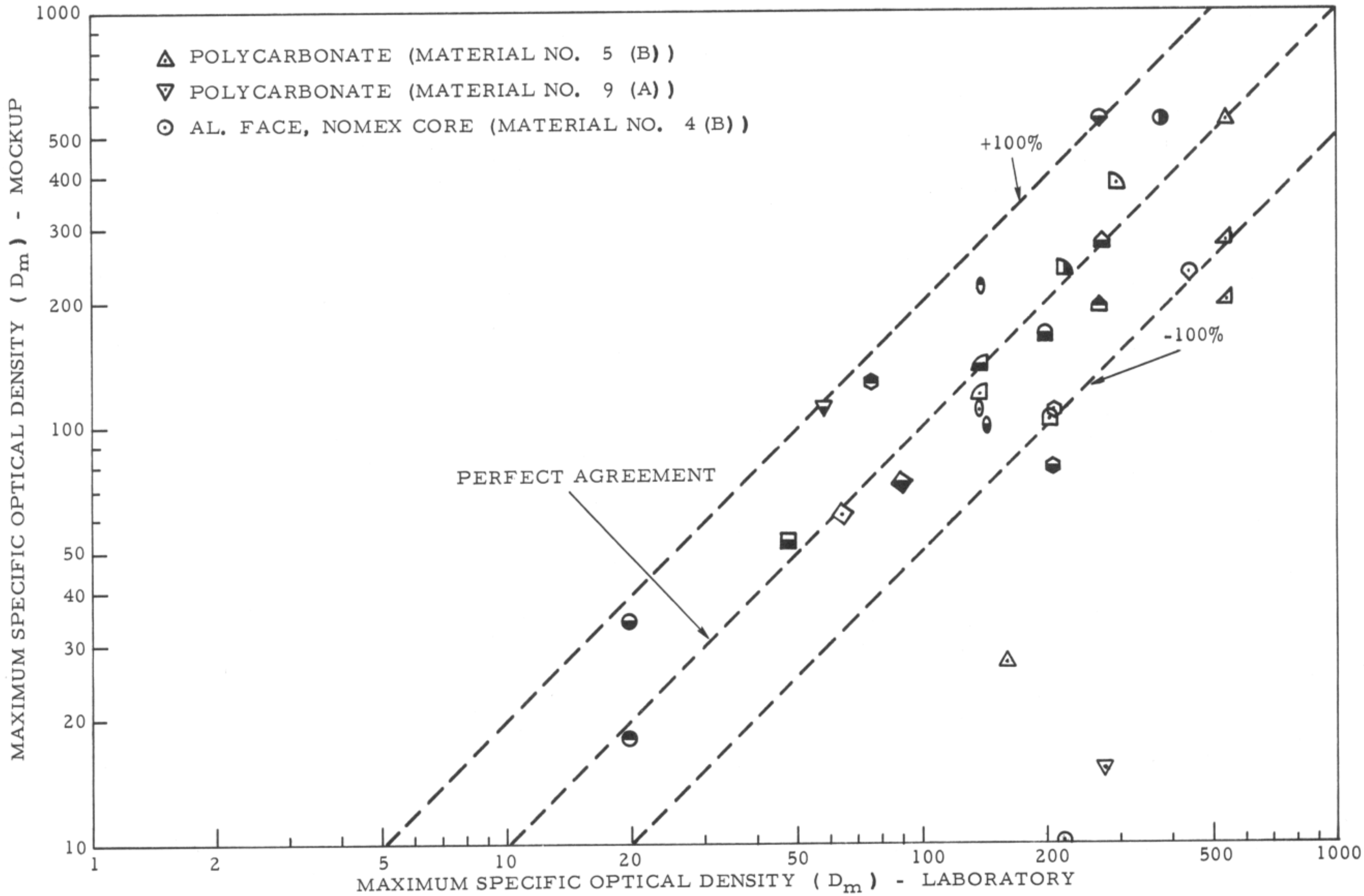

FIGURE 4. COMPARISON OF MAXIMUM SMOKE ACCUMULATION IN THE NBS SMOKE CHAMBER AND L-1011 CABIN MOCKUP (REF. 12)

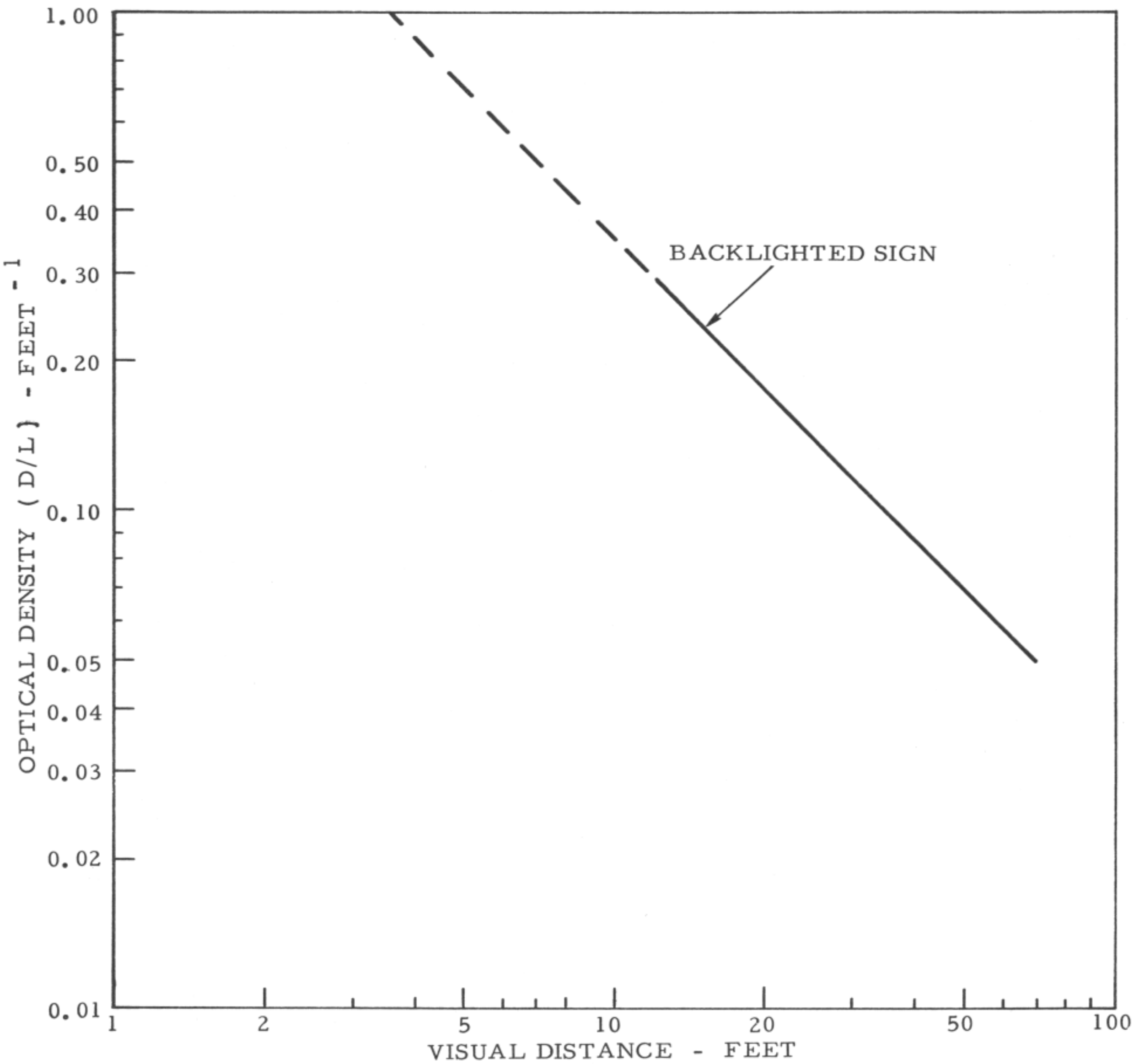

FIGURE 5. EXPERIMENTAL RELATIONSHIP BETWEEN VISIBILITY AND OPTICAL DENSITY (REF. 16)

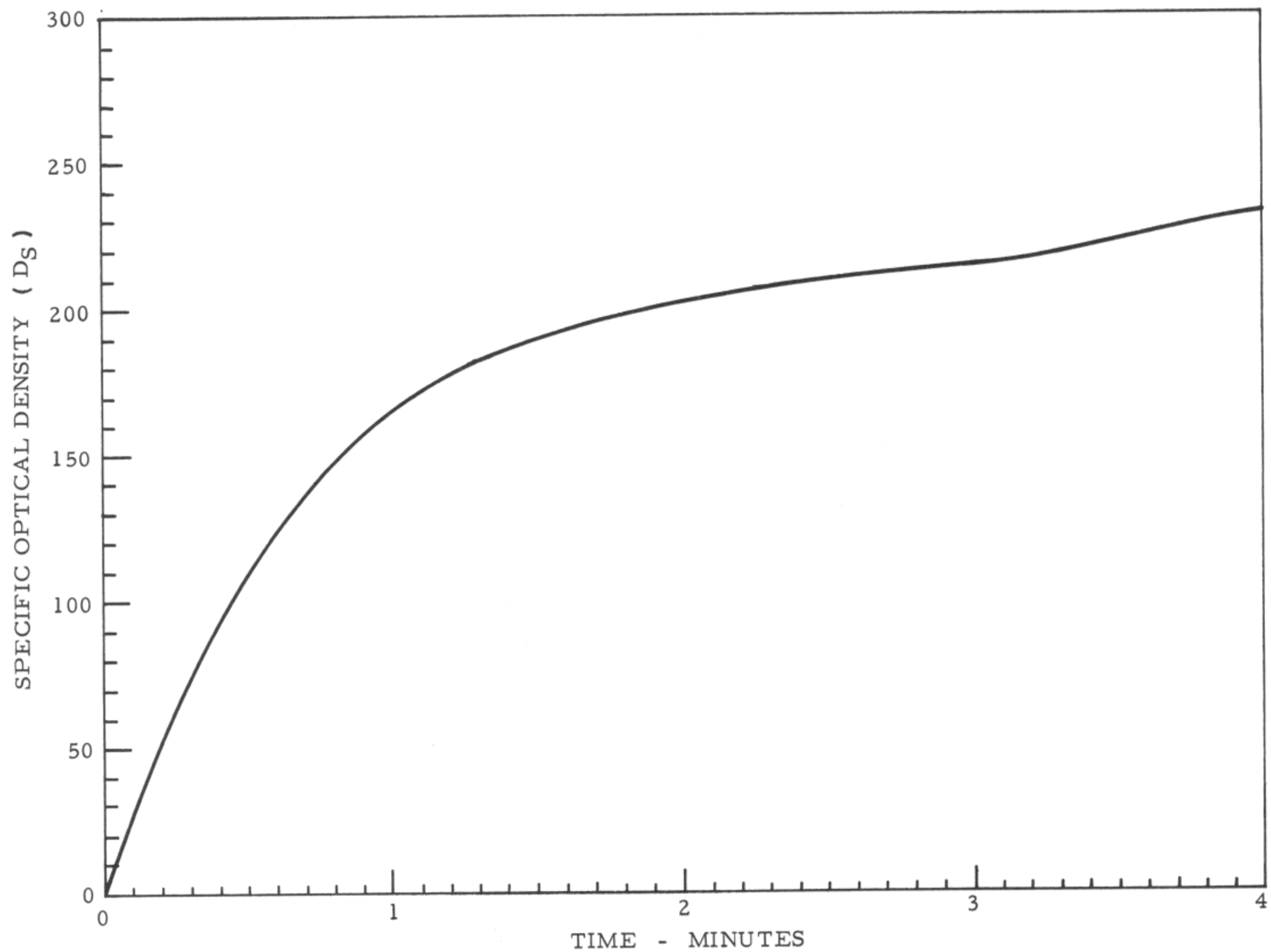

FIGURE 6. SMOKE ACCUMULATION IN THE NBS SMOKE CHAMBER FOR A CEILING PANEL CONSTRUCTED OF A NOMEX CORE WITH REINFORCED FIBERGLAS FACES

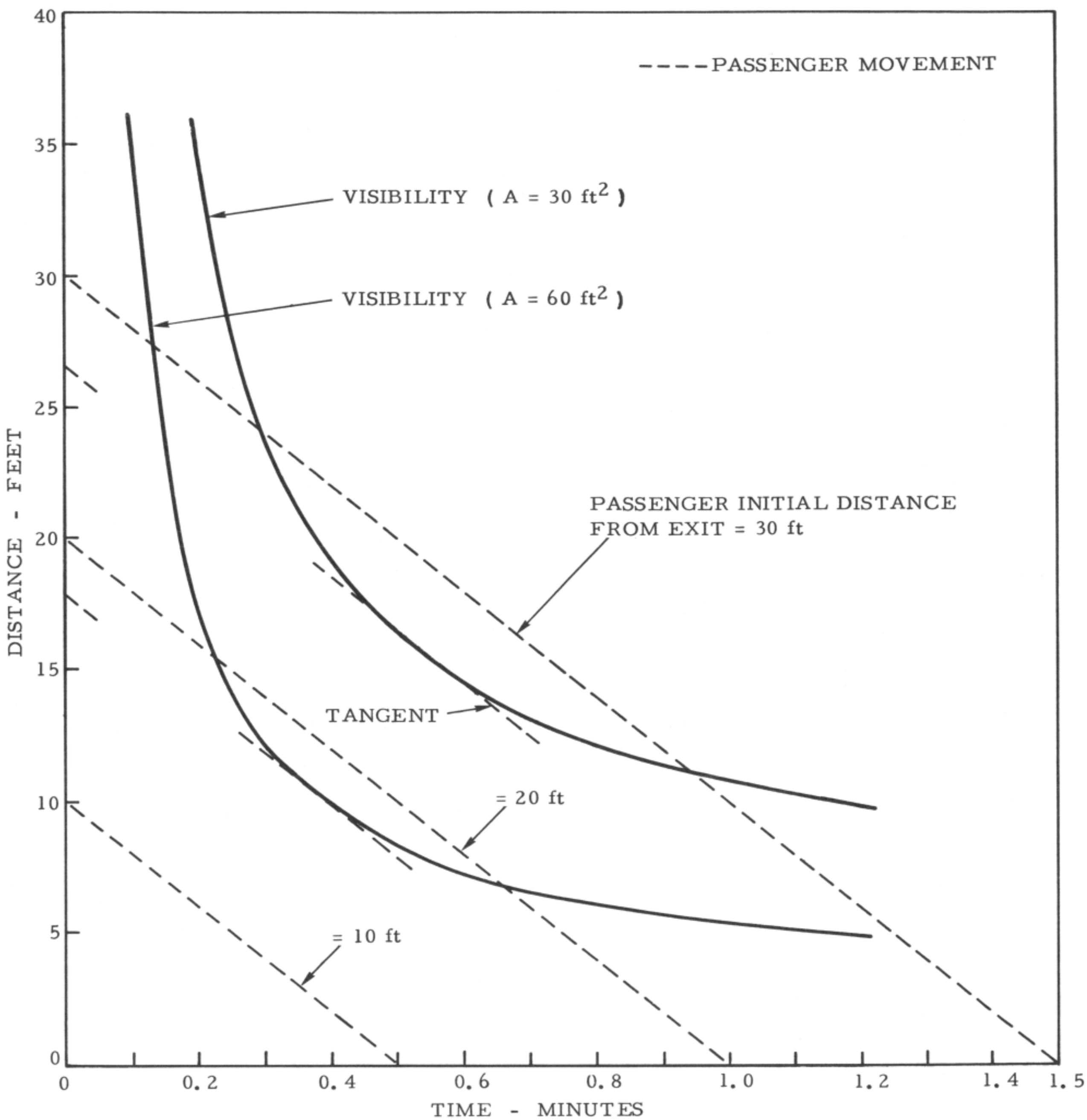

FIGURE 7. VISIBILITY LOSS IN A 15,000 CUBIC FOOT CABIN DURING A CEILING FIRE ASSUMING A CONSTANT AREA OF FIRE ENVOLVEMENT

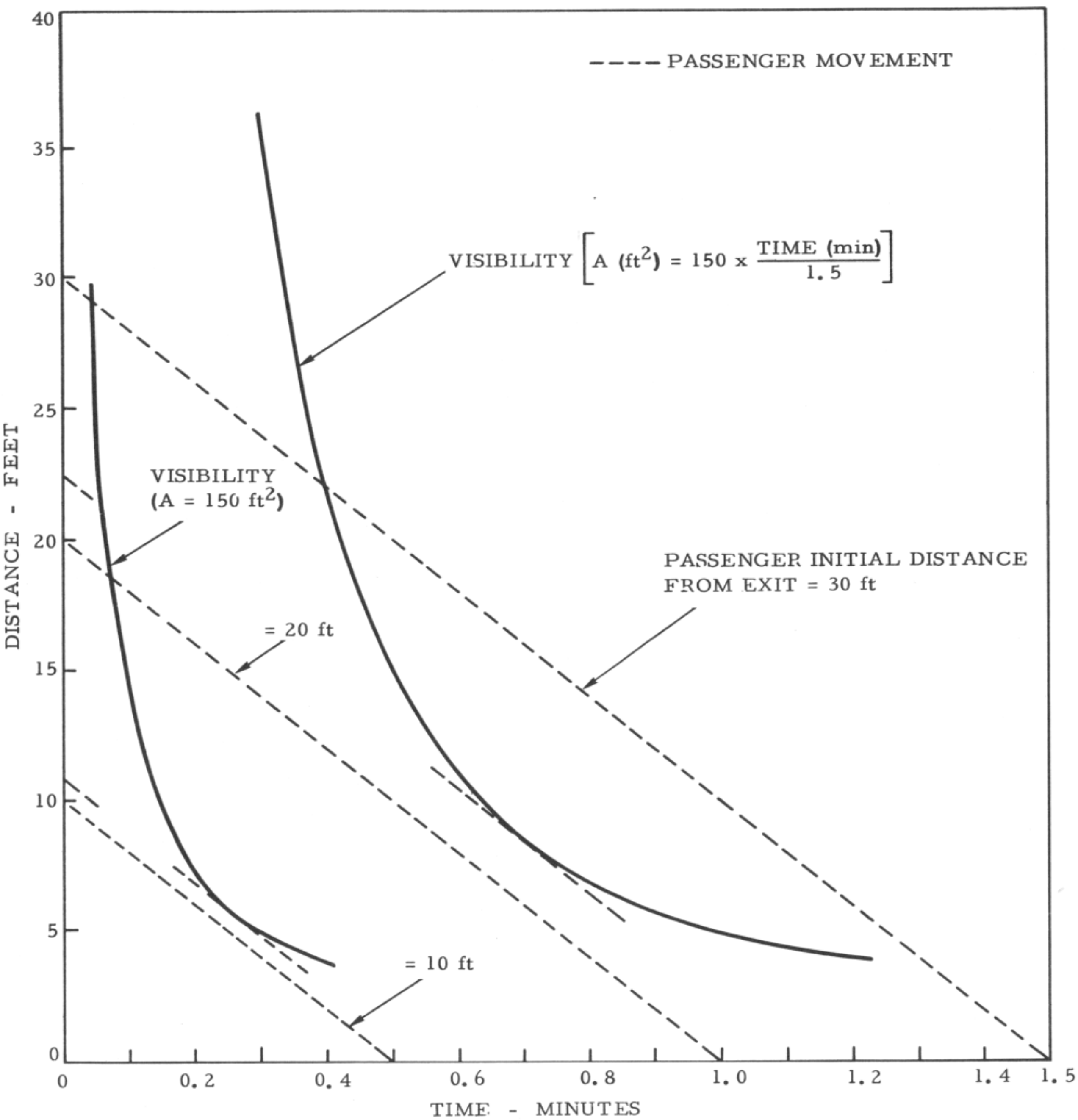

FIGURE 8. COMPARISON BETWEEN FLAME SPREAD AND COMPLETE IMMERSION TYPE CEILING FIRES IN A 15,000 CUBIC FOOT CABIN IN TERMS OF VISIBILITY LOSS

APPENDIX A

NOV 15 1973

AFS-120

Aircraft cabin material smoke emission (FS-100-69-103) (181-521-01X)

Chief, Airframe Branch, AFS-120

ARD-520

This is in regard to the current research and regulatory work aimed at developing an airworthiness standard to limit smoke emission by aircraft cabin interior materials (smoke rule).

As discussed on November 5 by Mr. McGuire of your office and Mr. Branting of this office, the need has arisen in the regulatory project to explore other test method approaches for determining actual cabin visibilities in smoke conditions. In this regard, we request that a detail study be conducted by NAFEC under the current research project on cabin materials and that the results of the study be compiled in a report and submitted to this office. The report should include comprehensive information on the following:

1. The pros and cons of the NBS test method and other test methods (such as XP-2) and a sound justification as why the NBS method was selected for the smoke rule program. This should include in-depth information on the rationale behind the tests and the relevance (or non-relevance) of the tests to cabin fire conditions.

2. The relationship of NBS test data to actual human visibility in full scale cabin conditions. This should include a discussion of factors and test results pertinent to full scale fire conditions, and sample calculations which project laboratory test data for various D_s values to full scale visibility conditions. One of the main objectives of this is to provide a rational data base which can be used in assessing the safety benefits of various D_s values against the costs of obtaining these values in actual airplanes (cost information currently is being sought from industry).

Since the smoke rule project is of highest priority for rule making, we request that the report be submitted to this office by December 12, 1973. Enclosed is a copy of Briefing Memorandum AFS-120/73-21, dated October 26, 1973, which outlines the overall plan of action and time schedule for the smoke rule regulatory project.

Original signed by
N. N. Shapter

N. N. SHAPTER

Enclosure

cc:AFS-100/AFS-120/AFS-123/ANA-420
BRANTING:AFS-123:jct:X68283:11/12/73

AFS-120/73-21

Initialed by Date

BRIEFING MEMORANDUM
Engineering and Manufacturing Division

Prepared by: H. Branting
AFS-123

Date: September 26, 1973
Revised: October 26, 1973

SUBJECT: Plan of Action; Draft NPRM on Cabin Materials Smoke Emission

DESCRIPTION OF TASK

On August 8, the NPRM package for the cabin materials smoke rule was presented to the Regulatory Council. The draft notice proposed smoke limits (NBS chamber test) of $D_s = 100$ @ 90 seconds, and $D_s = 200$ @ 4 minutes for the cabin materials covered by current FAR 25.853 flammability standards. No retrofit provision was included in the draft.

The council deferred action on the draft and on August 9, 1973, directed that it be revised and presented again at a later date. Specifically, the council directed that:

1. A retrofit provision be combined with the proposed rule and suggested consideration be given to:

   a. Including a double standard in the proposal, e.g., specific optical density $D_s = 100$ for retrofit materials and $D_s = 16$ (or some other combination) for newly certificated airplanes; or;

   b. Exploring other test method approaches for determining actual cabin visibilities in smoke conditions.

2. The revised proposal presentation include a comprehensive discussion on availability of materials, alternatives available, specific costs and other related information as necessary to support the proposal.

ACCOMPLISHMENTS TO DATE (AUGUST 9 TO OCTOBER 26)

1. Preliminary cost data received from Lockheed.

2. Six accident reports reviewed for smoke and toxic gas data.

3. Replied to McBride (Nader Group) petition.

PLAN OF ACTION

The following outline describes the work which is planned as means of accomplishing the overall task on the smoke NPRM.

1. Obtain cost data as affected by D_s limits from manufacturers with regard to new airplanes and retrofit. (Lockheed, Douglas, Boeing, and Dupont). Receive data by 12/1/73. Companies will be checked on November 15 and an on-site discussion of data will be arranged to assure 12/1/73 date.

2. Study NTSB data on effects of smoke in order to help assess visibility and physiological contributions during accidents. Complete by November 23.

3. Obtain retrofit cost data from airlines by December 1, 1973, (AFS-300 prime).

4. Study practicality of using tests to correlate material characteristics with visibility in full scale installation (NAFEC). Complete by 12/15/73.

5. Assess and correlate information and data obtained on cost and alternate test methods and analyze impact of new proposed rules of the aviation community. Complete by January 15, 1974.

6. Revise Smoke Rule Project Report including cost discussion. Complete by January 30, 1974.

APPENDIX B **USERS LIST** November 21, 1973
SG/sa

4-5800 AMINCO-NBS SMOKE DENSITY CHAMBER

PLASTICS and GENERAL

Allied Chemical Company
American Standard, Research Lab.
B.A.S.F.
Baychem Inc. (.A.G.) W. Germany
Bell Labs.
Diamond Shamrock Corp.
Dow Chemical Co. U.S.A.
Dow Chemical Co. (Freeport)
E.I. DuPont (Engr. Test Ctr.)
E.I. DuPont (Plastics)
Eastman Chemical Corp.
Ethyl Corp.
Ferro Corp.
Firestone Rubber & Chem.
G.E. Corp. (Schenectady)
G.E. Corp. (Plastics)
G.E. Corp. (Wire & Cable)
G.E. Corp. (Appliances)
General Tire Corp.
B.F. Goodrich Chemicals Co.
Goodyear Tire and Rubber Corp.
W.R. Grace Corp.
Ciba-Geigy Corp.
I.I.T. (Supernaunt)
Johns Manville Corp.
Koopers Corp.
Marbon Div. of Borg-Warner
Michigan Chemical Co.
Mobay Chemical Corp.
M.M.M. Corp.
Monsanto Chemical Corp. (Dayton)
Monsanto Research Center (St. Louis
Samuel Moore & Co.
N.L. Industries
Olin Corp. (2)
Owens Corning Fiberglass
Polyplastex-United
P.P.G. Industries
Raychem Corp.
Rohm and Haas Corp.
Stauffer Chemical Corp.
Union Carbide Corp.
Uniroyal Ltd. (Canada)
Uniroyal Inc. (Mishawaka)
Weyerhaeuser, Technical Ctr.
G.E. Corp. (Coshocton Ohio)

TEXTILES

American Enka Corp.
Armstrong Cork Corp. (3)
Bigelow-Sanford Corp.
Brookline Carpet Corp.
L.E. Carpenter Co.
Columbia Coated Fabrics Corp.
Congoleum Industries
Deering-Milliken Corp.
E.I. DuPont (Fibres)
Firestone Synthetic Rubber & Latex
German Fire Laboratory (W. Germany)
G.A.F. Corp.
B.F. Goodrich Corp.
Ludlow Corp.
Monsanto (Textiles)
Monsanto (M.P. Div.)
Reeves Brothers
Vinyl Prod. Ltd. (G. Britain)
CSIRO-Bldg. Res. (Victoria, Aust.)
Wool Bureau Inc.
Wool Bureau Ltd. (Intl. Sec.)

GOVERNMENT, UNIVERSITIES and INDEPENDENT LABORATORIES

E.P.A. (NBS) (U.S. Govt.)
F.A.A. (U.S. Govt.)
Finland State Lab. of Fire Tech.
French Military Mission
Hardwood Plywood Mfg. Assn.
Directorate of Supplies (India)
Material Systems Inc.
Mtls. Tech. Lab. (Aminco)
N.A.S.A. (Houston-U.S. Govt.)
National Bureau of Stds. (U.S. Govt.)
National Research Council (Canada)
Naval Air Devel. Ctr. (U.S.Govt.)
Naval Ship R & D (U.S. Govt.)
New York City Transit Authority
Ontario Research Foundation(Canada)
Southwest Research Institute
Stanford Research Institute
U.S. Testing Company
Underwriters Labs. Inc.
University of Maryland
University of Trondheim (Norway)
Univeristy of Utah

AEROSPACE

British Aircraft Ltd. (G. Britain)
McDonnell Douglas Corp.
Sud Aviation-Aerospatial (France)
Boeing Corp. (Seattle)

APPENDIX C

AMERICAN INSTRUMENT COMPANY
DIVISION OF TRAVENOL LABORATORIES, INC.

8030 Georgia Avenue
Silver Spring, Maryland 20910
589-1727 (301)

Mr. Eldon B. Nicholas
Federal Aviation Agency NAFEC
Atlantic City, New Jersey

Aminco Ref: L-551-112173
November 21, 1973

Reference: Smoke Density User List

Dear Sir:

We have just shipped our 100th 4-5800 Aminco-NBS Smoke Density and will have delivered 106 by January 1, 1974.

In addition we expect orders from Ciba-Geigy (Great Britain), Messerschmidt-Bolkow (W. Germany), Registry of Shipping (Leningrad), Lumber Research Laboratories (Moscow), A Building Research Laboratory in Denmark and Two industrial users in France and Great Britain. Domestic inquiries which appear serious include an additional chamber for Southwest Research Institutes, Arthur D. Little, Magee Carpet, Brooks Air Force Base, G.S.A. and Battelle. We can safely estimate a minimum of 130 to 140 by 1975 especially if the Japanese inquiries break through.

I have enclosed 1 copy of the current NFPA Draft and our new reprint which is a combination of a NBS Tech News (July 1973) Article & Tech Note 757 which is no longer in print. I have also enclosed other NBS articles no longer in print but available from us.

I hope to see you in Bar Harbour and will attend your Committee Meeting on December 5th. Should it be helpful I would be pleased to provide any additional materials to, or meet with your standards officials.

Very truly yours,

Samuel Greenberg
Samuel Greenberg
Applications Engineer

SG/sa
Enc: Users List
Reprints 501, 395A, 473A, 481
NFPA Draft

TWX: 710-825-9621
TELEX: 89-8412
CABLE CODE: Aminco Silver Spring