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A TWO-ZONE STRATEGY FOR DEVELOPMENT OF INTERIM FIRE, SMOKE, AND TOXICITY STANDARDS FOR AIRCRAFT CABIN MATERIALS

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FAA/NAFEC
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PREFACE

This outline provides a strategy for developing an interim fire safety standard for aircraft cabin materials. The strategy represents the state-of-the-art in cabin fire safety research and requires a modest research and development effort to verify certain aspects and to finalize operating parameters in the test methods. This outline represents a team effort by the staff of the Cabin Fire Safety Program in NAFEC's Fire Safety Branch. Expertise in the areas of material fire testing, toxicity, smoke, and fire dynamics was brought to bear on this task to develop a strategy for an interim standard.

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INTRODUCTION

Numerous approaches have been proposed for developing fire safety standards for aircraft interior materials. Most approaches fall into one of two categories. In the first, all interior materials would be subjected to a flammability test, a smoke test, and a toxicity test. Either all three tests must be passed independently or the tests must be passed via some combined weighting function. In the second category, a material is exposed to a single fire test and the resulting flammability, smoke and toxic gases are assessed to determine material hazard. The general problem with these two approaches is that few materials are simultaneously low in flammability, smoke, and toxic emissions. Standards based on the above two approaches invariably are not strict. Furthermore, correlating the hazards of all materials in such a scheme with full-scale results has not been successfully performed to date.

The Crash Fire Scenario

The range of conditions possible after a crash is infinite. However, more than likely if the crash is impact-survivable will be an intact fuselage with slight inclination from its normal horizontal orientation. Furthermore, the case of interest involves a major post-crash fuel fire. Without such a fire, any interior involvement of materials can be expected to be slow in development and containable during the several minutes required to evacuate the aircraft.

Recent modeling and full-scale tests at NAFEC of such a scenario have clearly shown the pronounced stratification of heat and smoke generated in the cabin from an external fuel fire.

Theoretical and experimental results in other laboratories have also been developed and show how the combustion products at the ceiling of an enclosure act to irradiate the floor and lead to flashover conditions.

The recently completed study of the effects of an external pool fire on hazard development within a wide-body (C-133) fuselage clearly illustrates the stratification of heat and smoke as illustrated below in summary form.

a) Heat:

A major and important finding of this test program is the stratification of cabin hazards that occur during a cabin fire. Significant stratification occurred for all fire sizes and wind conditions. The most significant was with high winds pushing the flames toward the fuselage, since that condition produced the highest interior cabin temperatures. In these tests, a distinct layer of hot gases extended from the ceiling down to the 6-foot level. The hot upper layer eventually heated the much cooler lower layer and some mixing occurred. This generally increased the temperature of the lower levels. Figures 1 and 2 are representations of data indicating the cabin temperature from the fire door through the cabin to the aft exit. There is a large increase in temperature early in the tests near the fire door, with very little increase near the exit door. However after this initial period the temperature rise for a given height was fairly constant throughout the cabin.

b) Smoke:

The only measurement of smoke taken during this test program was its effect on visibility (e.g. the amount of light reduction over 1 foot). In all tests conducted, a large degree of stratification of the smoke occurred. As tests were conducted in the C-133, the ceiling and sidewall above 5 feet quickly became covered with soot, while below 5 feet the sidewall remained fairly clean. Figure 3 shows smoke stratification during a typical large pan fire test with the wind blowing the flame towards the opening. The figure shows smoke levels 30 feet from the fire. The amount of stratification can easily be seen at that location.

This tendency of the hot combustion products to stratify was further documented in full-scale fire tests with a surplus DC-7 fuselage exposed to a 20-foot-square pool fire. Figures 4 and 5 are typical temperature stratification data for these tests. Model tests also show this effect, and table 1 shows some typical smoke transmission data.

From all these fire tests, the stratification phenomena has been well established. Recently published work at the Factory Mutual Research Corporation demonstrates how such ceiling combustion products radiate to the floor area and generate the pyrolysis conditions leading to flashover.

A Two-Zone Strategy

Because substantial heat and smoke produced by the external fuel fire will exist at the ceiling, modest evolution of smoke and toxic gases from ceiling materials will not modify the cabin hazard significantly. Pyrolysis products from the ceiling materials and upper parts of side panels will remain in the upper gas layers of the cabin. This region will be hot enough under the normally severe circumstances that inhalation will be fatal regardless of the ceiling composition. A stringent rate of heat release standard for the ceiling and sidewall materials is necessary, however, so that the ceiling involvement does not force the upper layer of hot gases to expand to the lower levels of the cabin. The Radiant Panel test (ASTM E-162) should be adequate for this purpose. All materials in the upper zone should be subjected to this test.

For the upper zone materials, a high heat flux smoke test and a high temperature toxicity exposure test will also be employed. However, the smoke emission and toxic gas production limits will be reasonably high because stratification effects will keep these products close to the ceiling in this proposed scenario.

In the lower zone of the cabin, the initial hazard will be caused by non-flaming pyrolysis of materials. Heat from the hot ceiling area will radiate to the floor. In addition, heat from the external pool fire will radiate through melted windows, open doors, and fuselage breaks to these lower materials. The pyrolysis products are generally more toxic under these nonflaming conditions and they also obscure escape routes. This lower level must be kept habitable if egress is to remain feasible. Thus all materials in the lower level must pass stringent nonflaming toxicity and smoke standards. Fortunately, correlation of small-scale nonflaming pyrolysis tests with full-scale results is both experimentally demonstrated and theoretically defensible. The combustion tube is a good candidate for laboratory scale production of toxic species. The NBS smoke chamber is proposed for the smoke standard.

It is further recommended that in the lower zone the presently used vertical burn test be continued in use. This will continue to minimize the threat of in-flight fires. It will furthermore minimize the ignition potential of firebrands falling from overhead stowage during the aforementioned fire scenario.

Proposed Test Methods

Table 2 shows the matrix of tests proposed for a two-zone treatment of interior cabin materials. The four test methods are the Vertical Bunsen Burner Test (ASTM F501), the Radiant Panel (ASTM E-162), a modified NBS Smoke Chamber, and the combustion tube. More detailed descriptions of these test methods can be found in Appendices A, B, C, and D.

A modified NBS Smoke Chamber would be used for smoke. Lower zone materials would be subjected to nonflaming irradiation of 2.5 watts/cm^2. Upper zone materials would be subjected to nonflaming irradiation of 5 watts/cm^2. Chamber modification is required to provide a heater capable of higher heat flux, such as the Mellen furnace currently used at NAFEC.

A combustion tube furnace would be used for toxic gas generation. Lower zone materials weighing 250 milligrams would be exposed to a radiant unidimensional heat source at a temperature of 500°C. Upper zone materials would be tested similarly but at a temperature of 750°C. Qualification of a material would involve both animal exposure and sampling of specific gases.

Lower zone materials would also be subjected to the Vertical Bunsen Burner Test as presently required by FAA regulations. Thus, aircraft would continue to be protected from in-flight fires starting with cigarettes or other small ignition sources. Because of the severe heat flux environment caused by external fuel fires at the ceiling, upper zone materials will be tested with the ASTM E-162 Radiant Panel Test.

Research Requirements

There are two aspects of the work needed to verify and support this two-zone strategy. In the one category is laboratory work, especially toxicity. In the other is fire dynamics type work.

In the laboratory scale work, the flammability and smoke tests require no work other than support of the written standard as it is developed in detail. With the Radiant Panel test and the NBS Smoke Chamber, some additional data may have to be collected on specific materials. However, this cannot be considered a major effort at this time. No development work is necessary for the Vertical Bunsen Burner Test.

For the toxicity standard a major cooperative effort between NAFEC and CAMI is imperative if the required data is to be developed in 6 to 8 months. The FAA does not have material data for the two exposures specified under the two-zone strategy. Assistance from NASA may also be necessary to obtain this data within a tight schedule. Existing resources between the FAA and NASA should be adequate for this task so long as the resources are redirected at the task of developing a specific set of standards.

In the area of fire dynamics, the full-scale and modeling tests at NAFEC must be redirected to focus on stratification effects and radiative exposure conditions within the fuselage. Achieving this requires modest adjustment to the current NAFEC program. Characterization of material exposure conditions could be greatly aided by the proposed NASA 737 project at Houston and by refocusing mathematical modeling work at NASA/JPL and FAA/University of Dayton on the tractability and behavior of smoke in the fuselage cabin. It is further desired that information along these lines can be derived from FAA current work at Factory Mutual Research Corporation.

The required support work for a standard can be accomplished within 6 to 8 months only if a truly cooperative effort can be conducted among FAA and NASA participants. It is required that a high level interagency task force be created. This task force would have to have managerial powers over the program elements and would have to work closely with the SAFER Technical Committee on Cabin Material Hazards.

Summary

The state-of-the-art in cabin fire safety provides an intermediate basis for the adoption of standards for interior materials. The phenomenology of the fire problem provides a basis for concentration on non-flaming pyrolysis of materials as a source of smoke and toxic gases.

Non-flaming pyrolysis tests are more repeatable than flaming tests and they do not suffer from scale effects as do fire tests. Thus, a two zone strategy provides a promising avenue for the establishment of an interim safety standard in a short time frame.

The interim standard would employ strict standards on toxic gases and smoke produced by low level heat on low level materials. The standard would employ looser smoke and toxicity criteria to ceiling and upper zone materials under more severe incident heat fluxes. For flammability, upper zone materials would be subjected to the ASTM E-162 Radiant Panel and lower zone materials would be subjected to the existing Vertical Bunsen Burner Test (ASTM F 501).

Development of these intermediate specifications would still require a high-priority joint effort between NASA and FAA over a six to eight month time frame.

The two-zone strategy for regulation provides some sophistication in that materials are tested according to their placement in the aircraft cabin.

APPENDIX A. FLAMMABILITY: ASTM E-162 RADIANT PANEL

Background

The ASTM E-162 Radiant Panel is a well-known test method throughout industry. This test method was developed by the National Bureau of Standards in the early 1960's and became an ASTM standard test method in 1967. A study of the radiant panel as a method for measuring the flammability characteristics of aircraft interior materials was first made in 1962-63 using the equipment at NBS and recommended in Technical Report ADS-3, January, 1964, as a method for qualifying materials. The method was again recommended by NAFEC in July, 1968, to be adopted in the FAR for the heavier and composite type materials (NA-68-30, Final Report). This method is presently included in the Transportation Systems Center's guidelines for sidewall and ceiling panels used in ground transportation vehicles.

Summary of the Method

The radiant panel test method is described in detail in American Society of Testing and Materials (ASTM) Standard test method E-162 "Surface Flammability of Materials Using a Radiant Heat Energy Source."

Basically this is a method of measuring the surface flammability of a material. It employs a radiant heat source consisting of a 12 by 18 inch radiant panel in front of which an inclined 6 by 18 inch specimen of material is placed. The orientation of the test specimen is such that ignition is forced at its upper edge and the flame front progresses downward. The specimen surface is exposed to an incident heat flux of 4.4 w/cm^2 at the upper edge, decreasing to 0.5 w/cm^2 at the lower edge.

A factor derived from the rate of progress of the flame front and another relating to the rate of heat liberation by the material under test are combined to provide a flame spread index (Is).

Criteria

1. Materials from the upper zone will be tested by the radiant panel test shall have a flame spread index (Is) not to exceed 35.

2. Drippings shall be self-extinguished on contact with the floor.

3. Specimens shall be wrapped around the back and sides with aluminum foil while being tested.

4. One inch mesh wire screen shall be used on all thermoplastics to prevent speciment from falling out of holder.

Advantages

1. Apparatus is presently in use at NAFEC as well as the major airframe manufacturers.

2. Measurement of surface flame spread rates can be determined.

3. Flame spread index is related to the heat given off by the burning specimen.

4. Apparatus is an ASTM Standard with documented within-laboratory repeatability and between-laboratory reproducibility.

APPENDIX B

SMOKE: MODIFIED NBS SMOKE CHAMBER

Background:

The standard NBS smoke chamber is widely used in government and industry to evaluated smoking tendencies of materials at a fixed radiant heat flux of 2.5 $^{W}/cm^2$. The chamber consists of an 18-cubic-foot (ft^3) enclosed box, vertical specimen holder, a radiant heater, a propane-air burner, and a photometric system using an incandescent lamp and a phototube receiver. The NAFEC modified NBS smoke chamber consists of the above components with the exception of a Mellen® variable radiant heat flux furnace (Mellen Model TEN-2500-3X3, Mellen Company, Inc., Penacook, N. H.) in place of the standard radiant heater and installation of a calorimeter to calibrate the new furnace. The propane-air burner is not used for these nonpiloted tests. Nonpiloted tests provide an excellent method to characterize the pyrolysis of test materials through smoke information. Such a test discriminates against unacceptable "smoky" materials. It also provides information on materials which autoignite. One drawback is found in testing materials that melt when exposed to radiant heat. These materials (foams, nylons, and some thermoplastics), when placed in a vertical orientation, tend to drip out of the specimen holder (away from the radiant heat source). The non-piloted test is also characterized by better repeatability than the piloted ignition test.

Summary of Method

The National Bureau of Standards (NBS) Smoke Chamber is well suited to obtain smoke density information from the pyrolysis of aircraft cabin interior materials. The standard NBS chamber, modified with a variable radiant heat flux furnace, provides nonpiloted material exposure conditions which can model the fuselage interior environment cabin in the event of a survivable, postcrash fire situation. Two heat flux levels (2.5 watts per square centimeter ($^{W}/cm^2$) for materials in the lower zone and 5.0 $^{W}/cm^2$ for materials in the upper zone) are selected to adequately cover the conditions necessary to cause pyrolysis of cabin materials. Standard piloted ignition tests of materials are not considered to be pertinent since this interim standard is focused on smoke information from pyrolysis only. Smoke information is obtained from the standard NBS photometric system supplied with the chamber. Test materials are prepared in accordance with the NBS smoke chamber standard procedure (Standard Test Method for Smoke Generated by Solid Materials, National Fire Protection Association, NFPA 258, Boston, Massachusetts, 1976).

Criteria

Three samples of each material in the lower zone will be tested at 2.5 $^{W}/cm^2$. Initial chamber temperature (from a thermocouple located on the back wall of the chamber) will be a minimum of 95°F. Test procedure is conducted in accordance with NFPA 258. Smoke information in the form of light transmittance data is used to calculate Specific Optical Density (D_s) at 90 seconds and 4 minutes. For the 2.5 watts/cm^2 nonpiloted condition, a D_s of greater than or equal to 25 by 90 seconds and 50 by 4 minutes for any of the three samples constitutes an unacceptable material.

Three samples of each material in the upper zone will be tested at 5.0 watts/cm^2. Initial chamber temperature will be a minimum of 105°F. For the 5.0 watts/cm^2 nonpiloted condition, a D_s of greater than or equal to 100 by 90 seconds and 200 by 4 minutes for any of the three samples constitutes an unacceptable material.

Any material that autoignites within 90 seconds for either exposure condition (2.5 watts/cm^2 or 5.0 watts/cm^2) will automatically constitute an unacceptable material, regardless of D_s criteria.

<u>Advantages</u>

1. The NBS Smoke Chamber is widely used, standardized by NFPA and near standardization by ASTM, and the methodology is well defined.

2. There should be no scaling problems between the NBS Smoke Chamber and the full-scale fire scenario for the case of radiation induced pyrolysis.

APPENDIX C

TOXICITY: COMBUSTION TUBE

Background

At present, in the toxicity area, there are no well established and universally used tests like the vertical Bunsen burner test for flammability or the NBS Smoke Chamber for smoke. In fact, much toxicity data on aircraft materials have been obtained by taking gas samples as additional data with existing tests like the NBS Smoke Chamber and the Ohio State University Rate of Heat Release Apparatus.

The current technique used both at NAFEC and at the FAA's Civil Aeromedical Institute is the combustion tube furnace. Extensive data on both gas yields and on animal incapacitation and death have been developed at both FAA facilities on the combustion tube.

While other tests are being developed and proposed around the world for a toxicity standard for building materials, the adoption of such tests will be a time-consuming effort. On an interim basis, the Combustion Tube is the sole candidate for aircraft materials because of the following reasons:

1. NAFEC and CAMI already have the required apparatus and operating experience.

2. Operation is relatively inexpensive and simple.

3. Test variables are reasonably well understood.

4. Test procedures are established.

This is the only device that the FAA is in a position to implement as an interim standard within 6 to 8 months.

Summary of Method

Material specimens are to be conditioned at 70°F and 50-percent relative humidity for 24 hours prior to testing. Three replicate tests are required. Materials will be tested on a constant weight basis. However, materials will be ranked on a unit area basis.

The CAMI animal exposure system will be used to certify materials. However, animal responses should be recorded electronically in order to provide a permanent record for regulatory purposes. The minimum average time-to-incapacitation for material certification will be 10 minutes.

Samples of upper-zone materials weighing approximately 250 milligrams will be exposed to a unidimensional radiant heat source, at a temperature of 750°C (1382°F), for 5 minutes. An airflow rate of 2 liters per minute will be maintained over the surface of the sample during the test. Samples of lower-zone materials will be tested in a similar fashion, but at a temperature of 500°C (932°F). Three replicate tests will be required.

The thermal decomposition products will be collected in liquid-filled bubblers or sample bags. The collected samples will be analyzed for HCN, H_2S, and CO, CO_2, respectively.

Both exposures will be nonpiloted tests. However, it is anticipated that a number of materials will autoignite at the higher exposure temperature.

Criteria

Additional testing will be done to determine the performance of existing aircraft materials at the two exposure conditions specified for the upper and lower zones. However, it is probable that the qualification will involve a rather severe criterion for the lower irradiation of the lower-zone material (e.g., time of incapacitation, t_i, greater than 20 minutes) and a less severe limit for the upper-zone material (e.g., t_i of 10 minutes). The incapacitation times will be statistically correlated with the primary toxicants (CO, HCN, H_2S, CO_2) so that quality control yields of those gases will enable the calculation of a time of incapacitation during production runs.

Some developmental work is needed to obtain unidirectional heating inside the combustion tube furnace. This is necessary to realistically expose composite materials such as sidewall and ceiling panels.

Advantages

1. Significant data are already available from the combustion tube on gas species produced from aircraft materials and on animal incapacitation.

2. Test protocols are relatively simple, fast, reproducible, and inexpensive.

APPENDIX D

FLAMMABILITY: VERTICAL BUNSEN BURNER TEST

Background

The vertical Bunsen burner test is a simple test presently utilized for testing the majority of materials used in aircraft cabins for showing compliance to the FAR. This method was first introduced into the FAR in October 1967 for panels, curtains, coated fabrics, and insulation. The FAR was expanded, in May 1972, to include panels, fabrics, padding, plastics, insulation, coated fabrics, and carpet. There have recently been several questionable issues brought forth on the use of this test, such as (1) interpretation of the measurement of burn length expecially on panels, (2) purity of the synthetic gas referenced (Mathison B gas), interpretation of test procedure and measurements. The vertical test method was published as an ASTM standard test method for aerospace vehicles in 1977. This method ASTM F501 more clearly describes the apparatus and procedure to be followed than the one referenced in the present FAR.

Summary of Method

The vertical Bunsen burner test is described in detail in American Society for Testing and Materials (ASTM) Standard Test Method F501-77 titled "Aerospace Materials Response to Flame, with Vertical Test Specimen (For Aerospace Vehicles Standard Conditions)."

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, 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 at least 1600°F. 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. Specimens are tested in the thickness used in the aircraft, except that the seat cushions (foams) are tested in 1/2 inch thickness.

The test procedures consist of exposing the specimen to the 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 flame time (self-extinguishing time). Burn length is measured as the distance from the original edge to the farthest evidence of irreparable damage to the specimen, not including areas sooted, stained, or discolored.

Criteria

1. The vertical Bunsen burner test will be utilized for testing all materials in the lower zone of the cabin.

2. In addition to materials in paragraph (b), blankets, pillows, pillowcases, headrest covers, and other materials furnished by the airlines and carried in the passenger compartment will be tested by this method.

3. Burn length - not to exceed 6 inches (average of 4 tests).

4. Flame time after removal of the ignition source - not to exceed 10 seconds (average of 4 tests).

5. Flaming drippings shall be self-extinguishing on contact with the chamber floor.

6. Fabrics shall still meet the above limits after the prescribed washing or dry cleaning (at least three washings or dry cleanings).

7. Foam seat cushion material tested in 1/2 inch thickness with the test cabinet door in the open position.

8. If a sprayed on slipcoat (Urespray®) is to be used on a foam seat cushion, a section including the slipcoat shall be tested.

9. If a gluestrip is to be included as part of the makeup of a seat cushion, a section including the gluestrip shall be tested.

<u>Advantages</u>

1. Ease of operation.

2. Low operating and equipment costs.

3. Methodology is already well established and standardized.

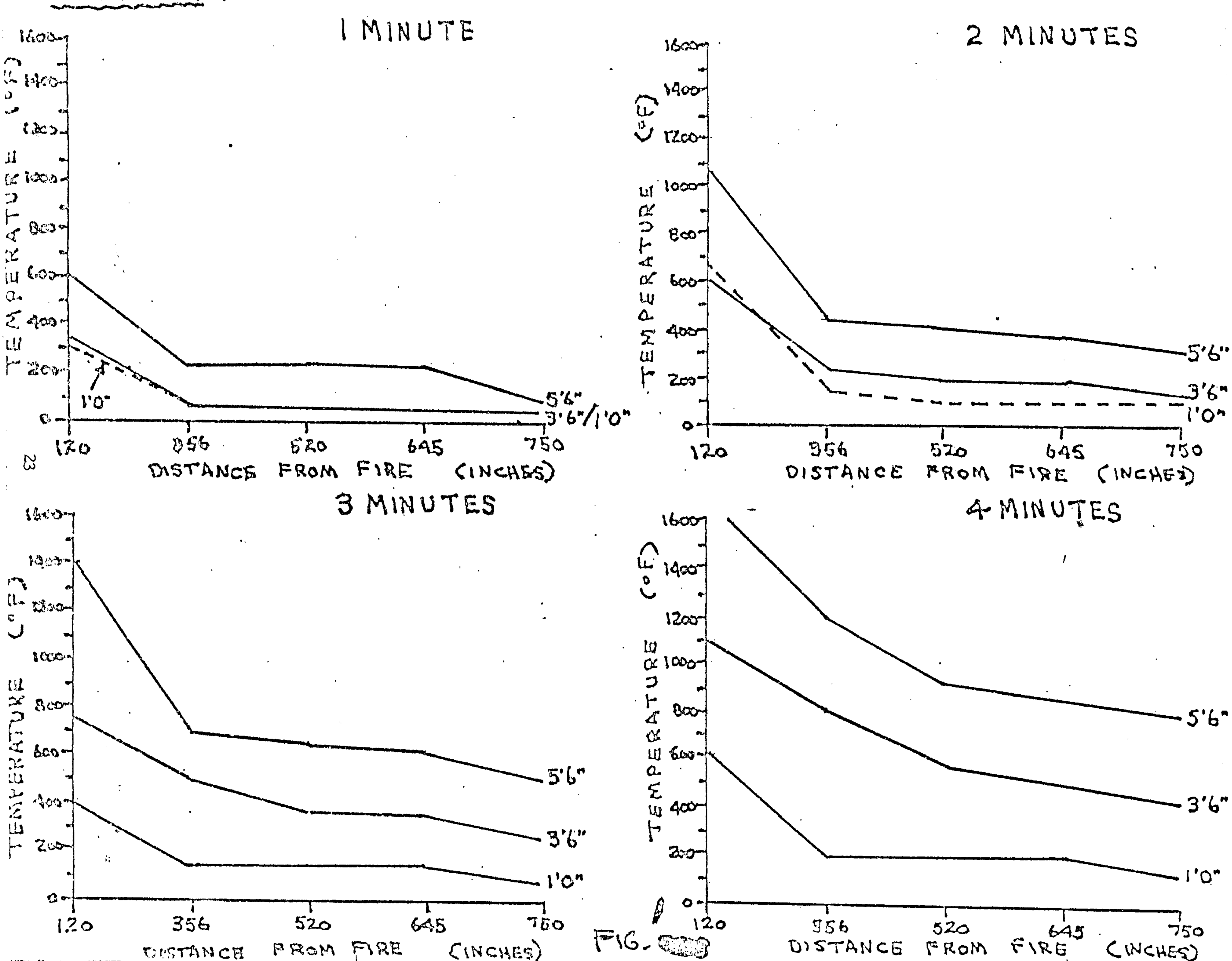
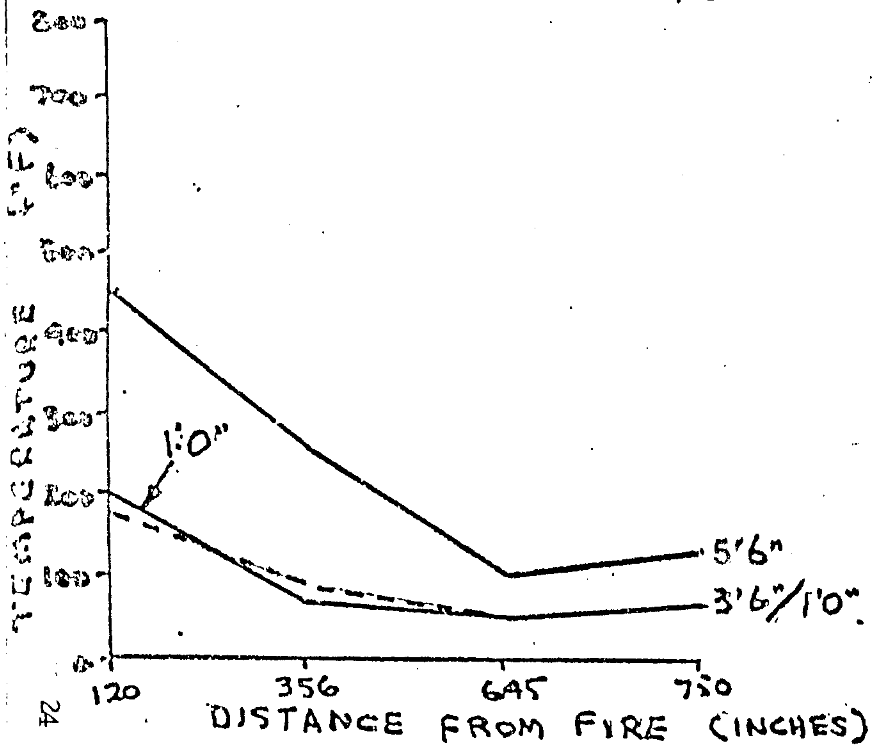

1 MINUTE
2 MINUTES
3 MINUTES
4 MINUTES
TEMPERATURE (°F)
0
200
400
600
800
1000
1200
1400
1600
120
356
520
645
750
DISTANCE FROM FIRE (INCHES)
5'6"
3'6"/1'0"
1'0"
3'6"

FIG.

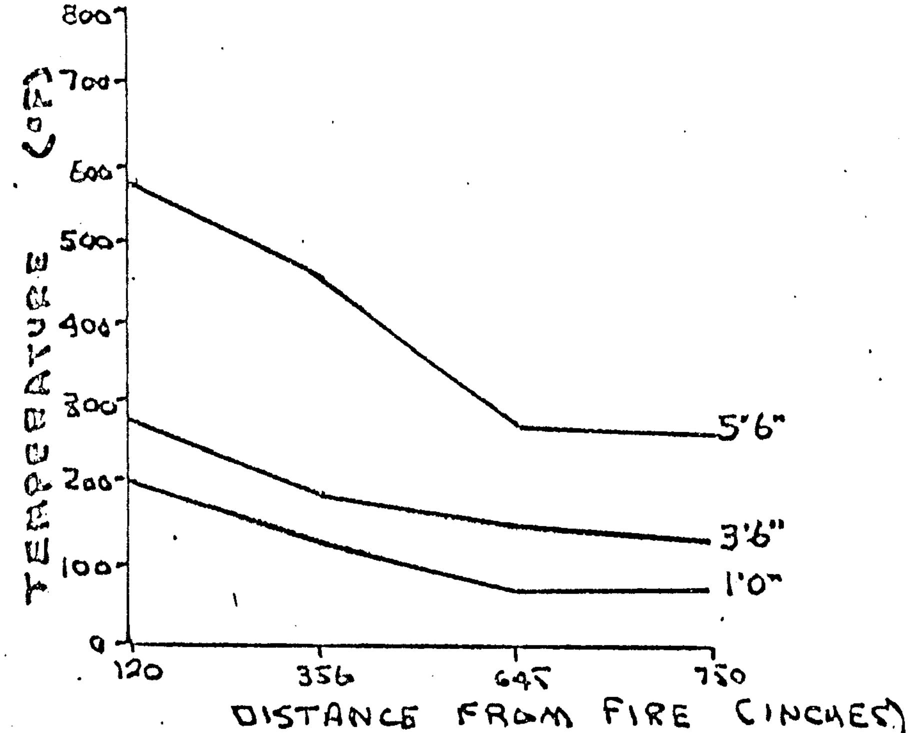
Test No. 66

TEST 66

1 MINUTE



2 MINUTES



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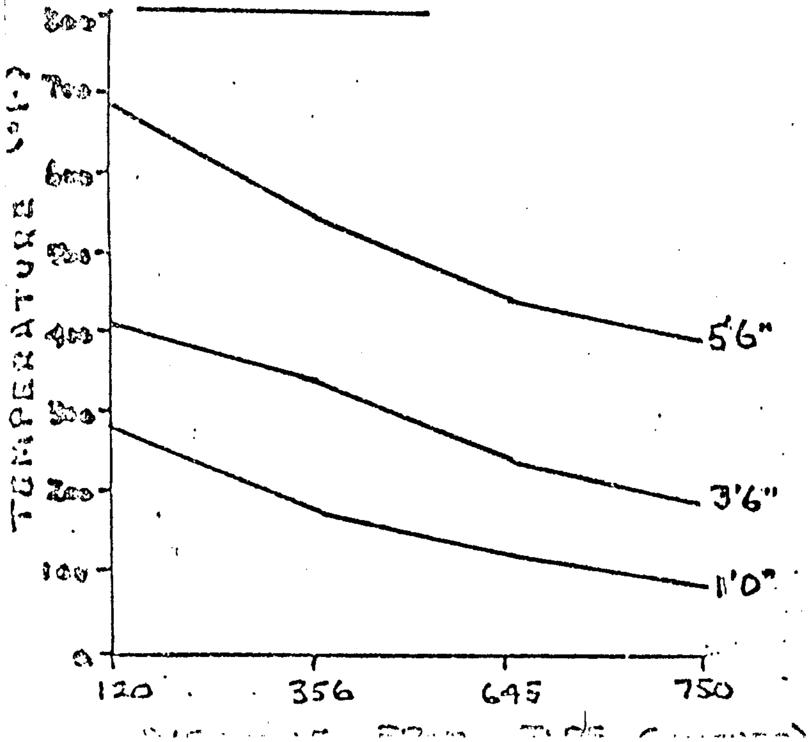
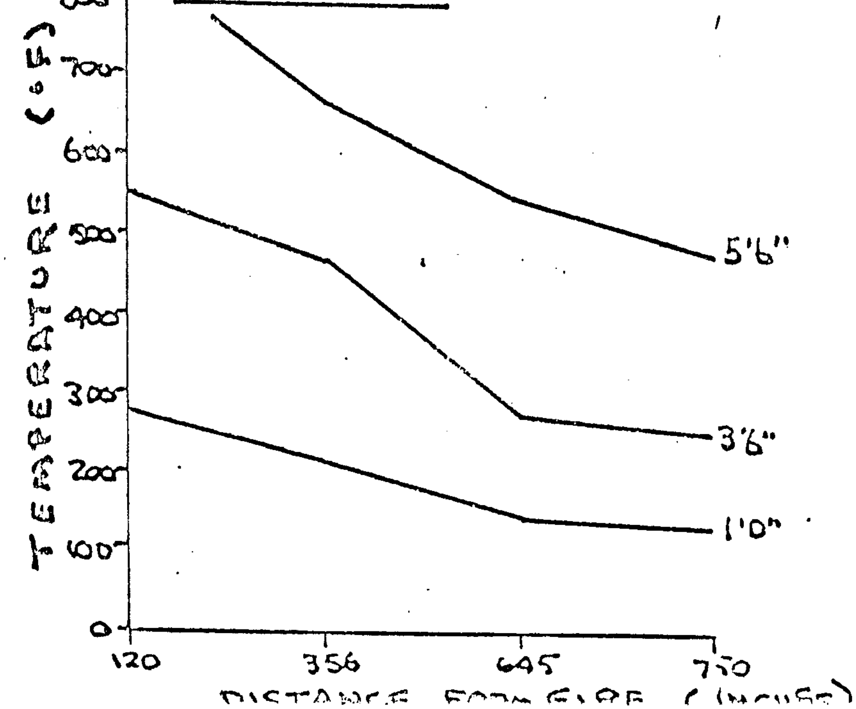


4 MINUTES



Test No. 66

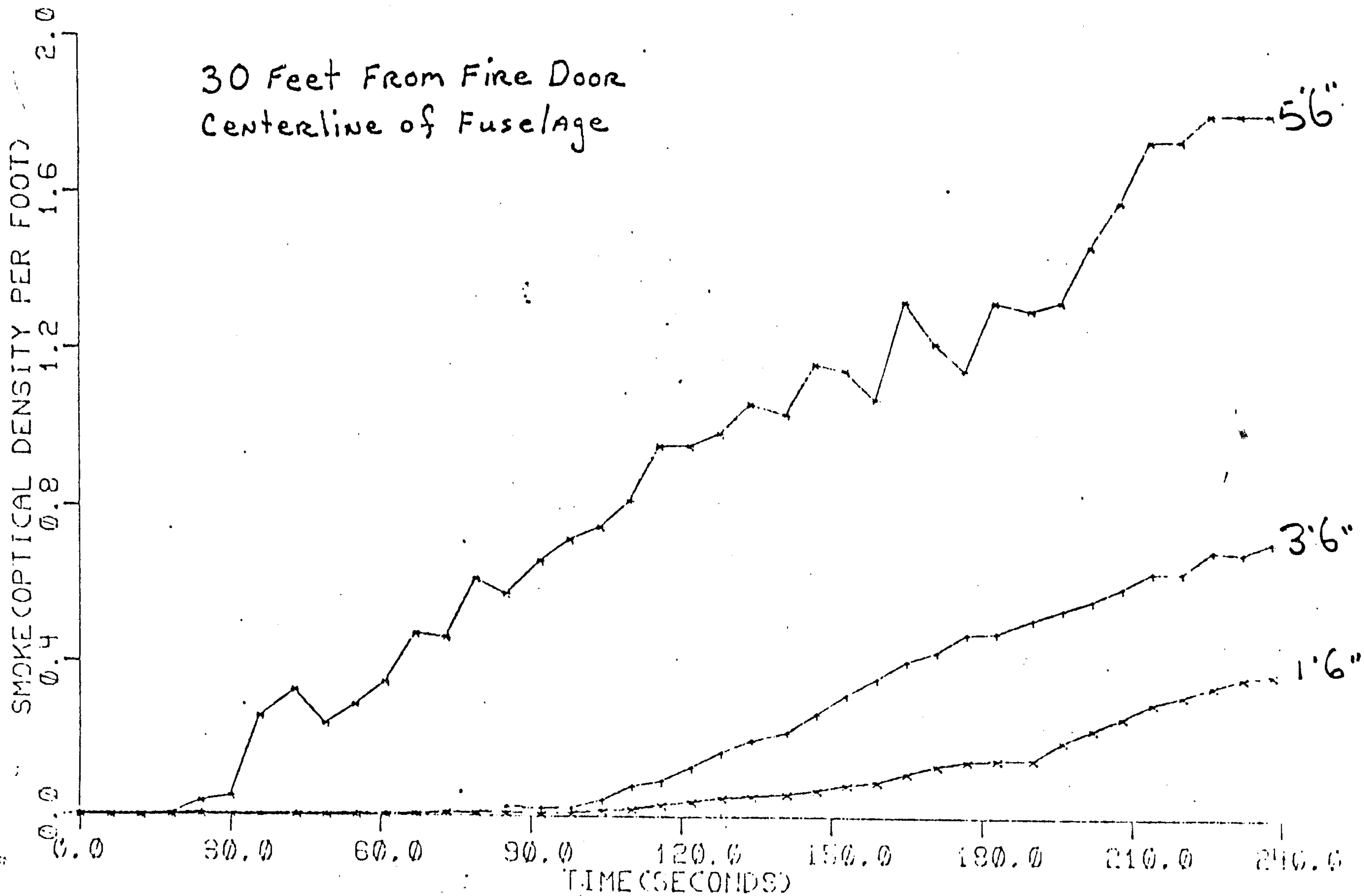


FIG. 3[illegible]

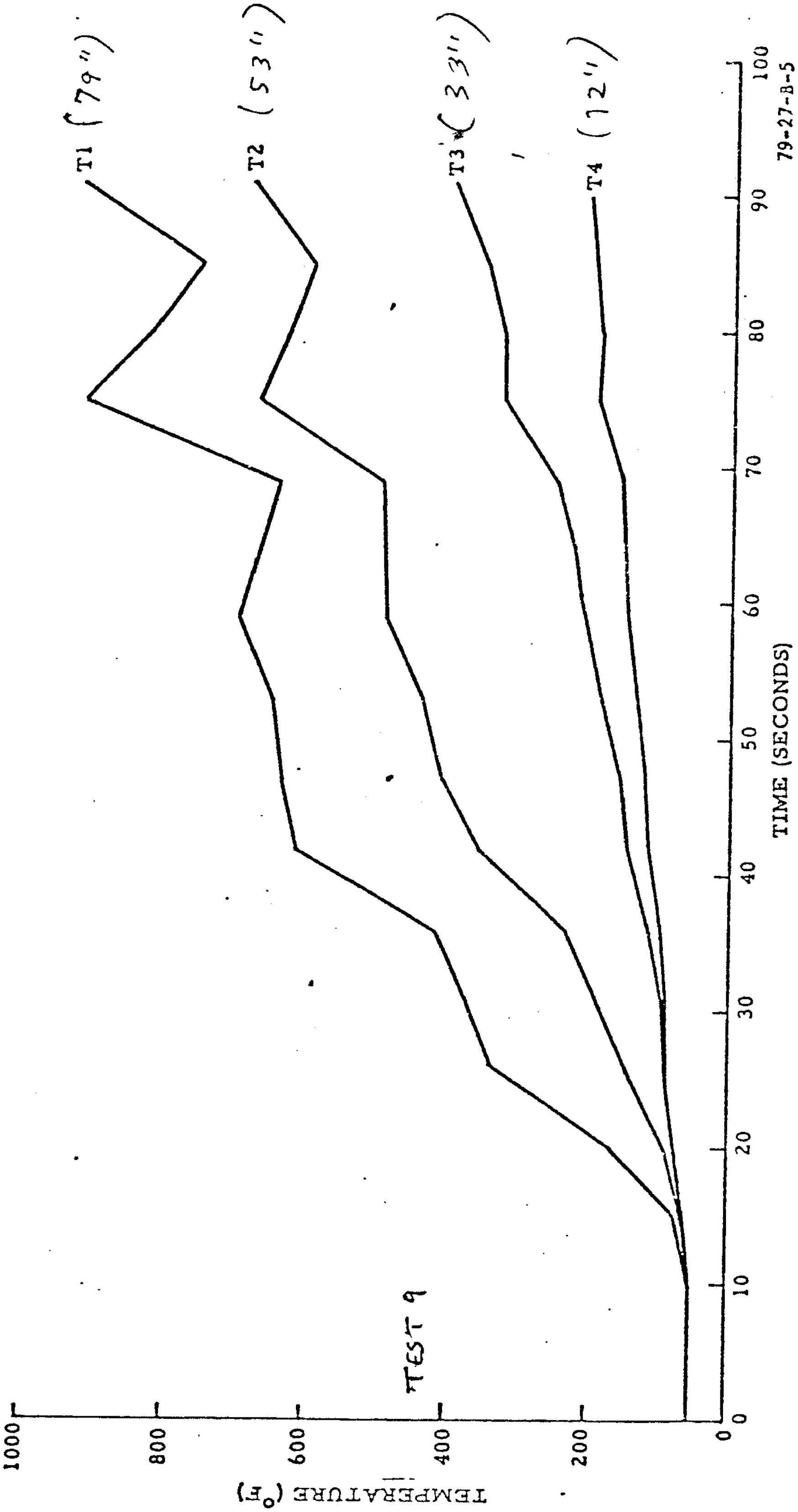

T1 (79")
T2 (53")
T3 (33")
T4 (12")
TEST 9
TEMPERATURE (°F)
1000
800
600
400
200
0
0
10
20
30
40
50
60
70
80
90
100
TIME (SECONDS)
79-27-B-5

FIGURE 4

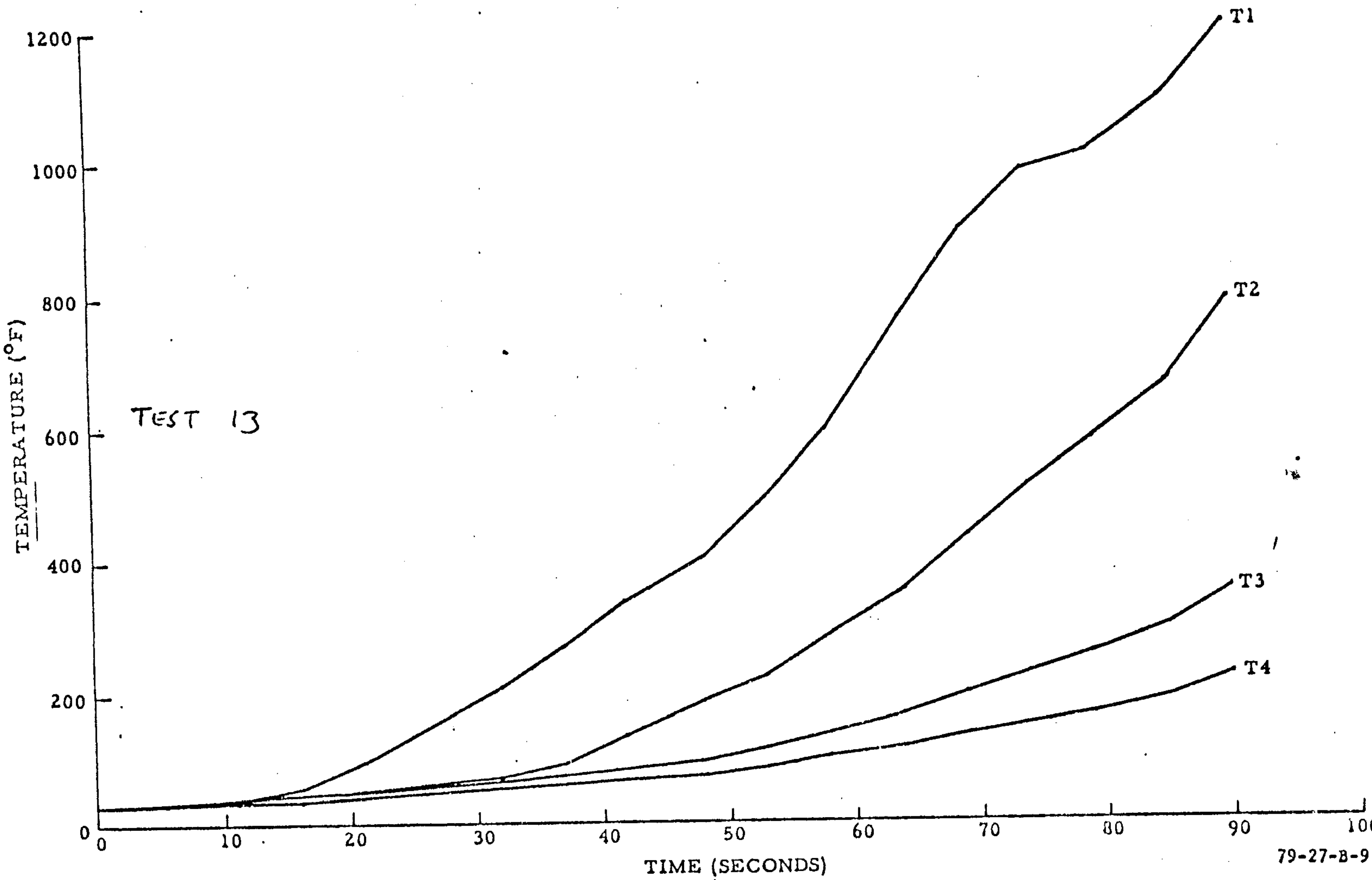

TEST 13
TEMPERATURE (°F)
1200
1000
800
600
400
200
0
0
10
20
30
40
50
60
70
80
90
100
TIME (SECONDS)
T1
T2
T3
T4
79-27-B-9

FIGURE 5

TABLE [illegible]. LIGHT TRANSMISSION DATA

Test Run	Laser Identity	Laser Transmission (percent) at Various Times Into Test After Fuel Ignition (s) 10	20	30	40	50	60
50	A *	99	35	21	13	14	14
	B **	100	98	89	90	70	54
51	A	96	21	12	9	9	9
	B	100	98	84	87	69	40
52	A	63	12	14	11	9	12
	B	100	98	86	80	46	37
53	A	68	20	13	11	10	10
	B	100	99	91	44	17	16
54	A	78	21	11	12	10	8
	B	100	99	95	55	20	18
55	A	89	24	9	9	8	8
	B	100	99	88	77	24	8

* Top Laser (transmission length is 2ft.)
** Bottom Laser (transmission length is 3 ft.)

	LOWER ZONE	UPPER ZONE
SMOKE	Modified NBS Smoke Chamber Non-Piloted Test 2.5 Watts/CM^2 of Radiant Exposure	Modified NBS Smoke Chamber Non-Piloted Test 5.0 Watts/CM^2 of Radiant Exposure
TOXICITY	Combustion Tube Non-Piloted Test Temperature Exposure of 500°C	Combustion Tube Non-Piloted Test Temperature Exposure of 750°C
FLAMMABILITY	Vertical Bunsen Burner Test (ASTM F 501) Existing Exposures	Radiant Panel Test (ASTM E-162) Existing Exposures

TABLE 2
TEST MATRIX