

NAFEC TECHNICAL LETTER REPORT

NA-77-53-LR

FIRE TESTING OF CABIN MATERIALS USED IN
COMMERCIAL AIRCRAFT

by

Constantine P. Sarkos
Joe C. Spurgeon
Eldon B. Nicholas
Richard G. Hill

ANA-420

September 1977

FEDERAL AVIATION ADMINISTRATION
NATIONAL AVIATION FACILITIES EXPERIMENTAL CENTER
Atlantic City, New Jersey 08405

This paper was presented at a symposium and workshop entitled "Polymeric Materials and Their Use in Transportation" at the Polytechnic Institute of New York, April 27 - 29, 1977.

Summary

The purpose of this paper is to familiarize individuals with the kinds of materials currently used in the cabin interior of a commercial airliner, to describe some of the more important fire tests used to evaluate these materials, and to summarize the behavior of these cabin materials when subjected to each of the fire test methods. Specifically, a detailed description is presented of the following respective test methods for flammability, smoke, and toxic gas emissions: vertical Bunsen burner test, National Bureau of Standards (NBS) Smoke Chamber, and a combustion tube furnace test. Fire test data on 75 cabin materials are summarized for burn length, flame-out time, specific optical density (D_s) of smoke, and yields of hydrogen cyanide (HCN) and carbon monoxide (CO). A description is given of an interim full-scale test facility that will be completed in the near future for studying the characteristics of a postcrash fire in a simulated wide-body cabin.

Background

The interior of a commercial aircraft cabin is lined and furnished with a large quantity and great variety of synthetic and natural polymeric materials. Under fire exposure conditions of sufficient intensity, any of these materials can ignite, burn, and emit heat, smoke, and toxic fumes. In order to minimize the danger associated with the involvement of interior materials in a cabin fire, the FAA has sought to promulgate standards to limit the selection of materials to those meeting certain fire safety levels. Initially, emphasis was placed on the problem of in-flight cabin fire. Flammability regulations were first adopted in 1947 with a requirement that cabin materials burn no greater than 4 inches/minute in a horizontal orientation when subjected at one end to a Bunsen burner flame. Control of flame spread rate was intended to provide sufficient time for the extinguishment of an incipient fire. These regulations remained in effect during a period when the major concern in aircraft fire safety was directed toward engine and fuel spillage fires rather than the ignition of the interior materials themselves. With the availability of new and better fire resistant materials, the FAA was able to upgrade the materials flammability regulations in 1967, and again in 1972. Presently, under Federal Aviation Regulation (FAR) 25.853, except for an insignificant quantity of small parts, all interior materials must be "self-extinguishing" in a vertical orientation when subjected to a Bunsen burner flame along the bottom edge (reference 1).

The crash of a Boeing 727 at Salt Lake City in 1965 is considered by many people to have kindled the concern and controversy which persists over the potential fire hazard in a habitable enclosure constructed of synthetic materials (reference 2). A fire originating at a ruptured fuel line underneath the cabin floor instantly spread at first impact into the cabin, which remained intact during the entire crash deceleration. The hazard created by the rapid fire involvement of the cabin materials was believed to have contributed to the heavy loss in life. One important aspect stressed by the survivors was the very heavy smoke that obscured vision and seriously impaired the ability of passengers to evacuate the cabin. The concern with smoke emissions fostered the development in the late 1960's by government and industry of a number of laboratory-type smoke-measuring devices (reference 3). Of those available test methods, the NBS Smoke Chamber was considered by FAA to be the most promising for characterizing the smoke emission characteristics of aircraft cabin materials. In 1975, the FAA issued a proposed regulatory notice to govern the selection of cabin materials based on the NBS Smoke Chamber test (reference 4). This notice, in conjunction with an earlier advanced notice, was most effective in encouraging industry to develop and market new low-smoke materials.

The Salt Lake City crash in 1965 also provided the first indication in an actual accident of the potential dangers associated with the toxic combustion products emitted by burning cabin materials. As part of an extensive crashworthiness program by industry and government arising out of this accident, FAA contracted with the Bureau of Standards to measure the smoke and toxic gas emissions of a large number of aircraft interior materials (reference 5). These early efforts resulted in the expansive growth of FAA in-house facilities capable of combustion gas analysis and toxicity evaluations. Laboratories and resources were further improved following the successive accidents in Chicago in December of 1972, which received wide publicity over passenger fatalities attributed to cyanide poisoning. In December 1974, the FAA issued an advanced regulatory notice soliciting responses from the public on a series of questions related to the combustion toxicity of cabin materials (reference 6). Although many respondents shared FAA's concern with this problem area, caution was also expressed about taking precipitous action until suitable test methods could be developed.

Since the early 1970's, considerable research in combustion toxicity has been undertaken in the United States, with perhaps the most

comprehensive programs at the University of Utah (reference 7). The FAA has concentrated on the development of a materials toxicity test method using either gas analysis methods and/or animal exposure systems. A cooperative program between the FAA's National Aviation Facilities Experimental Center (NAFEC) and Civil Aeromedical Institute (CAMI) utilizing this approach was recently completed based on the analysis of 75 inservice materials (references 8, 9).

Description of Typical Cabin Materials

In order to systematically describe and study the interior materials used in a wide-body cabin, it was found useful to consider the materials by usage categories. Table 1 contains descriptive information on typical materials found in each of the 10 categories. The panels are the cabin lining materials which constitute the sidewall, stowage bin, ceiling, and partition surfaces. From a fire safety consideration, panels are clearly the most important category because of their (1) large surface area and (2) upper cabin location where peak fire temperatures are expected. Panel construction is somewhat similar in the three wide-body jets, consisting essentially of a decorative laminate bonded to a fiberglass sheet facing which is bonded to a Nomex honeycomb core. However, the decorative laminates are notably different, depending on the end use and type of aircraft. They can consist of Tedlar[®] films ranging in thickness from 2-10 mils, or 12-15 mil Tedlar[®] /vinyl laminates. Evaluation of the decorative laminates can be considered an important process since they can be readily pyrolyzed and burned during a cabin fire. The National Aeronautics and Space Administration (NASA) and the airframe manufacturers have undertaken a major program to develop and fabricate sandwich panels exhibiting improvements in flammability, smoke, and toxic gas emission characteristics (reference 10). Sandwich panels are relatively lightweight, ranging from about 2.5-6 lbs/yd². The older narrow-body jets are lined with vinyl/aluminum sidewalls and vinyl/fiberglass hat-racks, headliners and ceilings, although many are now being retrofitted with wide-body kits consisting of sandwich panel construction.

Passenger seats constitute three usage categories--foams, fabrics, and coated fabrics. Seat cushions are made of fire retardant (FR) urethane foam. In order to provide optimum comfort and wear, the cushion is actually comprised of bonded sections of urethane foam having different densities (1.4-5.0 lb/ft³). Although urethane foam is quite flammable by itself, the seat upholstery fabric and ticking do add a degree of ignition protection. Presently, the most popular seat

upholstery fabric found in commercial aviation is the wool/nylon blend at a 90/10 ratio. These have replaced the Nomex[®] upholstery fabrics which were prevalent when the wide-body jets were first introduced into service. The coated fabrics are used primarily for seat arm-rests and seat bottom diaphragms, and thus are used in far smaller quantities than either the seat upholstery or cushions.

Wool carpets are used extensively as floor covering material in today's jet airliners. Although the floor does constitute a relatively large surface area within the cabin, floor coverings are not expected to become highly involved in a cabin fire beyond the immediate vicinity of the fire origin.

Polycarbonate is used exclusively in wide-body jets for the construction of passenger service units and modules. It has replaced the far-smokier ABS found in the older narrow body aircraft, and can be processed to pass the proposed FAA smoke rule. In some of the earlier B-747's, the window reveals were also formed from polycarbonate although a changeover was made in the later models to the sandwich panel construction.

The remaining four categories in table 1 consisting of cargo liners, transparencies, insulation, and elastomers are not considered as important as the previously discussed categories from a postcrash fire safety viewpoint. In this fire situation, cargo liners are not expected to contribute significantly to the hazard existing in the cabin compared to materials contained in the cabin itself. Transparencies and elastomers are similarly of less importance because of their relatively small abundance. Finally, although thermal and acoustical insulation can constitute almost 25 percent of the weight of cabin nonmetallic materials, it is not expected to pose a major fire threat because of its low resin content and isolation between the fuselage skin and interior sandwich panel.

Of the many factors which must be taken under consideration during the selection of cabin interior materials, perhaps the greatest attention, after fire safety, is given to weight and cost. The approximate weight of nonmetallic materials, excluding seats, in the passenger cabin of a typical B-727 (narrow body) or B-747 (wide body) aircraft is approximately 3,500 and 9,400 pounds, respectively. Respective costs of these materials in the B-727 and B-747 are approximately \$350,000 and \$1,250,000. Incorporation of improved fire-safe materials into a typical wide-body cabin is an expensive proposition. In a recently

completed study, the recurring cost of improved materials in a "hypothetical" wide-body cabin was estimated at about \$300,000 (reference 11). Recurring costs do not include, for example, the expense of developing a new production design or purchasing additional manufacturing equipment, nor operating costs which estimated over a 20-year period would practically equal the recurring cost.

Seventy-five interior materials used in wide-body transport aircraft were fire tested for the purpose of determining toxic gas emission levels (reference 8) and other properties. The samples were obtained with the cooperation of major transport and seat manufacturers. They were first screened to verify compliance with FAA flammability requirements (FAR 25.853) and tested in the NBS Smoke Chamber (reference 12) for comparison of smoke densities with those limits proposed for rule-making (reference 4). The flammability, smoke, and toxic gas emission characteristics of the 75 materials as measured is discussed below. Table 2 contains a description of the materials, including chemical composition, thickness, unit weight, designation (category) and cabin use. Descriptive information on makeup and chemical composition was provided by the manufacturers.

Flammability

The flammability test apparatus prescribed by the FAA in FAR 25.853 for testing interior materials is based on Federal Test Method Standard No. 191, Method 5903.2 (reference 12). A photograph of the apparatus is shown in figure 1. The essential parts of the apparatus consist of a Bunsen burner ignition source, a synthetic gas mixture of specified composition, a ventilated metal cabinet to provide a draft-free environment, a rigid specimen holder to assure rigid specimen support, a stopwatch, and a graduated scale. The Bunsen burner flame height is adjusted to 1 1/2 inches in order to produce a flame temperature of 1600°F minimum. The distance between the lower edge of the test specimen and the top of the burner is 3/4 inch.

The test specimen is a rectangle 2 3/4 inches by 12 inches with the long dimension in the vertical position. Specimens are conditioned to 70°F and 50-percent relative humidity for a minimum of 24 hours (also applicable to smoke and toxicity test specimens). Specimens are tested in the thickness used in the aircraft, except that seat cushions are tested in 1/2-inch thickness. Seat fabrics that have a warp and fill direction must be tested in both directions to determine the critical flammability condition.

The simple test procedure consists of exposing the specimen to the Bunsen burner flame for a prescribed period of time. The time interval after removal of the burner to the cessation of specimen flaming is defined as the flame time. Burn length is the distance from the original edge to the farthest evidence of damage to the specimen due to flame impingement, including areas of partial consumption, charring, or embrittlement, but not including areas sooted, stained, warped, or discolored. FAR 25.853 specifies a 60-second burner exposure time for panels, and a 12-second exposure for the remaining material categories listed in table 1. The allowable burn lengths are 6 and 8 inches, respectively. Flaming time cannot exceed 15 seconds for all material categories. The major assets of the vertical test are ease of operation, rapid testing, low operating and equipment costs, and dual application for quality control.

A bar graph of the burn lengths and flame times measured for the 75 materials is shown in figure 2. The data have been grouped into usage categories to facilitate analysis, with each category arranged either by increasing weight (e. g., panels, foams) or into subgroups with similar chemical compositions (e. g., fabrics, thermoplastics). The data are for one test only, although a minimum of three specimens must be tested per FAR 25.853. Since a small, immobile flame that can vary in duration from one test to another is observed on some materials after removal of the burner flame, flame time generally is less reproducible than burn length. This probably accounts for the random distribution of flame times, compared to burn lengths, in some usage categories.

When the panel specimens were subjected to the burner flame, the decorative laminate rapidly burned and withdrew from the ignition source. For a number of panels, material flaming ceased before the burner was removed. In figure 2, panel burn length varies from 2 to 5 inches and is a measure of the burn length along the decorative laminate. Very little damage was experienced by the Nomex[®] honeycomb core, which was directly exposed along the bottom edge of the specimen to the burner flame. The honeycomb core appears to offer excellent resistance to flame penetration, as verified by the test results for bare honeycomb material (panel component No. 40). This finding has been also observed in larger scale flame penetration studies using a burner simulating the heat output of a large fuel fire (reference 14). Another interesting observation is that panel components are more flammable when tested individually than as an assembled sandwich. Most notable in this respect is the epoxy-coated bonding laminate (panel component No. 39).

Urethane seat cushions used in air transport cabins are flame retardant treated to produce a "self-extinguishing" characteristic. The first seven materials in the "Foams" category in figure 2 are urethanes arranged sequentially with increasing density. Flame times appear to decrease as a function of urethane density; however, burn lengths appear to be somewhat invariant. Examination of the test samples reveals that the latter is a misleading parameter since it is observed that the consumption by flame of material clearly diminishes with increasing density. The long flame time for material No. 102, which was a rigid polyethylene flotation cushion, is the result of a small, wick-like flame.

Very little burning was experienced by the three fiberglass insulations (Nos. 27, 66 and 115a), each containing a different resin binder, and the two elastomers. A burn length of 6.3 inches was measured for material No. 28, which was an insulation batting cover composed of aluminized Tedlar[®] interwoven with a nylon tear stopper.

The test results for the fabrics exhibited several interesting trends. These fabrics included wool, wool/nylon blends, wool/PVC blends, cotton, rayon, cotton/rayon, modacrylic, and Nomex[®]. A lightweight FR cotton ticking (No. 93) experienced the fastest flame spread rate, an average velocity of about 0.7 in/sec, and the longest burn length was recorded by a modacrylic drapery (No. 127). The most fire-resistant fabrics were the rayon (No. 95) and cotton/rayon blend (No. 130). Both burned 1 inch or less and flaming ceased immediately after burner removal. Materials Nos. 82, 96, and 81 are wool/PVC fabrics displayed in the order of increasing PVC content. Burn length and flame time both decrease with increasing PVC content, demonstrating the benefit in flame retardancy that may be achieved by PVC blending. One of the PVC coated fabrics (No. 97) produced an unusually long flaming time. Compared to the other coated fabrics which had cotton or nylon backings, No. 97 was less than half the weight and was constructed of a polyester backing.

Flooring materials were some of the heaviest materials tested, and thus had a natural tendency to resist ignition. An important observation that must be made when conducting the vertical test is the flame spread across the backside surface of the specimen, which is observable by the use of a mirror. Material No. 34 is a wool pile carpet with a urethane foam padding. The burn length was significantly longer for this material than a similar wool pile carpet without padding (No. 33).

The thermoplastic materials, consisting of various blends or laminates of PVC, ABS or acrylic, and polycarbonate and polyphenylene oxide sheets, generally exhibited shorter burn lengths than other major usage categories. The unusually long flame times were for a polycarbonate injection molded material (No. 32) and a polyphenylene oxide thermoformed material (No. 117).

Cargo liners and transparencies, which are considered lesser usage categories, both exhibit relatively good resistance to small flame ignition.

FAA is presently studying the characteristics of four different flammability test procedures; i. e., Ohio State Rate of Heat Release Apparatus (reference 15), ASTM E-162 Radiant Panel for Surface Flammability (reference 16), ASTM D-2863 Limiting Oxygen Index (LOI) Method (reference 17), and thermogravimetric analyses. An advanced test method that describes the behavior of a material subjected to intense heat and flame simulating a large postcrash cabin fire might be advantageous as a supplement to the existing vertical Bunsen burner standard which generally addresses the ignition resistance of a material to a small flame, which is more analogous to an in-flight incident. Both the Ohio State and E-162 test methods expose relatively large specimens to intense radiant heat and flame. The E-162 method appears more suitable for the measurement of surface flame spread rate, while the Ohio State method was designed primarily for heat release rate determinations. The Ohio State method, which is a fairly new test still undergoing development, had several design and data output features that are relevant to describing actual fire conditions, viz., (1) capability of vertical and horizontal specimen orientation, (2) selection of incident heat flux level, (3) determination of release rate values, and (4) display of rate changes with time.

Test results from a typical decorative honeycomb ceiling panel tested in the Ohio State Apparatus at two incident heat flux levels are shown in figure 3. The discrete peaks indicate the involvement of the decorative laminate and honeycomb core. The burning duration and total heat release from the decorative laminate is similar at both the high and low incident heat levels. However, at the high heat level the honeycomb core starts burning at about 30 seconds and releases significant quantities of heat. Conversely, at the low heat level a gradually increasing but fairly minimal involvement of the honeycomb core is evident.

In the LOI test method, the minimum concentration of oxygen that will allow ignition of a small sample is determined. Compared to the vertical Bunsen burner test, the LOI offers better discrimination between advanced polymers under development for future cabin usage. Anaerobic char yield determined by thermogravimetric analysis has been proposed as a parameter for indicating the relative fire safety of polymers (reference 14). However, the utility of the previously discussed flammability tests will be judged in the end on the basis of comparisons made with future full-scale cabin fire tests.

Smoke

The NBS Smoke Chamber (reference 18) was the test procedure considered most promising to control the smoke emission qualities of a cabin interior material (reference 4). A photograph of the smoke chamber is shown in figure 4. The essential components are an 18-ft³ closed, chemically-resistant enclosure; a radiant heater and propane/air burner for simulating flaming and nonflaming fire conditions; a vertical holder for mounting a 3-inch-square specimen; a 3-foot, vertical photometric system for the continuous measurement of percentage light transmission through the generated smoke; and a millivolt recorder. The radiant heater is set at 2.5 watts/cm² (2.2 Btu/ft²-sec). The final data format is usually a plot of specific optical density against time.

There are numerous features of the smoke chamber worth summarizing which attest to its wide popularity.

- a. It can test materials in the thickness used in their application.
- b. The use of two standard exposure conditions tends to differentiate between flaming and nonflaming (smoldering) smoke emissions.
- c. The chamber is sealed; this is a favorable feature not found in other tests which allow undetermined amounts of smoke to escape.
- d. A vertical photometric system averages out stratification effects.
- e. The fraction of light transmission (T) is used to compute the optical density (D), which is defined as

$$D = \log (1/T)$$

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

f. Test results are expressed in terms of specific optical density (D_s), representing the optical density measured over unit path length (L) within a chamber of unit volume (V) produced by a burning material of unit surface area (A). Thus,

$$D_s = D (V/AL)$$

and test results expressed as specific optical density may be related to (1) areas of materials which potentially could be involved in a fire, (2) distances of light paths from observers to exitways, and (3) the volume of enclosed space.

g. A continuous smoke concentration recording is more beneficial than the ultimate total weight of smoke obtained by filter deposition methods.

h. The smoke chamber has sufficient resolution to continuously measure the quantity of smoke released for most cabin materials. It is capable of recording optical densities up to 5.0, corresponding to light transmission values of 0.001 percent.

i. Only the front surface of the material or composite is exposed to ignition, thus representing a realistic cabin combustion condition.

The NBS Smoke Chamber is commercially available from the American Instrument Company. Since its commercial introduction in the early 1970's, over 220 smoke chambers have been purchased, including many by countries outside the United States. The NBS Smoke Chamber is by far the most widely used test method for the measurement of smoke emission characteristics of solid materials.

The aforementioned notice of proposed rulemaking on smoke included, for most material usage categories, specific optical density acceptability limits of 100 and 200 at 90 seconds and 4 minutes, respectively (reference 4). Within 4 minutes, most cabin materials achieve peak accumulated smoke production, and 90 seconds is the FAA demonstration requirement for passenger emergency evacuation. An allowable specific optical density of 100 was proposed for the less smoky cabin materials such as fabrics and insulations. Limiting D_s values were essentially set at levels to eliminate the smokier materials from cabin usage.

A bar graph of the specific optical density values at 90 seconds and 4 minutes for the 75 materials is shown in figure 5. The materials have been grouped in the same manner as previously for flammability. These smoke data reflect one test at the flaming exposure condition and were measured coincident with the gathering of bag samples for gas analysis (reference 12). The relative smoke emission characteristics of typical inservice cabin materials, however, is displayed.

Because of their composite construction, panels have a tendency to produce higher smoke levels within the first 90 seconds of the test than most of the remaining usage categories. Six of the 13 panels exceeded a D_s value of 100 at 90 seconds. The major smoker in the panel construction is the epoxy resin used in the fiberglass facings and as an adhesive. Since the decorative laminate is rapidly eliminated upon heat and flame exposure, the epoxy sublayers are subsequently exposed early in the test. Early smoke generation is predominant in the perforated acoustic panels (e.g., material Nos. 37 and 43), where apparently the exposure of the epoxy and scrim materials is even faster. Epoxies were selected amongst other considerations because of their excellent peel strength, long shelf life, and relatively low cost. NASA and the airframe manufacturers are presently evaluating improved resin systems, such as modified epoxies and phenolics, bismaleimides, and polyimides (reference 10).

Under the thermal exposure conditions used in the smoke chamber, urethane foams are consumed quite rapidly. After about 1 minute, the bulk of the specimen is eliminated from the vertical holder, and material combustion is limited to melted drippings collected in the sample trough. As shown in figure 5, except for material No. 73, the rate of smoke emission increased with foam density. Compared to the polyether types, the polyester urethanes (material Nos. 143a, 104, and 143c) produced higher smoke emission levels. In fact, material No. 143c produced a higher smoke emission rate and maximum specific optical density than any of the 75 materials.

Smoke from the fiberglass insulations was barely detectable and from the silicone elastomers was relatively low.

The seat upholstery fabrics used in air transport cabins are generally low smokers. Only the two wool/PVC blends exceeded a D_s value of 100 at 4 minutes. Material Nos. 82 and 96 are wool/PVC blends and No. 81 is a PVC fabric which were previously shown to exhibit improved

flammability with increasing PVC content. Interestingly, a reduction in smoke emissions was also found with increasing PVC content, demonstrating that improvements in flammability are not always achieved at the expense of greater smoke emissions.

PVC coated fabrics are inherently smoky materials. Although used abundantly in the older narrow body aircraft, they are significantly less used in wide bodies except for seat parts.

Except for an aluminum faced structural flooring panel (material No. 9), smoke levels were generally high for flooring materials. The popular wool carpets (material Nos. 33, 34, and 52) which take a finite time to heat up and burn, exhibit low smoke levels at 90 seconds but D_s values are up around 400 after 4 minutes.

A wide range of smoke emission values were found for the thermoplastic materials, probably more so than any other usage category. The PVC plastics blended or laminated with ABC or acrylic, and the polyphenylene oxide produced copious amounts of smoke compared to the polycarbonates. The smokier thermoplastics are found in small quantities in the passenger cabin primarily as complex door parts and seat tray and surround panels. Large surface area thermoformed items such as passenger service assemblies and light defectors are constructed of the less-smoky polycarbonates. NASA and the airframe manufacturers are evaluating advanced low-smoke thermoplastics, including polyethersulfone, polyphenylene sulfide, polysulfone, chlorinated PVC, modified polycarbonate, etc. (reference 10).

The smoke emission characteristics of the cargo liners can be altered, for example, by adding asbestos (material No. 118a) to reduce the overall levels, or by coating with Tedlar (material No. 25) to delay smoke evolution. Of the two transparencies tested, the acrylic was by far smokier than the polycarbonate.

A number of plastics manufacturing companies are developing and evaluating improved materials with potential application in aircraft cabin interiors. Table 3 contains flammability and smoke data on some of the newer materials which have been tested by NAFEC. An untreated nylon fabric backed with neoprene foam is flammable by conventional standards, although publicized large-scale seat tests demonstrate significant protection provided by the backing material. Smoke emissions from wool/nylon blends can be altered considerably by changing the relative quantities of the constituent fibers. Neoprene foams are now available with smoke emission levels significantly lower than were attainable several years ago. New thermoplastics such as polycarbonate,

polysulfone, polyethersulfone, and chlorinated PVC produce relatively low smoke levels, especially the sulfonated materials. Polyvinylidene fluoride is a candidate replacement for the decorative laminated finishes presently used in panel construction.

Toxic Gas Analysis

A cooperative program at NAFEC and CAMI on combustion toxicity of cabin materials has resulted in the development of an animal response test apparatus that can be used in conjunction with gas analysis methods. Development of the former has been described previously (reference 19). The latter was developed at NAFEC for generating toxic combustion products for subsequent chemical analysis and is shown in figure 6. The basic components of this flow-through system consist of an annular furnace and temperature control module, a quartz combustion tube for accommodating the sample, a vacuum pump for drawing air through the system, a manifold for dividing and passing the combustion tube effluent into four fritted bubblers containing appropriate collection liquids, and a series of downstream rotameters and a single upstream rotameter for controlling air and effluent flow rates, respectively.

The test procedure consists of first establishing the desired total airflow rate and dividing this into equal components through each bubbler. At the beginning of the test, the sample is manually injected into the isothermal zone of the combustion tube which in turn is properly positioned in the preset, hot furnace. Over the test duration the bubbler rotameters, which are each fitted with a needle valve, are continuously monitored and adjusted to maintain equal flow rates. The test is run for a period of 5 minutes. After the test, the bubbler contents are analyzed for hydrogen cyanide (HCN), hydrogen sulfide (H₂S), hydrogen chloride (HCl), hydrogen bromide (HBr), formaldehyde (HCHO), nitrogen dioxide (NO₂), sulfur dioxide (SO₂), and hydrogen fluoride (HF). Differential pulse polarography is used for the analysis of HCN, H₂S, HCl, HBr, and HCHO, UV/VIS spectrophotometry for NO₂ and SO₂ and ion selective electrodes for HF. Compared to combustion gas analysis methods used in the past, polarographic techniques have the advantage of simultaneously measuring multiple species and detecting the presence of interfering species. A detailed discussion of the analytical procedures is contained in reference 8. Carbon monoxide (CO) was measured by replacing the bubblers with a plastic bag for collecting the combustion products and analyzing the contents with a nondispersive infrared analyzer.

A 250-mg (milligram) sample is exposed to a temperature of 600°C for 5 minutes while maintaining an airflow rate of 2 lpm (liters per minute) through the combustion tube. Compared to 400 and 800°C, a combustion temperature of 600°C is more discriminatory in terms of combustion toxicity. In addition, at 800°C many materials have been found to decompose with similar, explosive velocity, and it is difficult to protect the exposed animals from thermal stress and anaerobic conditions (reference 19). The combination 250-mg sample weight and 2 lpm airflow rate provide oxidative conditions in the combustion zone and prevent overflow and saturation of the gas-collecting bubbler contents (reference 8).

The FAA's combustion tube flow-through system was selected after a study comparing it with the static approach represented by the NBS Smoke Chamber (reference 20). Tests on identical cabin materials revealed better reproducibility and higher acid gas yields with the combustion tube system. The collection of the total combustion mixture in the combustion tube system versus discrete sampling and uncertain wall losses in the smoke chamber are major differences between the two approaches. A preliminary study using an improvised combustion tube system indicated for a small number of nitrogen-containing cabin materials a correlation between animal toxicity measured at CAMI and HCN yields measured at NAFEC (reference 20). In contrast, a recent study concluded that the smoke chamber and standard operation procedure was not suitable for toxicity screening tests using laboratory animals, primarily because of the difficulty in evoking a behavioral response under standard test conditions (reference 21).

A detailed description of the analysis of the 75 cabin materials for the nine toxic gases is contained in reference 8. A bar graph of the yields in milligrams per gram of CO and HCN is shown in figure 7. These gases were selected because they appear to be the major toxicants of the nine gases selected. The gas yields for each material is the average of three tests. Repeatability, as indicated by the average relative standard deviation for the 75 materials, was 9 and 23 percent for CO and HCN, respectively. Oxidized species such as NO₂, SO₂, and HCHO were less repeatable, apparently because they are influenced to a greater degree by random variations in the combustion process. The materials are arranged within each usage category in figure 7 in the order of decreasing toxicity (reference 9).

Because of their layered structure, panels are difficult to compare using the combustion tube approach. In an actual cabin fire, only the

front face of the panel will probably be initially exposed to thermal stress, while in the combustion tube the total sample is immersed in radiant heat, including the core and backface materials. Involvement of the latter panel components is probably not representative of what would occur in an actual fire. However, a reliable more realistic test is not yet available.

All the panels produced CO, HCN, and NO₂, and the majority released HCl, HBr, and HF, with the latter produced by the decorative laminate. As was the case for most materials tested in the combustion tube, the yield of NO₂ was more than an order of magnitude less than the yield of HCN. Conversely, for the panels the yield of CO was about 10-40 times the yield of HCN, and this ratio was usually greater than 20. Panel component No. 40, which is a Nomex[®] honeycomb core for panel No. 37, produced more than five times the yield of HCN than any of the other panel components.

All the urethane foams produced CO, HCN, and HCHO, but very little NO₂ or H₂S, and no HBr. Urethane foam No. 143c produced the highest apparent yield of SO₂ of any of the materials, and twice as much HCl as the PVC foam (No. 86). This particular urethane was also the smokiest materials tested in the smoke chamber. Yet its yield of CO or of HCN was less than that produced by the other urethanes, which was apparently the reason for its relatively low toxicity. Although HCN was not detected from the rigid polyethylene flotation cushion (No. 102), this material produced a higher CO level than the remaining foams.

Fiberglass insulations and silicone elastomers produced low yields of CO compared to panels and most foams. The behavior of the melamine-fiberglass insulation (No. 27) was unique in that it was the only material which did not produce a detectable amount of CO. However, an HCN yield of 15 mg/g is considered to be relatively high, especially since the melamine binder constitutes only about 20 percent of the weight of insulation. Although HCN was not produced by the silicone elastomers, the aldehyde yields were exceptionally high compared to the materials in other usage categories.

For the fabrics, the highest CO yield was obtained from material No. 130, a cotton rayon blend, while the second and third highest CO yields were produced by cotton (No. 93) and rayon (No. 95), respectively. The modacrylic drape (No. 127) produced the highest yield of HCN of any of the materials tested. The wool (No. 88) and wool/nylon blends (Nos. 142, 70) also produced high yields of HCN, second to the

modacrylic in overall ranking. The wools were the only materials that produced H₂S in significant amounts. A proportionality existed between the amount of wool in the wool (No. 88) and wool/PVC blended (Nos. 82, 96) materials and the yield of HCN, although this type of relationship did not exist for CO yields.

The coated fabrics produced only CO and HCl in significant quantities, and the yields of these gases were inversely related. A direct relationship was apparent between toxicity and yield of CO.

The flooring materials that produced the highest yields of CO were the structural floors constructed of Nomex[®] honeycomb cores. The yields of HCN were greatest for the wool carpets (Nos. 33, 34), although significantly lower than the wool upholstery fabrics.

The thermoplastics can be divided into two groups based on chemical composition, the polycarbonates and the ABS/PVC blends and laminates. Polyphenylene oxide (No. 117) and polymethylmethacrylate (No. 99) are approximately intermediate in behavior to the two groups. The polycarbonate materials (Nos. 32, 116, 113) produced the highest yields of CO of any of the materials, significant yields of HBr but no HCN. The ABS/PVC materials (Nos. 100, 107, 85) produced much lower CO yields, high HCl yields, and relatively low HCN yields.

The CO yields of the cargo liners varied from moderate to low, with only the polyester (No. 10) producing HCN. The toxicity was directly related to the yield of CO.

The only gases produced by the transparencies were CO, HBr, and HCHO. Polycarbonate (No. 111) again produced the highest CO yield. Although the polymethylmethacrylate produced much lower CO yields, the fire retardant material (No. 108) produced more than four times as much CO as the untreated material (No. 109). However, the untreated material produced an exceptionally high yield of HCHO (63 mg/g).

Presently, an analysis of the CAMI toxicity data (animal incapacitation and death time) and the NAFEC gas analysis data for the same materials is in progress with the aim of correlating these data. Efforts are also underway now to understand more completely the relationships between toxic gas emissions in the combustion tube and NBS Smoke Chamber. Later, large and full-scale tests are planned for comparison with combustion tube data.

Full-Scale Tests

Perhaps the most controversial and provocative issue dealing with fire safety standards is the contention by some that laboratory tests are not generally indicative of material performance in a real fire. For example, critics describe the use of small specimens of constant area or weight, use of fixed fire exposure and ventilation conditions, or a specific specimen orientation as not reflective of an actual dynamic fire, although these laboratory design features are admittedly essential to assure control over the test conditions and repeatability of data. Large and full-scale tests have been stated to be necessary in order to study and understand the behavior of materials in real fires.

Past large-scale cabin fire test programs have been infrequent or limited in scope, primarily because of high cost and extensive technical support requirements. Some tests have been conducted in small test articles unrepresentative of real aircraft cabin volumes. In some post-crash fire programs, difficulties were encountered in controlling simulated external fuel spillage fires from effects of random ambient winds, which are known to effect the degree of flame penetration through cabin openings. Instrumentation has been incomplete at times or of questionable accuracy. Some programs have been "one-shot" destructive testing affairs that sometimes leave more questions than answers.

The FAA has recently completed preparation of a fire test facility, including a C-133 test article simulating a wide-body cabin, designed to hopefully overcome most past deficiencies. A plan view sketch of the facility is shown in figure 8.

A blockhouse on the right side of the C-133 contains electrical power terminals, including 115 volts ac and a 400 cps generator, controls for fuel pumping and storage, and a large-volume vacuum pump. A 28 volt dc rectifier is located outside of the blockhouse in a metal shed. Wiring from the blockhouse to the C-133 is routed through underground conduits surfacing on either side of the C-133.

The main trailer houses the mini-computer data acquisition system consisting of teletypewriter, Nova 3 computer, diskette, and X-Y recorder. Including the analog-to-digital (A/D) converters, this system is capable of storing and calibrating into engineering units, during the course of a test, 128 channels of digital data, and later plot this data on the X-Y recorder.

The instrumentation trailer contains the terminal boards for all transducer signal wires; A/D converters; facings, meters and calibration controls for all continuous gas analyzers; a test control panel; and continuous gas sampling vacuum pumps.

The test site has a number of fire safety features. The roadway leading to the C-133 aircraft is accessible to firefighters and equipment in case of an emergency. A fire hydrant is located near the tail of the aircraft. The interior of the C-133 fuselage is protected with a 6-ton total flooding CO₂ system.

Because of its large size, the C-133 was structured to resemble the cabin interior of a wide-body aircraft. The fuselage diameter of a C-133 is 200 inches, which is slightly smaller than that of a DC-10 (212 inches). Since the floor in a C-133 aircraft is located much closer to the belly than in a commercial transport, a wooden floor was installed about 3 feet above the cargo floor in order to provide a cabin contour similar to that of a wide-body jet. A photograph of the modified C-133 is shown in figure 9. The cross-sectional shape is similar to but slightly smaller than that of a DC-10. The enclosure between the cabin and cargo floors provides a protected area for the routing of electrical wires and plumbing lines, and the emplacement of the sensing cells from all continuous gas analyzers at a location fairly close to the sampling point (i. e. , minimal sample lag time). The wooden floor extends from the cockpit bulkhead to the rear cargo ramp, a distance of about 76 feet. In order to maximize volume, the test environment will include the tail section, extending beyond the aft end of the wooden floor, containing the rear cargo ramp. An 8-foot ceiling was installed along the length of the cabin floor. The calculated volume of the test article is 13,200 ft³.

Tests using the C-133 will be primarily related to survivable post-crash cabin fires, but can include large enclosure fire studies. A representative scenario consists of an external fuel -spill fire adjacent to an open door or small fuselage rupture. Initial testing in the C-133 will concentrate on this scenario. A fuel pan is located adjacent to a fuselage opening in the forward part of the aircraft. Flame penetration into the cabin is controlled and varied with a large fan simulating ambient wind. A door located near the aft end of the aircraft produces a cabin draft in this direction. Wind barriers surrounding all openings isolate the fuel fire and cabin environment from unpredictable ambient winds.

Considerable precautions have been taken to ensure that the test article will withstand the high-temperature cabin fire environment and remain usable for numerous fire tests. All combustible items were stripped from the aircraft. The cabin floor is covered with aluminum sheeting over asbestos paper to protect the wooden surface. Ceiling panels are constructed of ceramic fibrous insulation, attached to aluminum backing, and covered with a noncombustible fiberglass cloth. Sidewall panels are similarly constructed but without the aluminum backing. In tests with interior lining materials as part of the fire load, these materials will replace or cover the noncombustible protective lining.

In order to serve future full-scale testing requirements, provisions have been made for a large number of measurement locations throughout the test cabin. These measurements will be primarily of heat, smoke, and toxic gas levels within the cabin environment. Terminal boards inside the instrumentation trailer have the capacity for 300 transducer connections, including 200 thermocouple and 100 millivolt signals. The latter millivolt signals will emanate from a variety of transducers wired to any of 20 fire resistant terminal boxes, each containing 20 terminals, dispersed throughout the cabin along the sidewall and at the floor juncture.

The use of thermocouples for the measurement of air or surface temperature is extensive. Access into the cabin has been provided by the following means: (1) each ceiling panel in the forward and wing box sections contains a thermocouple that can be extended up to 6 inches below the ceiling (in the aft section every other center panel has this provision); (2) 40 asbestos thermocouple jacks, in groups of four, are dispersed throughout the cabin along the sidewall at the floor juncture; and (3) bulkhead fittings through the floor route thermocouple wires from beneath into the cabin. Most thermocouples are fabricated from ceramic-encased, inconel-sheathed, chromel-alumel wire.

Water cooling protection is required for the transducers designed to measure the high heat flux levels generated by an intense fire. Water supply and drainage lines with necessary valving for connecting 20 heat flux transducers at various cabin locations are installed beneath the cabin floor. Ten Gardon gauge heat flux transducers are available.

Smoke density is measured in terms of the reduction in transmission of a collimated beam of light extending from a light source to a detecting device.

Six fixed photometers are positioned at different stations along the cabin length. In addition, 20 portable, heat resistant conventional photometers under construction at the Bureau of Standards for support of the cabin lighting and exit awareness experiments will also provide smoke density stratification and decay readings.

Gas analysis of the cabin environment can be divided into two categories of gases: (1) abundant species like CO, CO₂, O₂, and hydrocarbons that are analyzed with continuous gas analyzers; and (2) toxic species in lesser quantities (HCN, HCl, SO₂, etc.) that are analyzed in the laboratory from batch samples. Four continuous analyzers are available for each of the following: CO, CO₂, O₂, and hydrocarbons. Each analyzer is installed in a portable, aluminum housing mounted on casters and located beneath the cabin floor as close as possible to the sampling inlet. Monitoring and calibration of the continuous analyzers will be accomplished in the instrumentation trailer. Batch sampling consists of collecting gases in small absorption tubes filled with glass beads coated with a sodium hydroxide solution. At the required stations, a batch sample is taken at 30-second intervals over the duration of the test. The samples are subsequently analyzed in the laboratory using a differential pulse polarograph and ion chromatograph. Several Miran I analyzers and small gas chromatographs are also used respectively for the continuous analysis of selected gases and identification of other species not previously selected.

Sprague-Dawley rats will be used in the tests to provide an indication of the response of a biological system to the cabin fire environment. Presently, two animal stations with three animals at each station is planned. Each animal will be tested in a motor-driven, rotating cage patterned after the design developed at CAML. Animals will be monitored with closed-circuit TV cameras. An attempt will be made during each test to determine the times of incapacitation (Ti) and death (Td) of the animals. Measurements will be made of the concentration of selected toxic gases, O₂ and CO₂, and temperature of the immediate air environment surroundings each animal station in order to provide insight into the identification of those hazards of a cabin fire appearing to be most harmful.

The extensive full-scale cabin fire tests planned by FAA will provide valuable information on the characteristics of postcrash cabin fires and the role of burning interior materials in the overall hazard. Parallel efforts are currently underway to improve the capabilities of existing laboratory tests for flammability, smoke, and toxic gas emissions. As data become available pertaining to the behavior of materials in

full-scale fires, attempts will be made to correlate these data with laboratory results. The ultimate objective is to develop a methodology for selecting cabin materials, based on laboratory tests, that has a proven relationship with the hazard created by a cabin fire.

References

1. DOT, Federal Aviation Administration, Airworthiness Standards: Transport Category Airplanes, Federal Aviation Regulations, Vol. III, Part 25, Transmittal 10, effective May 1, 1972.
2. Snow, C. C., Carroll, J. J., and Allgood, M. A., Survival in Emergency Escape from Passenger Aircraft, Federal Aviation Administration, Office of Aviation Medicine, Report AM 70-16, October 1970.
3. Yuill, C. H., et.al., The Control of Smoke in Building Fires - A State-of-the-Art Review, Materials Research and Standards, Vol. II, No. 4, 1971.
4. DOT, Federal Aviation Administration, Flight Standards Service, Transport Category Airplanes: Smoke Emission from Compartment Interior Materials, Federal Register, Vol. 40, p. 6505, February 12, 1975.
5. Gross, D., Loftus, J. J., Lee, T. G., and Gray, V. E., Smoke and Gases Produced by Burning Aircraft Interior Materials, Federal Aviation Administration, Report NA-68-36, June 1968.
6. DOT, Federal Aviation Administration, Flight Standards Service, Compartment Interior Materials: Toxic Gas Emission, Proposed Standards, Federal Register, Vol. 39, p. 45044, December 30, 1974.
7. Einhorn, L. N., et.al., The Physiological and Toxicological Aspects of Smoke Produced During the Combustion of Polymeric Materials, Annual Report 1973-74, Flammability Research Center, University of Utah, Report UTEC-MSE 74-060, July 1, 1974.
8. Spurgeon, J. C., Speitel, L. C., and Feher, R. E., Thermal Decomposition Products of Aircraft Interior Materials, Federal Aviation Administration, NAFEC, Report FAA-RD-77-20, (to be published).
9. Crane, C., et.al., Inhalation Toxicology: (I) Design of a Small-Animal Test System (II) Determination of the Relative Toxic Hazards of 75 Aircraft Cabin Materials, Federal Aviation Administration, CAMI, (report to be published).

10. Joint NASA-Boeing Conference on Sandwich Panels, July 22, 1976, Renton, Washington.
11. Starrett, P., Lopez, E., Silverman, B., Susersky, J., and Logan, J., Feasibility and Tradeoffs of a Transport Fuselage Fire Management System, Federal Aviation Administration Contract, Report FAA-RD-76-54, June 1976.
12. Sarkos, C. P., Measurement of Toxic Gases and Smoke From Cabin Interior Materials Using the NBS Smoke Chamber and Colorimetric Tubes, Federal Aviation Administration, NAFEC, Report FAA-RD-76-7, March 1976.
13. Federal Test Method Standard No. 191, Method 5903.2., Flame Resistance of Cloth; Vertical, July 9, 1971.
14. Kourtidis, D. A., et.al., A Composite System Approach to Aircraft Cabin Fire Safety, NASA TM X-73, 126, April 1976.
15. Smith, E. E., Measuring Rate of Heat, Smoke and Toxic Gas Release, Fire Technology, Vol. 8, No. 2, August 1972, pp. 237-245.
16. ASTM Test for Surface Flammability of Materials Using a Radiant Heat Energy Source (E 162-67), Annual Book of ASTM Standards, Part 18, 1974.
17. ASTM Test for Flammability of Plastics Using the Oxygen Index Test (D 2863-70), Annual Book of ASTM Standards, Part 27, 1970.
18. Tentative Standard Test Method for Smoke Generated by Solid Materials, NFPA 258-T-74, National Fire Protection Association, Boston, Massachusetts, May 1974.
19. Smith, P. W., Crane, C. R., Sanders, D., Abbott, J., Endecott, B., Material Toxicology Evaluation by Direct Animal Exposure, International Symposium on Toxicity and Physiology of Combustion Products, University of Utah, March 22-26, 1976.
20. Spurgeon, J. C., A Preliminary Comparison of Laboratory Methods for Assigning a Relative Toxicity Ranking to Aircraft Interior Aircraft Interior Materials, Part I - Laboratory Test Methods for Generating Toxic Combustion Products, Federal Aviation Administration, NAFEC, Report FAA-RD-75-37, October 1975.

21. Hilado, C. J., and LaBossiere, L. A., Evaluation of the Smoke Density Chamber as an Apparatus for Fire Toxicity Screening Tests, Combustion Toxicology, Vol. 3, No. 2, May 1976, pp. 103-116.

TABLE 1. CATEGORIZATION OF WIDE-BODY CABIN MATERIALS

CATEGORY	USAGE	DESCRIPTION (TYPICAL)	WEIGHT (OZ/YD ²)	THICKNESS (IN.)
PANEL	SIDEWALL, CEILING, STOWAGE BIN, PARTITION, ETC.	FINISH: TEDLAR [®] FILM FACINGS: EPOXY-FIBERGLASS CORE: NOMEX [®] HONEYCOMB	39.6-93.0	0.276-0.958
FOAM	SEAT CUSHION	FR URETHANE	11.3-38.8	0.5 *
FABRIC	UPHOLSTERY	FR WOOL (90%)/NYLON (10%)	11.3	0.037
COATED FABRIC	SEAT ARMREST	PVC/COTTON	26.9	0.058
FLOORING	CARPET	PILE: WOOL BACKING: POLYESTER PAD: URETHANE	51.3	0.345
THERMOPLASTIC	PASSENGER SERVICE UNITS	FR POLYCARBONATE	47.4	0.054
CARGO LINER	CARGO LINER	EPOXY-FIBERGLASS	35.1	0.039
TRANSPARENCY	WINDOW COVER	FR POLYCARBONATE	46.2	0.052
INSULATION	THERMAL AND ACOUSTICAL INSULATION	MELAMINE-FIBERGLASS	2.28	0.5 *
ELASTOMER	SEAL	SILICONE	86.3	0.094

* Maximum thickness, flammability, (FAR 25.853) and smoke (NPRM 75-3) tests

TABLE 2. DESCRIPTION OF MATERIALS

No.	Chemical Composition	Thickness (in)	Unit Weight (oz/yd ²)	Designation	Cabin Use
1	PVF/Epoxy-Fiberglas/Aramid Honeycomb/Epoxy-Fiberglas	0.388	48.5	Panel	Ceiling panel
2	Epoxy-Fiberglas/Aramid Honeycomb/Epoxy-Fiberglas (No. 1 without PVF finish)	0.376	39.6	Panel	Ceiling panel
6	PVF/Aramid Fiber-Phenolic	0.048	56.4	Panel component	Face for sidewall or window reveal (upper surface)
6a	PVF/Aramid Fiber-Phenolic	0.050	58.4	Panel component	Face for sidewall or window reveal (lower surface)
9	Aluminum/Aramid Honeycomb/Aluminum	0.371	86.3	Flooring	Floor
10	Fiberglas-Polyester	0.039	35.1	Cargo liner	Side cargo liner
12	PVF/Polyester-Chopped Glass/Aramid Honeycomb/Polyester-Chopped Glass	0.525	90.4	Panel	Overhead stowage door assembly
14	PVF/Nomex-Epoxy/Aramid Honeycomb/Epoxy Fiberglas	0.532	49.7	Panel	Acoustic wall panel
15	PVF/Aramid-Epoxy (Acoustic Skin for No. 14)	0.015	9.75	Panel component	Face of acoustic wall panel
18	PVF (Clear Film)	0.001	1.11	Panel component	Panel finish
20	PVF/Epoxy-Fiberglas/Aramid Honeycomb/Epoxy-Fiberglas/PVF	0.958	82.8	Panel	Partition
24	Epoxy-Fiberglas/PVC/Epoxy-Fiberglas	0.410	117	Flooring	Floor
25	PVF/Fiberglas-Epoxy/PVF	0.051	76.7	Cargo liner	Cargo liner
26	Fiberglas-Epoxy	0.013	16.3	Cargo liner	Cargo liner
27	Melamine-Fiberglas	1.19	5.43	Insulation	Fuselage insulation
28	Aluminized PVF/Nylon Scrim	0.007	1.33	Insulation	Cover for insulation batt
32	Polycarbonate	0.054	47.4	Thermoplastic	Molded part
33	Wool Pile/Polyester Backing/Latex Coating	0.265	51.8	Flooring	Carpet
34	Wool Pile/Polyester Backing/Latex Coating/Urethane Pad	0.345	51.3	Flooring	Carpet
37	PVF/Phenolic-Fiberglas Screen/Aramid Honeycomb filled with Phenolic-Fiberglas Batt/Phenolic-Fiberglas	0.517	77.2	Panel	Center ceiling panel
38	Epoxy Coated Phenolic-Fiberglas (Backing for No. 37)	0.017	18.4	Panel component	Backface of ceiling panel
39	Epoxy Coated Phenolic-Fiberglas (Adhesive used in No. 37)	0.018	17.6	Panel component	Adhesived used in ceiling panel

TABLE 2. DESCRIPTION OF MATERIALS (Continued)

No.	Chemical Composition	Thickness (in)	Unit Weight (oz/yd ²)	Designation	Cabin Use
40	Aramid Honeycomb filled with Phenolic-Fiberglas Batt (Core for No. 37)	0.451	10.8	Panel component	Ceiling panel core
41	Epoxy Coated Phenolic Fiberglas (Screen used in No. 37)	0.038	15.3	Panel component	Screen used in ceiling panel
42	PVF (Acoustic Skin for No. 37)	0.015	12.7	Panel component	Ceiling panel finish
43	PVF/Phenolic-Fiberglas Screen/Aramid Honeycomb/Aramid Honeycomb filled with Phenolic-Fiberglas Batt/Phenolic-Fiberglas	0.732	85.8	Panel	Drop ceiling panel
46	PVF/PVC/Phenolic-Fiberglas/Aramid Honeycomb/Epoxy-Fiberglas	0.500	79.2	Panel	Upper sidewall panel
50	Wool Carpet/Phenolic-Fiberglas/Aramid Honeycomb/Epoxy-Fiberglas	0.445	95.0	Panel	Lower sidewall panel
52	Wool Carpet/Epoxy Adhesive/Aluminum/Balsa Wood/Epoxy Adhesive/Aluminum	0.690	198	Flooring	Floor panel
56	PVC/Stainless Steel/Epoxy Adhesive/Aramid-Phenolic Honeycomb/Epoxy Adhesive/Stainless Steel	0.490	168	Flooring	Floor panel
60	Epoxy-Fiberglas	0.018	22.9	Cargo liner	Cargo liner
61	PVF/PVC/Phenolic-Fiberglas/Epoxy Adhesive/Aramid Honeycomb/Epoxy Adhesive/Phenolic-Fiberglas	0.500	69.1	Panel	Overhead stowage panel
66	Silicone-Treated Phenolic-Fiberglas	1.38	6.09	Insulation	Fuselage insulation
67	PVC/Phenolic-Fiberglas/Aramid Honeycomb/Epoxy-Fiberglas	0.273	68.1	Panel	Door liner
69	PVF/PVC/Phenolic-Fiberglas/Aramid Honeycomb/Epoxy-Fiberglas	0.531	93.0	Panel	Door assembly
70	FR Wool (90 percent)/Nylon (10 percent)	0.037	11.3	Fabric	Upholstery
73	FR Urethane	0.500	17.4	Foam	Seat pad
74	FR Urethane	0.500	12.4	Foam	Seat pad
78	Aramid	0.046	12.1	Fabric	Upholstery
79	FR Polyether Urethane	0.500	13.7	Foam	Seat cushion
80	FR Urethane	0.500	11.3	Foam	Seat cushion
81	PVC (untreated)	0.096	25.3	Fabric	Upholstery
82	FR Wool (76 percent)/PVC (24 percent)	0.039	12.6	Fabric	Upholstery

TABLE 2. DESCRIPTION OF MATERIALS (Continued)

No.	Chemical Composition	Thickness (in)	Unit Weight (oz/yd ²)	Designation	Cabin Use
84	PVC/Cotton (untreated)	0.058	26.9	Coated fabric	Arm rest cover
85	ABS-PVC (untreated)	0.060	56.4	Thermoplastic	Seat side panels and trays
86	PVC (untreated)	0.500	28.8	Foam	Flotation cushion and padding for seat back and arm rest
88	FR Wool	0.055	17.2	Fabric	Upholstery
89	FR PVC/Nylon	0.059	26.3	Coated fabric	Seat arm cap
92	Aramid	0.036	11.8	Fabric	Upholstery
93	FR Cotton	0.012	3.06	Fabric	Upholstery
95	FR Rayon	0.041	15.4	Fabric	Upholstery
96	Wool (49 percent)/PVC (51 percent)	0.044	13.8	Fabric	Upholstery
97	FR PVC-Polyester	0.018	11.4	Coated fabric	Seat bottom diaphragm
99	FR PVC-Polymethyl Methacrylate	0.044	39.6	Thermoplastic	Seat shroud
100	FR PVC/ABS	0.092	86.9	Thermoplastic	Seat shroud
102	FR Polyethylene (rigid)	0.500	13.7	Foam	Flotation cushion
104	FR Polyester Urethane	0.500	40.1	Foam	Seat cushion
107	ABS-PVC	0.127	122	Thermoplastic	Molded part
108	FR Polymethyl Methacrylate	0.054	46.6	Transparency	Scratch shield
109	Polymethyl Methacrylate	0.260	228	Transparency	Window pane
111	Polycarbonate	0.052	46.2	Transparency	Windscreen
112	Silicone	0.094	86.3	Elastomer	Door seals
113	PVF/Polycarbonate/PVF	0.431	151	Thermoplastic	
115a	Phenolic-Fiberglas	1.09	6.40	Insulation	Fuselage insulation
116	Polycarbonate	0.043	36.8	Thermoplastic	Passenger service units and luminaires
117	Polyphenylene Oxide	0.041	31.4	Thermoplastic	Flight station and lavatory parts
118a	Fiberglas-Epoxy/Asbestos	0.020	28.9	Cargo liner	Cargo liner
123	Silicone	0.124	116	Elastomer	Door seals
127	Modacrylic	0.032	8.63	Fabric	Drapery
130	Cotton/Rayon	0.040	15.0	Fabric	Upholstery
136	PVC/Cotton	0.057	28.3	Coated fabric	Upholstery
142	FR Wool (90 percent)/Nylon (10 percent)	0.035	10.3	Fabric	Upholstery

TABLE 2. DESCRIPTION OF MATERIALS (Continued)

No.	Chemical Composition	Thickness (in)	Unit Weight (oz/yd ²)	Designation	Cabin Use
143a	FR Polyether Urethane	0.500	13.9	Foam	Seat cushion
143c	FR Polyester Urethane	0.500	38.8	Foam	Seat cushion
144	PVF/Epoxy-Fiberglas/Aramid Honeycomb/Epoxy-Fiberglas	0.276	43.3	Panel	Wall panel

ABBREVIATIONS

ABS - Acrylonitrile/Butadiene/Styrene
 FR - Flame-retardant treated
 PVC - Polyvinyl chloride
 PVF - Polyvinyl fluoride

TABLE 3. FLAMMABILITY AND SMOKE CHARACTERISTICS OF IMPROVED MATERIALS

DESCRIPTION	Thickness (in.)	FAR 25.853		SMOKE (NPRM 75-3)		ASTM E-162 Flame Spread Index (Is)	ASTM D-2863 Limiting O ₂ (%)
		Burn Length (in.)	Flame Time (sec)	D _s (90 sec)	D _s (4 min)		
MODIFIED NYLON	.035	2.5	0	9.9	23	-	-
NYLON FABRIC/NEOPRENE FOAM	.080/.130	12	330	49	117	193	-
	.040/.150	10	121	31	102	163	-
WOOL/NYLON	.035	2.5	3	75	163	-	-
	.035	2.5	6	48	96	-	-
NEOPRENE COMPANY A COMPANY B	0.5	-	-	52	147	-	-
	0.5	-	-	65	144	-	-
POLYCARBONATE COMPANY C COMPANY D	.065	3.3	2	4.2	58	23	-
	.090	-	-	4.4	78	88	32
POLYSULFONE COMPANY E COMPANY C	.060	-	-	0	7	19	32
	.070	-	-	3.7	13	25	-
POLYETHERSULFONE COMPANY F COMPANY E	.137	1.5	0	0	4.4	-	-
	.125	4.3	0	0	1.5	-	-
CHLORINATED PVC	.065	2.5	0	13	89	3.4	-
POLYVINYLIDENE FLUORIDE LAMINATE FILM	.004	2	0	12	13	-	48
	.004	5.6	0	-	-	-	28

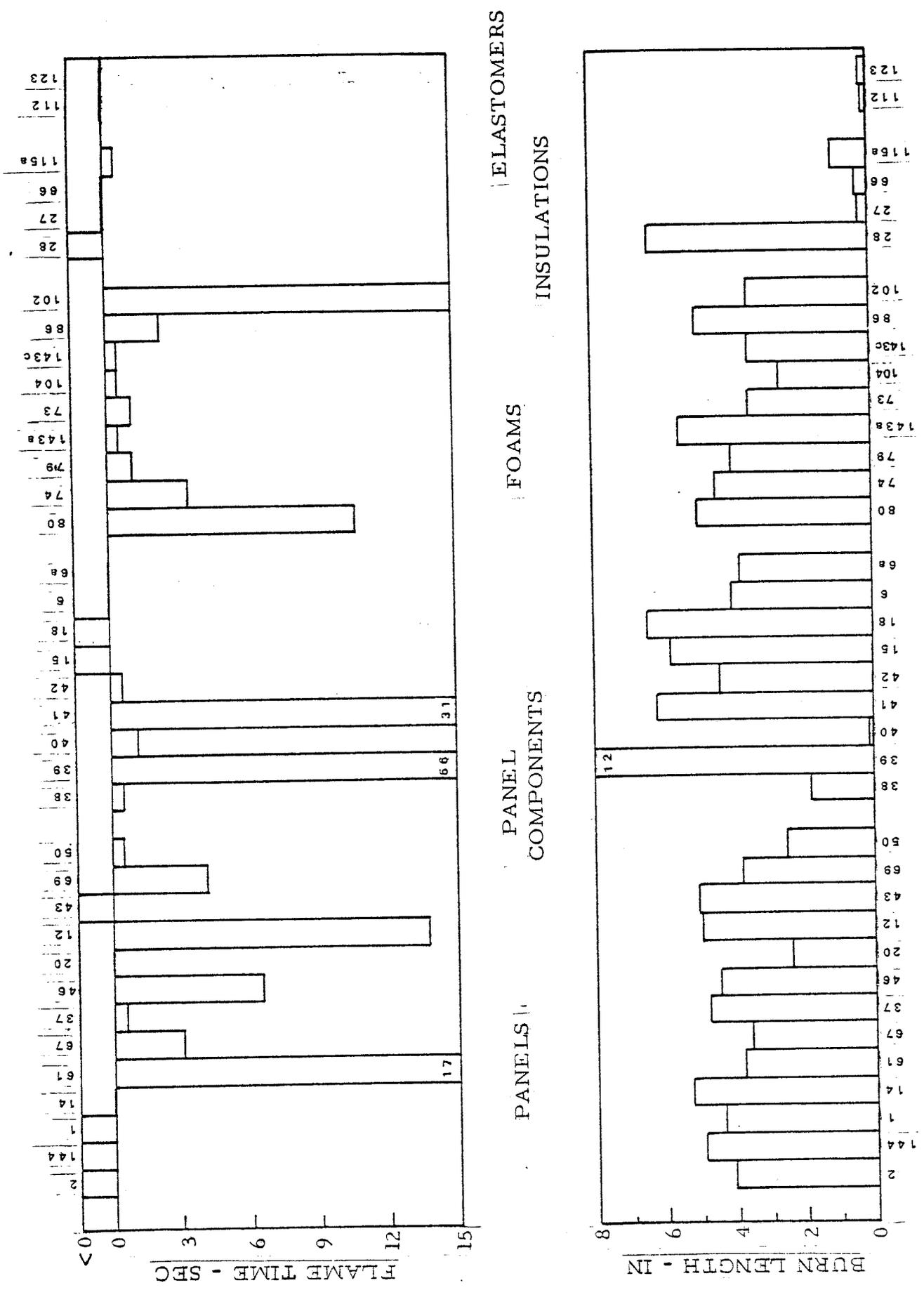
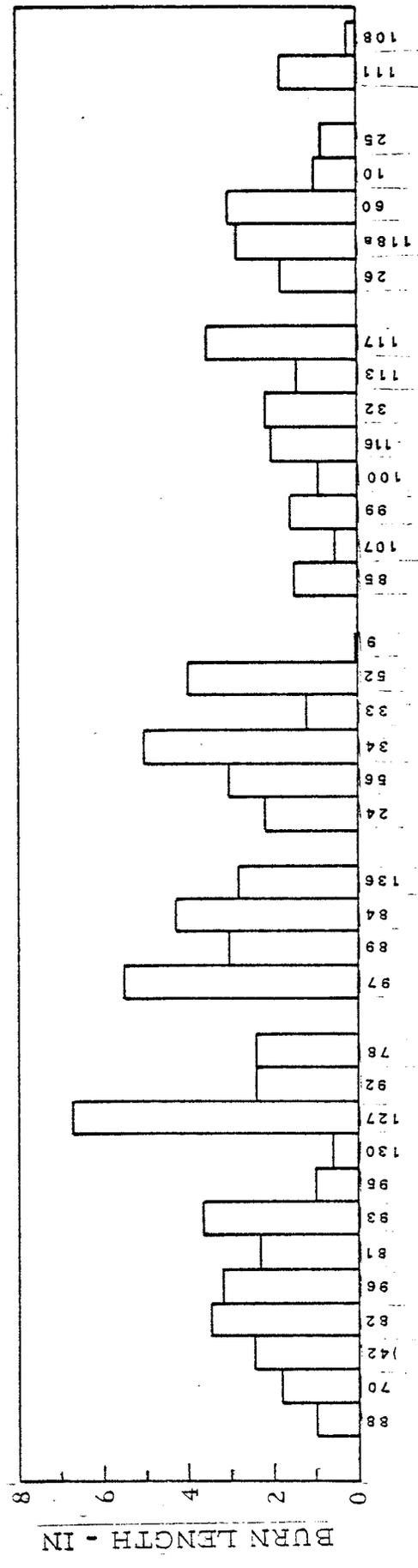
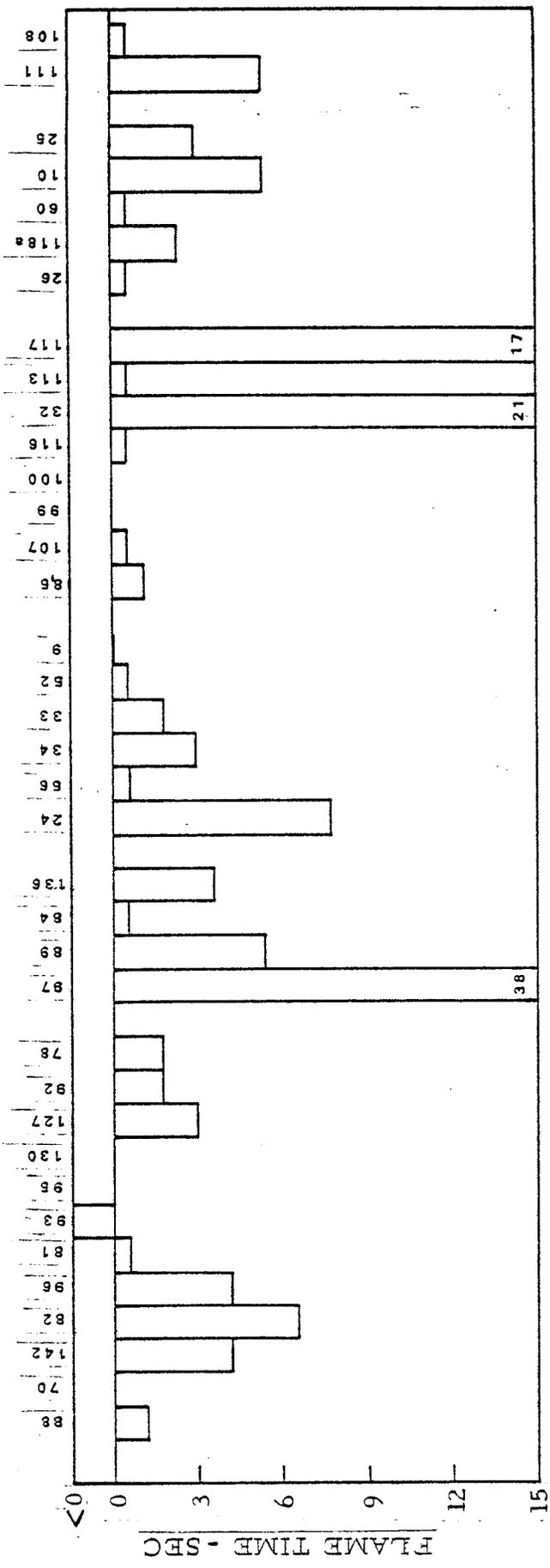


FIGURE 2. FLAMMABILITY CHARACTERISTICS OF 75 CABIN MATERIALS (SHEET 1 OF 2)

FABRICS | FLOORING | THERMOPLASTICS | CARGO LINERS | TRANSPARENCIE

FABRICS | COATED FABRICS

FABRICS



MATERIAL NUMBER

FIGURE 2. FLAMMABILITY CHARACTERISTICS OF 75 CABIN MATERIALS (SHEET 2 OF 2)

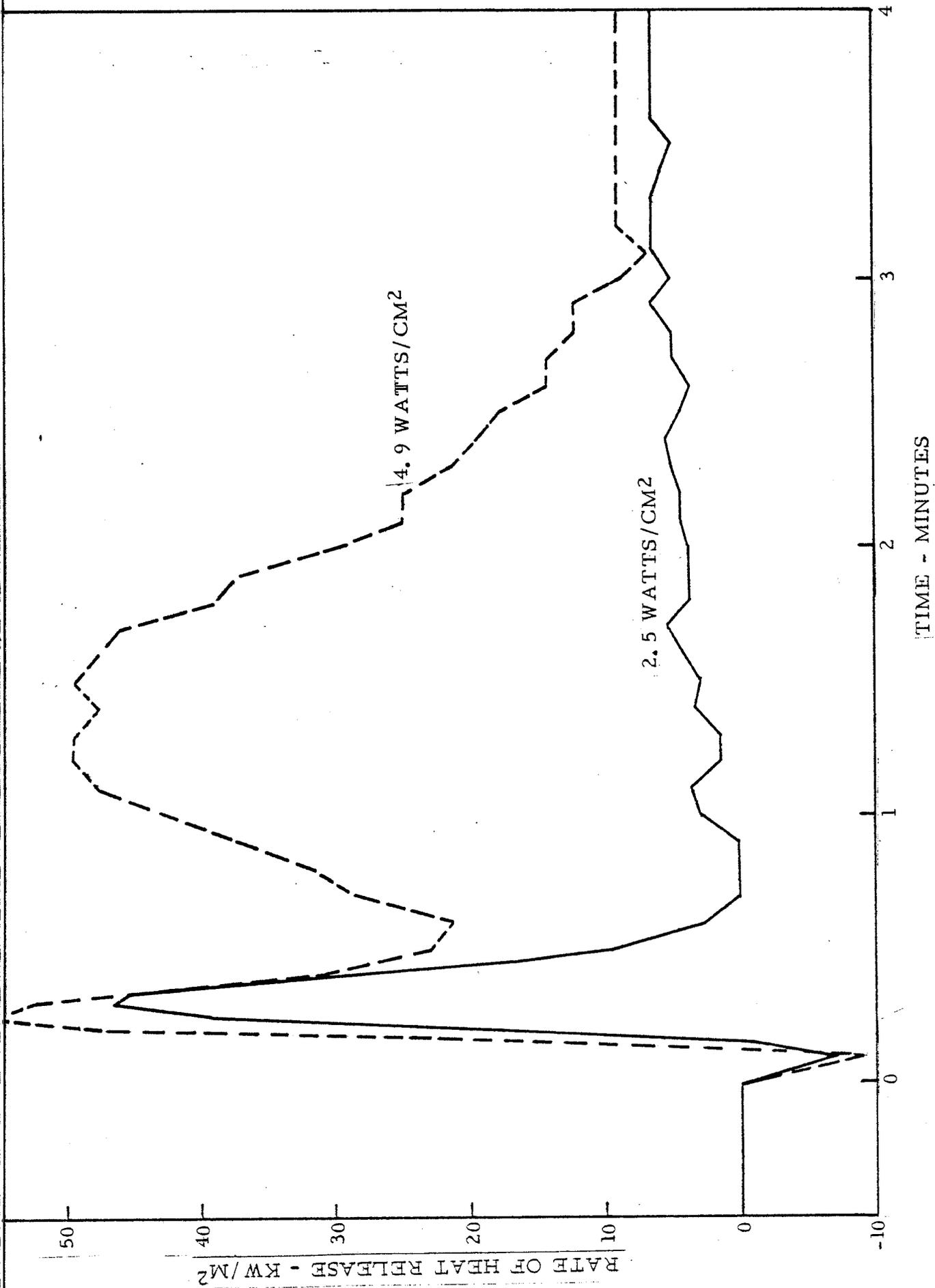


FIGURE 3. HEAT RELEASE RATE HISTORY OF CEILING PANEL AT DIFFERENT HEAT EXPOSURE LEVELS

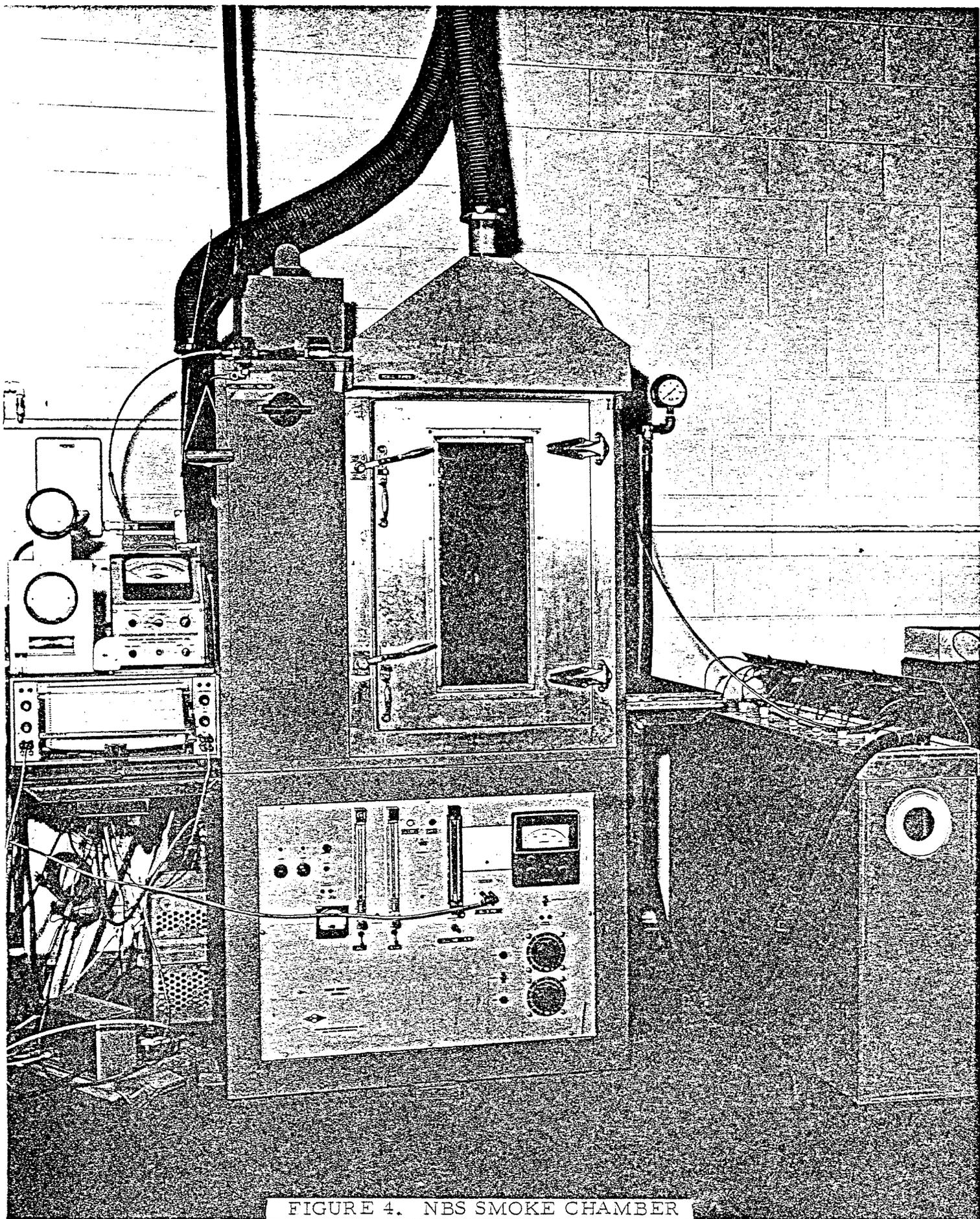
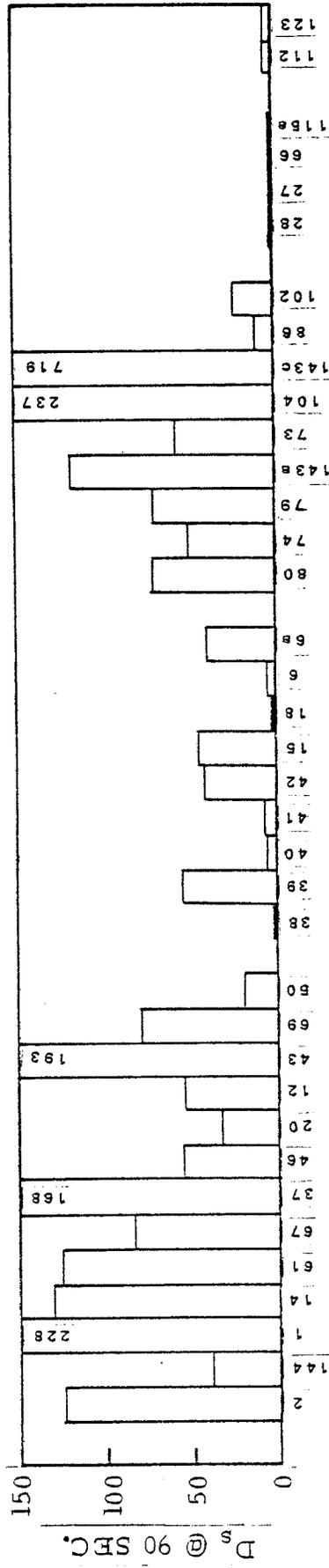
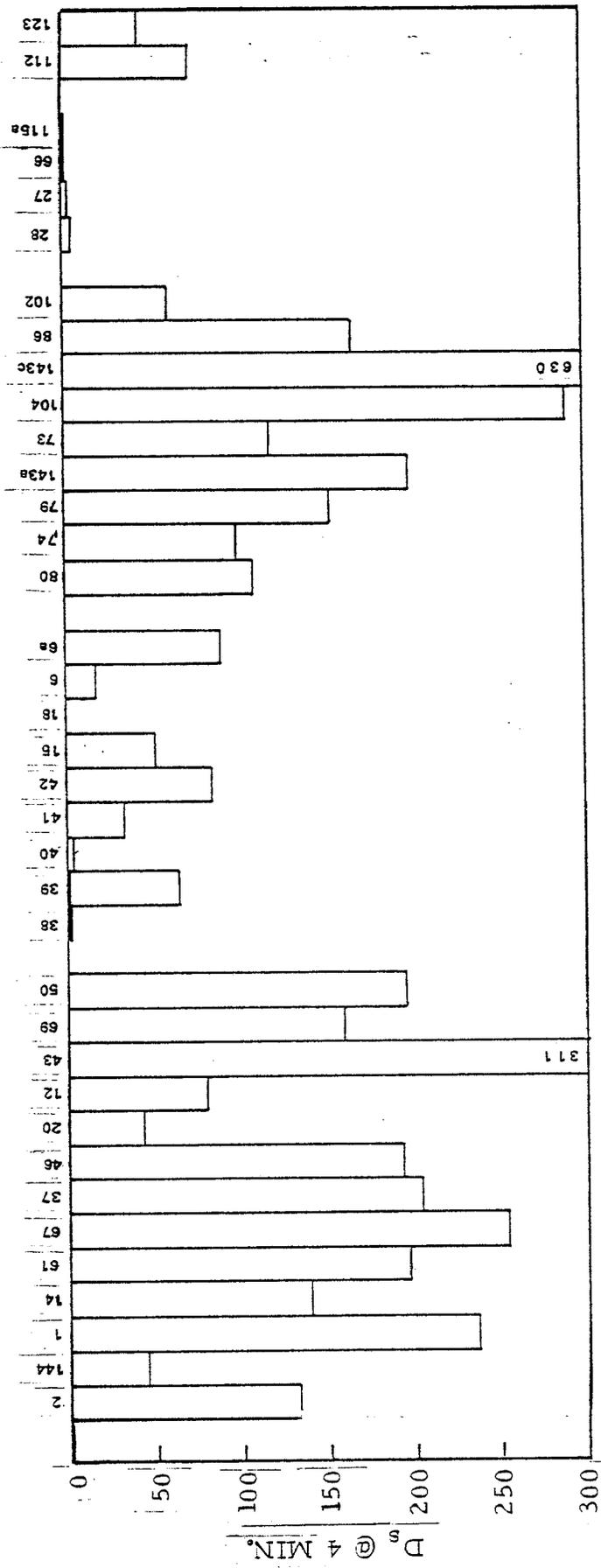
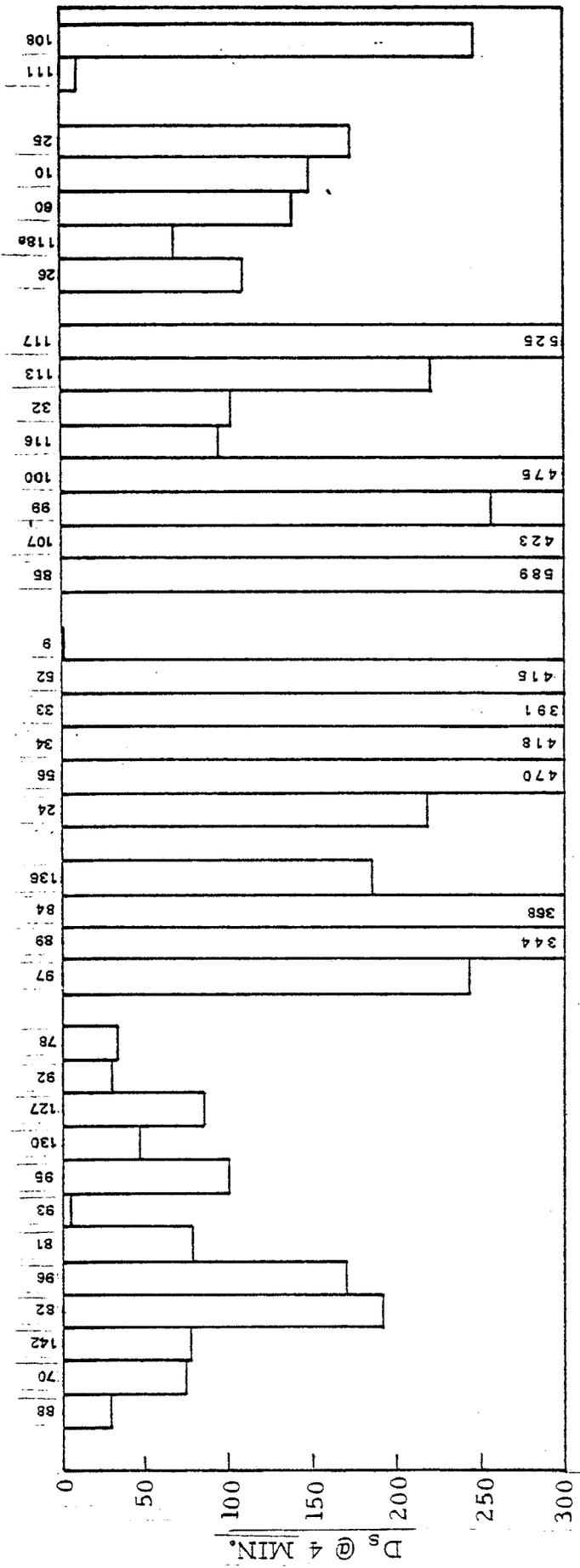


FIGURE 4. NBS SMOKE CHAMBER

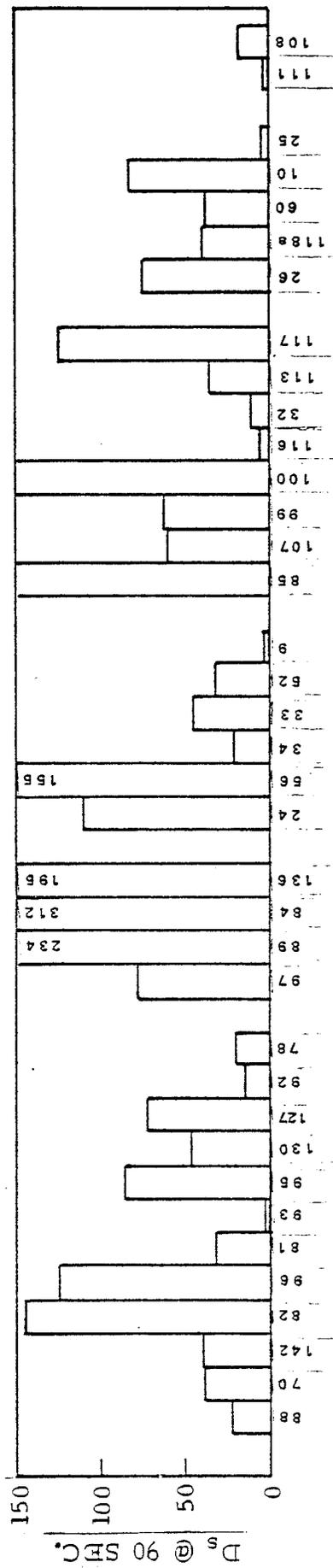


MATERIAL NUMBER

FIGURE 5. SMOKE EMISSION CHARACTERISTICS OF 75 CABIN MATERIALS (SHEET 1 OF 2)



FABRICS | COATED FABRICS | FLOORING | THERMOPLASTICS | CARGO LINERS | TRANSPARENCIES



MATERIAL NUMBER

FIGURE 5. SMOKE EMISSION CHARACTERISTICS OF 75 CABIN MATERIALS (SHEET 2 OF 2)

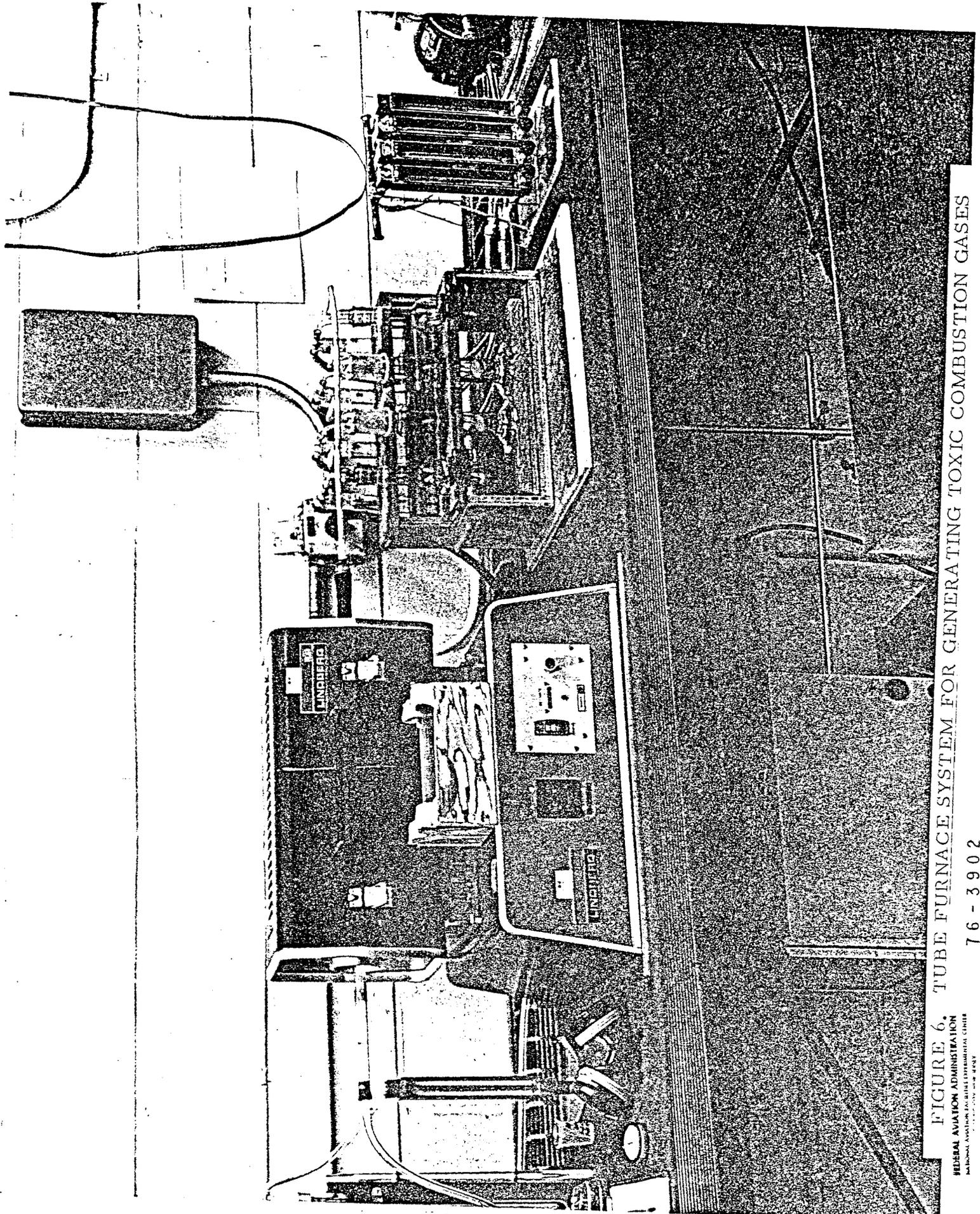
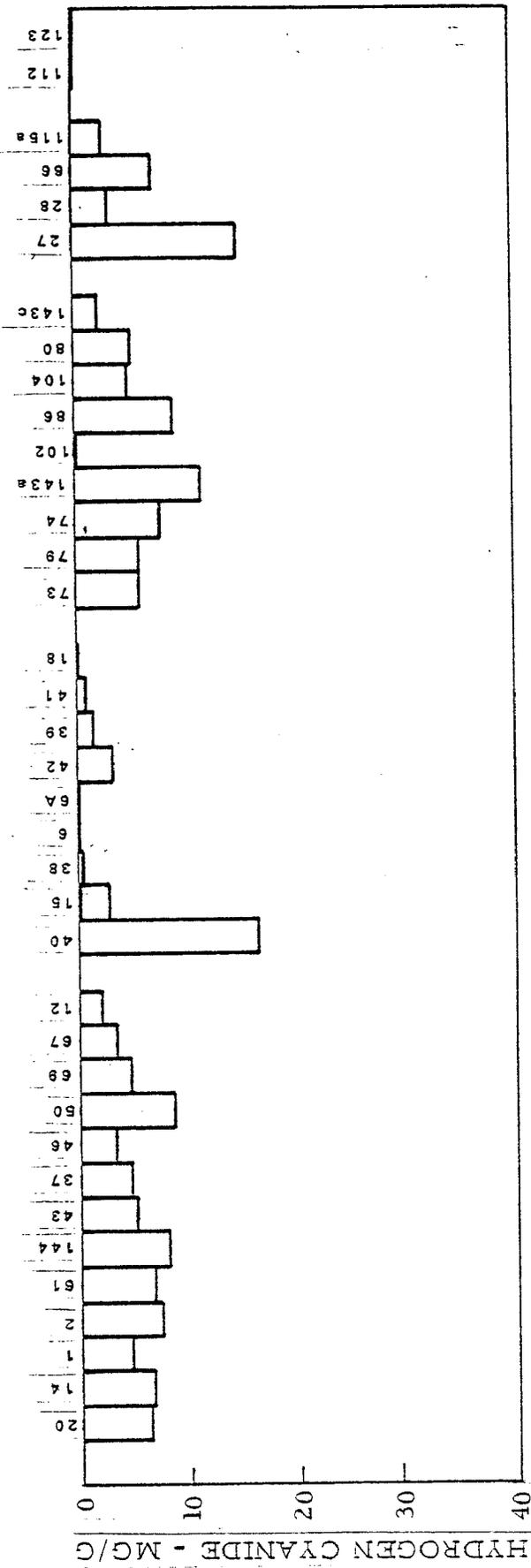


FIGURE 6. TUBE FURNACE SYSTEM FOR GENERATING TOXIC COMBUSTION GASES

FEDERAL AVIATION ADMINISTRATION
WILCOX AVIATION TOXICITY LABORATORY, CLEVELAND
OCTOBER 1964, PAGE 18

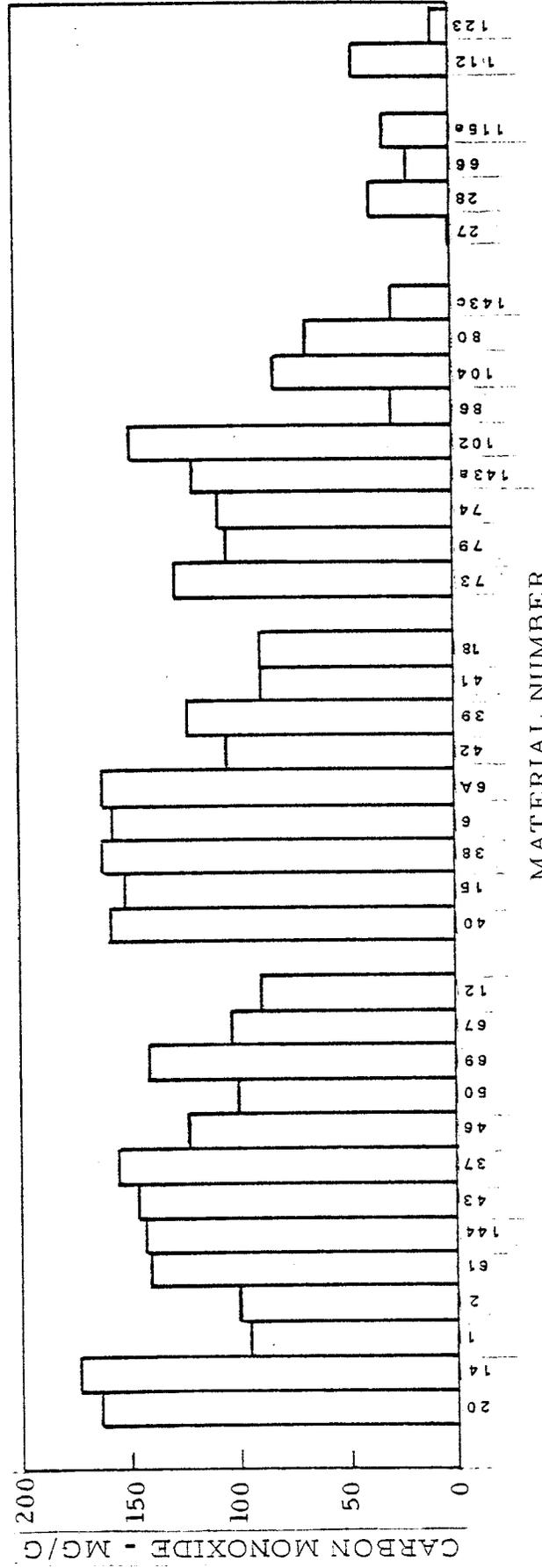
76 - 3902



ELASTOMERS
INSULATION

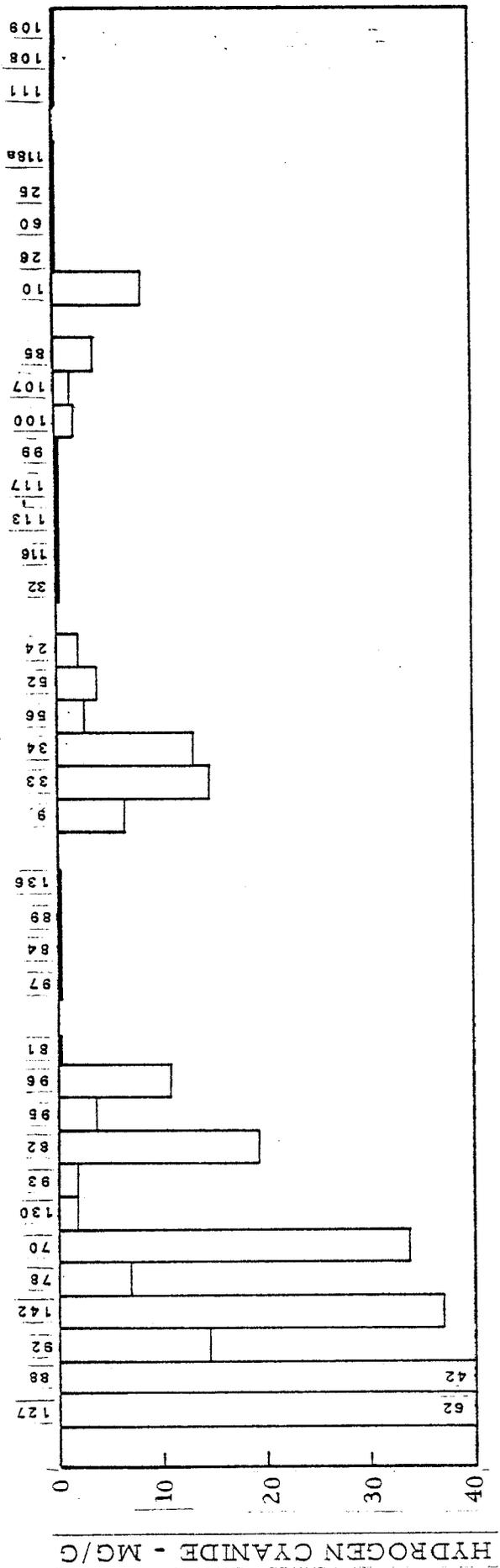
FOAMS
PANEL COMPONENTS

PANELS



MATERIAL NUMBER

FIGURE 7. TOXIC GAS EMISSION CHARACTERISTICS OF 75 CABIN MATERIALS (SHEET 1 OF 2)



CARGO LINERS

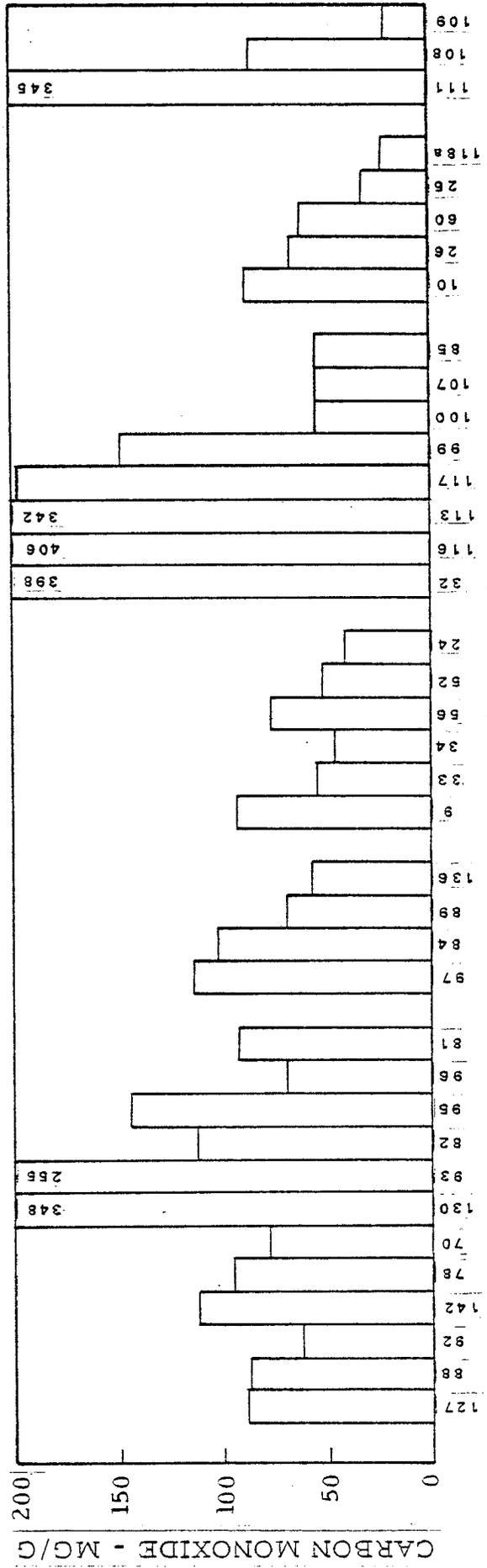
THERMOPLASTICS

FLOORING

COATED FABRICS

FABRICS

TRANSPARENCIES



MATERIAL NUMBER

FIGURE 7. TOXIC GAS EMISSION CHARACTERISTICS OF 75 CABIN MATERIALS (SHEET 2 OF 2)

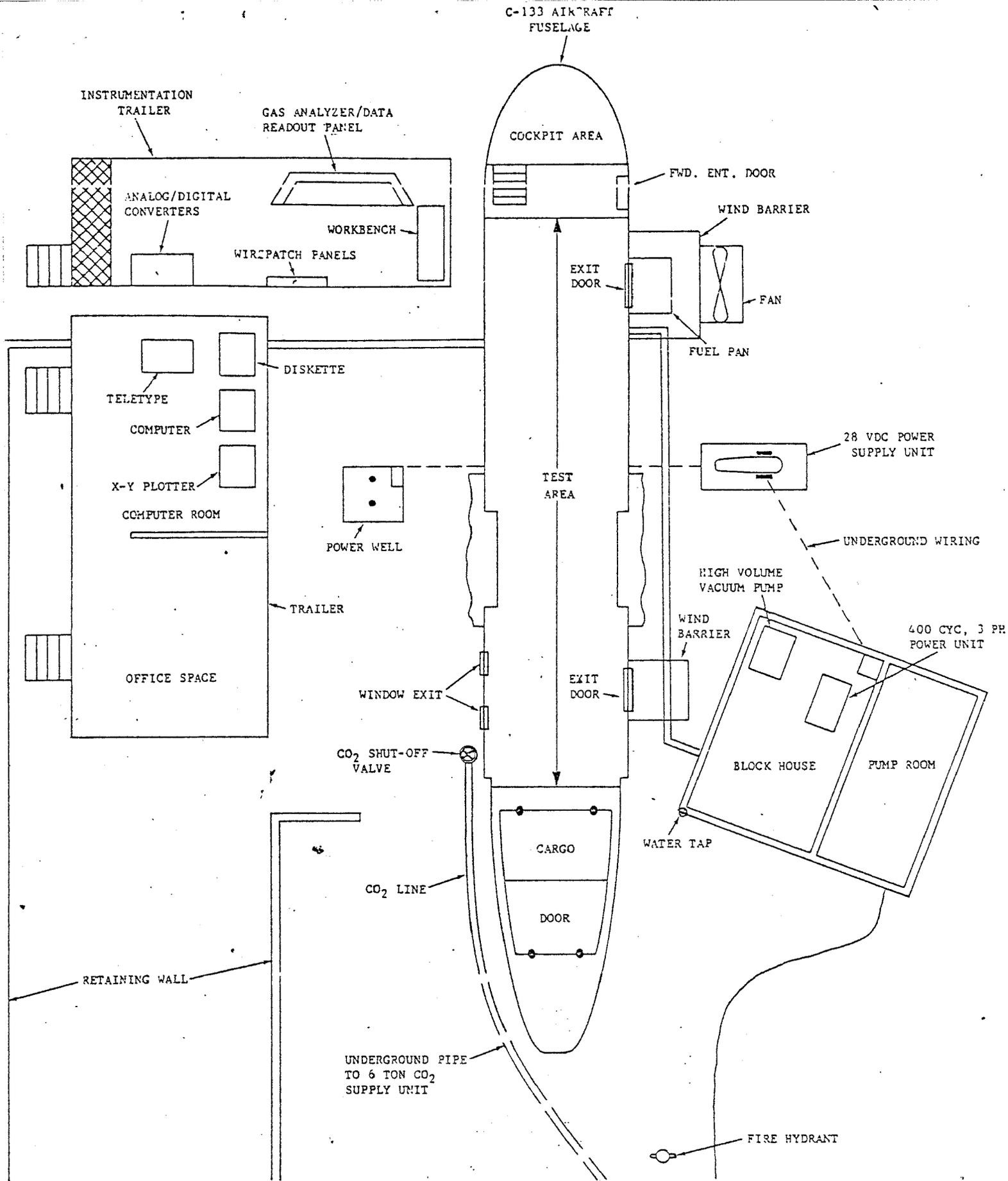


FIGURE 8. C-133 FIRE TEST FACILITY UNDER DEVELOPMENT.

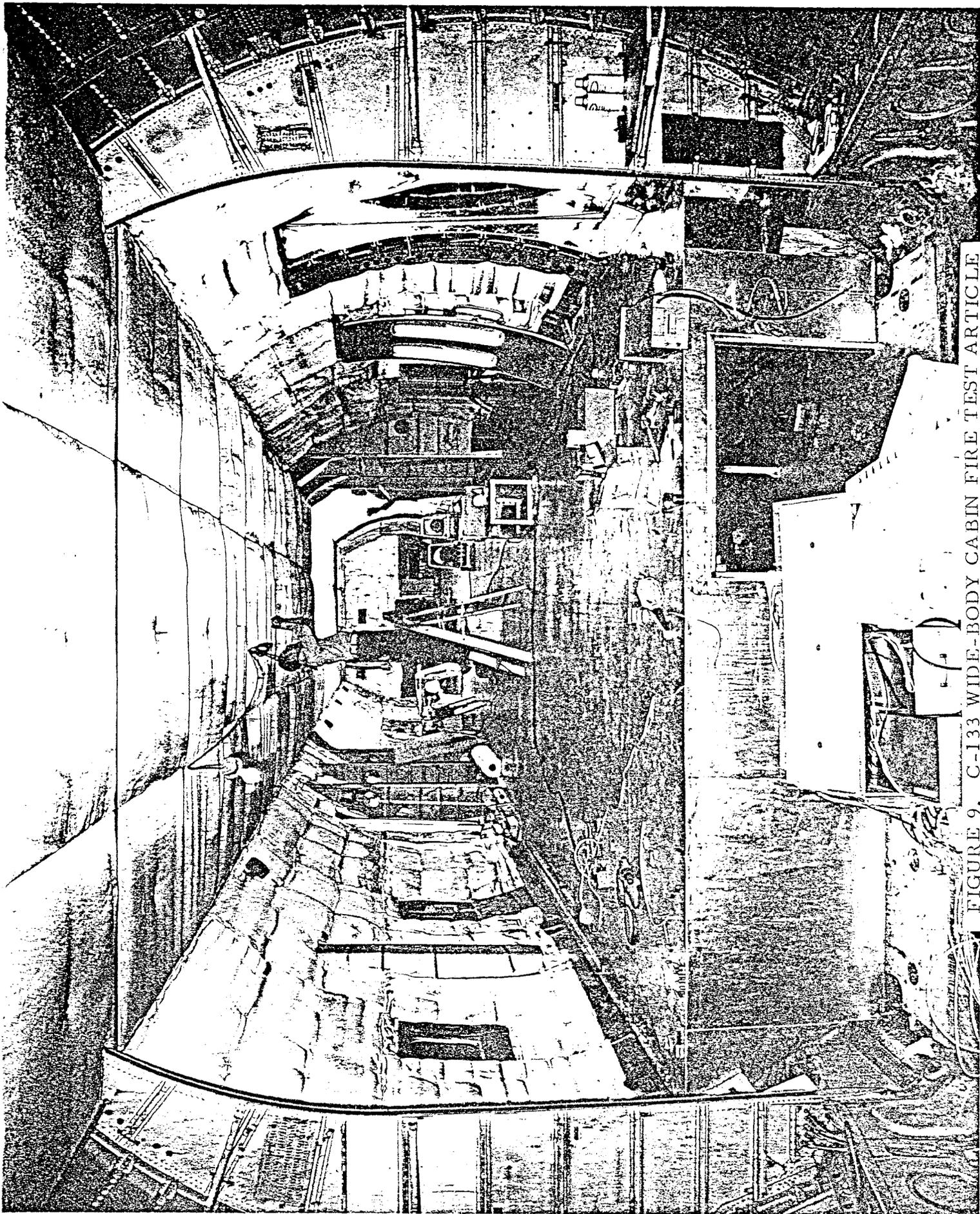


FIGURE 9. C-133 WIDE-BODY CABIN FIRE TEST ARTICLE

REPRODUCED FROM NASA REPORT

APPENDIX A

NA-77-53-LR

Distribution:

AED-1

ANA-1

ANA-2

ANA-4

ANA-5

ANA-64

ANA-100

ANA-200

ANA-300

ANA-400

ANA-500

ANA-600

ANA-700

ANA-420 (C. Sarkos) (30 copies)

ANA-523

ARD-1

AEM-1

AFS-1

ARD-520 (R. McGuire) (10 copies)

AFS-120 (H. Branting) (3 copies)