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TEST PLAN

PROGRAM AGREEMENT NO. 18-443

STUDY OF TOXIC GAS EMISSION CHARACTERISTICS OF BURNING CABIN INTERIOR MATERIALS

by
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Purpose

This document has been prepared to provide management and test personnel with information on the plan of action by ANA-420 in response to Request No. AFS-100-73-134 of the Flight Standards Service and ARD-522 Resume 183-522-03X dated March 22, 1973 and forwarded under ARD-1 letter to ANA-4 dated May 9, 1973.

Background

Work at NAFEC as early as 1963 was initiated to determine the combustible characteristics of aircraft cabin materials with the object of upgrading the FAR 25 flammability regulations first enacted in 1947. The primary goal was concerned with obtaining test data that could perhaps show the feasibility of reducing the maximum allowable burn rate of materials classified as "flame resistant" to 4 inches per minute or less. However, some concern was given to the smoke and toxic gas hazards of the materials. The test facilities of the National Bureau of Standards (NBS) were used in 1963 by NAFEC technicians to obtain the results contained in FAA Report ADS-3, dated January 1964. This report presented data on smoke emissions obtained from measuring the deposits of the particulate matter on a filter paper during the Radiant Panel Tests (ASTM-E-162). During these early tests, attempts were made to measure toxic gases without success. Since very large quantities of Polyvinyl chloride (PVC) plastics were used in commercial aviation for cabin interiors, HCl gas emission was of particular importance since large quantities of this gas could be expected because chlorine is the major constituent. The early tests showed that unless special precautions were taken soluble gases such as HCl, HCN, and NH_3 could be lost through absorption in the sampling lines before reaching the measuring apparatus.

The next attempt to measure toxic gases was made during the full-scale tests of a DC-7 airplane at NAFEC. The results of this study are contained in FAA Report ADS-44, dated December 1965, which presents toxic gas data. Infrared analyzers (Lira Model 200) were used to measure continuously CO concentrations simultaneously with the other cabin fire parameters of temperature, smoke, oxygen, and pressure. Bottle samples of the cabin air taken during the cabin fires measured incorrectly by a commercial laboratory did not show any evidence of toxic gases other than CO gas and unsaturated hydrocarbons. In addition to the DC-7 cabin tests, small-scale laboratory tests were conducted on individual samples of the interior materials installed in the airplane. In the later tests, colorimetric tubes attached directly to the pyrolysis chamber to minimize sampling line losses gave concentration readings in ppm of such gases as HCl, HCN, SO_2, $COCl_2$, H_2S, $NO + NO_2$, HF, and unsaturated hydrocarbons.

Following the B-727 survivable crash fire which occurred at Salt Lake City in November 1965, the project effort was reactivated and the scope of the work greatly expanded. More emphasis was placed on smoke emission produced by burning interior materials as a major life hazard. Survivors of the Salt Lake City fire had reported extremely dense smoke in the cabin which completely obscured their vision and made it very difficult to locate exit signs and openings during evacuation.

The NBS under an agreement with NAFEC conducted during the period of 1966-1968 both smoke and toxic gas tests simultaneously on some 140 representative materials either in use in aviation at that time or considered for future aircraft. The smoke measurements in terms of a specific optical density (D_s) and toxic gas measurements in terms of ppm in air inside an 18-cubic-foot chamber are contained in FAA Report NA-68-30, dated July 1968. Although a premature attempt was made at that time (FAA/AIA July 1968 Meeting) to use the data to establish acceptable smoke limits for rule making to bar from use the more smoky materials, the toxic gas data were to a large extent overlooked as a complication to the successful promotion of a smoke rule. An advanced Notice of a Proposed Rule Making (ANPRM 69-30) on smoke emission had been issued in July 1969 advising industry of FAA's intention to regulate smoke emission. This notice had a profound effect in stimulating interest in the problem of a uniform and valid method for measuring smoke and led to the adoption of the NBS Smoke Test Apparatus by the three major airplane companies as well as by the larger chemical companies. Extensive smoke test data furnished by Boeing, Douglas, and Lockheed through the Aerospace Industries Association (AIA) during the period of 1969-1972 were used to recommend to AFS-100 maximum allowable smoke limits (i.e., D_s of 100 in 90 seconds and from an analysis of the smoke data furnished by industry on some 250 materials contained in NAFEC Propulsion Branch Data Report No. 76 dated January 1971. Because effort was concentrated on first obtaining an early smoke rule, toxic gas work was not continued at that time either by NAFEC nor apparently by the aviation industry. This has resulted in a critical situation whereby toxic gas data for the newer materials used in the wide-bodied cabins are not available at this time.

During a series of fire tests with a 670-cubic-foot mockup in which complete seat assemblies, foam pads (10 pounds), and other materials were burned, CO readings were measured continuously with temperatures, smoke, oxygen, combustible gases, heat flux and pressure. In a few tests colorimetric tubes were used to measure HCl, HCN, NO_2, NH_3, and $COCl_2$. The results of this investigation into the nature of the flash-fire potential of materials are contained in FAA Report RD 70-81 dated December 1970.

Following the crash fires of a United Airlines B-737 at Midway Airport on December 8 and a North Central DC-9 at O'Hare Airport on December 20, numerous news items began appearing in the press alleging that medical records of the autopsied victims showed possible death as occurring from inhalation of HCN gas caused by the burning of interior materials, especially the urethane seat foam.

James Greenwood, APA-1, telephoned the Director of NAFEC on January 19 to ask for background information on the problem of toxic gas hazards and activities related to the study of the problem here that could be used to answer a news item appearing that day in the Washington Post. A status report titled "A review of NAFEC's Activities Related to Studies of Toxic Gases and Hazards in Air Transport Cabin Fires" was later prepared and forwarded to Public Relations Office (APA-1) in Washington.

AFS-120 personnel (H. Branting, A.J. Madayag, and R. Allen) advised the writer by phone that Flight Standards Service had decided to issue an NPRM on toxic gases (since revised to an ANPRM) and asked the writer to assist in formulating test criteria for specifying maximum tolerable toxic gas limits. The writer met with AFS-120 personnel on February 14-16 to review the toxic gas data contained in FAA Report NA-68-36 for the purpose establishing test criteria for rule making. Toxic gas limits obtained under the burning conditions of the NBS Smoke Test Apparatus were set for HCN gas at 20 ppm and HCl gas at 100 ppm. No limits were set for CO since all materials generate this gas as a natural process of combustion. Other toxic gases that occur less frequently were required to show levels of concentrations that would not be more lethan than the levels selected for HCl and HCN gases because of the lack of data. The following day at a joint meeting (See February 14-16 Trip Report) of AFS-100, AAM-100, and ARD-500 under the direction of H. H. Slaughter, presentations were made regarding the tentative toxic gas limits established the previous day. Tom Lee of the NBS discussed test procedures and the development of new analytical equipment for measuring the gases. Dr. Mohler of AAM-100 discussed CAMI's interest in the toxic gas hazards and the study sponsored by his division on the lethal effect found on rats exposed to various concentrations of toxic gases.

A joint meeting was held at NAFEC on March 21 with personnel of AFS-120, ARD-520, and ANA-400 to formulate a test program in response to the needs of Flight Standards Service. Program funding, schedules and goals were discussed and agreements were reached on the preparation and scope of a Form 9550 for AFS-120 to initiate a NAFEC agreement.

Objective

It is to be anticipated that a large number of tests, as previously performed to obtain the data for the smoke levels contained in the NPRM awaiting official release, will likewise be required to provide sufficient data on which to base toxic gas limits for future rule making. This is due to the very wide variety of plastic formulations represented by the interior construction and furnishings of passenger cabins as shown in the materials table contained in FAA Report NA-68-36. In order to set effective and realistic limits in terms of both providing adequate safety and taking full advantage of the latest developments in materials technology, it becomes necessary to evaluate a large number of materials covering the entire spectrum from those now in use to those that may be considered as promising candidate materials in the future. Toxic gas concentrations will be measured under both the flaming and smoldering conditions of combustion as provided by the 18-cubic-foot NBS smoke chamber using the latest analytical equipment. The data obtained on 3-inch-square sample materials in the nominal thickness used in the airplane, up to one-half inch in the case of seat foam, will be analyzed. Based on the data recommendations will be made to Flight Standards Service for an appropriate test procedure. Maximum allowable limits in ppm in air of the major toxic gases will be provided to AFS-120 for rule making. A ceiling on toxic gas emission will bar certain types of plastics which generate large quantities of HCl and HCN, such as for example the chlorinated vinyls and modacrylics. An essential part of the test program demands that the responsible engineer keep abreast of new developments in polymer chemistry that point to the future availability of safer materials that are still practical and competitive with present cabin materials. This type of expertise can best be achieved by maintaining close personal contact and cooperation with engineering personnel of the major chemical companies; the airplane companies - Boeing, Lockheed, and Douglas; the technical societies - NFPA and ASTM; other government agencies and through a literature search for new products in magazines such as Modern Plastics. Recent efforts to establish a maximum ceiling of 20 ppm of HCN for an NPRM ruling on toxic gases illustrates the process whereby such numbers are selected. An analysis of the NBS toxic gas data on the 140 materials tested had shown that although some materials such as the modacrylic fabrics and rugs exceeded by several times the 20 ppm ceiling, recent materials development made to meet improved flammability requirements,has made it possible to eliminate this material from use in aircraft. Another important consideration is that the toxic gas measurements utilizing the NBS apparatus are based on unit area rather than unit weight of the test specimen. This permits the use of materials such as those serving a decorative purpose as a thin section or as an overlay onto possibly a honeycomb or aluminum panel which otherwise would be barred as too toxic in a thicker specimen.

No tests with animals inside the NBS chamber during the emission of toxic gases are being contemplated at this time. Such tests are planned by the University of Utah under a RANN 2-year and three-quarter million-dollar grant.

Toxic gas tests on animals such as contained in CAMI's Report FAA-AM-71-41 dated November 1971 are of interest in attempting to set maximum concentration levels for rule making that are not only practical but also safe.

Test Facilities and Instrumentation

The fire test facility in building 203 will be modified and expanded to conduct the analysis of toxic gases generated inside the presently available NBS-AMINCO Smoke Measuring Test Apparatus.

The concentration of the toxic gases resulting from the burning of the 3-inch-square test specimens inside an 18-cubic-foot chamber will be measured by (1) Drager Colorimetric tubes; (2) Orion Specific Ion Detectors; (3) Perkin-Elmer Model 267 Infrared Spectrophotometer; and (4) Mine Safety Appliances, MSA Infrared CO gas Recorder, Model 200.

Test Specimen Materials

Initially materials will be selected from those now installed in the wide-bodied jet transports. Toxic gas data are lacking for the more recent materials introduced in aviation since completion of the NBS 1966-1968 tests. The assistance of Boeing, Lockheed, and Douglas engineers will be needed to assure that a representative sampling of all modern materials intended for aircraft will be furnished to NAFEC. It is estimated that the total of materials tested will be limited to 60 or less. In addition, as the test program progresses, materials furnished by industry that appear promising substitutes will also be evaluated.

Test Procedures

Preparation and burning of the test specimens will be conducted in the same manner as with the smoke tests. Smoke density measurements will be made simultaneously with the toxic gases readings. The only continuous measurements of toxic gases now available is that of CO gas. In order to obtain a time-history for other gases, it will be necessary to make individual measurements either using the tubes or using the ion detectors at various intervals of time such as at 1.5, 3, and 5 up to a maximum of 20 minutes. The colorimetric tubes as with the NBS 1966-1968 tests for NAFEC is expected to furnish most of the toxic gas data because of its relative simplicity of operation. The specific ion electrodes will be used as a backup measurement for HCl, HF, and NH_3 gases which readily ionize in water solutions. The IR spectrophotometer will also be used as a back-up instrumentation. This instrument is not selective of any particular component gas as the other two measuring devices. This instrument provides an absorption spectrum of all gases in the total mixture sampled and thus in effect provides an individual signature for each material. From a knowledge of the fluency at which different gases absorb radiation, it is possible to identify the deflections in the percent transmission curves and relate these both qualitatively and quantitatively to a particular gas. Thus, this type of record is useful in isolating gases that may not be suspected.

Since the emission of gases is not only dependent on the combustion process but also on the composition of the surrounding atmosphere, some tests should be made at lower than 21-percent oxygen to simulate an oxygen starved fire. This can be done by introducing nitrogen gas into the NBS chamber.

A. Laboratory-Scale Tests

Toxic gas measurements using the more sophisticated analytical devices (i.e., the specific ion current measurements and the IR radiation absorption spectra) are new to NAFEC personnel. Training in the use of such equipment is needed since its proper operation requires a knowledge of chemistry and skills in the handling of chemical solutions for the pH readings. Procedures for conducting several tests simultaneously on a number of different toxic gases have not as yet been formalized. Due to the relatively long list of possible candidate materials to be investigated within an 8-month period, it will not be possible to conduct very extensive tests on any one material to characterize its decomposition products completely. These products are extremely numerous and complex as shown in the NASA-Houston R&D off-gassing studies of spacecraft materials.

A minimum of six tests, three under flaming and three under smoldering combustion, will be conducted on each specimen using the Drager tubes. An IR spectrogram will be taken for each of the two modes of combustion on each specimen. The spectrograms will be scanned to identify the major individual gas components of the air sample. In addition to CO gas which will be recorded continuously, the major toxic gases to be measured will be HCl, HCN, $COCl_2$, HF, SO_2, NO + NO_2, NH_3, and H_2S. All these gases, with the first two predominating, were reported by NBS in the 1966-1968 tests for the cabin materials. Other gases may be present such as acrolein, hydrocarbons, and aldehydes. However, these are not expected to cause a severe toxic hazard. But, since many unusual chemical additives are used in the formulation of plastics to make these flame retardant or improve their properties, caution should be exercised against the possibility that a new toxic gas substance is not introduced in cabin fires. Knowledge of the material formulation can serve to pinpoint the presence of a suspected decompostion gas so that it is most important that the chemical composition of materials tested should be as complete as possible.

B. Cabin Mockup Large-Scale Tests

Toxic gas measurements will be conducted at different heights and locations inside a wide-bodied cabin mockup. Test specimens varying in surface area from 1 to 9 square feet such as floor, sidewall, divider, and ceiling panels as well as cabin furnishings including seats will be subjected to flaming and radiation fire exposure both singly and in combination. The test procedures will be similar to those used in the Lockheed-California study of smoke emission in the L-1011 mockup, except that toxic gas detectors will replace the smoke detectors except for the one overall smoke detector extending 9 feet in height from the floor to the ceiling. A minimum of four detectors placed 3 feet and 6 feet above the floor at the center and at one end of the mockup would be desirable. MSA LIRA gas recorders would be used to measure CO gas continuously as in previous NAFEC large-scale tests. Specific ion detectors would be used to measure HCl, HCN, HF, etc. as described in USAAMROL Technical Report 72-52, dated November 1972, covering large-scale helicopter tests conducted by Arthur D. Little, Inc. for the U. S. Army, Fort Eustis, Virginia.

Funding and Schedules

Preparation for the activity including purchase of equipment and supplies, training of NAFEC personnel at NBS, and contact with the aircraft industry to obtain cabin materials was completed in April 1973. Starting date for the test program, provided that cabin materials and analytical equipment are available, is forecast as of July 1973.

Funding for the balance of Fiscal Year 1973 to purchase equipment and supplies is approximately $15,000.

Completion of the laboratory-scale tests is scheduled for February 1974. However, procurement delays have already occurred from lack of funding which may extend this date.

Completion of the mockup-scale tests, unless run concurrently with the NAFEC laboratory tests by a contractor, is scheduled for December 1974. This is a very tight schedule reflecting the urgent need for the data by Flight Standards Service to implement a toxic gas rule at the earliest possible time.

It is estimated that $25,000 would be needed for preparing a suitable cabin mockup and providing the necessary instrumentation to conduct the tests in-house. Cost to contract this effort is estimated at $75,000 and could be completed by July 1974.

Manpower

It is estimated that 4.0 MY engineering and technician time would be allotted to this activity. An additional 3.0 MY would be needed to set up and conduct the mockup-scale tests simultaneously with the laboratory-scale tests.