PROPOSAL OF UNDERWRITERS' LABORATORIES, INC.

Study of Smoke Emission From Burning Aircraft Cabin Materials and the Effect on Visibility in a Wide Bodied Jet Transport

to

Federal Aviation Agency
RFP No. NA00-1-33 (PRN-1-618)

Closing Date: July 15, 1971

Part I - Technical Proposal

I. INTRODUCTION

The hazard from smoke generated by fire in occupied spaces has long been recognized and widely discussed. It is generally accepted that impairment of vision, through either light obscuration or eye irritation, is the most significant physical deterrent to escape during the early stages of fire. This is true particularly for fire within a passenger air transport cabin which is normally occupied by a relatively large number of persons who must be evacuated rapidly in the event of fire.

Numerous laboratory and field experiments have demonstrated that materials used within aircraft cabins produce large amounts of smoke quickly under fire exposure (1-6). In the interest of promoting greater safety for aircraft passenger, it is pertinent therefore to consider means for limiting aircraft interior materials to those of low smoke-producing potential. This produces requirements then for a test method to measure the smoke generating characteristics of materials, and for techniques to translate test results into predictions of visibility in aircraft cabins under actual fire conditions.

The present state of knowledge of test methods for smoke generation and their relationship to real fire conditions has recently been reviewed by a Task Group of ASTM Committee E-5, Sub IV (7). Although conclusions about the value of specific test methods were not possible there, the review does provide a well-documented overview of the current state of affairs. Perhaps the most significant need expressed is for large-scale tests through which the true hazard of smoke and meaningful endpoints can be defined.

The program proposed here is directed at filling that need for the specific case of aircraft cabin fires. The experiments proposed are in essential agreement with those suggested in the Request for Proposal, and have the main objectives of:

1.) Determining the applicability of specific optical density as measured in the NBS Smoke Chamber (8) to the prediction of smoke developed in a mock-up of a wide-body aircraft cabin. Particularly sought is a measure of the appropriateness of the scaling relationship for optical density represented by

$$D = D_s AL/V$$

where D_s is the measured specific optical density and D is the optical density over the path length L when smoke from sample area A is uniformly distributed over volume V.

4. Changes in the smoke after generation (settling, deposition, agglomeration) are independent of sample size, or volume and shape of enclosure.

5. Human vision through smoke is uniquely related to optical density measured photometrically.

If the above assumptions prove valid, then the application of D_s measured in the smoke chamber to real fires requires that the fire exposures used in the chamber bear predictable relationships to the real fire exposures.

Gross, et al (8) and Bowes and Field (11) have evaluated Assumptions 2, 3, and 4 collectively, under conditions of good mixing within the smoke enclosure. Although the experiments cannot be considered exhaustive, the results do provide a measure of confidence in those assumptions for volume ratios up to about 14 and sample area ratios up to about 15.

It is well to emphasize that forced mixing will usually be required in a large chamber if Assumption 1 is to be satisfied. For a situation wherein free convection is the sole driving force for transport of smoke throughout an inclosure, it may be expected that large gradients of smoke concentration will exist, particularly during the initial stages of the fire when the rate of heat release may be small. The effects of such gradients, particularly those due to stratification, may be expected to far outweigh the effects of any deviations from Assumptions 2, 3, and 4 during incipient fire conditions.

Numerous studies have been reported of the relationship between optical density and human vision through smoke. The results of some of these are summarized in Table 1. While there seems to be some agreement for a value of optical density of around 0.8-1.0 as the limit of visibility, Table 1 appears to be far from conclusive. For example, the correlation of Rasbash indicates a very strong dependence on viewing distance and the results of Shern and Operation School Burning differ greatly although both used wood smoke. Also, the apparent agreement of Operation School Burning with Bono and Breed may be fortuitous, since the observers were directly exposed to the smoke in the former but not in the latter work.

As mentioned, the use of specific optical density as determined in the NBS Smoke Chamber, to predict smoke produced under real fire condition requires that there be a predictable relationship between exposure conditions in the chamber and in the real fire. Unfortunately, little experimentation has yet been performed to determine possible relationships between various test methods for smoke and real fire conditions. The most definitive

TABLE 1

CRITICAL SMOKE LEVELS

Source	Burning Material	Viewing Distance (ft.)	Optical Density	Criterion Applied
Rasbash* (12)	Various	10 15 20	.96 .52 .42	(Empirical correlation of visibility of illuminated objects)
Kingman, et al (13)	Wood	2	1.30	Visibility of sign held 4 ft. away and illuminated by hand-held lamp in smoke filled room
Shern (14)	Wood	10	.13	Apprehension in observers without OBA in smoke-filled room
Gross, et al (8)	--	10	.80	Assumed value
Operation School Burning (15)	Wood	25	.70	Visibility and irritation - observers in smoke filled corridor
Bono and Breed (16)	Various	11.3	.82	Observation of exit signs from outside smoke filled room

*Correlation: $V = 1.40/D^{.767}$

where D is optical density per meter

V is distance of vision in meters

work is that of Christian and Waterman (17) who measured smoke produced by a number of interior finish materials in full-scale fires in a room-corridor arrangement, and compared the results to smoke measurements performed by various standard test methods. Their data indicated that of the methods studied, the Steiner Tunnel best represents the smoke produced by a fire which is spreading over the material of interest, while the NBS Chamber best represents the smoke produced when the material is completely engulfed by fire. This would indicate that the flame spread rate, which is accounted for in the Steiner Tunnel, can have an important influence on the amount of smoke produced in certain situations. It is pointed out, however, that the work of Christian and Waterman (17) was performed with fully developed room fires, and may not be strictly applicable to the early fire stages in an aircraft cabin. Nevertheless, it is well to note that application of small-scale smoke measurements to full scale may require consideration of the flame spread characteristics of the materials involved, as well as their smoke producing potential.

This question of the relationships between the conditions of fire exposure within the Smoke Chamber and in real fire situations, though extremely important, is outside the scope of the present proposal.

C. Scaling of Optical Density

The aforementioned scaling relationship for optical density

$$D = D_s AL/V \qquad (5)$$

has been derived on the assumption of perfect mixing of the smoke within volume V. Therefore any experimentation to evaluate the accuracy of scaling will have to take account of two separate effects, namely

1. deviations from Eq. 5 for perfectly mixed systems

2. deviations from perfect mixing

It would appear worthwhile to investigate these effects separately.

In perfectly mixed systems, three separate aspects of scaling are involved - - - the effects of optical path length (L), of dilution (V), and of sample area (A). There seems little reason work is that of Christian and Waterman (17) who measured smoke produced by a number of interior finish materials in full-scale fires in a room-corridor arrangement, and compared the results to smoke measurements performed by various standard test methods. Their data indicated that of the methods studied, the Steiner Tunnel best represents the smoke produced by a fire which is spreading over the material of interest, while the NBS Chamber best represents the smoke produced when the material is completely engulfed by fire. This would indicate that the flame spread rate, which is accounted for in the Steiner Tunnel, can have an important influence on the amount of smoke produced in certain situations. It is pointed out, however, that the work of Christian and Waterman (17) was performed with fully developed room fires, and may not be strictly applicable to the early fire stages in an aircraft cabin. Nevertheless, it is well to note that application of small-scale smoke measurements to full scale may require consideration of the flame spread characteristics of the materials involved, as well as their smoke producing potential.

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In perfectly mixed systems, three separate aspects of scaling are involved - - - the effects of optical path length (L), of dilution (V), and of sample area (A). There seems little reason to doubt that optical density is proportional to path length for a uniform suspension of smoke particles. Dilution of the smoke, on the other hand, involves changes in both the smoke concentration and the rates of settling and agglomeration, and deviations from the simple scaling law are to be expected. Large deviations were observed by Gross et al (8), particularly for very dilute smoke from non-cellulosic materials, and not all of these can be attributed to coagulation and settling.

Perhaps the greatest uncertainty is application of Eq. 5 to perfectly mixed systems will be with respect to the sample area A. A number of factors enter into this uncertainty. First, in the NBS Smoke Chamber it is possible to achieve a nearly uniform radiant heat flux over the entire sample area because the sample is rather small. The practical matter of constructing a suitable radiant heater will probably prevent comparable uniformity of heating with larger samples. Second, the availability of oxygen at the sample surface will certainly vary over the sample area, probably decreasing from bottom to top, and the variation will be much more pronounced for large samples than for the standard sample. Third, edge effects, if any, will differ for large and small samples since the perimeter to area ratio is inversely proportional to the sample dimension. Fourth, the effect of the pilot flame during flaming-ignition experiments in the NBS Chamber may not be duplicated in the large scale experiments. For example, if the pilot flame is scaled up to maintain the local heating of the sample lower edge constant (heat input proportional to edge length), then the heat input from the burner per unit sample area will be smaller for large samples than for small samples. All of these factors ... non-uniformity of heating, oxygen availability, edge effects, and pilot burner effects ... will cause the smoke generation per unit sample area to depend upon sample area to some degree.

It would appear therefore, that large deviations from Eq. 5 may be observed because of the effects of dilution and sample area in perfectly mixed systems. In order that these effects may be observed and identified, it will be necessary to perform experiments with large samples in a large enclosure with artificial mixing of the atmosphere. In this way the effects of imperfect mixing will be eliminated. A number of such experiments are included in the program proposed in the following section.

As mentioned previously, incomplete mixing and stratification of smoke within a large enclosure may cause the most significant departures from Eq. 5. These effects will be greatest when there is no forced airflow in the enclosure and free convection alone generates smoke movement and mixing. Introduction of airflow (simulating air conditioning of a cabin) will have two effects ... mixing and dilution of the smoke. Because air conditioning systems for aircraft involve high air flow rates (20-30 air changes per hour), it is expected that the air conditioning system will have a substantial effect on the smoke distribution within the cabin. Experiments with and without airflow are included in the proposed program.

III. PROPOSED PROGRAM

A. Standard Laboratory Tests

Thirty materials will be selected as representative of those used in aircraft passenger cabins in the following areas: floor, sidewall, ceiling, seat, window, and drapery. These will be subjected to smoke and flame spread tests using the Aminco commercial version of the NBS Smoke Density Chamber and a standard vertical flame spread tester. The proposed standard method for smoke measurement (ASTM) will be followed using 6 samples of each material, 3 each at flaming and nonflaming conditions. Flame spread will be determined according to Federal Specification No. CCC-T-191b, Method 5903T, using 3 samples of each material. Thus, a total of 180 smoke-density measurements and 90 flame spread measurements will be performed. On the basis of these, 12 materials will be selected for use in the full-scale mockup experiments -- two materials for each of the locations mentioned above. These will be chosen to represent good and marginal performance within the range of acceptability contained in the latest proposed requirements of FAR 25.853 for flammability, and any existing guidelines for limitation of smoke. Two materials will be selected from each of the floor, sidewall, ceiling, seat, window, and drapery types.

B. Cabin Mockup Experiments

1. Schedule of Experiments

Experiments using the twelve selected materials will be conducted in a full scale mockup of the cabin of a wide-body passenger transport such as the Boeing 747. Two locations in the cabin will be considered for each of the floor, sidewall, ceiling, and seat materials, and one location each for the window and drapery materials. Table 2 shows the designations used in this proposal to identify material types and locations in the cabin mockup, and also gives the corresponding locations as tentatively planned. These locations would be subject to change during the course of the work if experimental results indicated that other locations should be used.

Essentially three types of experiments would be conducted within the cabin mockup according to the three basic objectives of the work, namely to:

1.) investigate scaling of specific optical density to full-size aircraft cabins

2.) determine the relationship between human vision through smoke and optical density and identify if possible the effect of HCl gas generated by burning polyvinyl chloride materials.

Table 2

Sample Material and Location Designations

Material Type	Material Designations	Location Designation	Cabin Location
Floor	F-1, F-2	F-A	Near corner
Floor	F-1, F-2	F-B	Cabin center
Sidewall	SW-1, SW-2	SW-A	Cabin center near floor
Sidewall	SW-1, SW-2	SW-B	Cabin center near ceiling
Ceiling	C-1, C-2	C-A	Near end wall
Ceiling	C-1, C-2	C-B	Cabin center
Seat	S-1, S-2	S-A	Near corner
Seat	S-1, S-2	S-B	Cabin center
Window	W-1, W-2	W-A	Cabin center
Drapery	D-1, D-2	D-A	Cabin center

3.) investigate the effect of cabin ventilation on optical density and human vision

Item 1.) above corresponds essentially to Part I of the work outlined in the Request for Proposal having to do with mockup experiments. The experiments within this item have been planned here to systematically investigate the effects of five variables. These are: sample size, dilution volume, cabin location, heat flux, and sample material. Table 3 shows an experimental plan for 66 experiments to investigate these variables. This experimental schedule involves some deviations from the numbers of specific experiments suggested in the Request for Proposal; however, this appears to be justified in view of the advantages gained from separation of the effects of the various variables. Should the program be undertaken, rearrangement of the 66 experiments would be possible, of course.

As discussed in the previous section, it seems worthwhile to investigate the effects of sample size and dilution volume independently of any effects of imperfect mixing and stratification of the smoke. Experiments 1-24 in Table 3 are designed for that purpose. In these experiments, four materials, each at one location, would be subjected to conditions simulating the exposure produced in the NBS Smoke Chamber while the atmosphere within the chamber is thoroughly mixed by suitable fans. Three sample sizes -- 1, 2, and 3 feet square -- would be used for each material with both flaming and non-flaming exposure.

The remainder of the experiments in Table 3 would be performed without forced mixing of the cabin atmosphere and thus would show the effects of incomplete mixing. Experiments 25-42 would show the effect of sample location within the cabin using one sample of each type and all of the designated locations. Again, the exposure conditions of the standard chamber test would be used. Experiments 43-54 would be conducted to determine the effect of exposure conditions on the smoke developed. Heat fluxes of 1/2 and 1-1/2 times the standard exposure would be used. Finally, Experiments 55-66 would utilize the second material sample of each type in order to indicate any effects of different material samples at each location.

Items 2 and 3 above correspond to the requirements of Part II of the suggested test requirements of the Request for Proposal dealing with visual and airflow experiments. No additional experiments are planned for visual tests without airflow in the cabin since these can be performed concurrently with those shown in Table 3. During 24 of those experiments (to be selected later),

Table 3

Schedule of Cabin Mockup Experiments - Zero Airflow

Exper. Nos.	Type	Location	Material	Heat Flux Btu/ft^2sec	Size - ft^2 Smouldering	Size - ft^2 Flaming	Forced Mixing	Variable Evaluated
1-6	Floor	F-A	F-1	2.2	1, 4, 9	1,4,9	Yes	Size & Dilution
7-12	Sidewall	SW-A	SW-1	2.2	1, 4, 9	1,4,9	Yes	Size & Dilution
13-18	Ceiling	C-A	C-1	2.2	1, 4, 9	1,4,9	Yes	Size & Dilution
19-24	Drapery	D-A	D-1	2.2	1, 4, 9	1,4,9	Yes	Size & Dilution
25-28	Floor	F-A,F-B	F-1	2.2	*	*	No	Location
29-32	Sidewall	SW-A,SW-B	SW-1	2.2	*	*	No	Location
33-36	Ceiling	C-A, C-B	C-1	2.2	*	*	No	Location
37-40	Seat	S-A, S-B	S-1	2.2	*	*	No	Location
41-42	Window	W-A	W-1	2.2	*	*	No	Location
43-46	Floor	F-A	F-1	1.1,3.3	*	*	No	Heat Flux
47-50	Sidewall	SW-A	SW-1	1.1,3.3	*	*	No	Heat Flux
51-54	Ceiling	C-A	C-1	1.1,3.3	*	*	No	Heat Flux
55-56	Floor	F-A	F-2	2.2	*	*	No	Material
57-58	Sidewall	SW-A	SW-2	2.2	*	*	No	Material
59-60	Ceiling	C-A	C-2	2.2	*	*	No	Material
61-62	Seat	S-A	S-2	2.2	*	*	No	Material
63-64	Window	W-A	W-2	2.2	*	*	No	Material
65-66	Drapery	D-A	D-2	2.2	*	*	No	Material

*Sample size for Experiments 25-66 will be selected on the basis of results from 1-24.

human subjects will observe appropriate exit signs or eye charts though the smoke generated in the cabin. Viewing distances of 5, 10, and 20 feet will be used, and the eyes will be protected from the smoke in one half of the experiments and unprotected in the other half. The 24 tests will utilize 8 of the material samples including at least one polyvinyl chloride in order to observe the effect of eye irritation from HCl gas.

Eighteen of the experiments in Table 3 will be repeated under airflow conditions which simulate air conditioning of the cabin. Normal airflow rates, as well as one-half and double normal rates will be used. Both instrument measurements of smoke and visual observations will be made using the same viewing distances as in the experiments without airflow, with both protected and unprotected eyes.

2. Experimental Method

The full-scale experiments will be performed in a mockup of an aircraft cabin as described in the next section. In all of these experiments, smoke will be generated by exposing the samples to a pilot flame and/or radiant heat duplicating as nearly as possible the conditions produced in the NBS Smoke Density Chamber. Optical density will be determined throughout the investigation using six light source-photocell systems having three-foot light paths. These will be arranged to show the vertical variation of optical density at two cabin locations at different distances from the smoke source.

The majority of the experiments (66) will be performed without airflow through the cabin, although 24 of these will involve forced mixing of the cabin contents by 4 fans suitably placed with respect to the smoke source. During 24 of these experiments, observers will be stationed within the mockup to report visbility of signs at distances of 5, 10, and 20 feet from the observers. In one half of these experiments the observer's eyes will be protected from the smoke by suitable masks or goggles; in the other half the eyes will be unprotected. It may prove desirable to use some form of breathing apparatus for both types of visual experiments.

Eighteen of these 66 test will be repeated with airflow in the cabin to simulate the situation created by air conditioning the cabin. The air will be blown into the cabin through vents, and exhausted through return openings which simulate the sizes and locations of air conditioning openings in the aircraft. Flow rates corresponding to about 12, 24, and 48 air changes per hour will be used to simulate one-half normal, normal, and twice normal airflow. In these experiments, measurements of optical density will be made using the photocell equipment, and visual observations will be made as well.

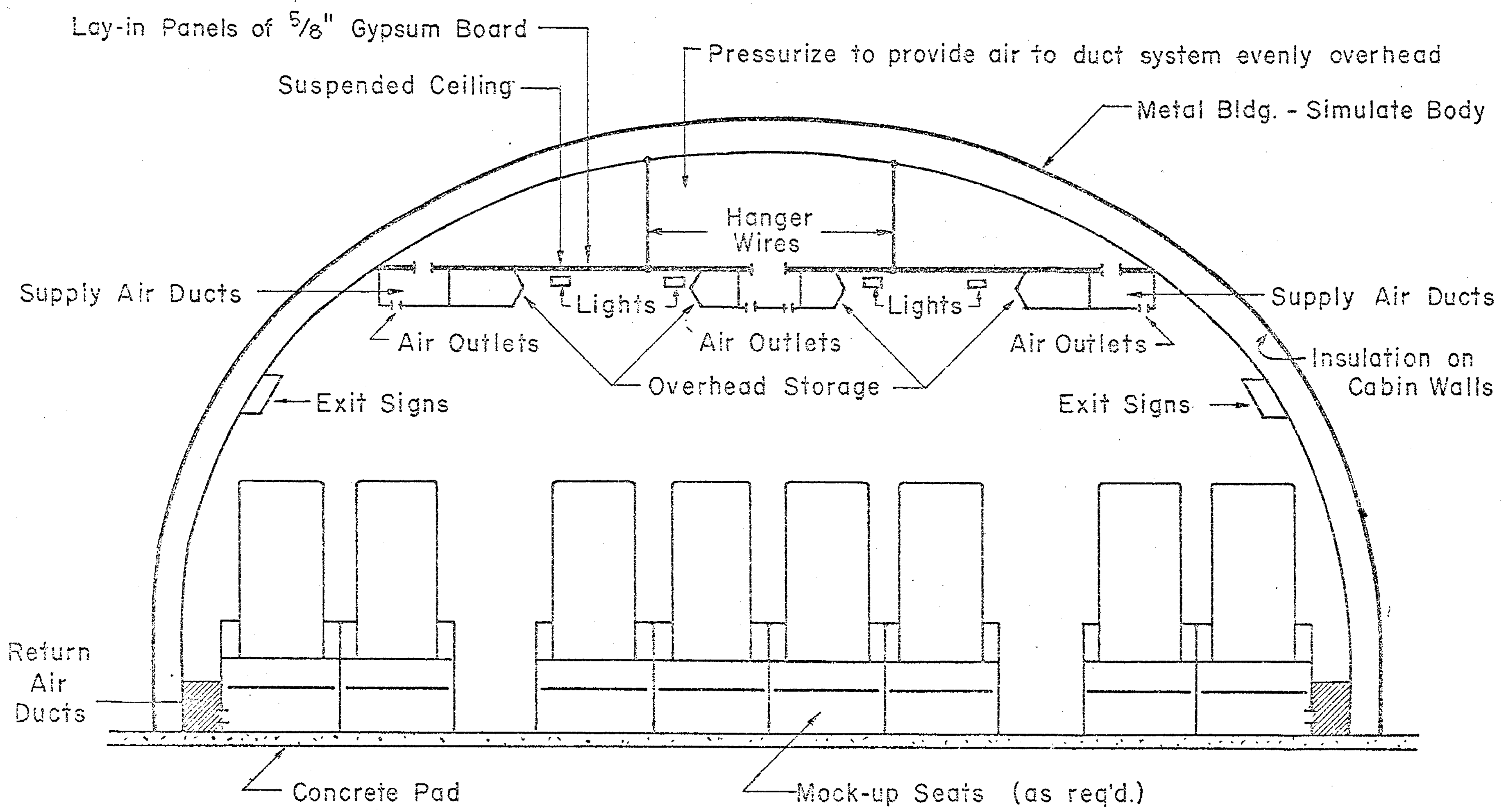
Throughout the investigation, still photographs and color motion pictures will be made to document important aspects of the work.

3. Equipment

The basic cabin mockup will be fabricated using a quonset-type structure manufactured by Wonder Building. This metal building will be 24 feet wide, 20 feet long, and 12 feet high inside. A cross-section sketch of the mockup is shown in Figure 1. Straight side walls and a flat ceiling will be added to the structure to produce an inside width of about 20 feet and an inside height of about 10 feet, corresponding to the widest cabin section of the Boeing 747. Spaces between the basic building shell and the side walls and ceiling will be used as plenums to carry the ventilation air as required.

The mockup will be fabricated adjacent to one of the existing laboratory buildings so that it is entered directly from the building. Air supply for the airflow experiments will be provided by a centrifugal blower taking air from the laboratory building. Airflow rates of approximately 800, 1600, and 3200 CFM will be required. The mockup will be equipped with insulation batts, hatracks, partitions, and air distribution system. Some of these are depicted in Figure 1.

One, two, and three foot square samples of appropriate interior materials will be obtained from aircraft manufacturers or their suppliers. These will be cut or fabricated to size in the Laboratories' own shop facilities.



CROSS SECTION OF PASSENGER CABIN MOCK-UP
OF WIDE BODIED JET TRANSPORT

Radiant heaters for exposing the sample will be fabricated in 1, 2, and 3 foot square sizes. Present plans are to use electric heating coils and to build these in 1 sq. ft. modules using 1, 4, and 9 modules to make up the three heater sizes. Radiant heat output required of the basic module will be about 3500 watts to provide maximum outputs of about 3500, 14,000, and 31,500 watts for the 1, 2, and 3 foot heaters, respectively. Each module would be controlled by a variable transformer, the heaters would be adjusted using suitable radiometers to measure the radiant heat flux. The heaters will be designed for use at any desired location in the cabin mockup.

Light transmission in the cabin mockup will be measured at 6 locations using photocell-light source equipment identical to that used in the NBS Smoke Density Chamber. Six such units will be obtained from American Instrument Company for that purpose. Photocell outputs will be recorded with suitable chart recorders.

Airflow in the cabin, intended to simulate air conditioning, will be provided by a centrifugal blower capable of delivering at least 4000 cfm. Presently available information indicates that normal airflow conditions in the Boeing 747 produce 0.4 air changes per minute, corresponding to 1600 cfm for the 4000 cu. ft. mockup. Experiments with double the normal airflow thus require 3200 cfm.

For experiments in which good mixing within the cabin mockup is desired, 4 circulating fames 20 in. in diameter will be provided. These will be arranged to mix the entire atmosphere without causing undue airflow over the test sample.

Ancillary equipment for measuring and recording airflows, temperatures, gas concentrations, and humidities will be provided as needed.

C. Results

The data generated in the small scale tests and the full scale mockup will be compared and analyzed in order to develop an acceptable method for predicting amount and rate of smoke accumulation in an aircraft cabin when a particular material is burned. The technique will take account, as far as possible, of measured values of specific optical density, cabin configuration, material location and size, airflow in the cabin, and nonuniform distribution of smoke. For these purposes, amount of smoke will be characterized by optical density per foot in the cabin. Observations of signs and eye charts within the cabin will be used to relate optical density measured photometrically to visibility.

IV. PROGRAM ADMINISTRATION AND SCHEDULE

Organization charts following show the corporate and engineering structure of Underwriters' Laboratories, Inc. and the proposed organization of the program. The program would be conducted within the Fire Protection Department, which is shown in detail on the Engineering Operations Chart. As shown on the program organization chart, Mr. G. T. Castino would manage the project, reporting administratively and technically to Mr. J. A. Bono, Assistant Chief Engineer, and Dr. W. J. Christian, Consulting Engineer, Fire Protection. Mr. Castino would be assisted by Mr. J. Thiel in the area of small scale tests and Mr. J. R. Beyreis in the area of large scale tests. Engineering assistants and technicians would participate in both areas as required.

The program is planned to meet the schedule suggested in the Request for Proposal. Separate tasks and their estimated completion times are as follows:

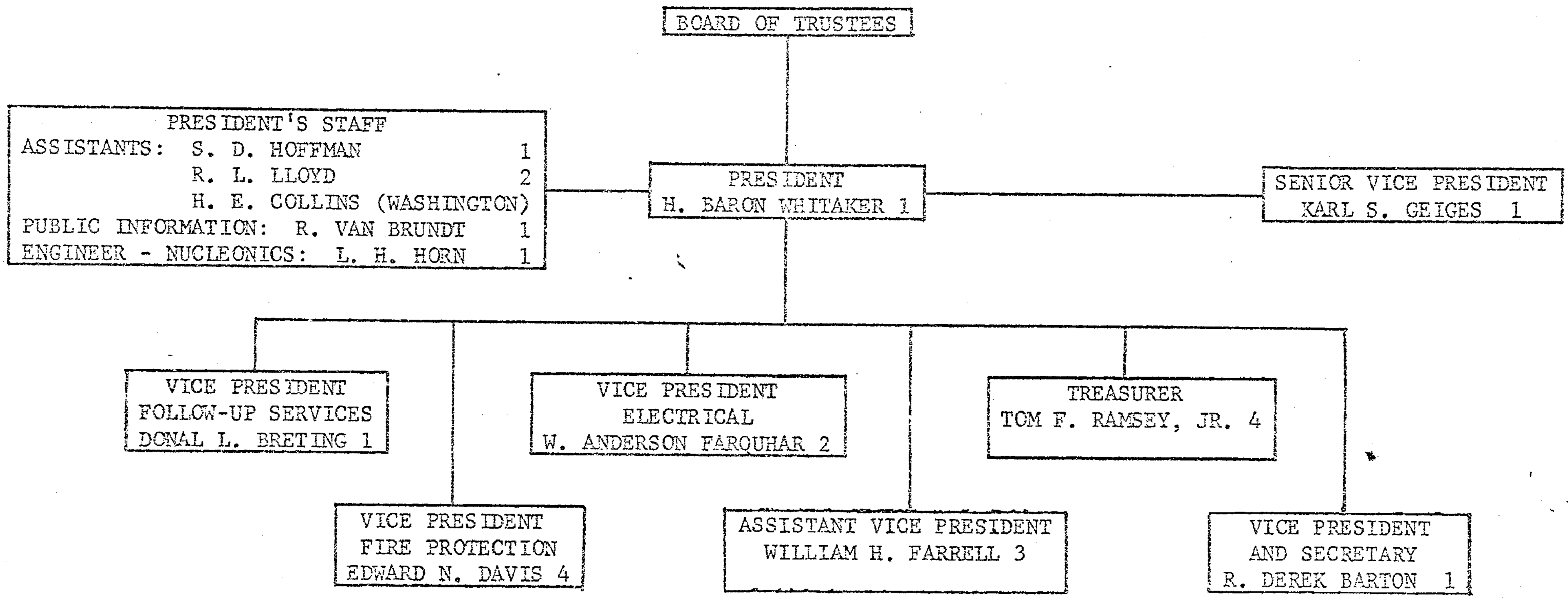
Task	Month After Contract Start in Which Completed
Laboratory Tests	2
Completion of Cabin Mockup	2
Completion of Ignition Source	3
Shakedown and Exp. 1-24	4
Exp. 25-66	6
Airflow experiments (18)	7
Data analysis and repeat experiments	10
Submission of Draft Report	12
FAA review of draft	13
Submission of Approved Report	14

Letter progress reports will be submitted monthly as specified.

UNDERWRITERS' LABORATORIES, INC.

CORPORATE STRUCTURE

Issued: 4-29-68
Revised: 6-28-71



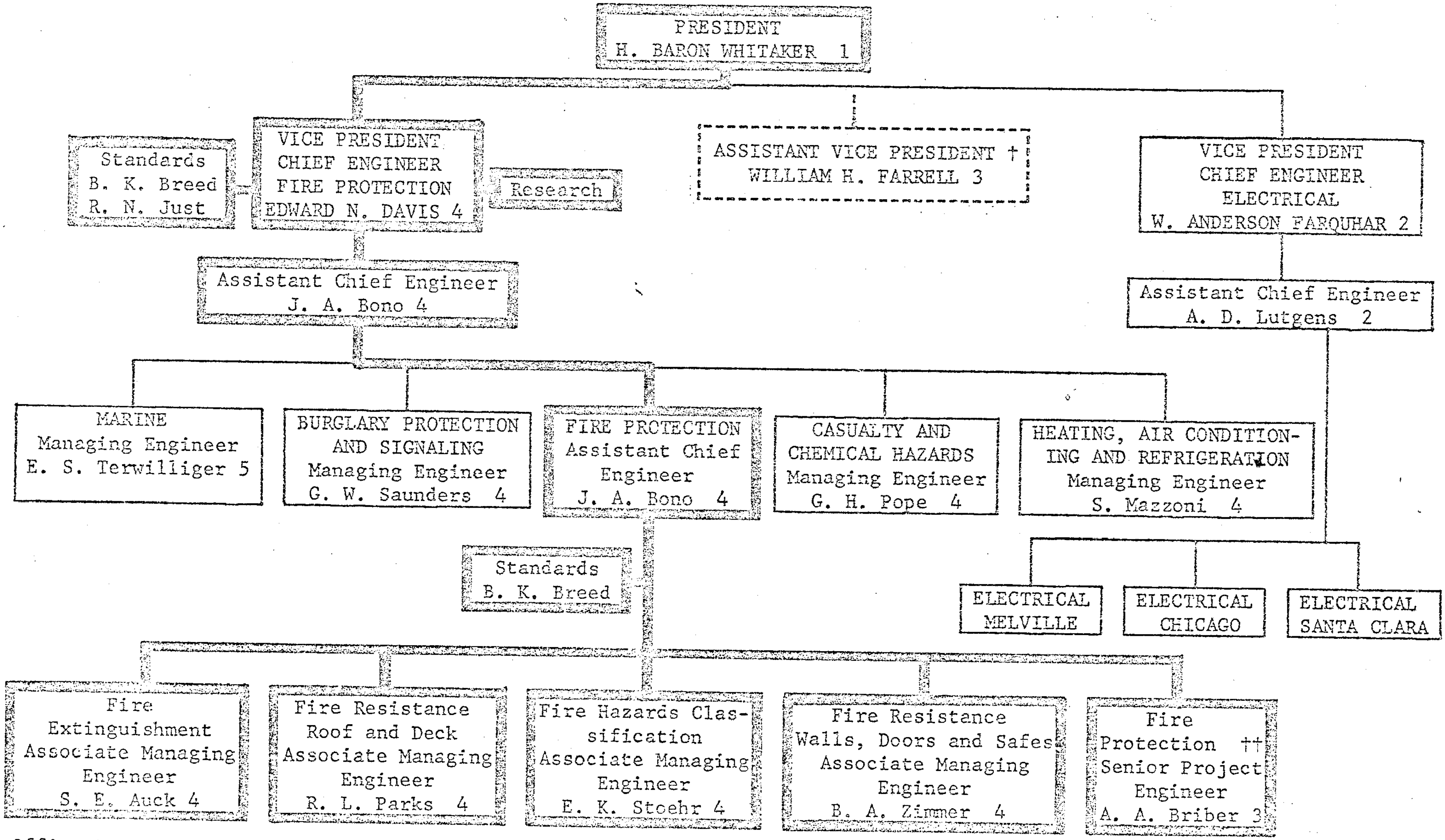
<u>Office Location Key:</u>

1. Corporate Headquarters
   207 East Ohio Street
   Chicago, Illinois 60611
2. 1285 Walt Whitman Road
   Melville, Long Island, New York 11746
3. 1655 Scott Boulevard
   Santa Clara, California 95050
4. 333 Pfingsten Road
   Northbrook, Illinois 60062
5. Tampa East Industrial Park
   2602 Tampa East Boulevard
   Tampa, Florida 33619

UNDERWRITERS' LABORATORIES, INC.®

ENGINEERING OPERATIONS
(FIRE PROTECTION DETAIL)

Issued: 4-29-68
Revised: 6-28-71



Office Location Key:

1. Chicago, Illinois
2. Melville, Long Island, New York
3. Santa Clara, California
4. Northbrook, Illinois
5. Tampa, Florida

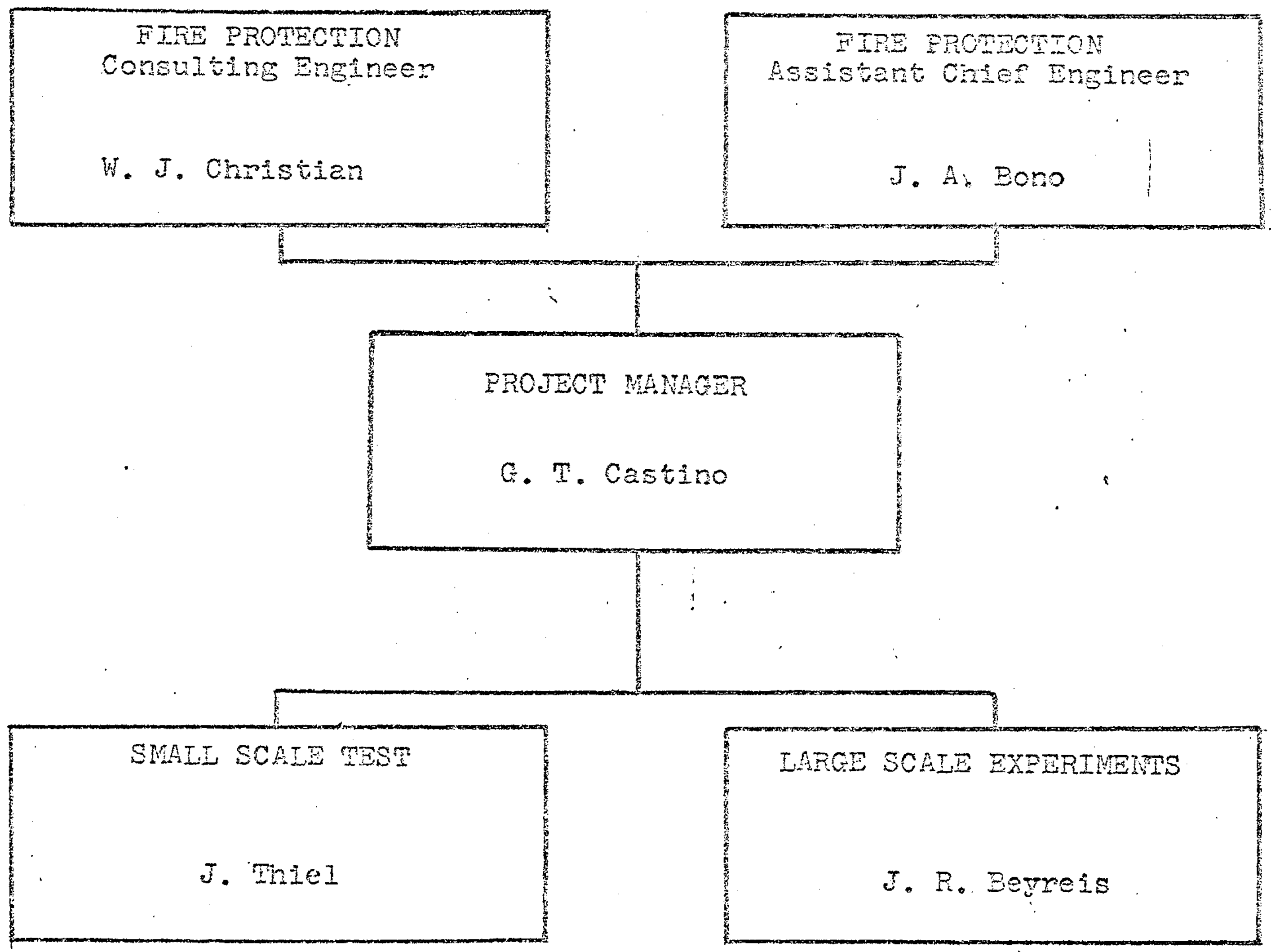
† - SANTA CLARA OFFICE
Administrative
Responsibility

†† - SANTA CLARA OFFICE
Coordination of Non-
Electrical Departments
Coordinating Engineer

UNDERWRITERS' LABORATORIES, INC.

Proposed Project Organization

Issued: 7-9-71



V. UL QUALIFICATIONS

A. General

UL is an independent, not-for profit corporation organized under the laws of the State of Delaware. It is a membership corporation without stock. Its Certificate provides that under no circumstance can its assets be distributed, but must, in the case of dissolution, pass in trust to any successor organization dedicated to pursuit of the same objectives as the Laboratories. The membership is drawn from persons in the following categories: Government body or agency, public safety body or agency, consumer interest, safety expert, standardization expert, education, insurance industry, public utility, and office of the corporation. The present membership comprises 124 persons from these categories, all having a significant interest in safety, but none of whom is a manufacturer of products that could be submitted to the Laboratories for listing. The Laboratories is managed by a Board of Trustees of sixteen persons drawn from the same categories as the membership.

The largest testing for public safety organization in the world, UL has been in operation since 1894. Its main or executive office is in Chicago, Illinois, with additional offices and laboratories in Melville, New York; Northbrook, Illinois; Santa Clara, California, and Tampa, Florida. It has inspection centers and representatives located in about 190 cities in the United States and in 29 foreign countries including Canada and Mexico.

Engineering functions at UL are divided between six departments: Electrical; Burglary Protection and Signaling; Casualty and Chemical Hazards; Fire Protection; Heating, Air-Conditioning and Refrigeration; and Marine.

The staff of over 1900 includes 424 engineers of which approximately one-third are Registered Professional Engineers in one or more states. In addition to their engineering work, many of those engineers participate in, and contribute to professional societies and technical committees which evolve standards and rules applying to the maintenance, and use of products and assemblies with regard to safety. These include electrical and non-electrical products for use in ordinary locations, electrical and non-electrical products for use in hazardous locations where combustible gases, vapors, and dusts may be present, fire protection equipment, and fire resistant constructions.

Included in the more than 300 groups in which the staff has membership are code panels of the National Electrical Code, National Fire Protection Association Committees, American Society for Testing and Materials (ASTM) Committees, and U. S. National Committee of the International Electrotechnical (IEC) Commission.

UL publishes a number of lists, standards, research bulletins, and pamphlets. Among these are the following:

Research Bulletins

Life Hazards and Nature of the Products Formed When Chlorobromomethane Extinguisher Liquid is Applied to Fires.

The Lower Limit of Flammability and the Autogenous Ignition Temperature of Certain Common Solvent Vapors Encountered in Ovens.

The Spontaneous Ignition and Dust Explosion Hazards of Certain Soybean Products.

Survey of Available Information on the Toxicity of the Combustion and Thermal Decomposition Products of Certain Building Materials Under Fire Conditions.

The Compatibility Relationship Between Mechanical Foam and Dry-Chemical Fire-Extinguishing Agents.

Burning, Arcing, Ignition, and Tracking of Plastics Used in Electrical Appliances

Study of Smoke Ratings Developed in Standard Fire Tests in Relation to Visual Observations

Lists

Building Materials

Fire Protecting Equipment

Electrical Construction Materials

Electrical Appliance and Utilization

Hazarous Location Equipment

Lists - continued

Accident, Automotive, Burglary Protection Equipment

Gases and Oils Equipment

Marine Products

Products and equipment which have been tested by UL and meet the constructional and test requirements for their safe use are given in the above Lists and Classification Index. Many of the requirements are specified in the approximately 250 published Standards of UL. Some 105 of these published Standards are approved as American National Standards.

In addition to its activities in safety evaluations and testing, UL conducts research programs which are appropriate to its mission and capabilities as the need arises. These programs may be sponsored by government, industrial clients, trade associations, or by UL itself. The Laboratories does not indiscriminately seek research programs of all kinds. Rather, UL offers its services on a not-for-profit basis in the conduct of research for which its staff and facilities are particularly well suited, and which is of such a nature as to further its mission of promoting public safety. The program proposed here is of such a nature, as indicated by the foregoing description of the Laboratories' mission and the following summaries of company experience, personnel, qualifications, and available facilities.

B. Research Projects and Other Experience

The following examples of current and past programs in fire research and engineering are presented as an indication of UL's capacity to perform fire research, particularly that related to the measurement of smoke and its effect on visibility.

Comparative Testing of Building Materials for Smoke Generation Characteristics

Sponsor: National Bureau of Standards/Underwriters' Laboratories

An experimental study was conducted to explore the measurement of smoke-production of a number of building materials using three test apparatuses, namely: 1.) the National Bureau of Standards Smoke Density Chamber, 2.) a modification of that chamber which provides for progressive flaming of the test sample, and

3.) the Steiner Tunnel Test Method for Fire Hazard Classification of Building Materials, Standard UL723 (ASTM E-84) (NFPA-255). Seventeen different materials were used, including plastics, woods, cellulosics, and various composites of these. The experimental work was conducted partially at National Bureau of Standards by G. T. Castino during his tenure as Research Associate there, and partially at Underwriters' Laboratories. Although analysis of the data is not as yet complete, the results tend to indicate that the progressive flaming apparatus may have application to the determination of smoke production during a spreading-fire situation, whereas the standard NBS chamber method appears to be most appropriate for materials in a fully-developed fire situation.

<u>Calibration and Correlation Testing of the NBS Smoke Density Chamber</u>
Sponsor: Underwriters' Laboratories

The program was undertaken to calibrate the Underwriters' Laboratories equipment for measuring smoke density (Aminco Smoke Density Chamber), and to participate in the National Bureau of Standards round-robin test program. Preliminary calibration tests were performed with 12 materials yielding maximum specific optical densities ranging from 18 to 752. The round-robin test program, conducted with 10 materials, showed that reproducible test methods were attainable for a wide variety of materials under flaming and nonflaming exposure conditions.

<u>A Study to Evaluate the NBS Smoke Density Chamber for Measuring Smoke Producing Characteristics of Carpets</u>
Sponsor: Underwriters' Laboratories

Although a great deal of attention has been devoted recently to the flammability of carpets, little has yet been done in investigating the smoke production potential of these materials. This investigation was an initial study of the applicability of the Smoke Density Chamber developed by the National Bureau of Standards to carpet materials. Particular attention was given to the determination of the reproducibility of data, special problems involved with data interpretation, adequacy of the equipment, and possible improvements in the test method.

The results showed that the reproducibility of the data was acceptable. In addition, a number of experimental difficulties peculiar to the carpet samples were identified and possible remedies suggested.

Fire Hazard Classification of Materials

Underwriters' Laboratories routinely performs evaluations of the fire hazards of materials using a number of recognized test procedures. A large percentage of this work is conducted in the Steiner Tunnel in accordance with UL Standard 723, Fire Hazard Classification of Building Materials (ASTM E-84, NFPA-255) for evaluating flame spread, smoke developed, and fuel contributed ratings of conventional building materials. Flame spread determinations are also performed as the need arises by the radiant panel method (ASTM-162) and by various small scale tests such as Federal Specifications CCC-T-191b, Methods 5902, 5903T, and 5906; DOC-FF-1-70, and various ASTM tests for flammability of plastics. Smoke density measurements are also performed using the Aminco version of the NBS Smoke Chamber.

Fire Hazard of Plastic Diffusers in Dual Purpose Fixtures
Sponsor: Rohm and Haas Company

The object of the investigation was to study the action of plastic diffusers of specific acrylic and polystyrene types when mounted in dual-purpose fixtures and exposed to fire conditions. These tests were supplemented by other work related to the performance of plastic under fire exposure. In the investigation the fixtures in operating condition were subjected to representative floor fires, elevated fires and small impingement fires, to determine whether the plastic enclosures would burn in place or fall out, and to measure temperature rise and smoke development. A special room was constructed for this purpose. In order to establish some relationship between the smoke observations during fire tests in the specially constructed room and the numerical smoke developed value established by Underwriters' Laboratories, Inc., fire hazard classification method, Standard UL723, sections of the plastic material were tested in the fire hazard equipment.

Study of Smoke Ratings Developed in Standard Fire Tests in Relation to Visual Observations
Sponsor: Manufacturing Chemists Association

This investigation was directed toward establishing the relationship between smoke ratings of various building materials as developed by Underwriters' Laboratories, Inc. Steiner Test Method for Fire-Hazard Classification of Building Materials, Standard UL723 (ASTM E-84) (NFPA-255) (ASA A2.5 1963) and the loss of visibility in a room in which the smoke from the rating tests was collected. For this purpose, the smoke developed by materials in the Steiner tunnel was collected in room with a volume of 3600 cu. ft. Visual observations and photographs of various illuminated exit signs within the room were used to establish the correlation between smoke developed rating and loss of visibility.

Materials investigated included red oak flooring, 1/4 and 3/8 inch plywood, 3/4 inch treated plywood, 1/4 inch tempered hardboard, 1/2 inch cellulosic tile, poly (vinyl-chloride) flat and corrugated panels, polyester reinforced corrugated panels, 1/32 and 1/16 inch plastic laminates adhered to steel, gypsum board and asbestos cement board, 1/16 inch plastic laminates not bonded, polyethylene film mechanically secured to mineral fiberboard, vinyl wall coverings adhered to asbestos cement board, paint coatings on 3/8 inch plywood, 5/8 inch mineral fiberboard, and 1 inch glass fiberboard.

Although general correlation existed between the Smoke Developed rating of a material and the loss of visibility incurred in the smoke accumulation room, variations occured and were largely credited to the fact that the Fire Hazard Classification method of smoke rating is representative of the total smoke developed in a ten minute interval, without respect to when the smoke is produced, whereas the density readings in the smoke accumulation room are sensitive to the time element.

<u>Survey of Available Information on the Toxicity of the Combustion and Thermal Decomposition Products of Certain Building Materials under Fire Conditions</u>
Sponsor: Underwriters' Laboratories

A survey was conducted of available information on the comparative life hazards resulting from inhalation of the combustion and thermal decomposition products of certain plastic or wooden and other cellulosic building materials under fire conditions. Pertinent published technical literature was reviewed, and also some hitherto unpublished data furnished by members of the plastic industry. Some of the most significant or typical references relating to the life hazards of the combustion and decomposition products of certain building materials under fire conditions are discussed briefly in connection with the survey, and a bibliography of 297 references is appended.

The available data indicate that plastic, wooden, or other cellulosic building materials under certain fire conditions may produce toxic gases or vapors in concentrations dangerous to persons when inhaled, depending on the nature of the material or combinations of materials, the amount involved, the conditions of burning or heating (including oxygen excess or deficiency), and the circumstances of the specific situation. Any close distinctions in the life hazards presented by the various building materials in this connection, however, or a classification of the comparative hazards of the materials with respect to their combustion and thermal decomposition products, is difficult on the basis of the present data because of wide differences in the test procedures and conditions by which the data were obtained.

Comparative Fire Exposures of Glass and Plastic Glazing
Sponsor: General Electric Company

Two glazing materials, 1/4-in. plate glass and 3/16-in. and 1/4-in. polycarbonate plastic sheet, were exposed to simulated building fires to obtain information on their perforances with respect to penetration, ignition, flame propagation, and smoke production. Fires of low and high intensity on both the interior and exterior of the building were simulated. Times required for softening, fallout, and ignition of the plastic glazing were determined; and photoelectric measurements of smoke produced during burning of the plastic were made.

A Test Method for Measuring the Flame Propagating Characteristics of Flooring and Floor Covering Materials
Sponsor: U. S. Public Health Service

A test method was developed for the measurement of the flame propagating characteristics of flooring and floor covering materials. In the evolution of the test equipment and the testing procedure, consideration was given to the potential fire hazards created by flooring and floor covering materials and the effect of various ignition sources on the performance of these materials in a fire situation. Tests were conducted on a variety of commercial (low pile) and residential (plush and shag) carpetings, with and without various underlayments.

Investigation of Fire Hazard in Computer Equipment
Sponsor: International Business Machines

In this investigation, the possibilities for flame propagation and combustion of a power supply unit for a computer system were considered. Tests were conducted on the power supply unit by subjecting various components to open flame under controlled conditions

Despite exposure to an open-flame ignition source, it was not possible to induce flame propagation beyond the component subjected to the exposure under the specified conditions. When the flame source was removed, burning immediately decreased and was subsequently self-extinguished. The resistance to spread of fire within the machine is directly related to the character of the materials used. Components which could serve as a path for flame propagation, demonstrated no tendency to sustain flame beyond the area to which the igniting source was applied.

Temperatures of Unprotected Columns, Beams, and Plates in Exterior Fires
Sponsor: American Iron and Steel Institute

Columns, beams, and plates were located outside a fire chamber to determine the temperatures of the unexposed structural steel members when subjected to wood-crib burning inside the chamber.

The information developed from these investigations was used in the derivation of equations which may be used in calculating temperatures of unprotected structural steel members when subjected to fire from inside a building.

C. Project Personnel

The experience of the UL staff represents many years of activity in fire hazard evaluations of materials, particularly determinations of flame spread and smoke developed, by numerous standard test methods as well as by extensive full-scale research. The following resumes of key engineering personnel who would participate in the proposed program indicate the broad experience that the staff would bring to the project.

BEYREIS, JAMES R.

J. R. Beyreis, Project Engineer, Fire Protection Department, has been with Underwriters' Laboratories, Inc. since June 1966. He received the Bachelor of Science Degree from Valparaiso University in June 1966, is a Registered Professional Engineer, and has been actively engaged in engineering and research for five years. Since 1967, Mr. Beyreis has been responsible for several full scale fire research programs, including:

Full scale room burn-out tests to obtain measurement of fire development characteristics and the effect of the fire on unprotected exterior structural members.

Wood crib burn-out experiments to determine fuel burning rates and flame heat transfer properties.

Full scale fire endurance test to evaluate the fire resistance of a partially protected spandrel beam.

Fire Test in a Full Scale Office Building Mock-Up.

Comparative Fire Exposure of Glass and Plastic Glazing.

He has also participated in other full scale fire research investigations, including:

Fire endurance test to evaluate the fire resistance of a unitized hotel guest room.

Full scale investigation of foamed plastic insulated wall panels.

Fire endurance tests to evaluate the effectiveness of water film protection of unwired glass.

Mr. Beyreis' other activities have included work in developing computer programmed analytical methods for prediction of thermal performance in fire resistive construction and assignments with respect to fire tests in accordance with Standards ASTM E119, ASTM E84, and ASTM E162.

Mr. Beyreis is an associate member of American Society of Civil Engineers and a member of National Society of Professional Engineers.

Reports and publications include:

"Properties of Wood Crib Flames," (With H. W. Monsen and A. R. Abbasi), Fire Technology, May 1971.

"Temperatures of Unprotected Columns, Beams, and Plates in Exterior Fire," Underwriters' Laboratories, Inc. Bulletin of Research, in preparation.

BONO, JACK A.

Jack A. Bono, Assistant Chief Engineer, Fire Protection Department, has twenty-four years of experience in Fire Protection work at Underwriters' Laboratories, Inc. Mr. Bono is a graduate of Northwestern University with a Bachelor of Science Degree in General Engineering in June 1946.

Mr. Bono is also author of various technical articles on fire protection.

Mr. Bono is connected with the following committees:

Associate Member - National Fire Protection Association.

Member - National Society of Professional Engineers.

Member - Illinois Society of Professional Engineers.

Member - Society of Fire Protection Engineers.

Member - Qualifications Board of the Society of Fire Protection Engineers.

Active Member - National Fire Protection Association Committees on Fire Tests (Chairman) and Fire Department Equipment.

Former Member - National Fire Protection Association Committees on Portable Extinguishers (Chairman), Dry Chemical Extinguishing Systems, and Carbon Dioxide Extinguishing Systems.

Chairman - Subcommittee 1 of American Society for Testing Materials Committee E-5 on Fire Tests.

Member - Model Code Standardization Council.

CASTINO, GUY T.

Guy T. Castino, Engineering Group Leader, Fire Protection Department, has 11 years of experience in fire protection work at Underwriters' Laboratories, Inc. He received his Bachelor of Science Degree in Mechanical Engineering from the University of Illinois in June 1960.

Between 1960 and 1968 Mr. Castino directed testing projects of building materials to establish flammability, heat generation, and smoke emission properties under a variety of fire exposures. This work included supervision of calibration and correlation test series associated with Laboratories' Northbrook, Illinois and Santa Clara, California Steiner Tunnel installations.

In 1968, Mr. Castino began a 1-1/2-year project at the National Bureau of Standards to study smoke measurement techniques and participate in the later stages of the development of the smoke density chamber. This research and development work at NBS included: (1) conducting an evaluation study of the first commercially produced smoke density chamber and subsequent preparation of a report on the study and (2) preparation of the first draft of the chamber test standard.

Mr. Castino is currently acting as a specialist on fire research and engineering work concerned with:

(A) Flammability testing of building materials.

(B) Research programs on smoke measurement methods.

(C) Research and development programs on flammability of flooring and floor covering materials.

(D) Preparation of reports for Federal Government Agencies, including: U. S. Coast Guard, U. S. Department of Commerce, and U. S. Department of H. E. W.

Mr. Castino has authored a number of technical papers and articles concerned with flame*spread and smoke generating characteristics of building materials and is connected with the following organizations:

Associate Member - National Fire Protection Association.

Member - Society of Fire Protection Engineers.

Member - Illinois Society of Professional Engineers.

Member - National Society of Professional Engineers.

Member - American Society of Testing Materials Committee on Fire Tests; active in task groups studying floor coverings, general smoke measurements, smoke density chamber, and flame spread calculations.

Member - American National Standards Institute Committee on Fabric Flammability.

Member - General Services Administration Committee on Air Handling Systems; co-authored special report on "smoke-load" calculation techniques using smoke density chamber data, while working with this committee.

Recent publications concerning fire problems include:

(A) "Fire Safety Testing of Plastic Materials for Building Construction," White paper for distribution to concerned governmental agencies and authorities of jurisdiction, November 1966.

(B) "Fire Underfoot," Article on flammability testing of floor coverings, appearing in March 1970 issue of the Architectural and Engineering News Magazine.

(C) "Testing, Evaluation and Follow-Up Inspection Capabilities Related to Prefabricated Housing Units and Components," White paper report for distribution to concerned governmental agencies, March 25, 1970.

(D) "The Steiner Tunnel Test - Its Use In Fire Testing Mobile Home Interior Finishes," White paper for distribution to concerned governmental agencies and authorities of jurisdiction, April 7, 1970.

(E) "Flame-Propagation Classification of Flooring and Floor-Covering Materials," tentative standard method of test, dated February, 1971.

(F) "Comparative Fire Exposures of Glass and Plastic Glazing," report to sponsor, dated May 17, 1971.

(G) "Fire, Strength, Physical Property and Identification Testing of Reinforced Plastic For Boat Hulls," report to sponsor, dated May 19, 1971.

CHRISTIAN, WILLIAM J.

Dr. W. J. Christian, Staff Consulting Engineer, Fire Protection, has been with Underwriters' Laboratories since October 1970. He received the Doctor of Philosophy Degree in Chemical Engineering from Illinois Institute of Technology in 1957, and has been actively engaged in research and engineering for 18 years. Between 1961 and 1970, Dr. Christian directed the fire research activities at IIT Research Institute, as well as related research in heat transfer, fluid dynamics and combustion. The numerous programs carried out under his direction included:

Flammability Characteristics of Vehicle Interior Materials,

Investigation to Evaluate Cellular Plastics from a Fire Performance Standpoint,

Fire Hazards of Combustible Building Materials,

Determination of Fire Buildup and Conditions Supporting Room Flashover,

Aircraft Ground Fire Suppression and Rescue Systems Study,

Shelter Habitability in Existing Buildings Under Fire Exposure, and

Fire Rating of Rug and Carpet Materials.

Dr. Christian has authored numerous technical papers and is connected with the following organizations:

Member - American Society for Testing and Materials.

Associate Member - National Fire Protection Association.

Member - Information Council on Fabric Flammability.

Member - Committee on Fire Research - National Academy of Sciences.

Member - Editorial Advisory Board - Journal of Fire and Flammability.

Recent publications concerning fire problems are:

"Relation of Building Occupancy and Design to Use of Combustible Materials of Construction" (with T. E. Waterman) 3rd Fire Protection Seminar, Ill. Inst. of Tech. (March, 1969).

"Fire Behavior of Interior Finish Materials," (with T. E. Waterman), Fire Technology, November, 1970.

"Effect of Location and Area Coverage on Flame Spread Over Interior Finish Materials," (with T. E. Waterman), Fire Journal, Vol. 65, No. 4, July 1971.

"Characteristics of Full-Scale Room Fires," (with T. E. Waterman) to be published in Fire Technology, Vol. 7, No. 3, August, 1971.

"Ability of Small Scale Tests to Predict Smoke Developed by Materials in Large Fires," (with T. E. Waterman) pending publication.

D. Facilities

The proposed program would be carried out at the Laboratories' Northbrook facility, where the majority of the fire protection work is performed. The Northbrook facility consists of a 148 acre site with a complex of buildings providing approximately 280,000 square feet of floor area for office and laboratory space. The facilities of the Fire Protection Department would be used for the major portion of the project, although facilities of the other departments could be made available as required.

The Fire Protection Department, with a staff of about 65, has a great variety of standard and specialized equipment, as well as several large fire test rooms within which large scale fire experiments are performed. The following partial listing is provided as an indication of the adequacy of the Laboratories' facilities for conduct of the proposed work, although not all of the equipment would be required.

1. Three fire test rooms approximately 40 by 40 by 50 ft high, 36 by 66 by 21 ft high, and 60 by 60 by 16 ft high equipped with afterburners for smoke elimination.

2. American Instrument Company version of the NBS Smoke Chamber.

3. Radiant panel apparatus for measurements of flame spread according to ASTM E-162.

4. Apparatus for vertical tests of flammability according to procedures similar to methods 5902 and 5903.

5. Steiner Tunnel for measuring flame spread, smoke developed, and fuel contributed according to ASTM E-84.

6. Floor furnace, approximately 14 by 18 ft for evaluation of fire endurance of floor sections.

7. Wall panel furnace, approximately 16 by 14 ft high for evaluation of fire endurance of wall panels.

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