NASA Technical Memorandum 78523

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Conference on Fire Resistant Materials (Firemen)

A Compilation of Presentations and Papers

Sponsored by NASA Headquarters
Held at
Ames Research Center
Moffett Field, California
April 13-14, 1978

Edited by Demetrius A. Kourtides

October 1978

17 JAN 1989
McDONNELL AIRCRAFT COMPANY

NASA
National Aeronautics and
Space Administration

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Conference on Fire Resistant Materials (Firemen)

A Compilation of Presentations and Papers

Edited by Demetrius A. Kourtides

National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, California 94035

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Preface

The proceedings of the NASA Fire Resistant Materials Engineering (FIREMEN) Program held at Ames Research Center, Moffett Field, California, on April 13, 14, 1978 are reported in this NASA Technical Memorandum. The purpose of this conference was to discuss the results of research of the National Aeronautics and Space Administration in the field of aircraft fire safety and fire-resistant materials. The program components include the following:

(1) Large-Scale Testing

(2) Fire Toxicology

(3) Polymeric Materials

(4) Bibliography related and/or generated from the Program

Contributions to this compilation were made by representatives from NASA Headquarters; NASA-Ames Research Center; NASA-Johnson Space Center; Douglas Aircraft Company; Boeing Commercial Airplanes Company; Lockheed California Company; Southwest Foundation for Research and Education; Solar Division, International Harvester Company; Massachusetts Institute of Technology; Jet Propulsion Laboratoty; and U.S. Navy, David Taylor Naval Ship Research and Development Center.

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WELCOME AND OPENING REMARKS

John A. Parker
Chemical Research Projects Office
Ames Research Center
Moffett Field, California 94035

Welcome and Opening Remarks

John A. Parker

Ames Research Center

I would like to welcome you at this review of the FIre REsistant Materials ENgineering (FIREMEN) program. There are three distinct programs supporting the aircraft fire safety program. They are (1) the FIREMEN Program (2) the Materials Research and Technology (R & T) Base Program and (3) the Aviation Safety Research and Technology Program. In this review we will primarily address the first program. The FIREMEN Program is a five year program and addresses itself to on-board interior aircraft fires. The Materials Research and Technology Base Program addresses itself to materials development and the Aviation Safety Research and Technology Program addresses itself to fire test methodologies and operating problems for aircraft.

The FIREMEN Program has three parts: (1) panels, conducted by the Boeing Aircraft Company, (2) seat development, conducted by McDonnell-Douglas Aircraft Company, and (3) thermoplastic materials and process development, conducted by Lockheed-California Company. Supporting these efforts are additional companies and Universities whose programs will also be reviewed.

It is expected that the advances achieved as a result of the FIREMEN Program will be used in all modes of transportation. Material development work is directed by the Chemical Research Projects Office, at Ames Research Center.

Testing activities are directed by the Johnson Space Center. Mr. Richard Bricker is the principal investigator. In addition, toxicological studies are principally directed by the Johnson Space Center.

In this review, the programs at both Centers will be reviewed as will the programs conducted by the aircraft manufacturers, industry and Universities. Again I would like to welcome you and solicit your comments during the discussion periods of the conference.

INTRODUCTORY REMARKS

John H. Enders
NASA Headquarters
Washington, D.C.

FIREMEN MID-TERM REVIEW

INTRODUCTORY REMARKS BY

JOHN H. ENDERS,
CHIEF, AVIATION SAFETY TECHNOLOGY BRANCH
NASA HEADQUARTERS
WASHINGTON, DC

NASA's legacy of aircraft fire safety research dates from the early days of its predecessor, the NACA. Figure 1 summarizes the evolution of this research within the NASA organization, reflecting the changing aspects of fire concerns over the years. This is, of course, a NASA-centered chart, and therefore does not give proper credit to extensive efforts made by other organizations in the aircraft fire safety field. In particular, FAA and the military services have carried out a great deal of aircraft fire research and development on existing equipment and currently-used materials to determine fire, flammability, smoke, and toxicology parameters.

NASA's role has traditionally focused on expanding knowledge and understanding of basic fire processes, and their involvement with the aircraft and its systems. The scope of the present fire research and technology effort is shown in Figure 2. The matter of interior materials involvement is comparatively new to NASA, stemming from the Apollo 204 spacecraft fire in 1967. While FAA and other organizations have a substantial on-going effort devoted to existing materials flammability, NASA is emphasizing the exploration of advanced materials and materials systems concepts, many of which challenge state-of-the-art capabilities in compounding, processing, and manufacturing. Many new polymers which offer potential improvements in fire behavior are scarce and expensive. The limited aviation market is not adequate to stimulate a vigorous exploration of these high risk, high cost concepts, so NASA initiated a 5-year, $4.3M augmentation of our basic research programs in 1976 to provide funding under contract to the industry in order to accelerate the examination of new materials applications. Figure 3 shows the approximate funding distribution of this augmentation, called FIREMEN (FIre REsistant Materials ENgineering). The program has heretofore emphasized materials development.

We are now moving into the final half of FIREMEN where large scale testing and evaluations of these advanced materials will be emphasized.

Figure 4 illustrates the materials systems of interest in the FIREMEN program. During the next two days we will hear presentations by various participants in the FIREMEN program reporting on status and progress to date in improved materials fireworthiness. This is not a final report on the program, but a mid-term review which normally would have been presented piecemeal in several in-house sessions. Because we feel that the ideas and concepts which have developed so far in the program should be shared with as broad a fire technology audience as possible, we decided to expand the review beyond in-house NASA management. We hope that the progress and problems reported on here will stimulate productive discussions among the participants and audience following the meeting and that the overall result will be to accelerate improvements in aircraft fire safety.

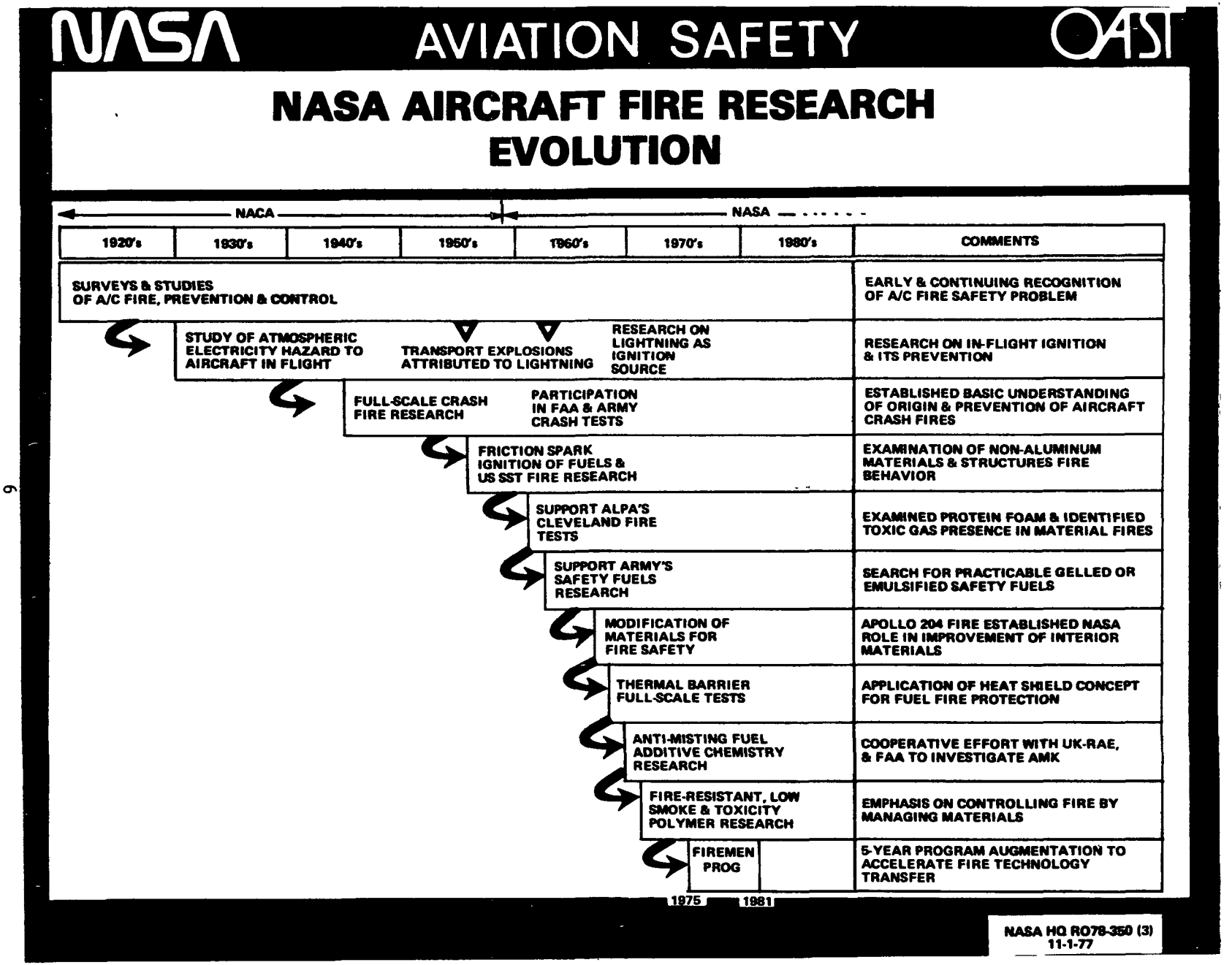
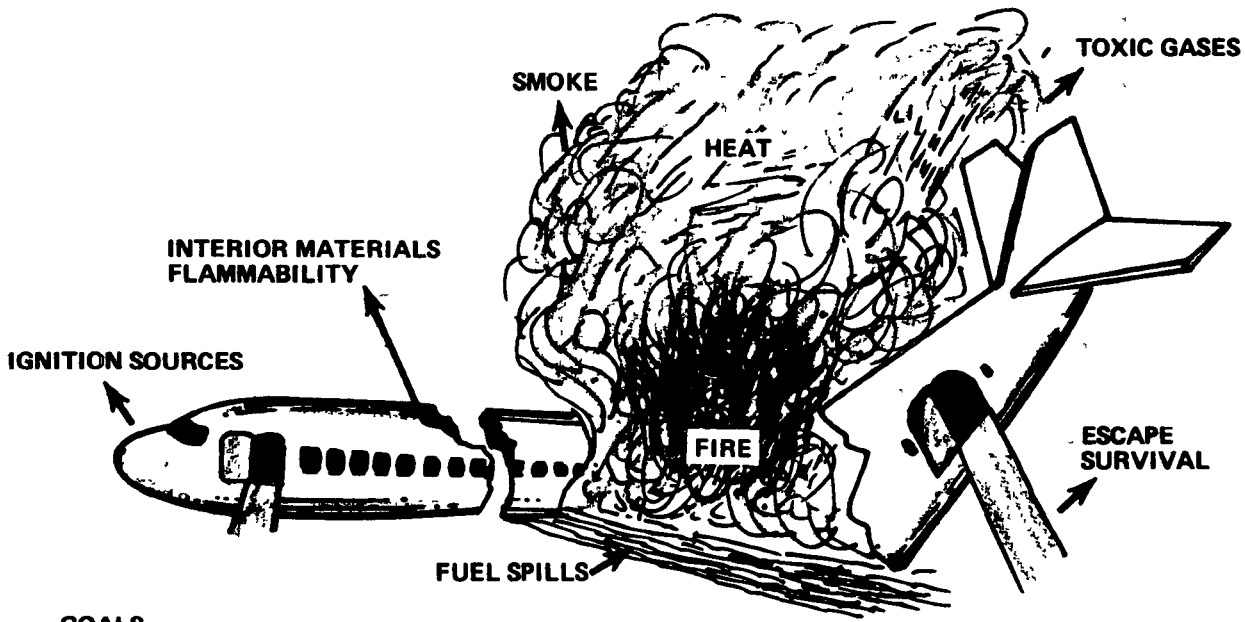

NASA
AVIATION SAFETY
OAST
NASA AIRCRAFT FIRE RESEARCH EVOLUTION
NACA
NASA
1920's
1930's
1940's
1950's
1960's
1970's
1980's
COMMENTS
SURVEYS & STUDIES OF A/C FIRE, PREVENTION & CONTROL
EARLY & CONTINUING RECOGNITION OF A/C FIRE SAFETY PROBLEM
STUDY OF ATMOSPHERIC ELECTRICITY HAZARD TO AIRCRAFT IN FLIGHT
TRANSPORT EXPLOSIONS ATTRIBUTED TO LIGHTNING
RESEARCH ON LIGHTNING AS IGNITION SOURCE
RESEARCH ON IN-FLIGHT IGNITION & ITS PREVENTION
FULL-SCALE CRASH FIRE RESEARCH
PARTICIPATION IN FAA & ARMY CRASH TESTS
ESTABLISHED BASIC UNDERSTANDING OF ORIGIN & PREVENTION OF AIRCRAFT CRASH FIRES
FRICTION SPARK IGNITION OF FUELS & US SST FIRE RESEARCH
EXAMINATION OF NON-ALUMINUM MATERIALS & STRUCTURES FIRE BEHAVIOR
SUPPORT ALPA'S CLEVELAND FIRE TESTS
EXAMINED PROTEIN FOAM & IDENTIFIED TOXIC GAS PRESENCE IN MATERIAL FIRES
SUPPORT ARMY'S SAFETY FUELS RESEARCH
SEARCH FOR PRACTICABLE GELLED OR EMULSIFIED SAFETY FUELS
MODIFICATION OF MATERIALS FOR FIRE SAFETY
APOLLO 204 FIRE ESTABLISHED NASA ROLE IN IMPROVEMENT OF INTERIOR MATERIALS
THERMAL BARRIER FULL-SCALE TESTS
APPLICATION OF HEAT SHIELD CONCEPT FOR FUEL FIRE PROTECTION
ANTI-MISTING FUEL ADDITIVE CHEMISTRY RESEARCH
COOPERATIVE EFFORT WITH UK-RAE, & FAA TO INVESTIGATE AMK
FIRE-RESISTANT, LOW SMOKE & TOXICITY POLYMER RESEARCH
EMPHASIS ON CONTROLLING FIRE BY MANAGING MATERIALS
FIREMEN PROG
1975
1981
5-YEAR PROGRAM AUGMENTATION TO ACCELERATE FIRE TECHNOLOGY TRANSFER
NASA HQ RO78-350 (3)
11-1-77

Fig. 1

NASA AVIATION SAFETY OAST

AIRCRAFT FIRE SAFETY RESEARCH & TECHNOLOGY



GOALS:

- IMPROVE UNDERSTANDING OF FIRE DYNAMICS
- SUPPORT DEVELOPMENT OF TEST METHODOLOGY
- PROVIDE IMPROVED MATERIALS TECHNOLOGY
- IMPROVE DETECTION & EXTINGUISHMENT TECHNOLOGIES
- EXPLORE MEANS OF REDUCING IGNITION & FIRE BUILD-UP RATE
- EVALUATE NEW TECHNOLOGY APPLICATIONS IN REAL DESIGNS (e.g. FIREMEN)
- PROVIDE BASIC R&T SUPPORT OT OTHER AGENCIES

NASA HQ RO78-354 (3)
11-1-77

Fig. 2

NASA AVIATION SAFETY OAST

FIREMEN PROGRAM
(FIRE RESISTANT MATERIALS ENGINEERING)

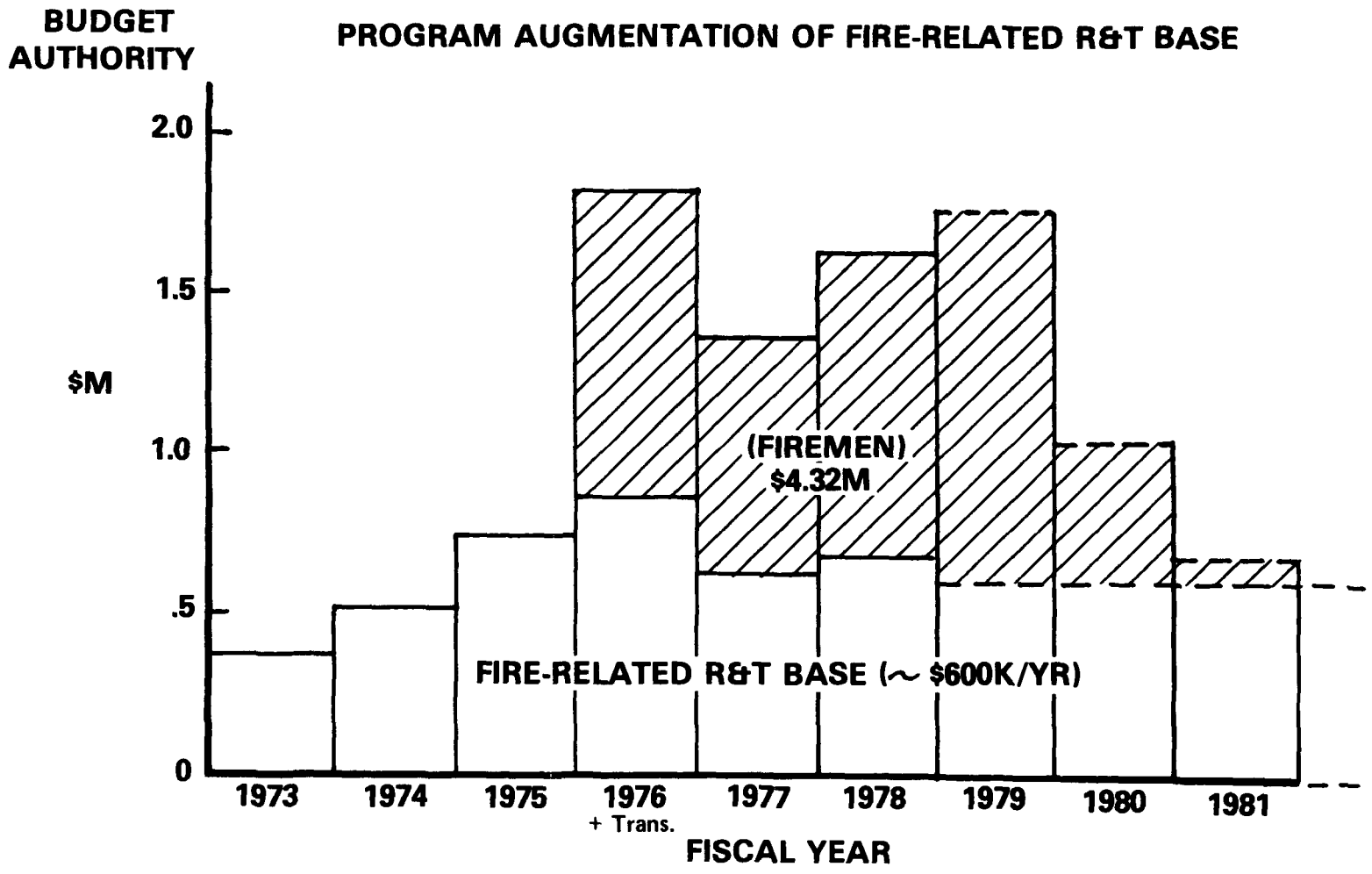


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Fig. 3

NASA AVIATION SAFETY OAST

FIREMEN PROGRAM: IMPROVED FIRE SAFETY IN AIRCRAFT INTERIOR MATERIALS

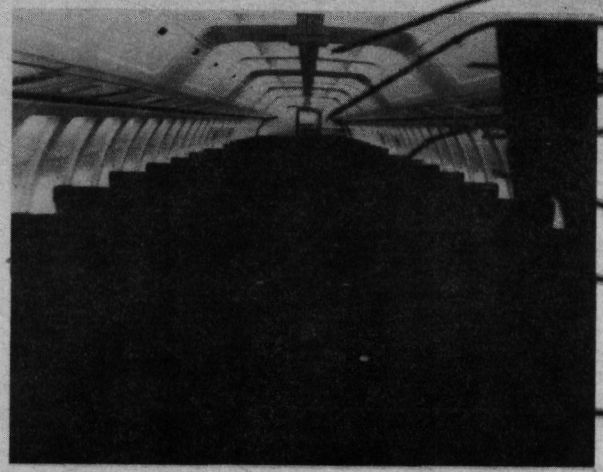

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Fig. 4

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SESSION A: LARGE SCALE TESTING

Session Chairman: John H. Enders
NASA Headquarters

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737 AIRCRAFT FLAMMABILITY TESTING

Richard W. Bricker
Johnson Space Center
Houston, Texas 77058

ABSTRACT

PRESENTATION ON JSC 737 AIRCRAFT FLAMMABILITY TESTING

The FAA has requested NASA/JSC to perform approximately 20 component and full-scale tests in a 737 fuselage located at JSC to provide validation data or indicate changes that need to be made to a fire math model (Dayton Aircraft Cabin Fire Model) developed for the FAA.

The instrumentation required for this test program is more extensive than in previous full-scale tests and in some cases is based on undeveloped techniques; therefore, some preliminary tests were conducted to evaluate the adequacy of planned instrumentation.

The objectives of the program were met in that it was verified that propagation of a fire could be determined from the sequential response of thermocouples located on a test specimen (such as a seat), and continuous weighing of the specimen during the test was accomplished. In addition, two different techniques for measuring smoke density were found to be comparable.

JSC/FAA INSTRUMENTATION VALIDATION TESTS

INTRODUCTION

The FAA has requested NASA/JSC to perform approximately 20 component and full-scale tests in a 737 fuselage located at JSC to provide validation data or indicate changes that need to be made to a fire math model (Dayton Aircraft Cabin Fire Model) developed for the FAA.

The instrumentation required for this test program is more extensive than in previous full-scale tests and in some cases is based on undeveloped techniques; therefore, some preliminary tests were conducted to evaluate the adequacy of planned instrumentation.

This report covers the results of these preliminary tests.

OBJECTIVES

The primary objective of these preliminary tests was to evaluate instrumentation techniques planned for use in a subsequent joint program with the FAA. The specific objectives were as follows:

1. Evaluate tracking of flame propagation on burning materials by the appropriate location of thermocouples on a given test specimen.
2. Measure the burning rate of the flammable materials (of a given test specimen) during the test by continuous weighing of the test specimen.
3. Evaluate the NBS photometric smoke measurement system and compare its results to those of a laser smoke measurement technique.
4. Evaluate the capability of a recently developed bidirectional gas flow device for measuring variable gas flows during flammability tests.
5. Collect gas samples and measure quantities for six gases (O_2, CO_2, CO, HF, HCN, and HCL).

TEST DESCRIPTION

Tests were conducted in a 737 fuselage utilizing jet A-1 fuel as the ignition source. The initial test specimen consisted of a mockup aircraft seat with state-of-the-art fire resistant aircraft seat cushion foam in the configuration shown in figure 1. The ignition source was one liter of jet A-1 fuel in a pan 12" x 12" located as shown in figure 1. The seat was suspended from a load cell with a cable and bridle system as shown in figure 1. To prevent excessive sidewise movement of the seat due to air currents, four right angle tabs were fastened to the floor at each leg position with approximately 1/4" clearance between the tab and leg. The bottom of each chair leg was approximately 1-1/2" above the aircraft floor to prevent contact with the floor due to support cable thermal expansion.

INSTRUMENTATION

The following instrumentation was installed on the seat and in the 737 fuselage:

1. Thermocouples - The seat foam for the initial test was instrumented with thermocouples as shown in figure 2. A temperature probe was located above the fuel pan to indicate approximate flame temperatures. Additional thermocouples were located on two thermocouple trees as shown in figure 3.

2. Load Cell - A 0-100 pound load cell was suspended from a bracket outside the fuselage directly above the seat position. A cable from the load cell traversed through a tube that penetrated the fuselage. A bridle attached at four points of the chair converged to a point directly above the chair C.G. where it was attached to cable suspended from the load cell (figure 1).

3. Smoke Measuring Equipment - Two devices were installed in a close proximity (figure 3) to measure the loss of visibility due to smoke production. A laser source located 3 feet from the sensor was used along with an NBS photometric smoke measurement system which has a light source one meter from the sensor.

4. Bidirectional Gas Flow Probe - A gas flow probe based on differential pressure was located as shown on figure 3.

5. Movie Cameras - Two movie cameras were located as shown in figure 3 to photograph the seat during the test. Color film was used at 24 frames per second (realtime) in both cameras.

6. Still Photography - Still color photographs of the test specimen were taken before and after the initial test.

7. Gas Collection and Analysis - Dry gas samples were collected for laboratory analysis by gas chromotography for O_2, CO_2, and CO. Samples were also collected in a bubbler system containing an aqueous solution for subsequent analysis for HF, HCN, and HCL. A more detailed description of the gas collection and analytical techniques and results is given in Figs. 4-5.

TEST RESULTS

After ignition of the jet A-1 fuel (that is, when the fire completely covered the fuel pan area), approximately one minute elapsed prior to significant involvement of the foam in the fire. The jet fuel and foam produced large quantities of smoke that obscured camera visibility approximately 1-1/2 minutes after ignition. The foam melted as it burned, which resulted in the dripping of many flaming particles. The fire burned out after approximately 6 minutes, and, although all of the seat bottom was gone, a large portion of the back remained as shown in

figure 6. The pre-test weight of the foam was 6.4 lbs and post-test weight of the remaining foam was 2.2 lbs for a total weight of foam burned or melted of 4.2 lbs.

Thermal Data - The temperature response and location of four centrally located thermocouples on the seat cushion and back for the first 5 minutes of the test are shown in figure 7. Peak temperatures were 1200 to 1400°F, occurring from 1 minute to 2 minutes when all of the temperatures gradually went down. This was apparently due to the foam and direct flame impingement receding from the thermocouples as the foam was consummed.

One of the test objectives was to determine the feasibility of tracking fire propagation through thermocouple response; figures 7 thru 12 are presented with this objective in mind. Since most of the thermocouples on the foam responded in the first 90 seconds, the time span used on figures 8 thru 10 is 100 seconds rather than the full five minutes used on the other figures. This expanded time scale permits a better view of the point in time at which the rapid temperature rise indicates flame impingement on the thermocouple. Figure 6 shows the spread of fire reaching four thermocouples on the seat cushion bottom. Thermocouple 3 is closest to the fire and on the side to which the air flow tends to direct the fire and consequently is the first to rise. Its initial reading of 250°F results from calling "time zero" the time at which the fuel pan is covered with fire, which is usually several seconds after ignition because of the slowness of jet A-1 to ignite. Temperatures from thermocouples 2, 4, and 1 follow in expected order based on the fire location and air flow pattern. The other three thermocouples on the seat bottom (figure 12, thermocouples 5, 6, and 7) do not show a significant spread in time. The opposite pattern occurs on the top of the same seat cushion, as shown in figures 8 and 9, and, as would be expected, the temperature rises occur 30-45 seconds later than on the bottom. All thermocouples on the fireside of the seat cushion back show a fairly definite and well spread point in time where a significant temperature rise occurs on this surface. Figure 11 shown the relatively lower temperatures occurring on the back side of the seat back as would be expected from the limited damage on this surface (as shown in figure 6).

Weight Loss Data - The weighing of the seat frame and foam during the initial test to determine the burning rate of the foam resulted in anomalous data. A weight loss of approximately 3 times the weight of the foam apparently resulted from some constraint or friction between the seat legs and the restraining tabs.

Additional tests resulted in weight loss close to that expected. A test was conducted using a non fire-retardant polyurethane foam which produced a weight loss with respect to time as shown in figures 13-14. An additional test was conducted with a much slower burning fuel (2-1/2 liters of jet A-1 in an 18" x 18" fuel pan located on top of the seat) with the results shown in figure 15. Both tests produced inherent minor inaccuracies concerning actual weight loss due to burning. While the foam was burning, considerable melting and dripping of flaming particles occurred, resulting in some weight loss of material that may not have been due to burning. The burning liquid fuel floats on water and after a period of time the water starts boiling, resulting in weight loss in addition to that of the burning fuel. The weight loss of the water can be determined after the test but not the rate or time of loss.

Smoke Density - A laser system and an NBS smoke density measuring system were used to measure the loss of visibility due to smoke during the initial test (fire retardant polyurethane foam). The comparative results are shown in figure 15. The initial levels of smoke density of 17% and 25% are mainly due to the smoke evolved from the hot ignitor prior to ignition of the fuel and during the time the flames cover the fuel pan. The laser system has a time delay smoothing circuit in the electronics which may account for the somewhat smoother data.

CONCLUDING REMARKS

Tests were conducted to evaluate instrumentation techniques for a subsequent joint program with the FAA. Most of the test objectives were met or a need for further testing established. As indicated by the test results, tracking of flame propagation across burning materials can be determined from temperature response of thermocouples located on the test specimen. Weighing of test specimens and determining the burning rate of materials during the test was achieved. Care must be exercised to insure that the test specimen being weighed does not have any external interference, otherwise inconsistent results occur.

Measurements of smoke density provided by the laser technique and NBS smoke measuring system were in fairly good agreement. A time delay smoothing circuit in the laser system provided more uniform data than the NBS system. Similar circuitry could be applied to the NBS system; however, eliminating significant excursions in the data may or may not be desirable.

Results of the gas flow measurements are inconclusive at this time. Further effort is planned in this area with some additional baseline air flow and flammability tests.

The time that elapses after ignition, but prior to full involvement of the ignition fuel results in premature response of thermocouples close to the fuel pan and also of the smoke density measurement system. A more rapid coverage of the fuel pan by the fire is desirable and an attempt to achieve this is being made.

The overall results indicate that the instrumentation planned for the JSC/FAA test program will provide useful data that will support the validation or indicate necessary changes to the fire math model.

JSC/FAA TEST PROGRAM INSTRUMENTATION VALIDATION TESTS

SEAT CUSHION FOAM TEST

OBJECTIVES

- EVALUATE TRACKING OF FIRE PROPAGATION WITH THERMOCOUPLES
- DETERMINE BURNING RATE DURING TEST
- COMPARE VISIBILITY MEASUREMENTS WITH LASER & NBS TECHNIQUE
- EVALUATE FACTORY MUTUAL TECHNIQUE FOR MEASURING GAS FLOW
- ASSESS HAZARD OF STATE-OF-THE-ART SEAT FOAM
- DETERMINE COMPATIBILITY OF DATA FORMAT WITH DACFIR MATH MODEL

TEST CONFIGURATION

- 20-FOOT TEST SECTION
- SEAT SUSPENDED FROM LOAD CELL
- BOTTOM AND BACK SEPARATED TO REDUCE CROSS EFFECTS
- ONE QUART OF JET A1 IN 12 INCH SQUARE PAN

INSTRUMENTATION

37 THERMOCOUPLES ON FOAM SEAT AND BACK

3 FOOT LASER AND 1 METER NBS APPARATUS IN CLOSE PROXIMITY

LOAD CELL FOR CONTINUOUS SEAT WEIGHING

FACTORY MUTUAL SYSTEM FOR LOW GAS FLOW MEASUREMENT

GAS COLLECTION AND ANALYSIS FOR NCN, HCL, HF, CO, CO_2, AND O_2

TWO COLOR MOVIE CAMERAS (24 FPS)

TV CAMERA

NASA-S-78-11427

SEAT TEST CONFIGURATION

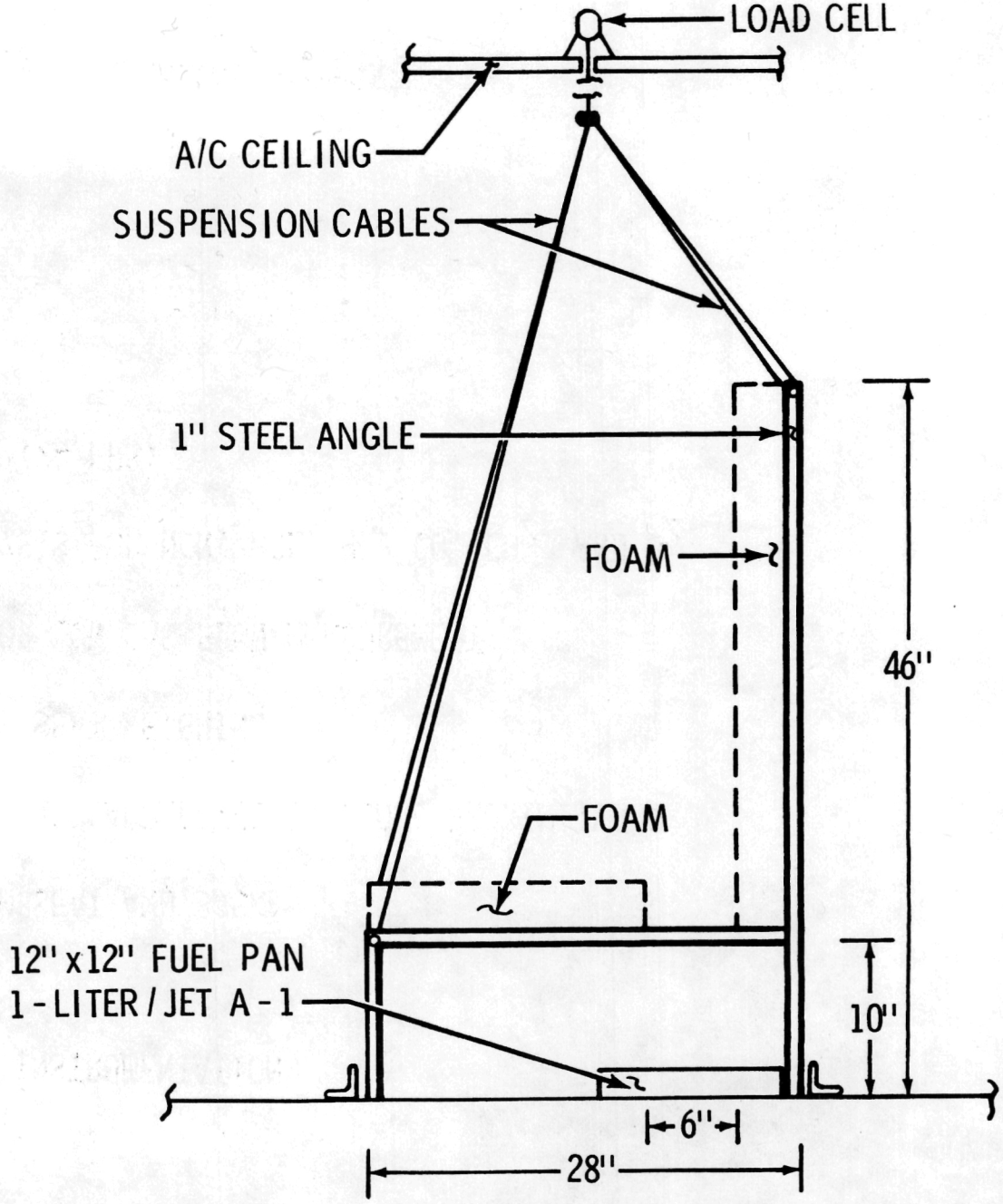

Fig. 1

INSTRUMENTATION

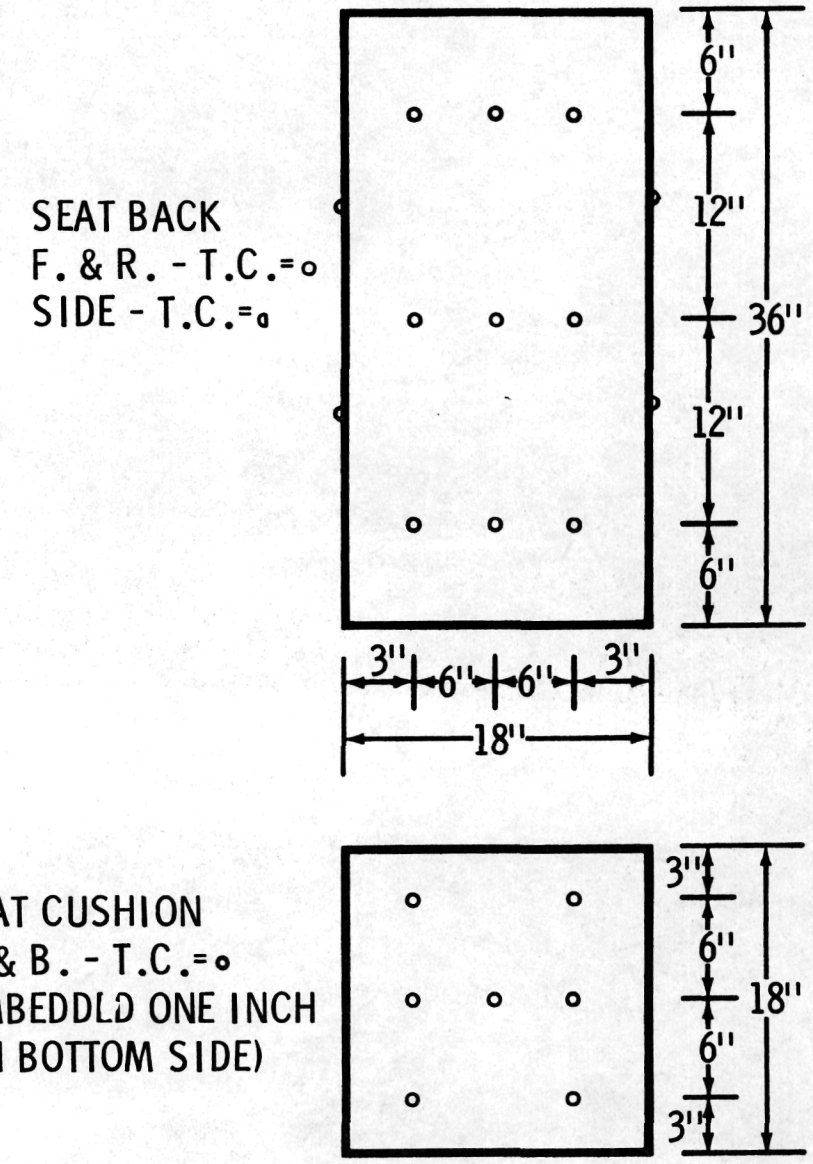

Fig. 2

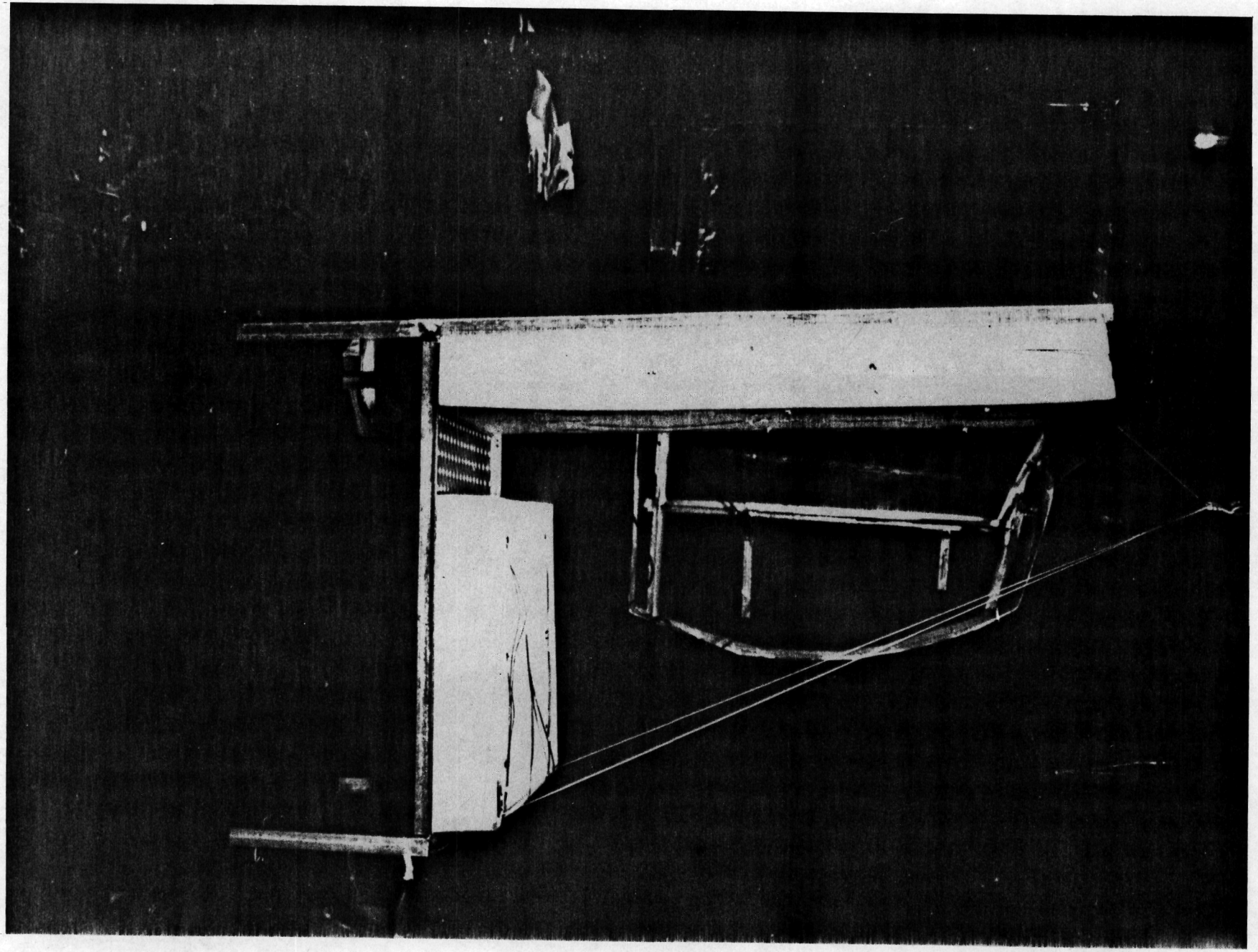

Fig. 3

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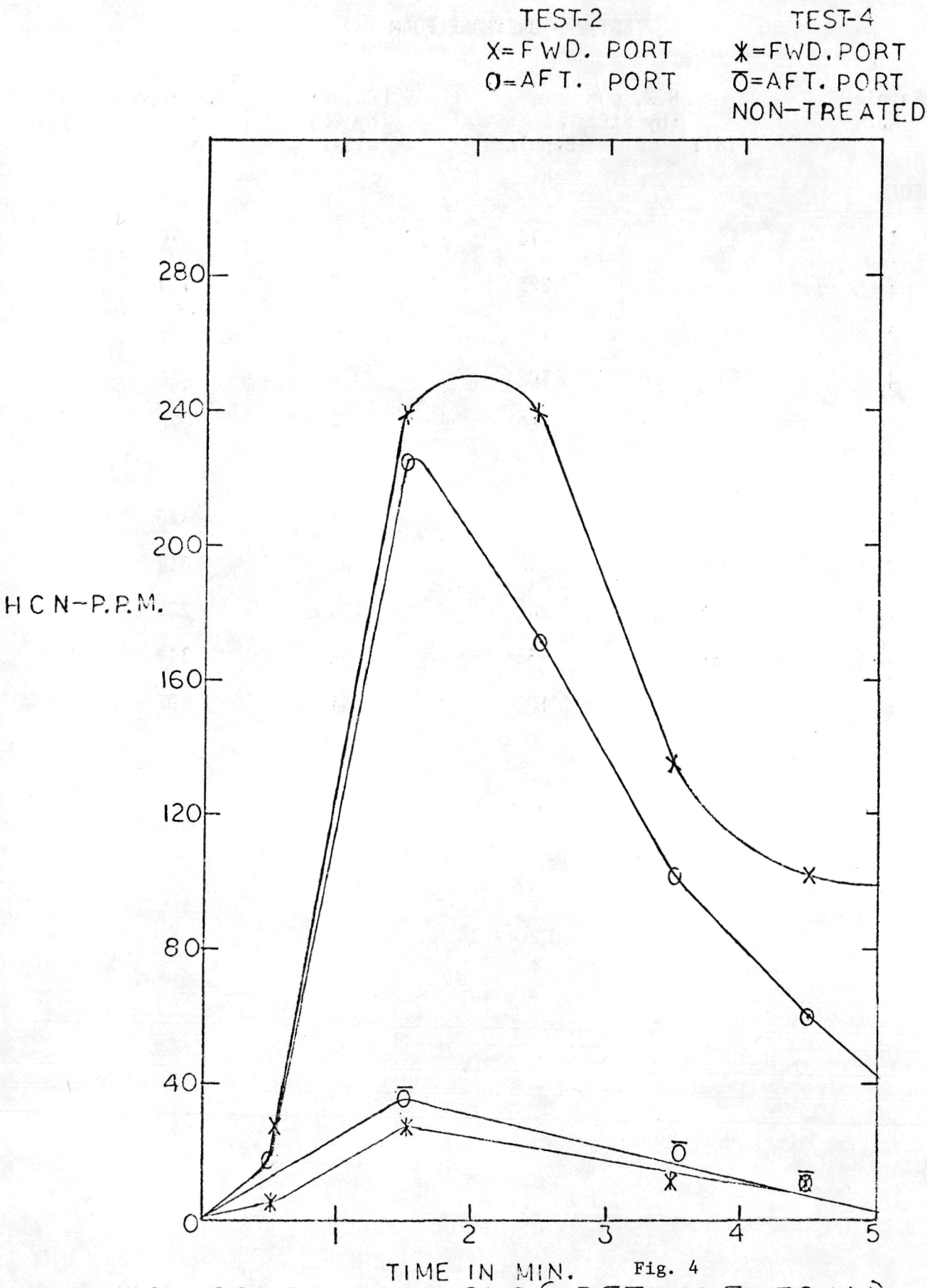


Fig. 4

HCN CONCENTRATIONS (URETHANE FOAM)

TEST 2 - URETHANE FOAM

Sample No.	HCN, ppm (by SIE) 16-1	Bubblers	HCN,ppm (by GC) 16-1	HCN, ppm (by IR) 32-1
FORE				
1	-	16	-	<70
2	-	225	-	154
3	-	171	-	86
4	-	102	-	<70
5	-	60	-	<70
AFT				
1	<6	13	<1	<70
2	272	240	165	314
3	210	240	130	228
4	87	135	68	114
5	56	102	54	97

Fig. 5

S- 78- 27026

Fig. 6

NASA-S-78-11426

SEAT FOAM TEST

SELECTED T.C.'s

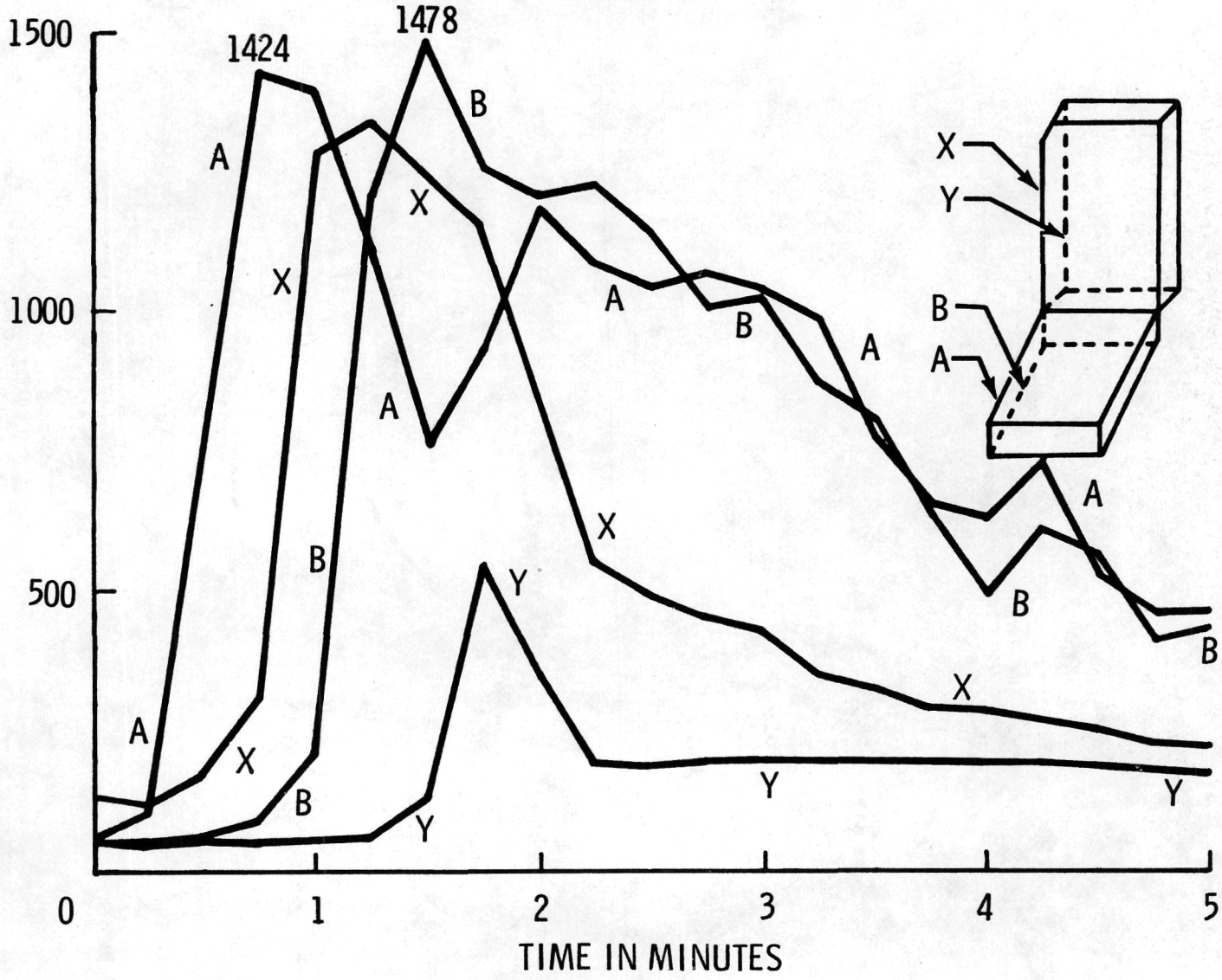


Fig. 7

NASA-S-78-11433

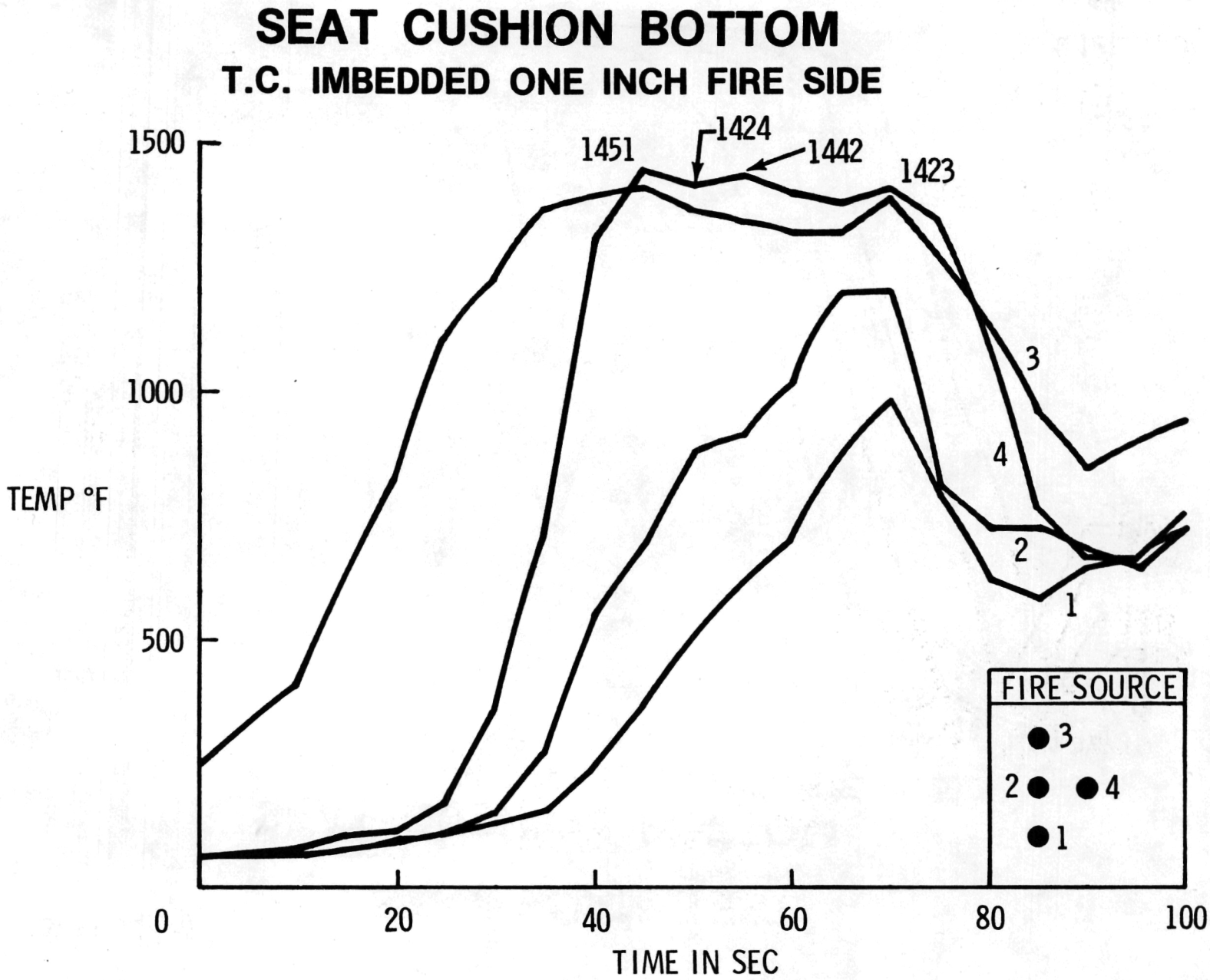


Fig. 8

NASA-S-78-11439

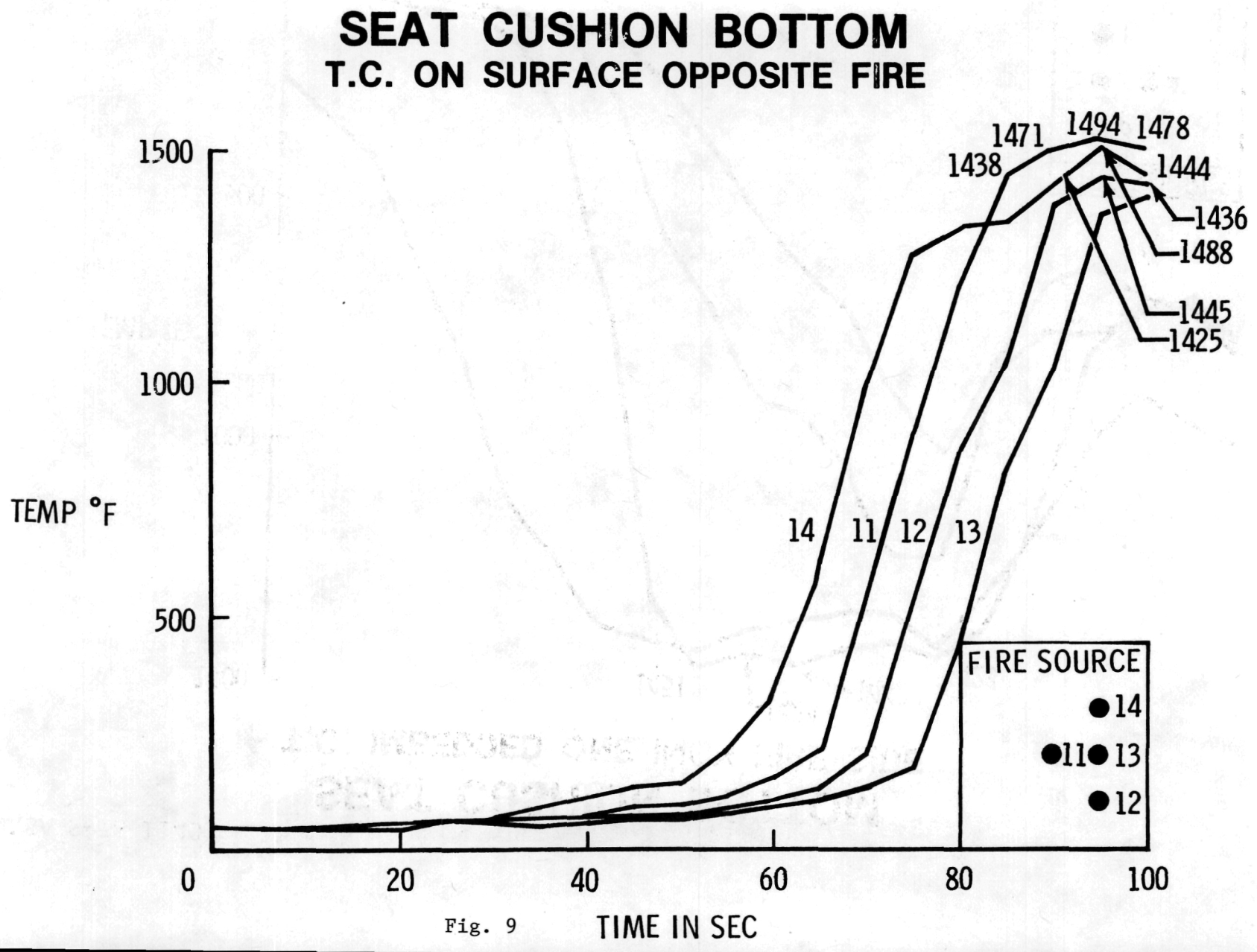


Fig. 9

NASA-S-78-11438

SEAT CUSHION BACK
T.C. ON SURFACE FIRE SIDE

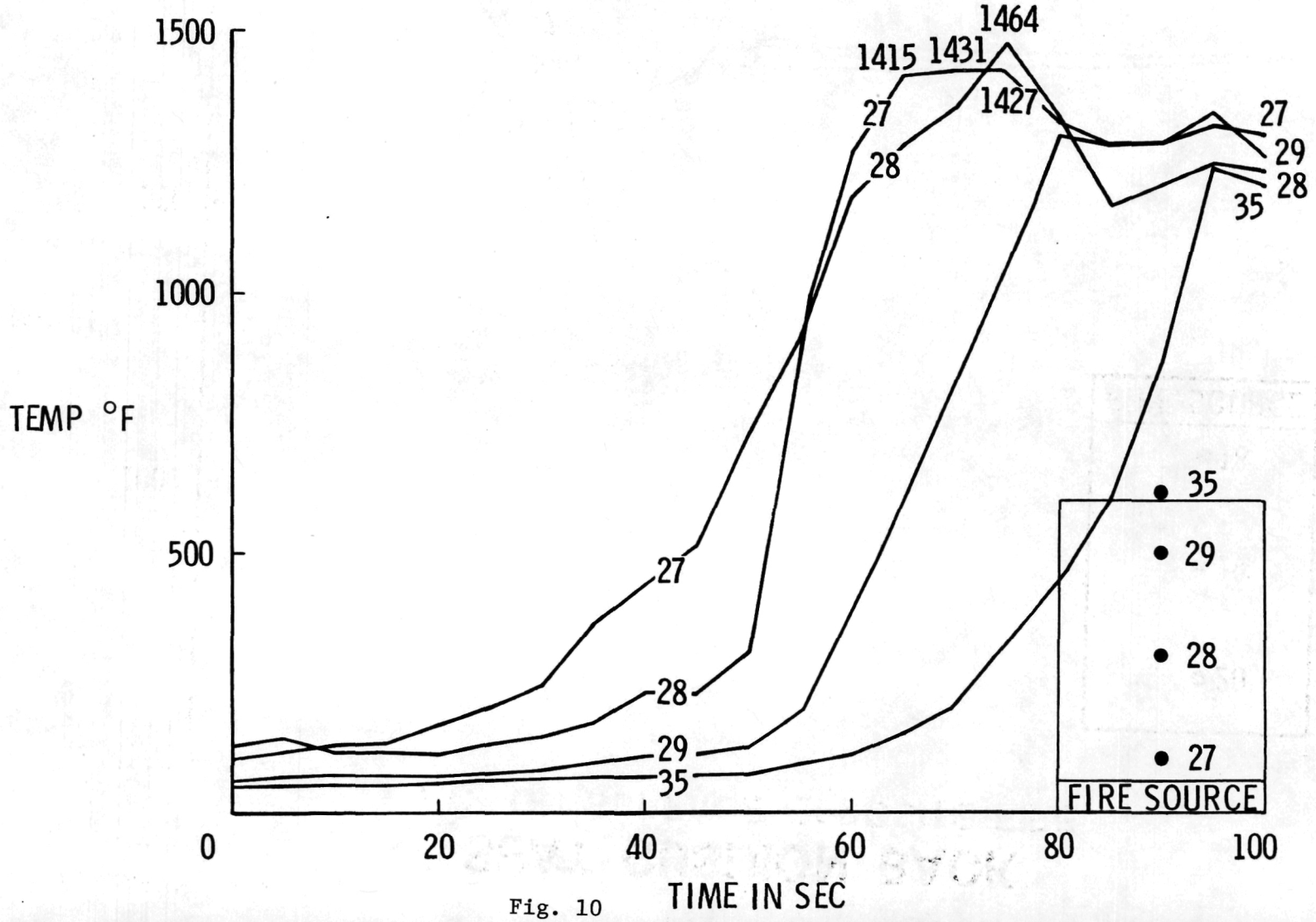


Fig. 10

NASA-S-78-11429

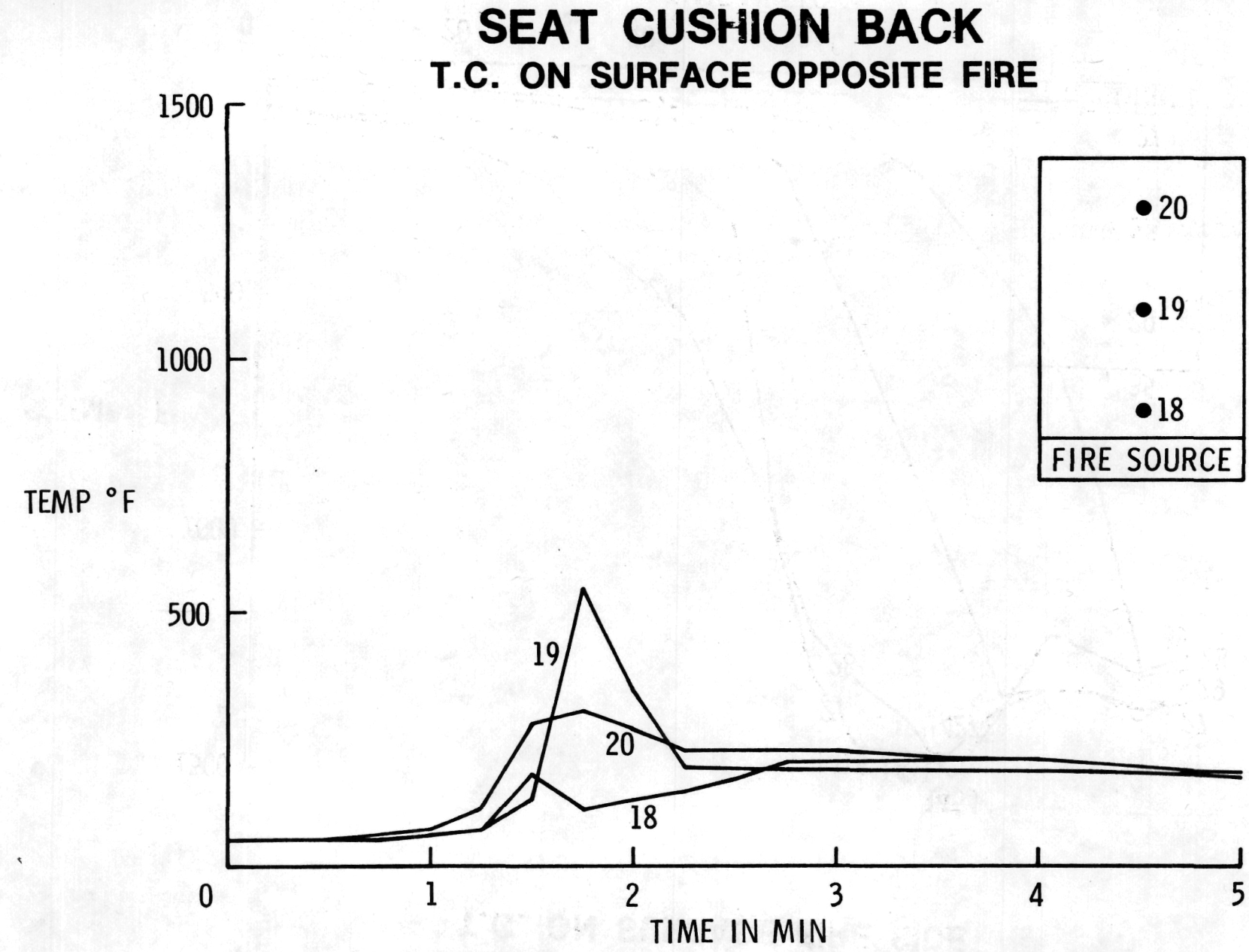


Fig. 11

NASA-S-78-11440

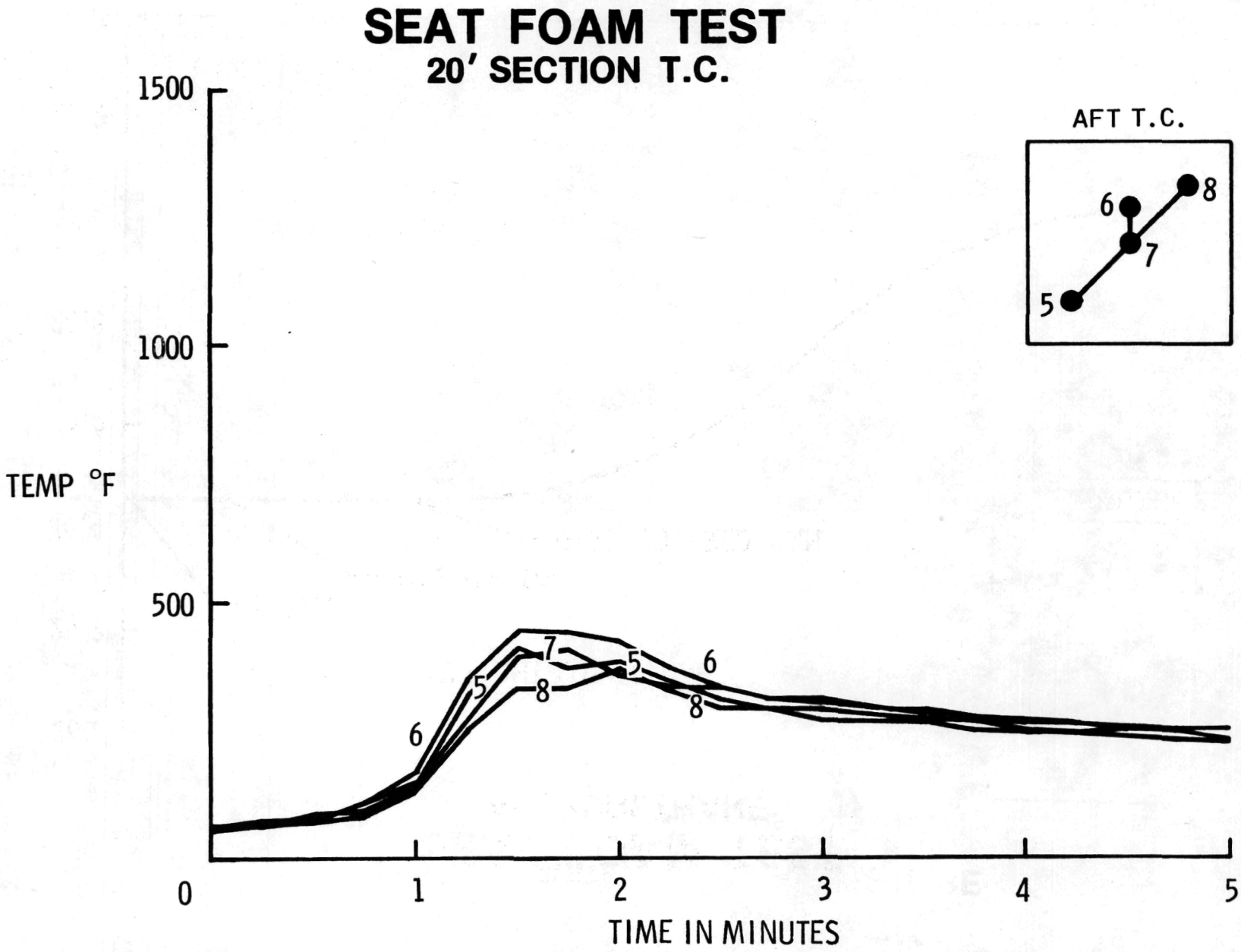


Fig. 12

NASA-S-78-11428

SEAT FOAM TEST
POLYURETHANE

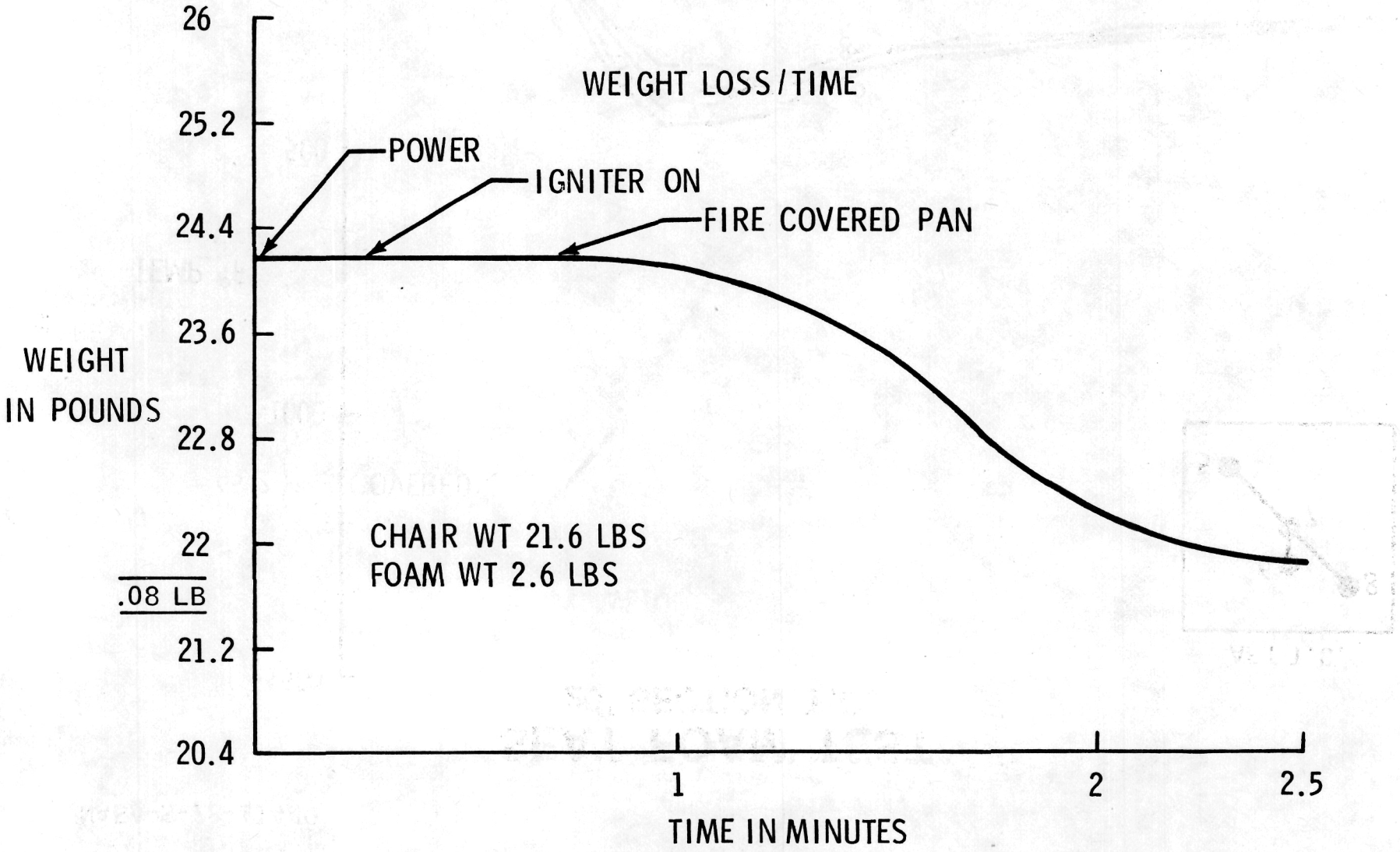


Fig. 13

NASA-S-78-11432

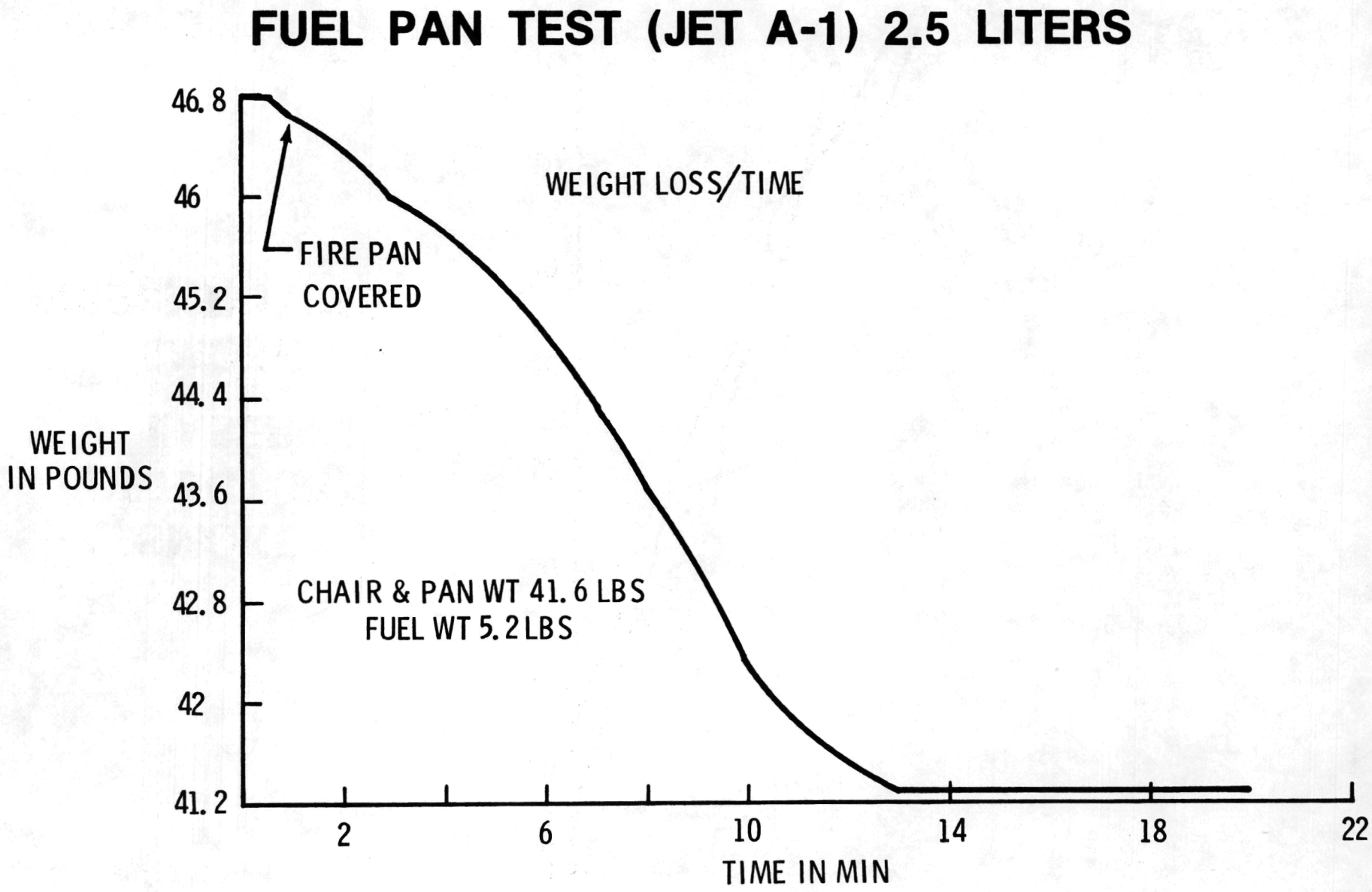


Fig. 14

NASA-S-78-11431

SMOKE DETECTOR/ LASER

SMOKE DENSITY/TIME

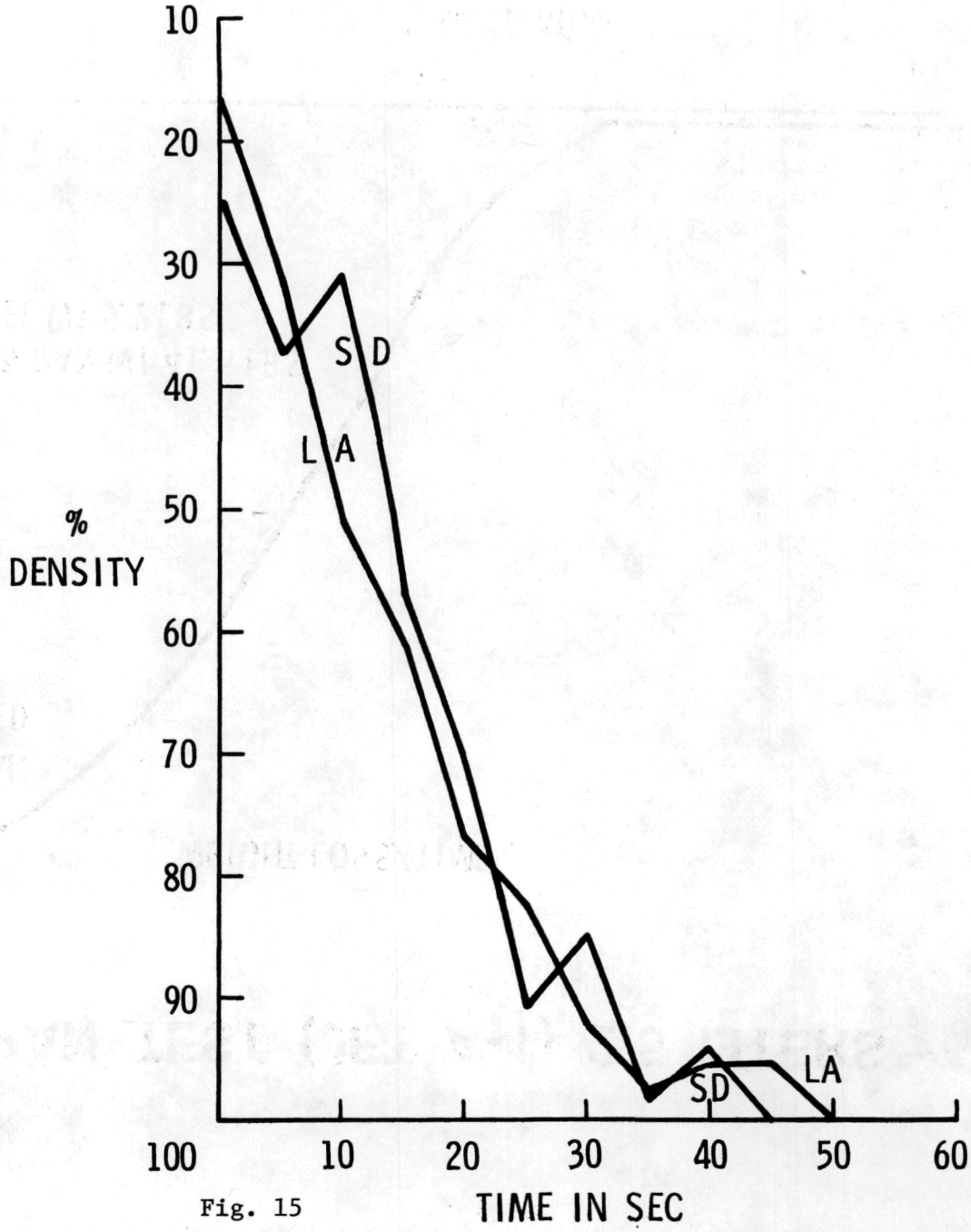


Fig. 15

DOUGLAS AIRCRAFT CABIN FIRE TESTS

David Klinck
Douglas Aircraft Company
McDonnell-Douglas Corporation
Long Beach, California 90846

DOUGLAS AIRCRAFT CABIN FIRE TESTS

(Abstract)

Industry and government have been independently active for many years in aircraft fire safety research and are currently joined in a mutual effort in the Firemen Program.

The fire safety research conducted at Douglas is a comprehensive multi-discipline program. A portion of this total program is in the area of full scale cabin fire simulation. The objectives of this phase of our work are to:

Establish the degree of hazard that may exist.

Develop solutions or improvements to the identified hazards and evaluate their effectiveness.

The scope of our IRAD work has included:

The development of a Cabin Fire Simulator.

Source fire studies.

Full cabin tests.

Module detection and extinguishment.

Module containment.

Burn-through resistance.

Effects of ventilation.

The past, current and planned research in support of the Firemen Program includes:

Ignition source tests and lavatory baseline test, 1977.

Passenger seat fire source tests, 1978.

Fire resistant lavatory panel tests (planned 1978).

Fire resistant seat tests (planned 1979).

The program summarized in this presentation was completed late in 1977 for Lyndon B. Johnson Space Center and consisted of 30 source fire tests and one baseline test.

The major objectives in this program were to:

a. Examine the thermal and environmental characteristics of three types of fuels burned in two quantities contained within a metal lavatory.

b. Determine the hazard experienced in opening the door of a lavatory containing a developed fire.

c. Select the most severe source fuel for use in a baseline test.

d. Evaluate the effect of the most severe source upon a lavatory constructed of contemporary materials. The results of this test will serve as a basis of comparison for future tests of new materials.

All tests in this program were conducted in the Douglas Cabin Fire Simulator (CFS) under typical in-flight ventilation conditions. Thirty tests were conducted of five fuel sources. In half of these tests, the door remained closed for the 30-minute test period. The door was opened 100 to 150 seconds after the fire had started in the remaining 15 tests. The fire in the baseline test was allowed to continue for a period of one hour. Data obtained during these tests included:

a. Heat flux and temperature profiles of the lavatory at 10 locations.
b. Cabin temperature variations.
c. Gas analysis for O_2, CO_2, CO, CH_4, HF, HCL and HCN.
d. Respiration and electrocardiogram data on an instrumented rat subject exposed in the cabin.
e. Color motion pictures were made of the baseline and ten opened door tests.

The conclusions reached on the program were:

a. The maximum load of simulated airline trash resulted in the most severe fire threat.
b. Opening the door of an involved module would be inadvisable.
c. Contemporary materials exposed to the selected source provided remarkable protection; however, the improvement in fire resistance of specific materials is advisable.
d. The baseline fire resulted in a survivable cabin condition; however, occupants of the cabin would have been subjected to severe discomfort from smoke.

DOUGLAS AIRCRAFT CABIN FIRE TESTS

IN SUPPORT OF

NASA FIREMAN PROGRAM

DOUGLAS IRAD PROGRAMS

8-GEN-21658

CABIN
FIRE
SIMULATOR

FULL-SCALE CABIN INTERIOR TEST PROGRAMS

PROGRAMS IN SUPPORT OF NASA FIREMAN

- IGNITION SOURCE AND LAVATORY BASELINE (JSC) 1977
- PASSENGER SEAT SOURCE FIRE (ARC) 1978
- FIRE RESISTANT LAVATORY PANELS (JSC) 1978
- FIRE RESISTANT SEAT TESTS (ARC) 1978-1979

DOUGLAS IRAD PROGRAMS — 1975-1988

- SOURCE FIRE STUDIES
- FULL CABIN TESTS
- DETECTION AND EXTINGUISHMENT
- MODULE CONTAINMENT
- BURN THROUGH RESISTANCE
- VENTILATION EFFECTS

8-GEN-21661

CHARACTERIZATION OF SECONDARY IGNITION SOURCES IN UNATTENDED COMPARTMENTS AND FULL-SCALE BASELINE TEST

PROGRAM OBJECTIVES

SECONDARY IGNITION SOURCES

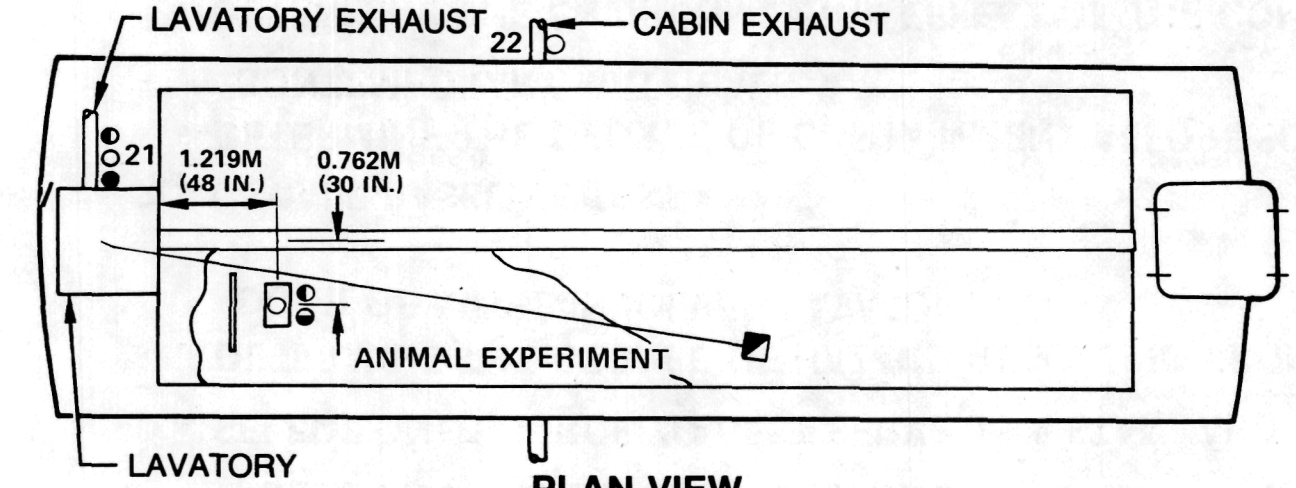
- DETERMINE THE THERMAL AND ENVIRONMENTAL EFFECTS OF VARIOUS FUELS BURNING IN A METAL LAVATORY.
- SELECT ONE SOURCE TO BEST SERVE AS A STANDARD.
- DETERMINE THE DEGREE OF HAZARD RESULTING FROM OPENING THE DOOR OF A FIRE-INVOLVED LAVATORY.

FULL-SCALE BASELINE TEST

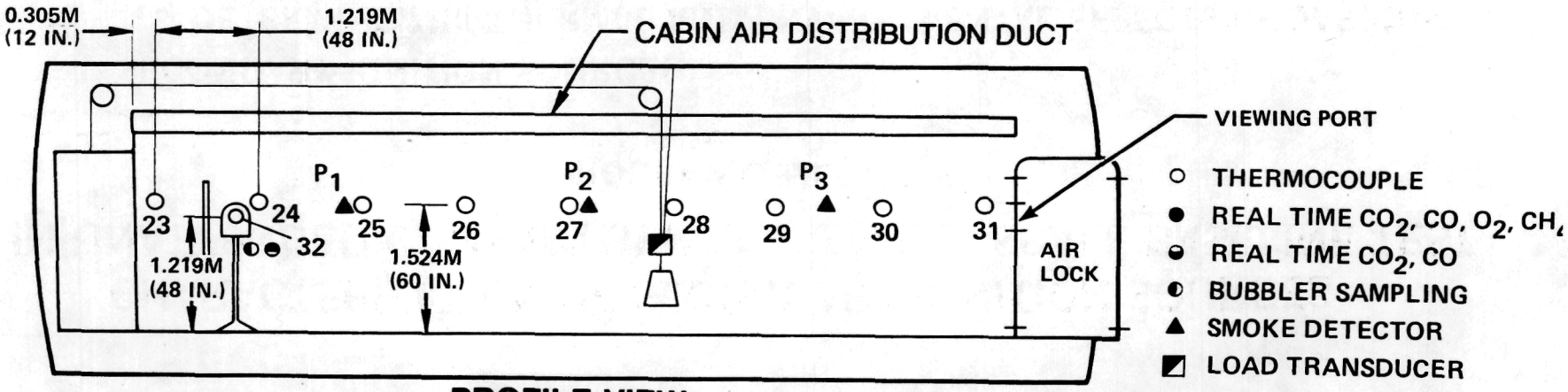
- DETERMINE THE DEGREE OF CONTAINMENT AFFORDED BY CONTEMPORARY MATERIALS.
- DETERMINE THE ENVIRONMENTAL EFFECT OF THE CONTAINED FIRE.
- PROVIDE A BASIS FOR MEASURING FUTURE IMPROVEMENTS.

8-GEN-21659

CABIN INSTRUMENTATION

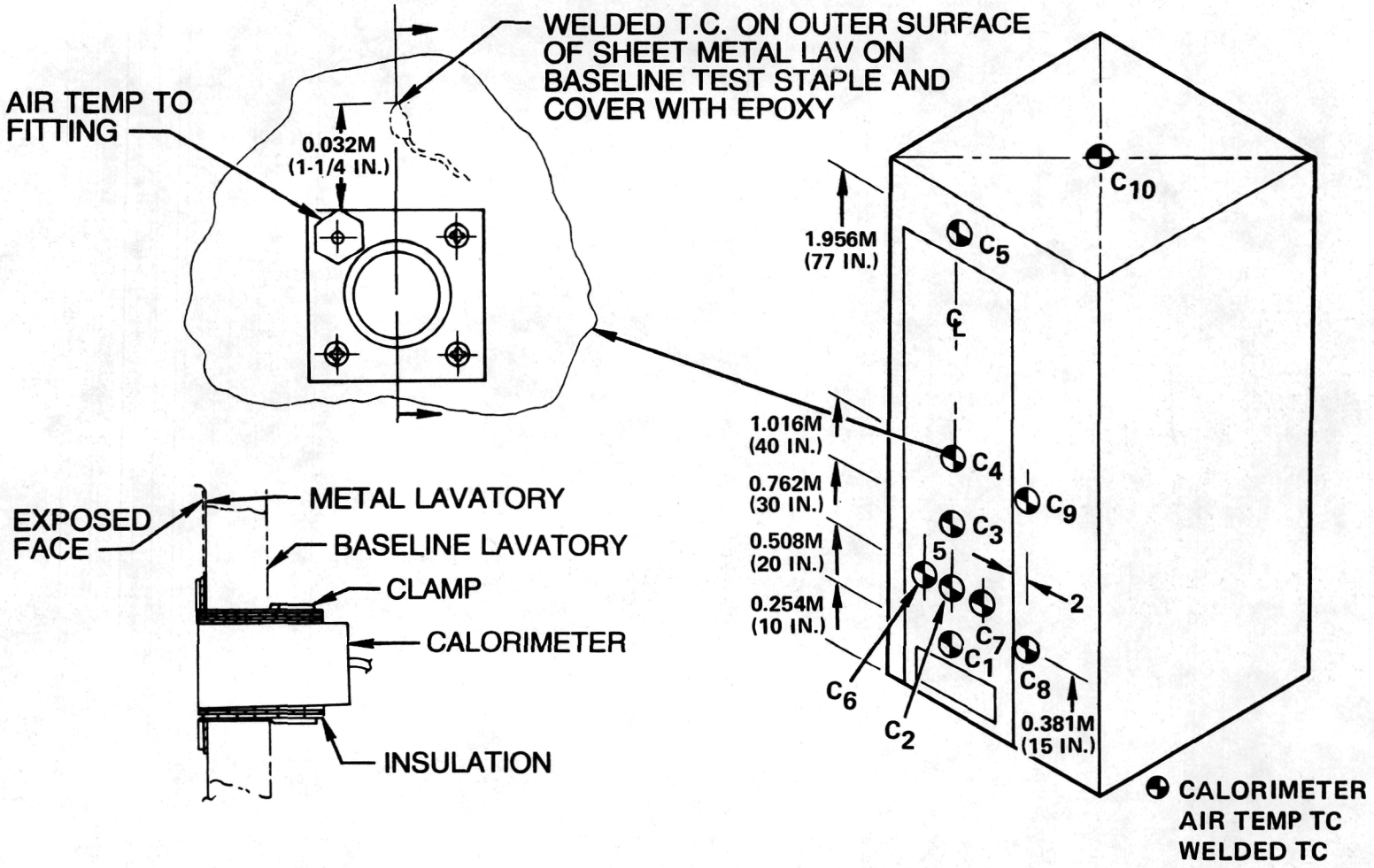


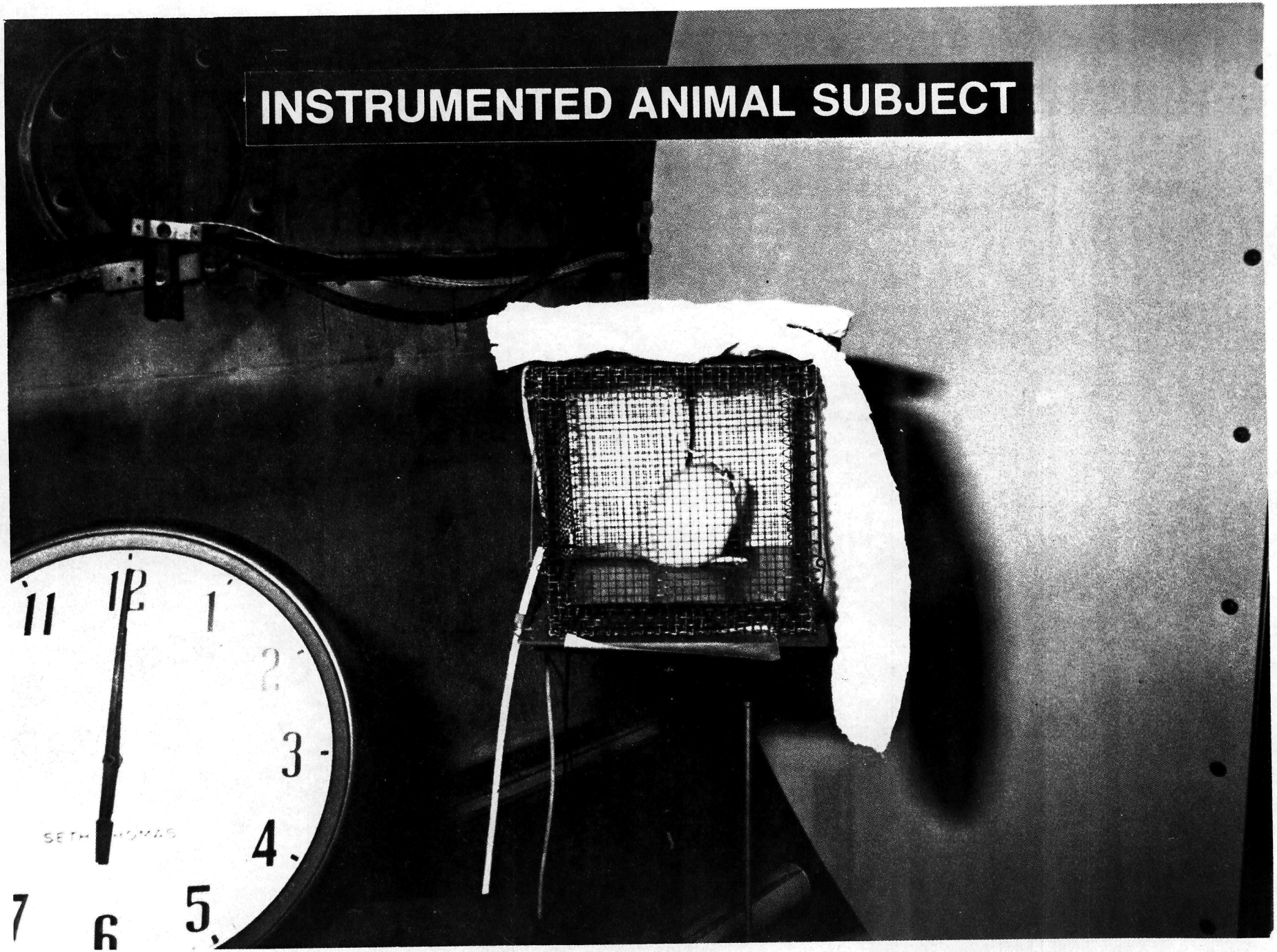
PLAN VIEW



PROFILE VIEW

LAVATORY INSTRUMENTATION




INSTRUMENTED ANIMAL SUBJECT
SETH THOMAS

SECONDARY IGNITION SOURCES

FUEL TYPE	COMPOSITION & WEIGHT PER UNIT	TESTS	QUANTITY	TEST CODE IDENTIFICATION CLOSED DOOR	TEST CODE IDENTIFICATION OPENED DOOR
SHREDDED PAPER	PER WIRE BASKET	3	ONE BASKET	SP( )AC	
	2.268 Kg (5 POUNDS)	3	ONE BASKET		SP( )AO
	SHREDDED UNUSED	3	TWO BASKETS	SP( )BC	
	NEWSPRINT	3	TWO BASKETS		SP( )BO
AIRLINE TRASH	PER TRASH BAG	3	TWO BAGS	AL( )AC	
	PAPER TOWELS	3	TWO BAGS		AL( )AO
	0.907 Kg (2 POUNDS)	3	FOUR BAGS	AL( )BC	
	PAPER CUPS	3	FOUR BAGS		AL( )BO
	0.045 Kg (0.1 POUNDS)				
	POLYSTYRENE CUPS				
	0.181 Kg (0.4 POUNDS)				
	POLYETHYLENE TRASH BAG				
	0.064 Kg (0.14 POUNDS)				
ARSON ATTEMPT	PER TRASH BAG	3	TWO BAGS	AA( )AC	
	AIRLINE TRASH AS ABOVE	3			AA( )AO
	LIGHTER FLUID				
	0.212 Kg (0.47 POUNDS)				

AIRLINE TRASH FUEL

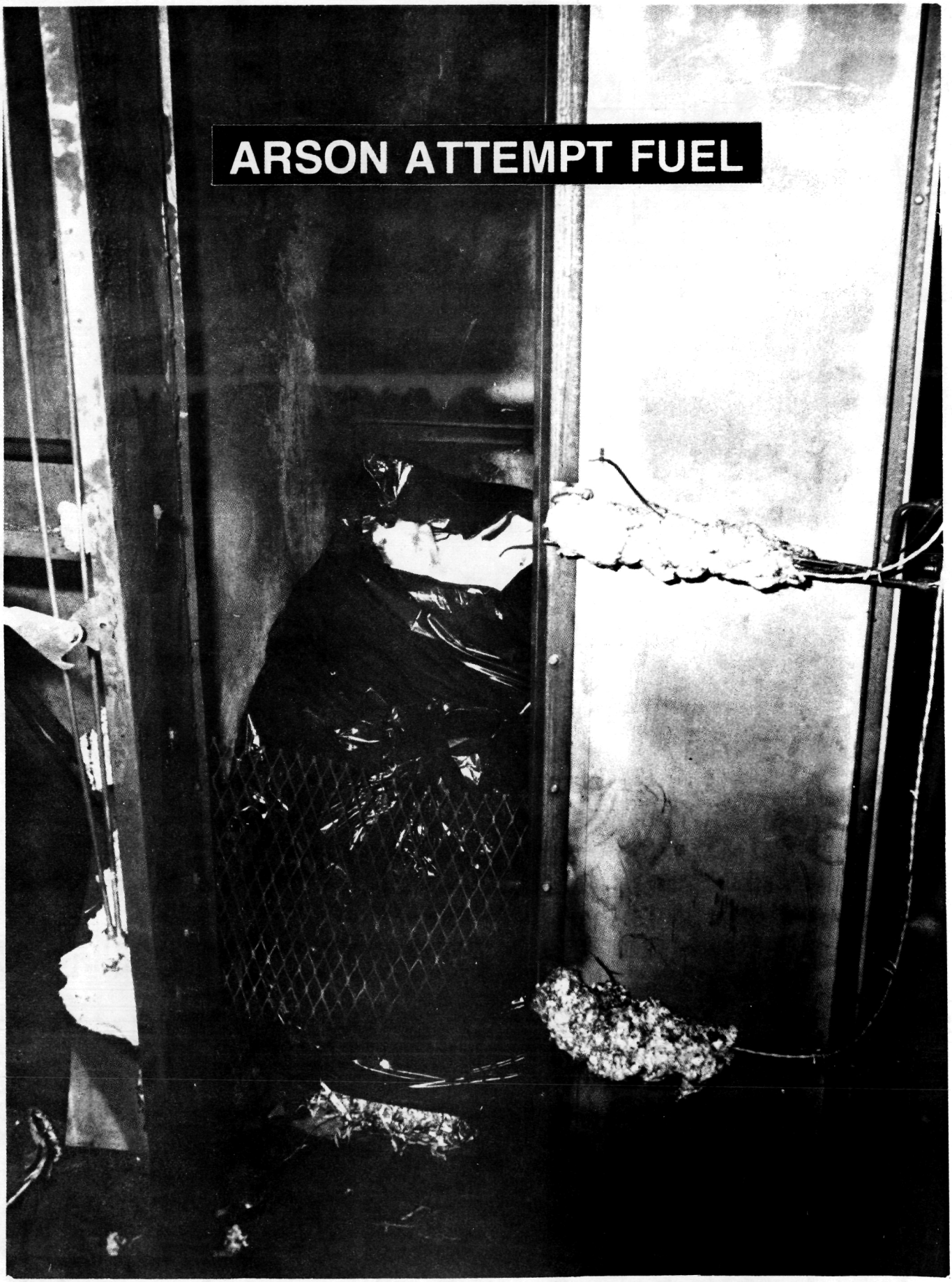
AL( ) AC & AO

AL( ) BC & BO

SHREDDED PAPER FUEL

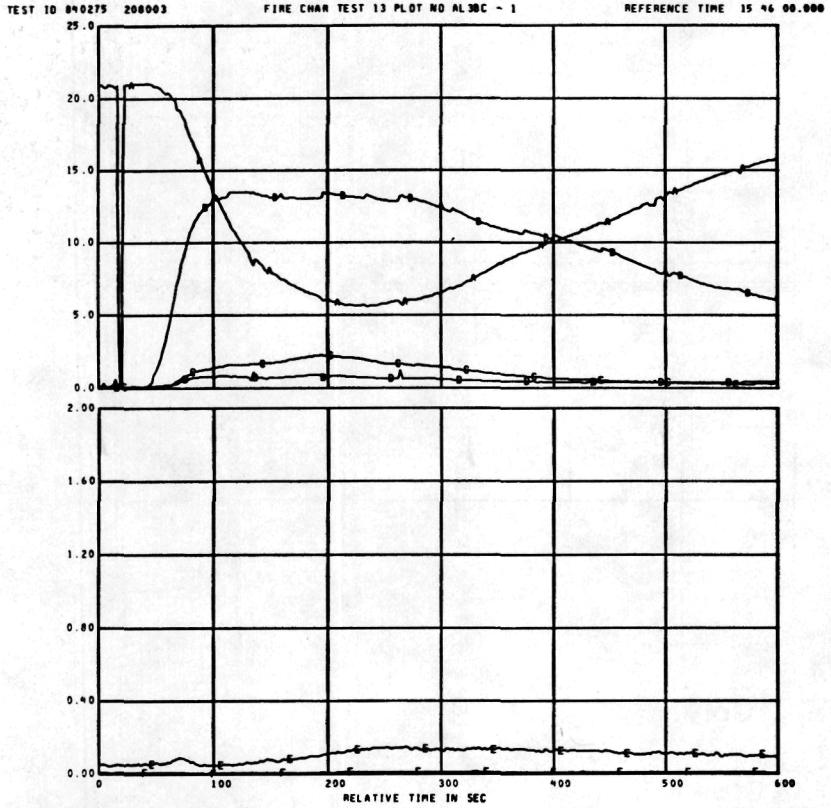
SP( )AC&O

SP( )BC&O


ARSON ATTEMPT FUEL

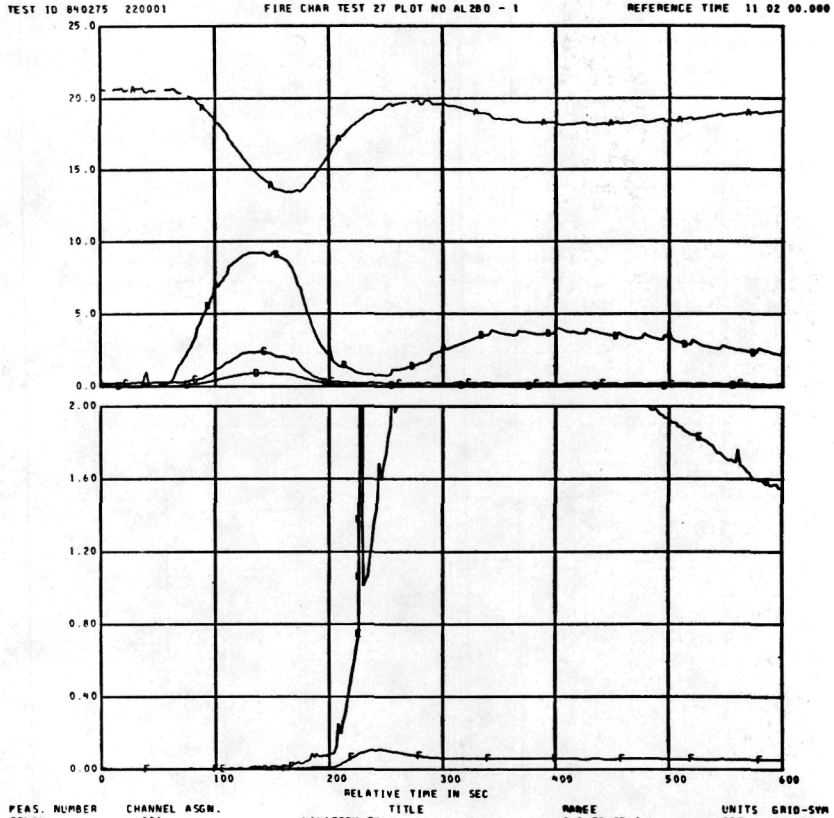
LAVATORY EXHAUST AND CABIN

GAS ANALYSIS AL ( ) BC & BO



MEAS. NUMBER	CHANNEL ASGN.	TITLE	RANGE	UNITS	GRID-SYM
O2LAV	091	LAVATORY O2	0.0 TO 25.0	PCT	AA
CO2LV	093	LAVATORY CO2	0.0 TO 25.0	PCT	AB
COLAV	088	LAVATORY CO	0.0 TO 25.0	PCT	AC
CH4LV	085	LAVATORY CH4	0.0 TO 25.0	PCT	AD
CO2CB	090	CABIN CO2	0.00 TO 2.00	PCT	BE
COCAB	084	CABIN CO	0.00 TO 2.00	PCT	BF

CLOSED DOOR

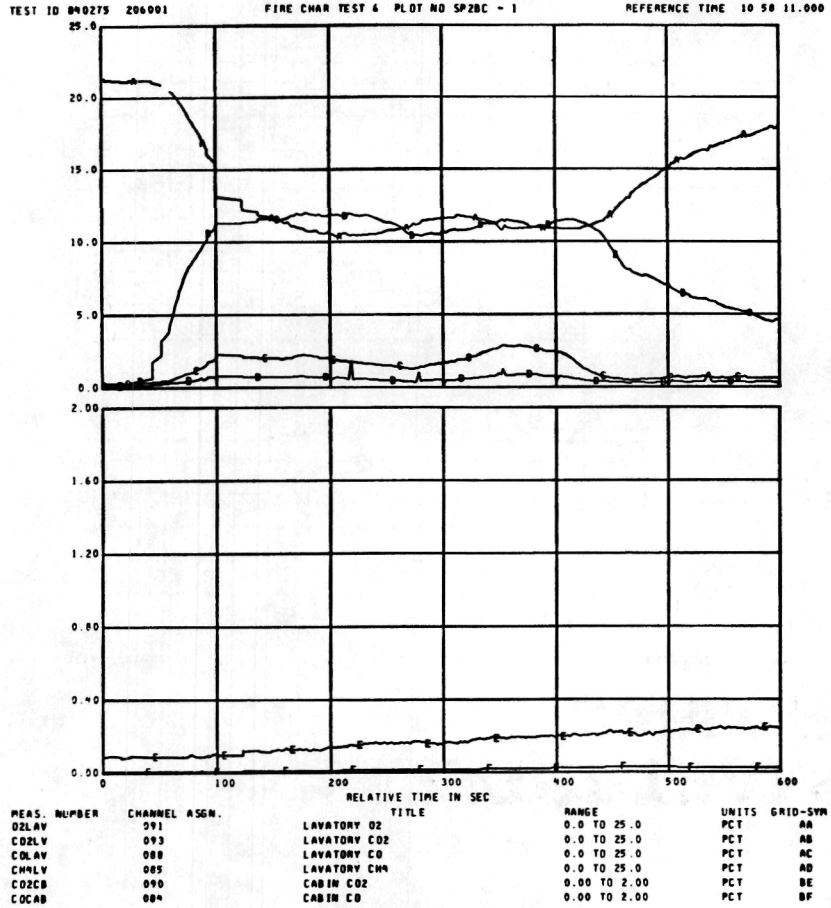


MEAS. NUMBER	CHANNEL ASGN.	TITLE	RANGE	UNITS	GRID-SYM
O2LAV	091	LAVATORY O2	0.0 TO 25.0	PCT	AA
CO2LV	093	LAVATORY CO2	0.0 TO 25.0	PCT	AB
COLAV	088	LAVATORY CO	0.0 TO 25.0	PCT	AC
CH4LV	085	LAVATORY CH4	0.0 TO 25.0	PCT	AD
CO2CB	090	CABIN CO2	0.00 TO 2.00	PCT	BE
COCAB	084	CABIN CO	0.00 TO 2.00	PCT	BF

DOOR OPENED AT 150 SECONDS

LAVATORY EXHAUST AND CABIN

GAS ANALYSIS SP ( ) BC & BO



MEAS. NUMBER	CHANNEL ASGN.	TITLE	RANGE	UNITS	GRID-SYM
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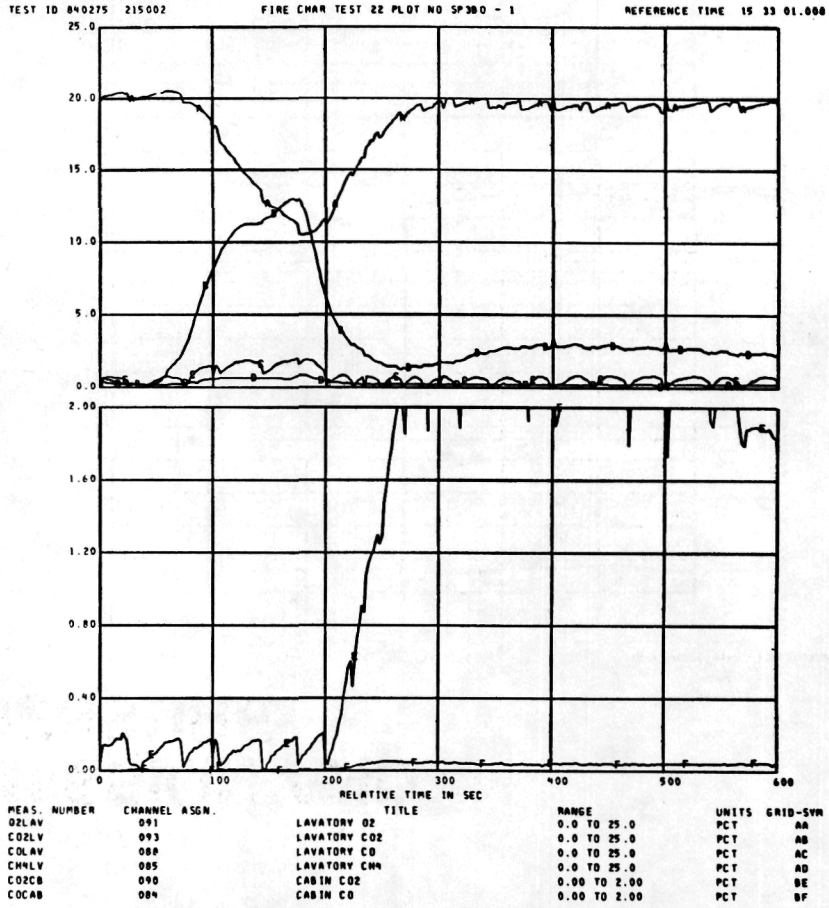
CO2LV	093	LAVATORY CO2	0.0 TO 25.0	PCT	AB
COLAV	088	LAVATORY CO	0.0 TO 25.0	PCT	AC
CH4LV	085	LAVATORY CH4	0.0 TO 25.0	PCT	AD
CO2CB	090	CABIN CO2	0.00 TO 2.00	PCT	BE
COCAB	084	CABIN CO	0.00 TO 2.00	PCT	BF

CLOSED DOOR



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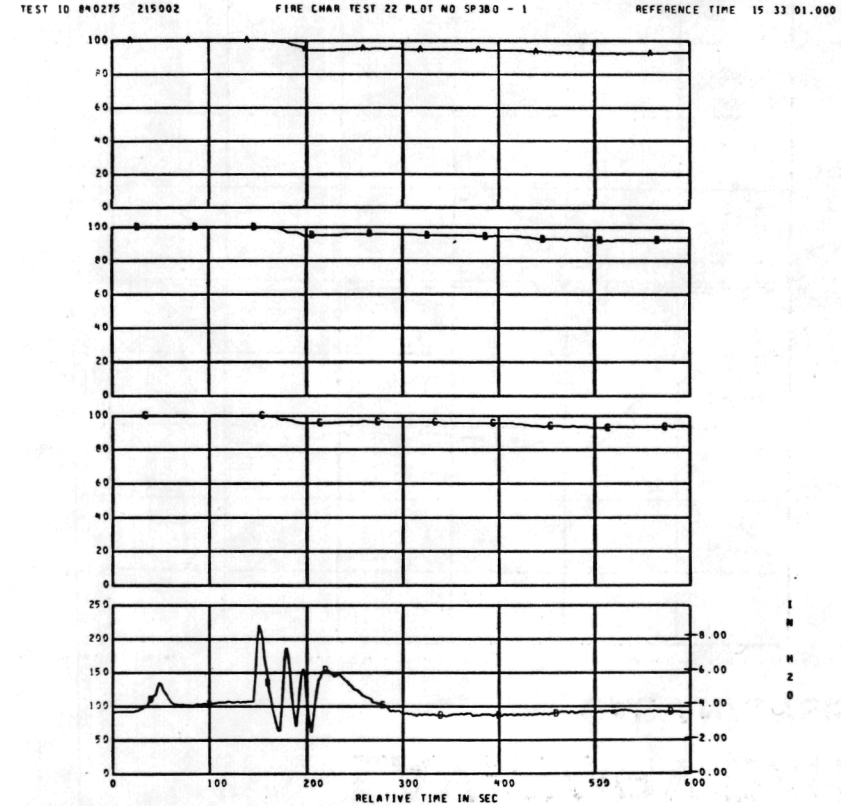
CO2LV	093	LAVATORY CO2	0.0 TO 25.0	PCT	AB
COLAV	088	LAVATORY CO	0.0 TO 25.0	PCT	AC
CH4LV	085	LAVATORY CH4	0.0 TO 25.0	PCT	AD
CO2CB	090	CABIN CO2	0.00 TO 2.00	PCT	BE
COCAB	084	CABIN CO	0.00 TO 2.00	PCT	BF

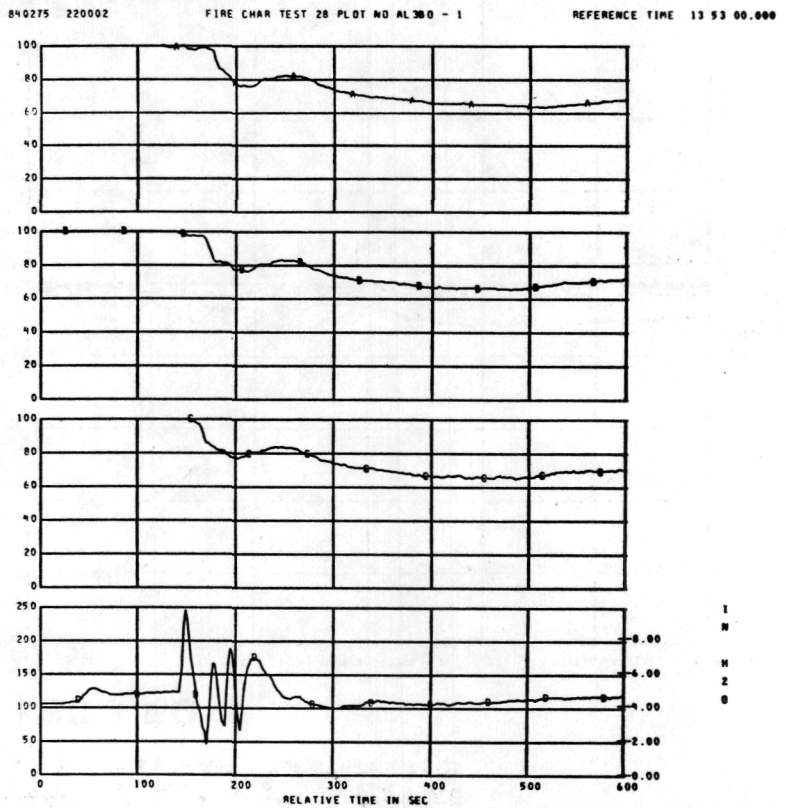
DOOR OPENED AT 150 SECONDS

LIGHT TRANSMISSION AND CABIN PRESSURE



MEAS. NUMBER	CHANNEL ASGN.	TITLE	RANGE	UNITS	GRID-SYM
P1	160	LIGHT TRANSMISSION "MOST WEST"	0 TO 100	PCT	AA
P2	161	LIGHT TRANSMISSION "MIDDLE"	0 TO 100	PCT	BB
P3	162	LIGHT TRANSMISSION "MOST EAST"	0 TO 100	PCT	CC
8 PRESS	098	CABIN DELTA PRESSURE	0 TO 250	MM H2O	DD

SHREDDED PAPER
10 POUNDS



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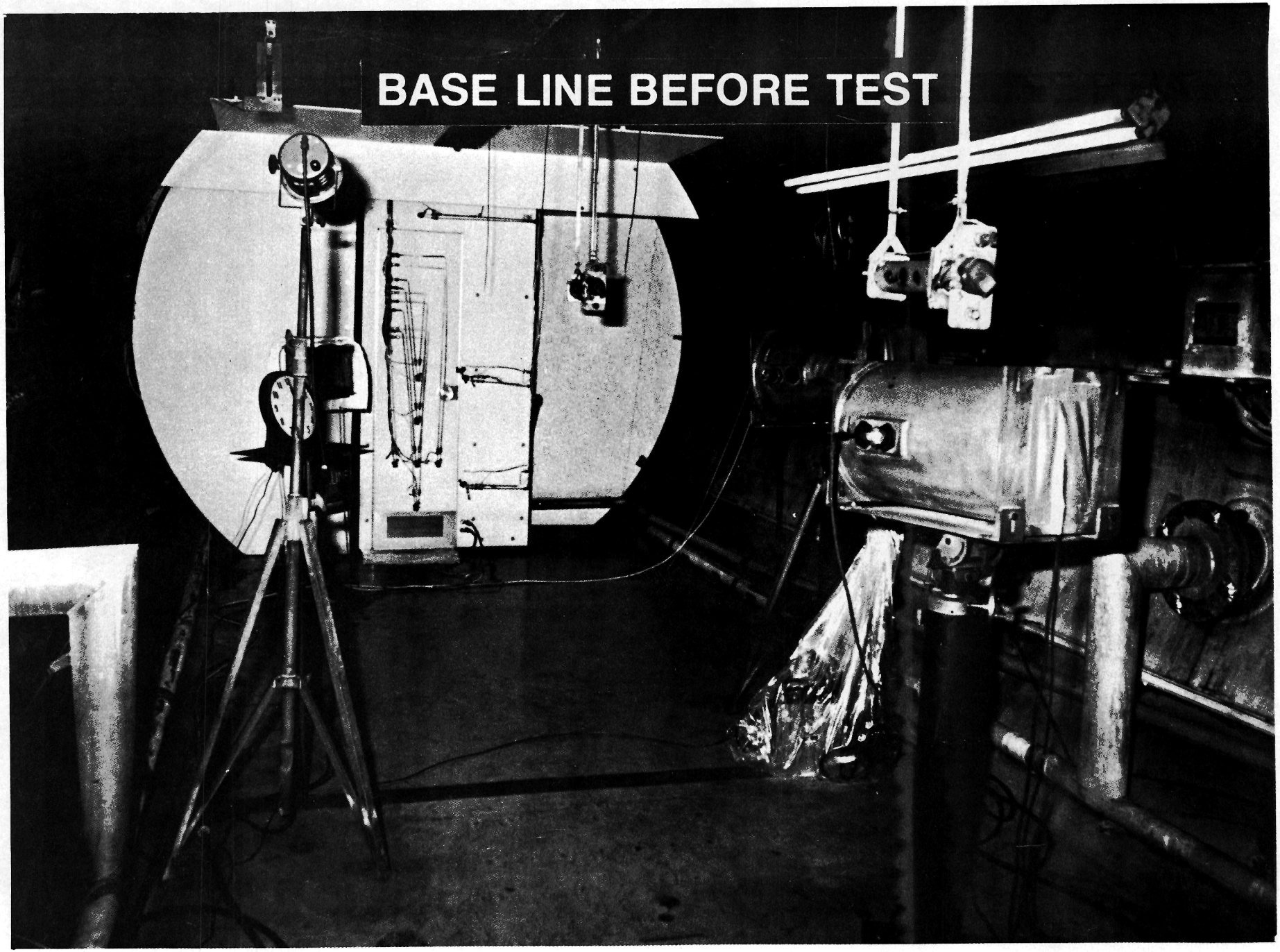
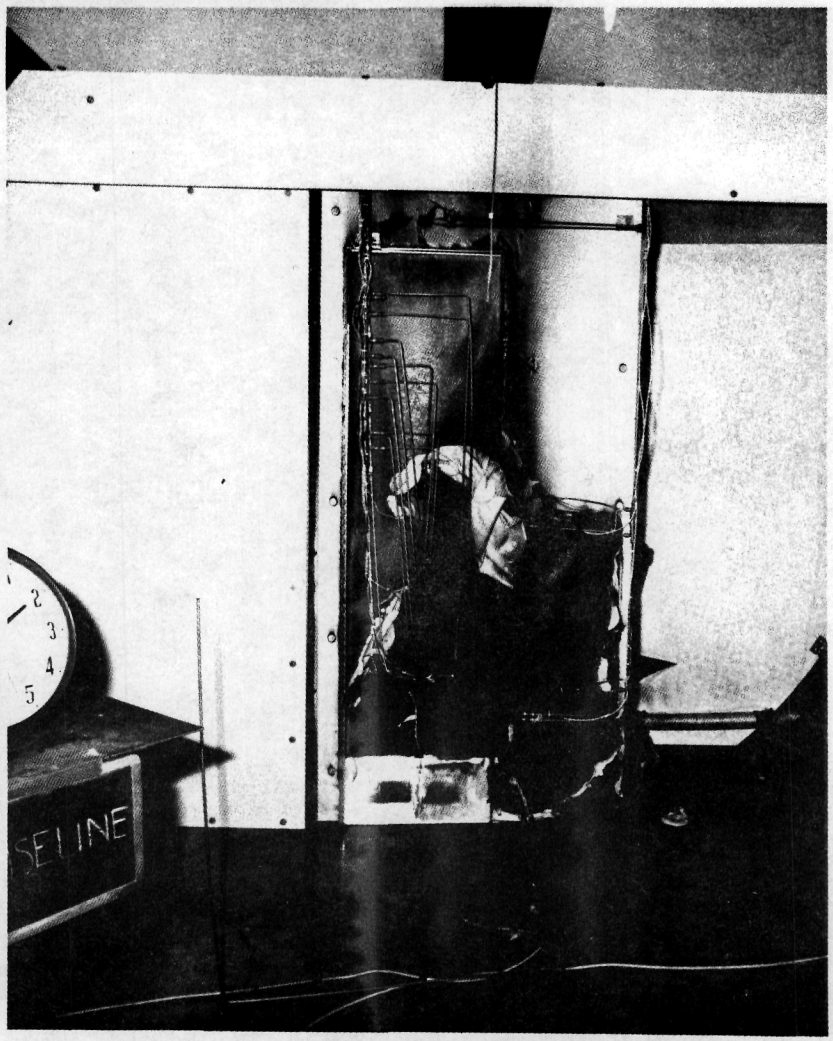
P3	162	LIGHT TRANSMISSION "MOST EAST"	0 TO 100	PCT	CC
8 PRESS	098	CABIN DELTA PRESSURE	0 TO 250	MM H2O	DD

AIRLINE TRASH
10 POUNDS


BASE LINE BEFORE TEST

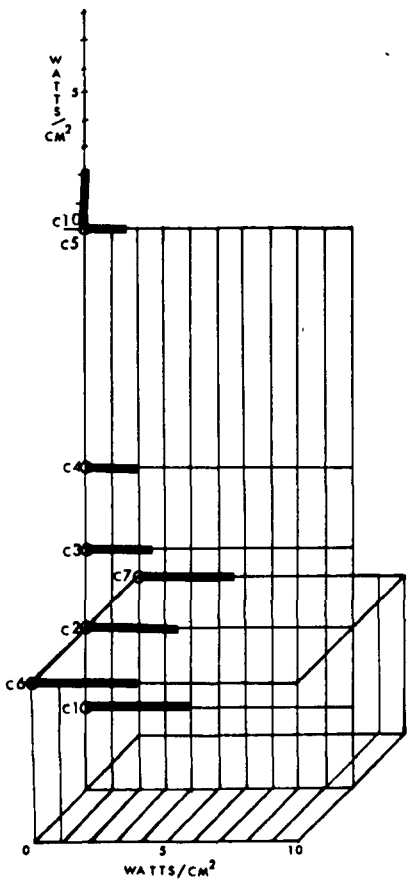
BASELINE FIRE EFFECTS

RESIDUAL FUEL REMAINING

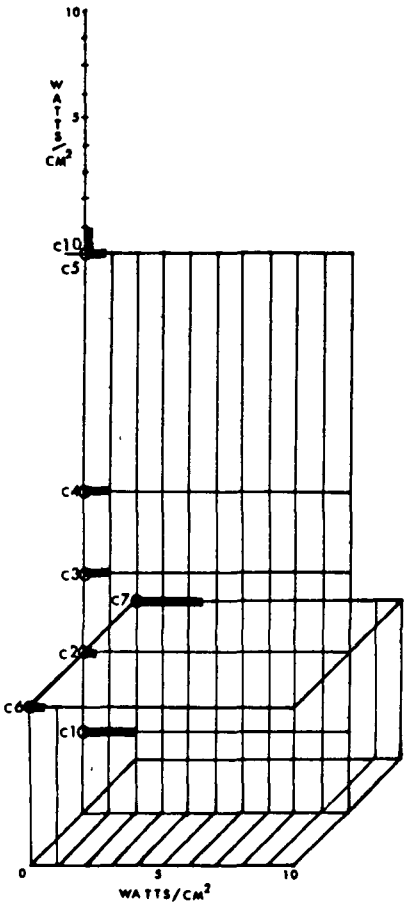


EXTERIOR OF LAVATARY

0–100 SECONDS AVERAGE Q

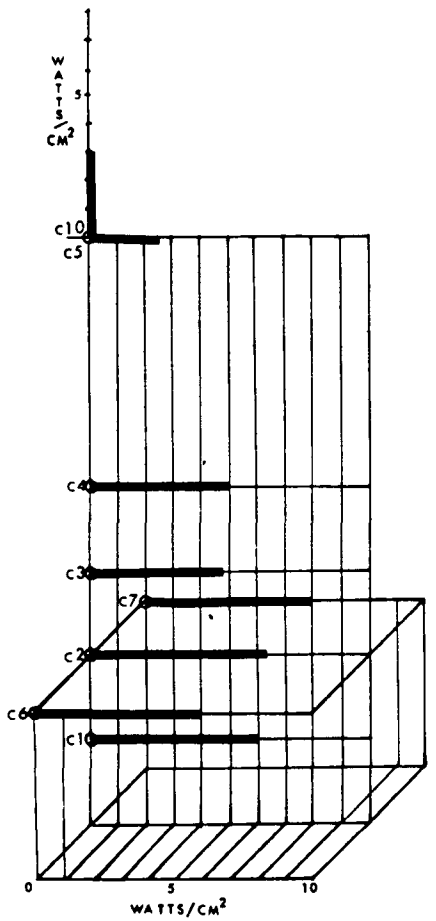


ALBC

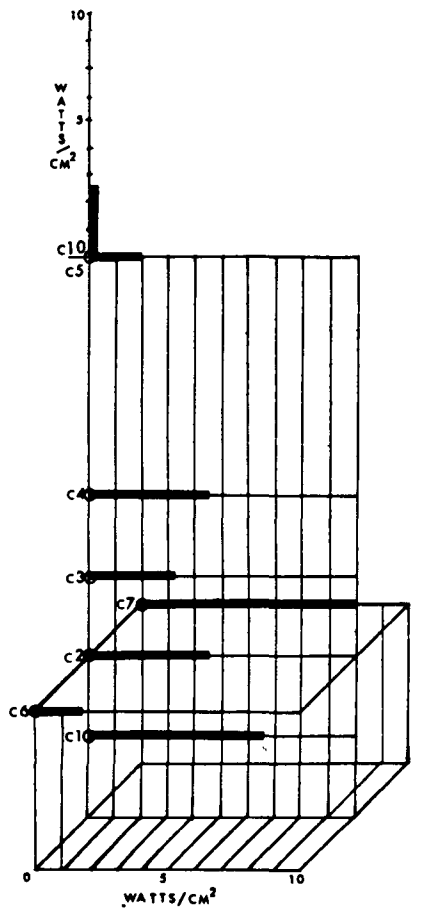


BASELINE

100–200 SECONDS AVERAGE Q

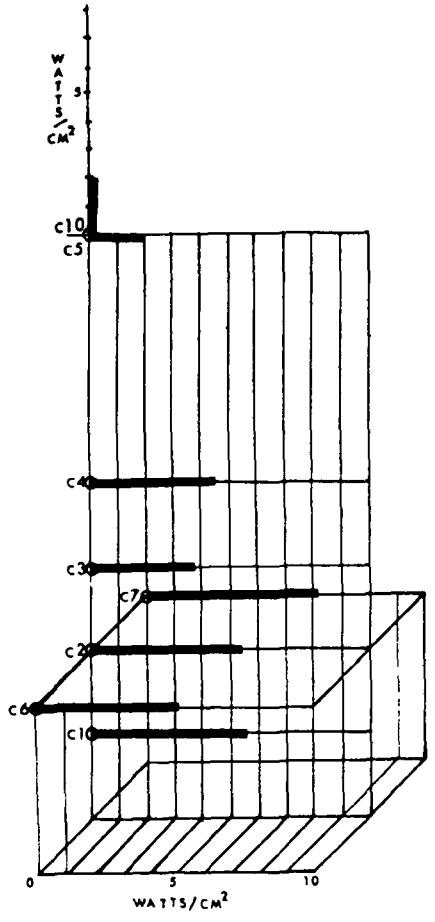


ALBC

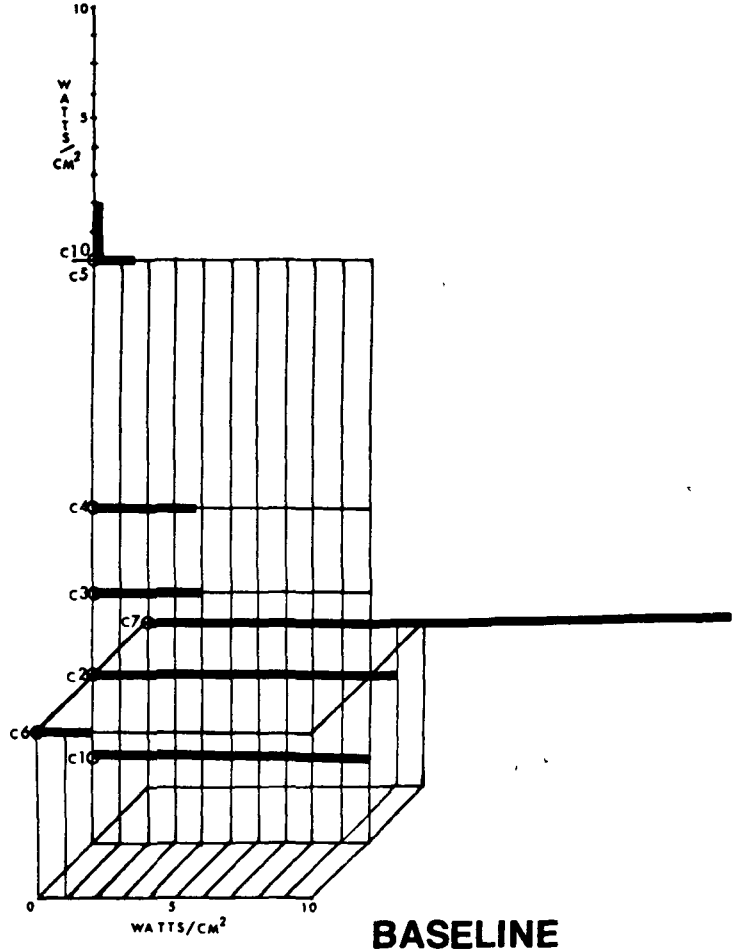


BASELINE

200–300 SECONDS AVERAGE Q

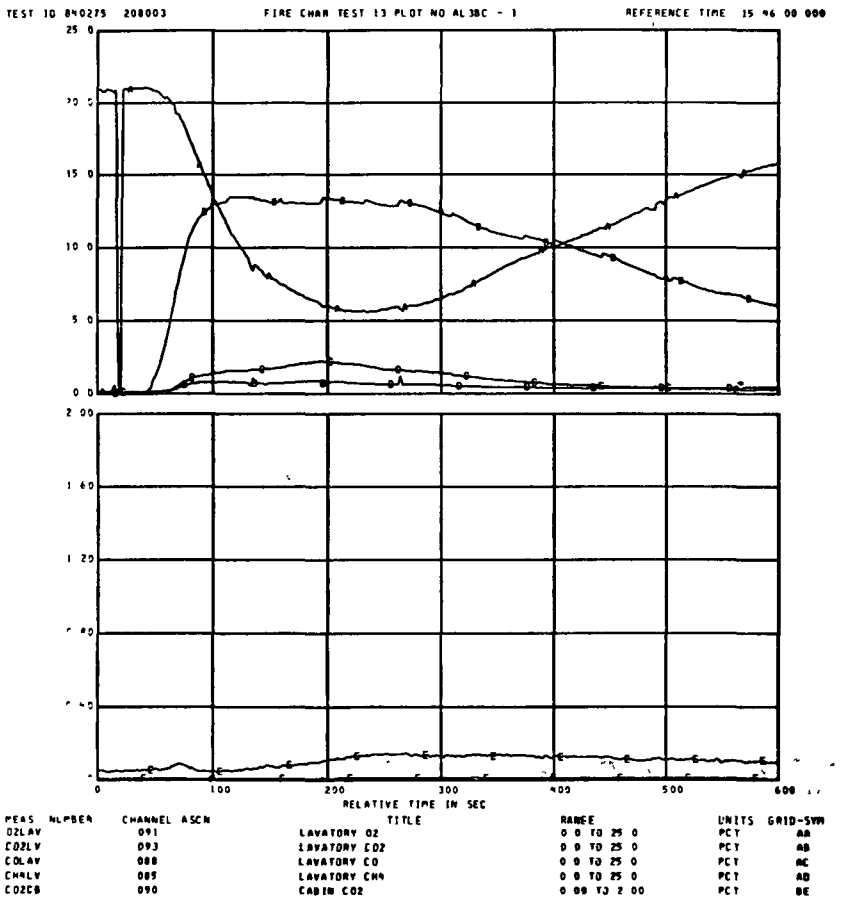


AL ( ) BC

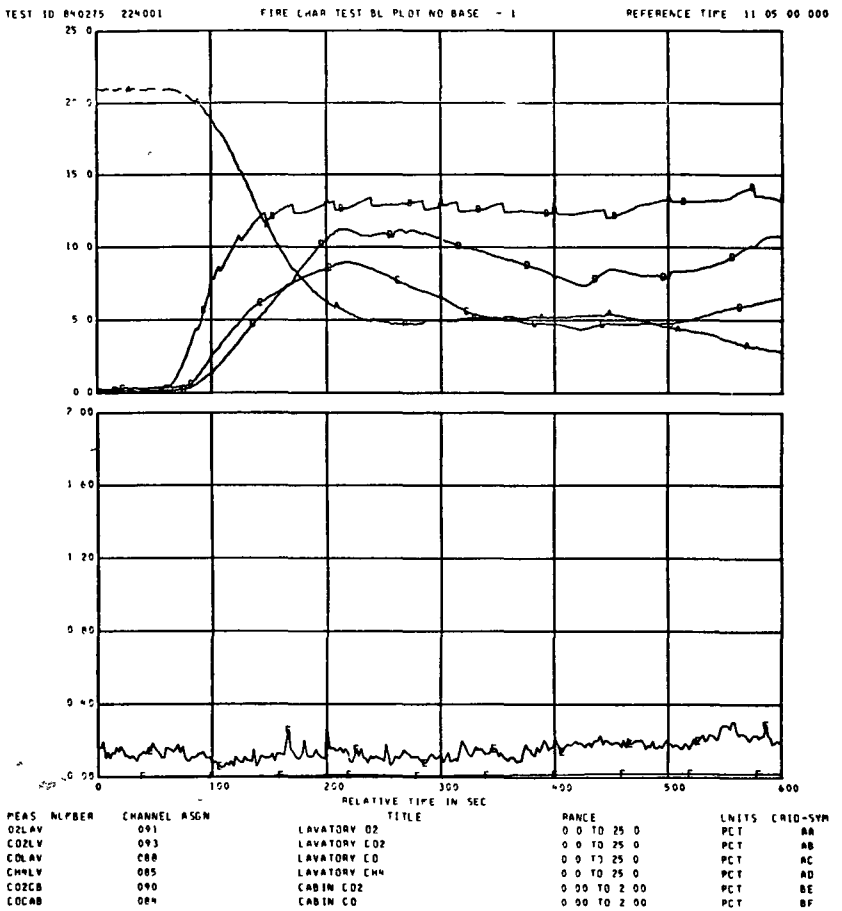


BASELINE

COMPARISON OF SOURCE FUEL AND BASELINE PRODUCTS OF COMBUSTION



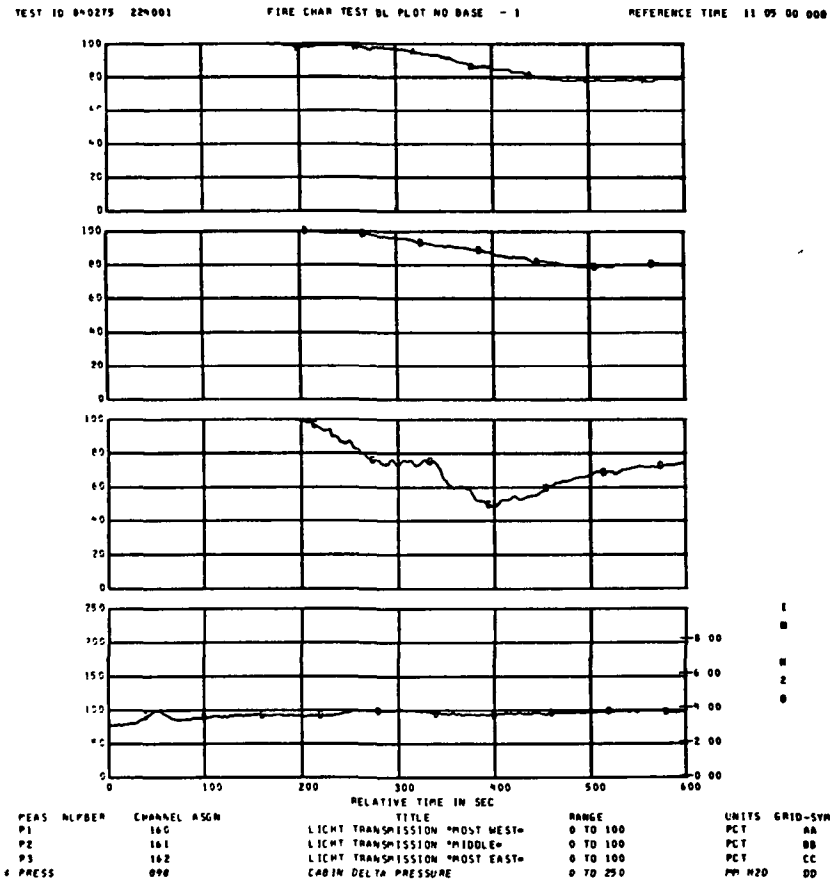
AL ( ) BC

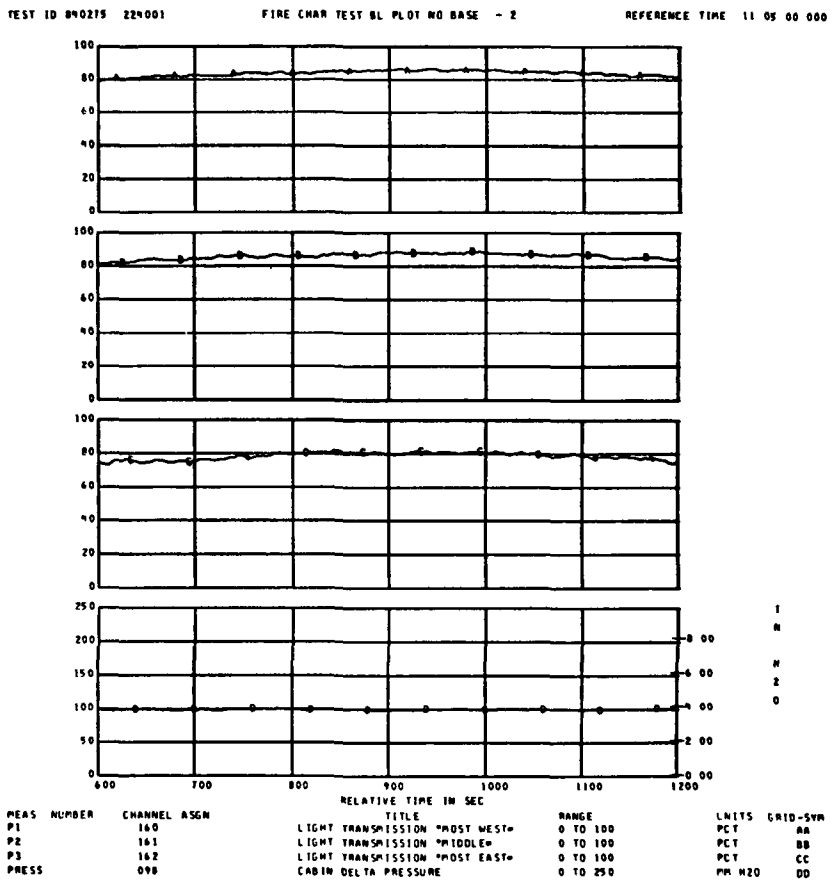


BASELINE

BASE LINE SMOKE DENSITY

0–1200 SECONDS





BUBBLER ANALYSIS FOR HCN, HCL AND HF

ANALYSIS OF THE CONTENT OF THE LAVATORY EXHAUST AND WITHIN THE CABIN WERE MADE OF 15 OF THE SOURCE FIRE SERIES AND THE BASELINE TEST USING A MINIATURE IMPINGER SYSTEM DEVELOPED AND FURNISHED BY NASA. SIX SAMPLES WERE TAKEN AT EACH LOCATION EACH FOR A PERIOD OF TWO MINUTES. IN THE SOURCE FIRE SERIES RANDOM RESULTS WERE OBTAINED. THE MAXIMUM QUANTITY DETECTED IN P.P. MILLION FOR THIS SERIES WERE:

GAS	LAVATORY EXHAUST	CABIN CLOSED DOOR	CABIN OPENED DOOR
HF	3.74 (AA)	12.7 (SP)	5.56 (SP)
HCL	458 (AA)	125 (AL)	125 (AL)
HCN	1.0 (AL & SP)	0.8 (AL & SP)	0.35 (AL)

IN THE BASELINE TEST THE FOLLOWING DATA WAS OBTAINED

	HF		HCL		HCN	
PERIOD	LAV.	CABIN	LAV.	CABIN	LAV.	CABIN
0-120	803	8.0	121	121	11	0
120-240	22	5.0	577	118	106	0
240-360	17	4.0	0	245	154	0
360-480	8	1.0	198	186	76	0
460-600	22	3.0	380	159	87	0
600-720	11	2.0	501	56	105	0

PROGRAM SUMMARY

IGNITION SOURCE CHARACTERIZATION TESTS

- NO ADVERSE EFFECTS ON ANIMAL SUBJECTS
- NO TOXIC GAS LEVELS DETECTED
- MOST SEVERE FIRE PRODUCED BY AIRLINE TRASH
- OPENING THE DOOR OF AN INVOLVED LAVATORY WOULD BE HAZARDOUS

BASELINE TEST

- ANIMAL SUBJECT SURVIVED WITHOUT ADVERSE SHORT- OR LONG-TERM EFFECTS SUPPORTING THE NONTOXIC LEVELS OF GAS DETECTED
- LAVATORY STRUCTURE CONTAINED THE FIRE
- AN EXTERNAL PROPAGATING FIRE DID NOT DEVELOP
- WEIGHT LOSS OF LAVATORY STRUCTURE WAS 24.73 POUNDS
- RESIDUAL SOURCE FUEL WEIGHED 1.14 POUNDS

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FIRE TESTING IN THE BOEING 707 CABIN SECTION

Everett A. Tustin
Boeing Commercial Airplane Company
Seattle, Washington 98124

FIRE TESTING IN THE BOEING 707 CABIN SECTION

E. A. TUSTIN

For the FIREMEN Program Review April 13, 1978

ABSTRACT

The goal of a FIREMEN funded contract is the definition of a laboratory test method ranking airplane interior materials by probable performance in post-crash and in-flight fires. A major task is the relation of laboratory results to full scale data. A large scale test facility for testing materials to the thermal threat of fuel fed and interior fires has been developed with quartz lamps and a propane burner in a twenty foot fuselage section. A method has been developed to analyze full scale data for the apparent heat, smoke and toxicant release rates of the material tested.

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Fire Testing in the Boeing 707 Cabin Section	1
Program Summary	2
I. Review of Phase I - Design Fire Source Selection	
Establishing a Post-Crash Design Fire Source (Cabin Temperature Graph)	3
Establishing an In-Flight Design Fire Source (Cabin Temperature Graph)	4
II. Simulated Fire Testing in Phase II	
Simulated Fire Test Fuselage	5
Cabin Instrumentation	6
Fire Simulating Apparatus	7
Equivalency of Heat Flux Distribution (Comparison of Heat Flux Lines)	8
Comparison of Test Results (Real Fire and Simulated Fire Damage and Toxicant Release)	9
Increased Heating from Reradiation (Explanation of Calorimeter Interpretation)	10
Adjustment for Maximum Heat Flux (Improved Simulation of the Fuel Fire Threat)	11
Comparison of Test Results (Real Fire and Modified Fire Simulation)	12
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PRESENTATION CONTENT	CHART
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FIRE TESTING IN THE BOEING 707 CABIN SECTION

NASA-JSC CONTRACT NAS9-15168

"DEVELOPMENT OF FIRE TEST METHODS FOR AIRPLANE INTERIOR MATERIALS"

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BOEING IR&D PROJECT

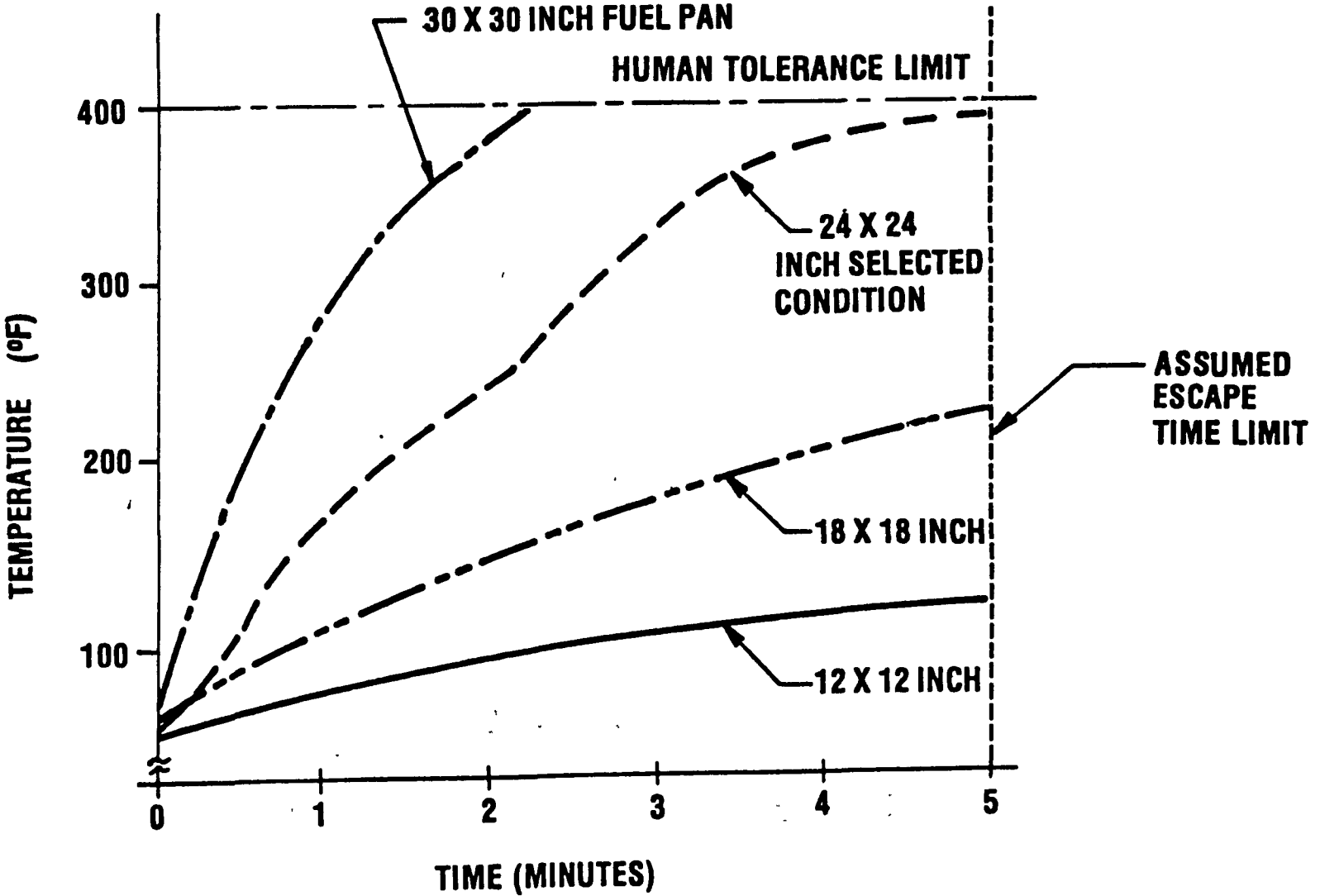
"FIRE TEST METHODS DEVELOPMENT"

PROGRAM SUMMARY

	PHASE I DESIGN FIRE TESTS	PHASE II SIMULATED FIRE TESTS	PHASE III DATA CORRELATION
NAS 9-15168	CONDUCT TESTS WITH REAL FIRE SOURCES IN NASA 737 FUSELAGE	TEST TWO CURRENT AND TEN NEW MATERIALS TO SIMULATIONS OF DESIGN FIRES	LAB TEST NASA TWELVE MATERIALS AND RECOMMEND METHODS WITH RESULTS RELATING WELL TO FULL SCALE DATA
BOEING IRAD	DEVELOP FULL SCALE TEST CONCEPT TO STUDY DESIGN FIRE SOURCES.	DEVELOP 707 TEST SECTION TO TEST MATERIALS WITH FIRE SIMULATIONS AND DEVELOP ANALYSIS METHODS	DEVELOP DETAILED CORRELATION BETWEEN LAB AND FULL SCALE TEST RESULTS BASED ON EVALUATION OF EIGHT CURRENT MATERIALS

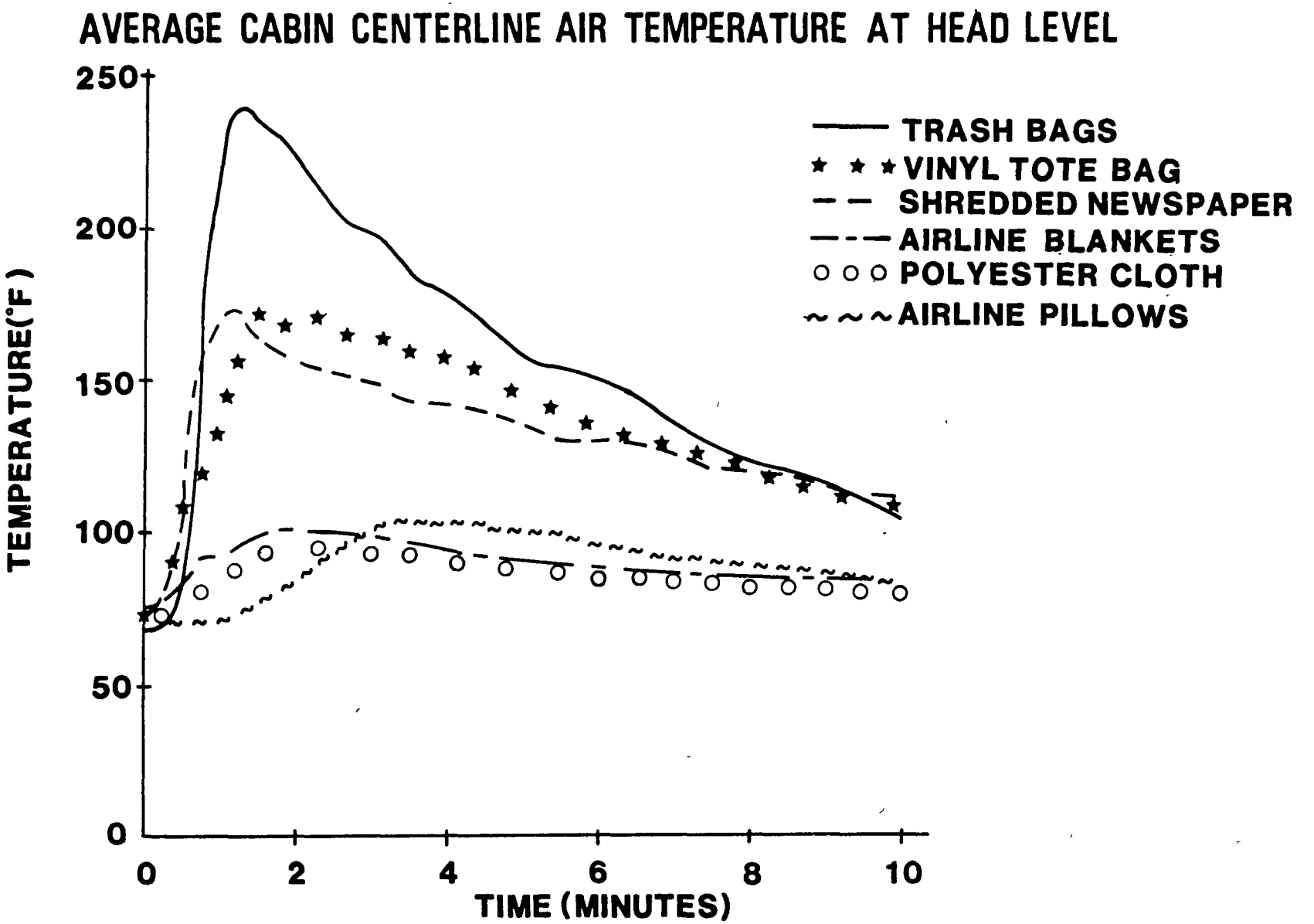
ESTABLISHING A POST CRASH DESIGN FIRE SOURCE
(56 FT. FUSELAGE)

AVERAGE CABIN CENTERLINE TEMPERATURE AT HEAD LEVEL

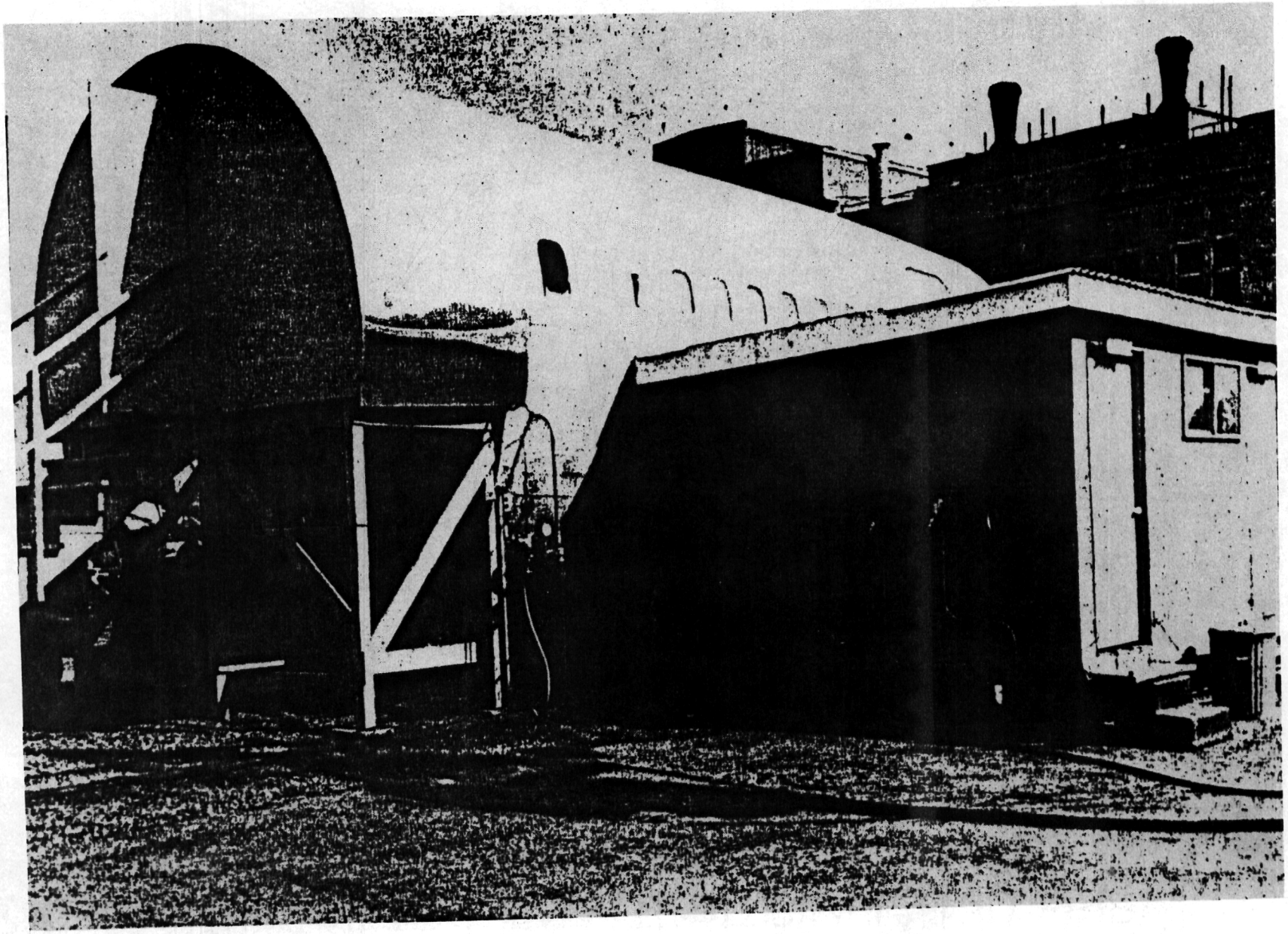


ESTABLISHING AN IN-FLIGHT DESIGN FIRE SOURCE

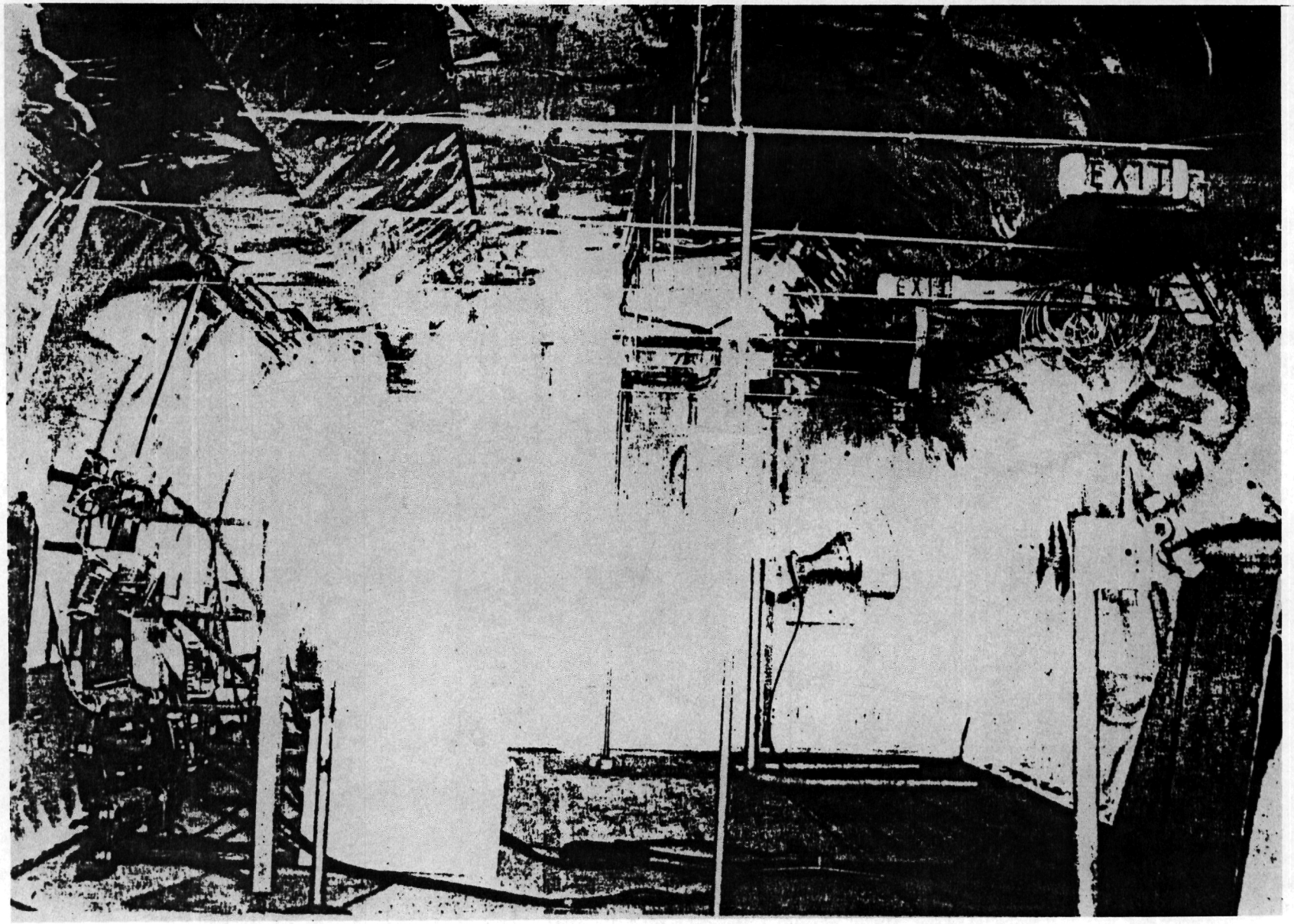
(56 FT. FUSELAGE)



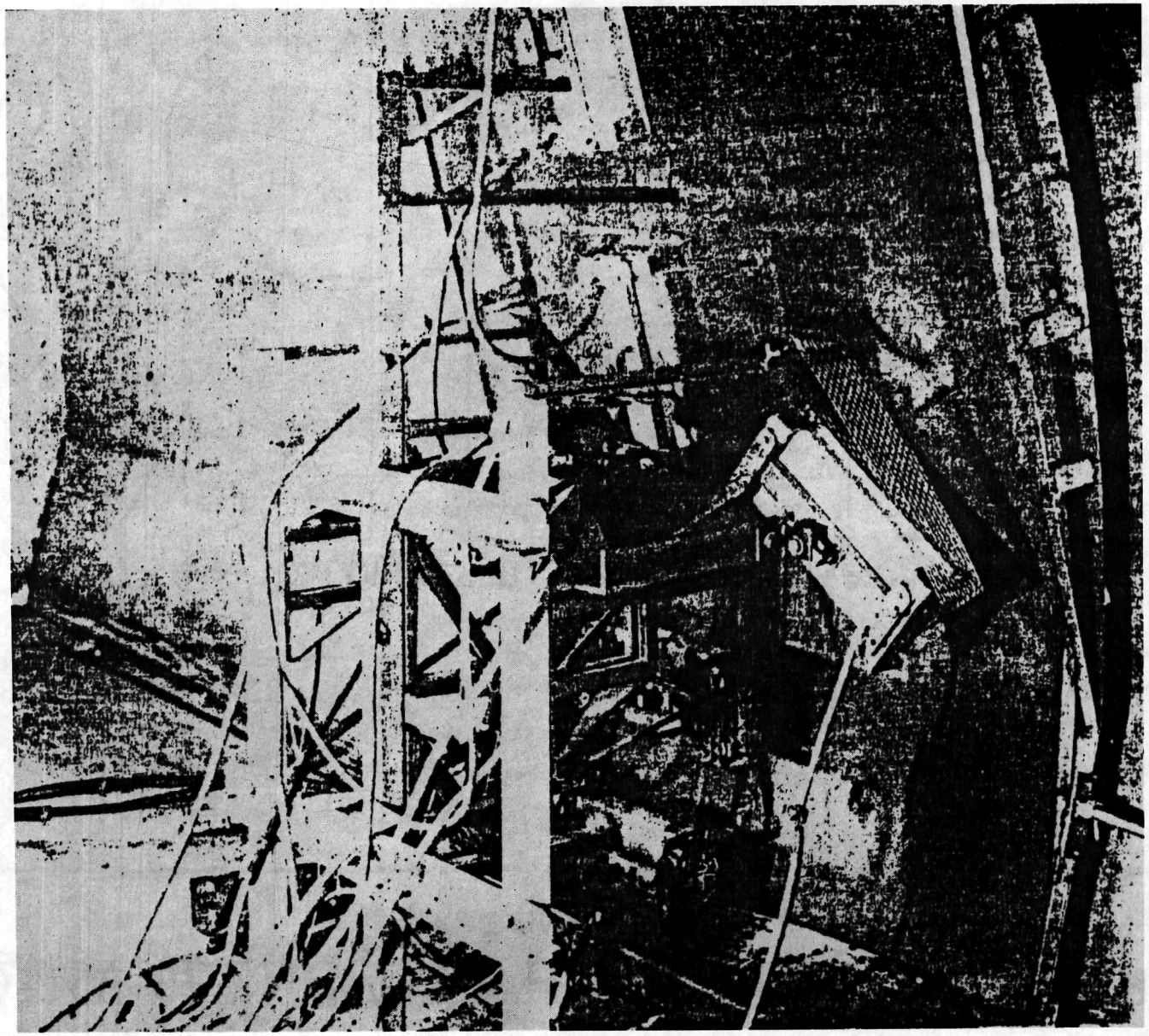
SIMULATED FIRE TEST FUSELAGE



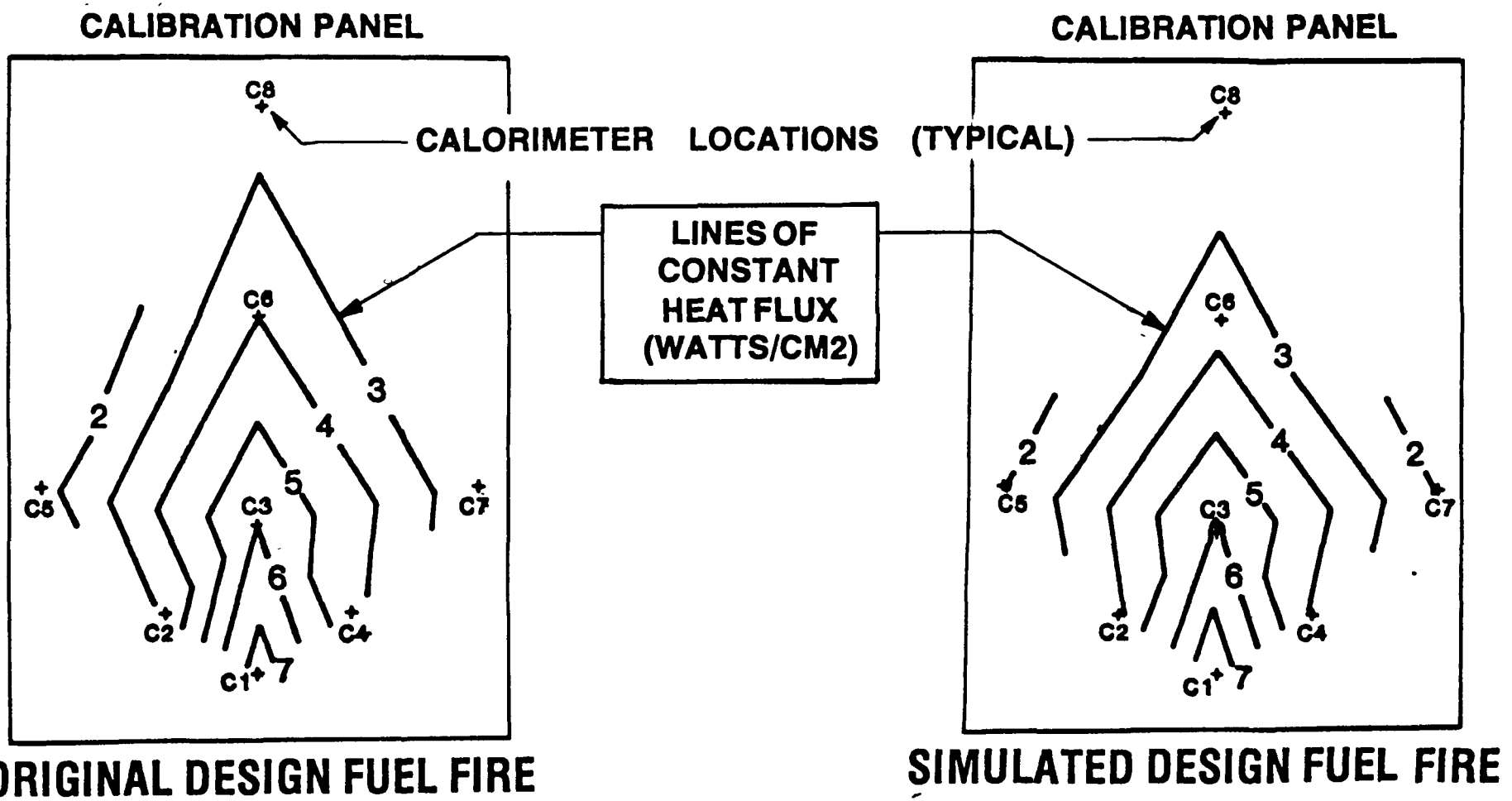
CABIN INSTRUMENTATION - SIMULATED FIRE



FIRE SIMULATING APPARATUS



EQUIVALENCY OF HEAT FLUX DISTRIBUTION

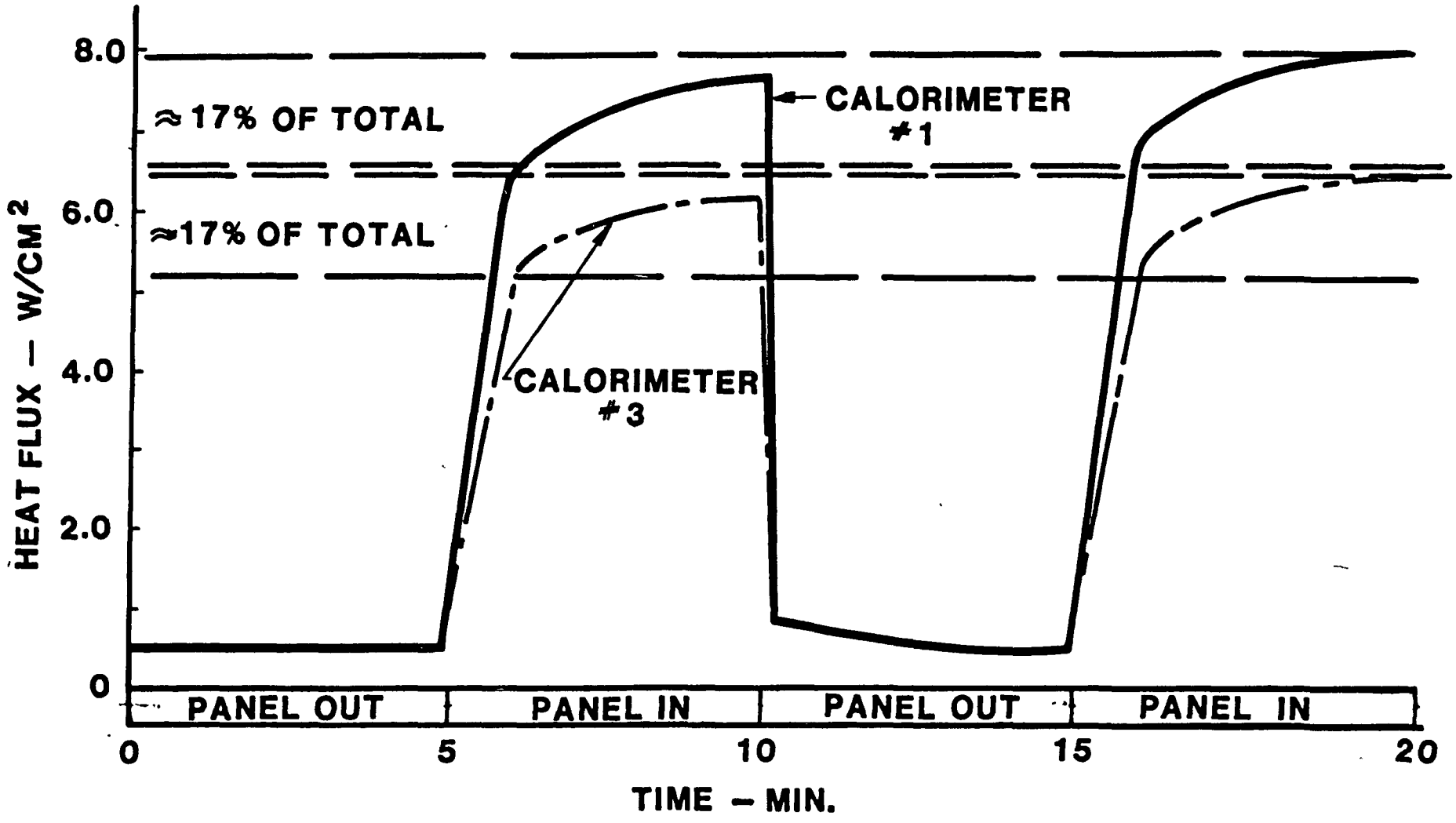


COMPARISON OF TEST RESULTS

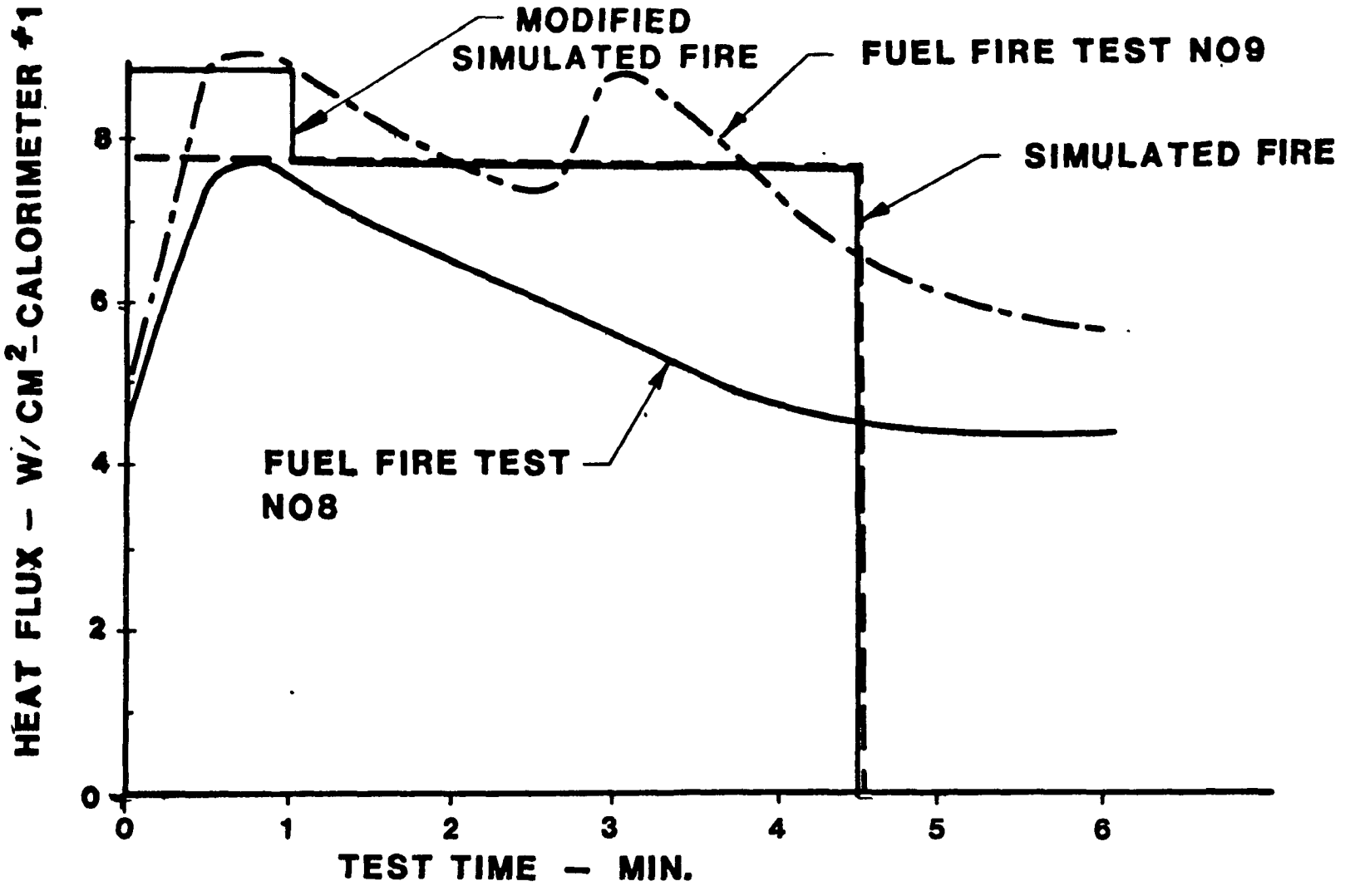
MATERIAL	FIRE DAMAGE %LOSS OF WT.		CALCULATED TOTAL TOXICANT RELEASE~10^{-2} LBS.					
			HCL		HF		HCN	
	NASA FUEL FIRE	BCAC SIM. FIRE	NASA	BCAC	NASA	BCAC	NASA	BCAC
POLYURETHANE SEAT FOAM	≈ 100	≈ 100	2.7	11.6	TRACE	0	0.4	1.4
FABRIC - BACKED VINYL	≈ 100	≈ 100	8.9	94.5	0.2	0	0	0
PVF / PVC / ALUMINUM LAM.	*9-13	5-10	1.18	33.0	0.4	1.4	0	0
PVF/EPOXY/POLY AMIDE-PHENOLIC H.C. SAND	27-32	12-13	4.5	5.4	0.2	3.4	.7	0.2

*DOES NOT INCLUDE ALUMINUM WT. LOSS

INCREASED HEATING FROM RERADIATION



ADJUSTMENT FOR MAXIMUM HEAT FLUX



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MODIFIED FIRE SIMULATION		8-14		11.0		1.3		0
PVF/EPOXY/POLY AMIDE-PHENOLIC H.C. SAND	27-32	12-13	4.5	5.4	0.2	3.4	.7	0.2
MODIFIED FIRE SIMULATION		18-19		15.0		4.4		TRACE

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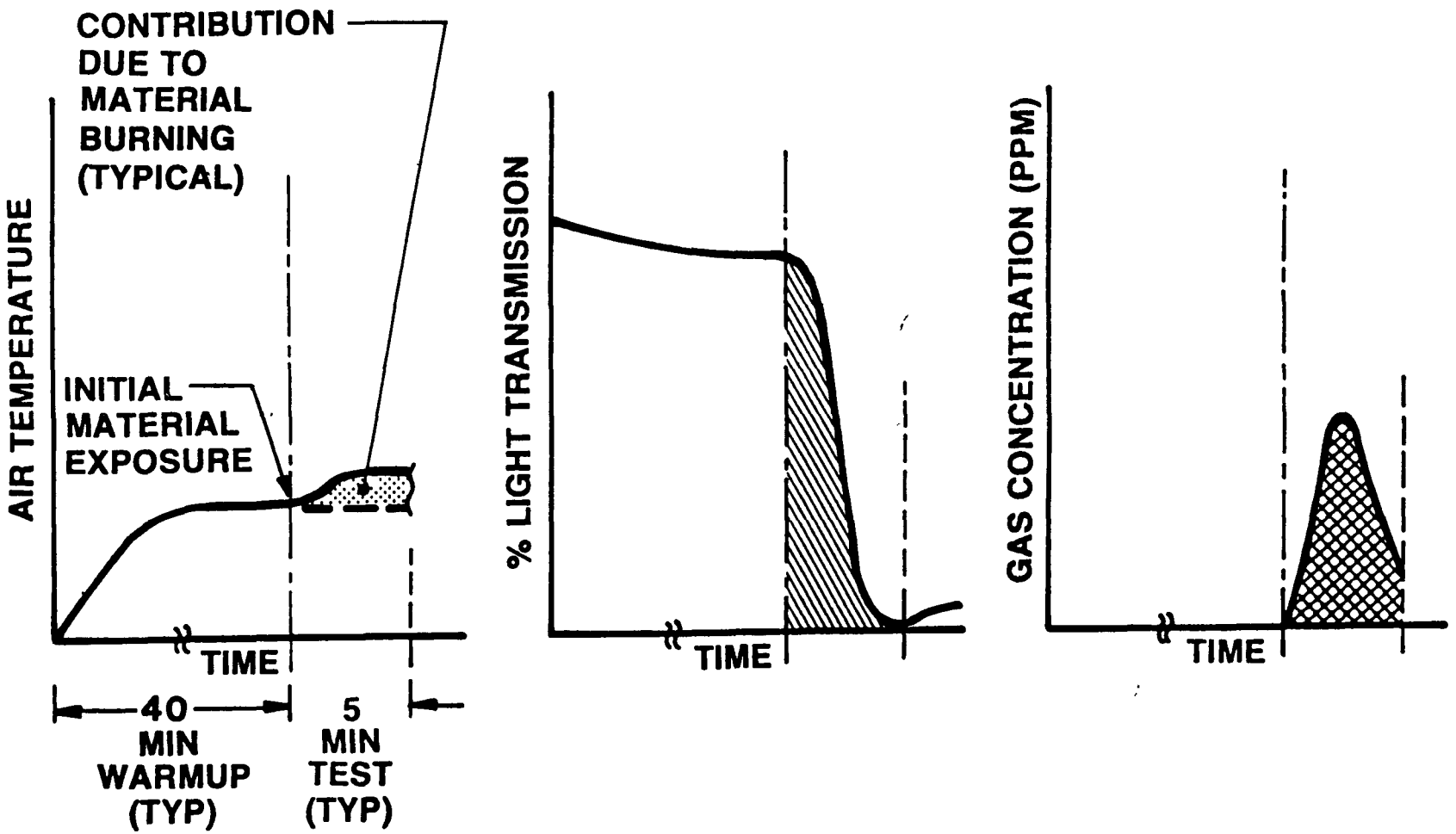
*DOES NOT INCLUDE ALUMINUM WT. LOSS

PROGRAM DIRECTION

- CONTINUE SIMULATION TESTING WITH NEW ADJUSTED HEAT
  - HEAT DAMAGE APPROACHING ACTUAL FROM PAN FIRES
  - TEST IS A VERY SEVERE FIRE EXPOSURE
  - TOXICANT RELEASE CORRELATION IS POOR , BUT SIMULATION WILL GIVE CONSERVATIVE MATERIAL SELECTION CRITERION
- INVESTIGATE TOXICANT RELEASE MEASUREMENT IN FUEL PAN FIRE IN BOEING 707 TEST SECTION

TYPICAL CABIN ENVIRONMENT DATA
SIMULATED DESIGN FIRES

POST CRASH FIRE SOURCE CONDITION



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DATA ANALYSIS EQUATIONS

HEAT RELEASE RATE

$$\overline{R_h} = \frac{P_c V_c C_p}{R \Delta t}\left(\ln \frac{T_c}{T_{co}}\right) + C_p\left[m_l + \frac{P_c V_c}{R \Delta t}\left(\frac{T_c - T_{co}}{T_c T_{co}}\right)\right]\left[\frac{T_c + T_{co}}{2} - T_l\right]$$

SMOKE RELEASE RATE

$$\overline{R_s} = \frac{m_x}{\rho} \cdot \frac{1}{\alpha L}\left[\log \frac{100}{\%T}\left(e^{\frac{m_x \Delta t}{\rho V_c}}\right) - \log \frac{100}{\%T_o}\right] \div \left[\left(e^{\frac{m_x \Delta t}{\rho V_c}}\right) - 1\right]$$

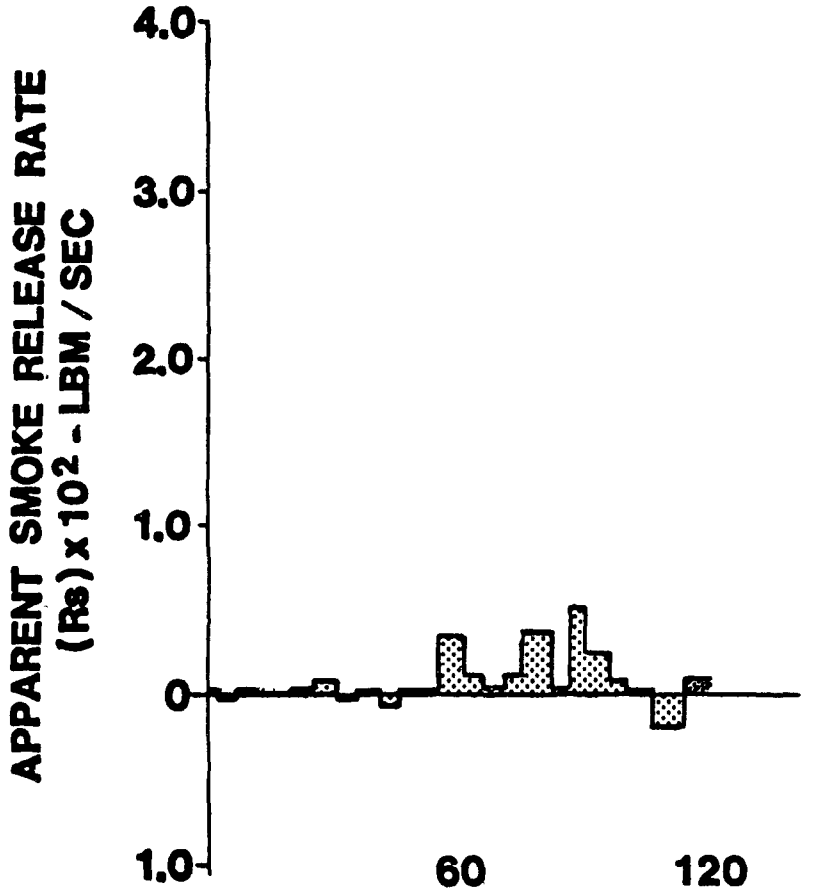
GAS RELEASE RATE

$$R_g = \frac{m_x}{\rho} \cdot \frac{1}{\gamma_g}\left[C_g\left(e^{\frac{m_x \Delta t}{\rho V_c}}\right) - C_{go}\right] \div \left[\left(e^{\frac{m_x \Delta t}{\rho V_c}}\right) - 1\right]$$

EQUATIONS BASED ON:

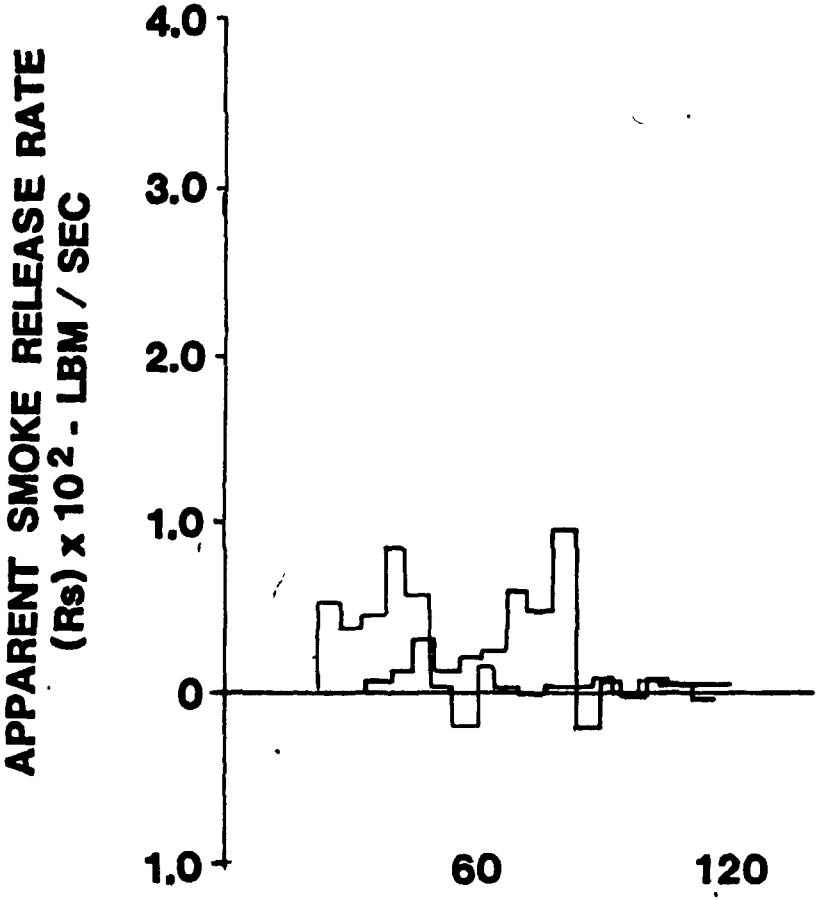
- INSTANTANEOUS DISTRIBUTIONS; INSTRUMENTATION AT AVG POINTS.
- PERFECT GAS LAWS ; BASIC THERMODYNAMIC AND HEAT TRANSFER THEORY
- PAST STUDIES ON SMOKE PARTICLES W/R TRANSMISSION BY OTHER INDIVIDUALS AND ORGANIZATIONS

SMOKE RELEASE RATES FOR INFLIGHT FIRE SOURCES



DESIGN INFLIGHT FIRE SOURCE

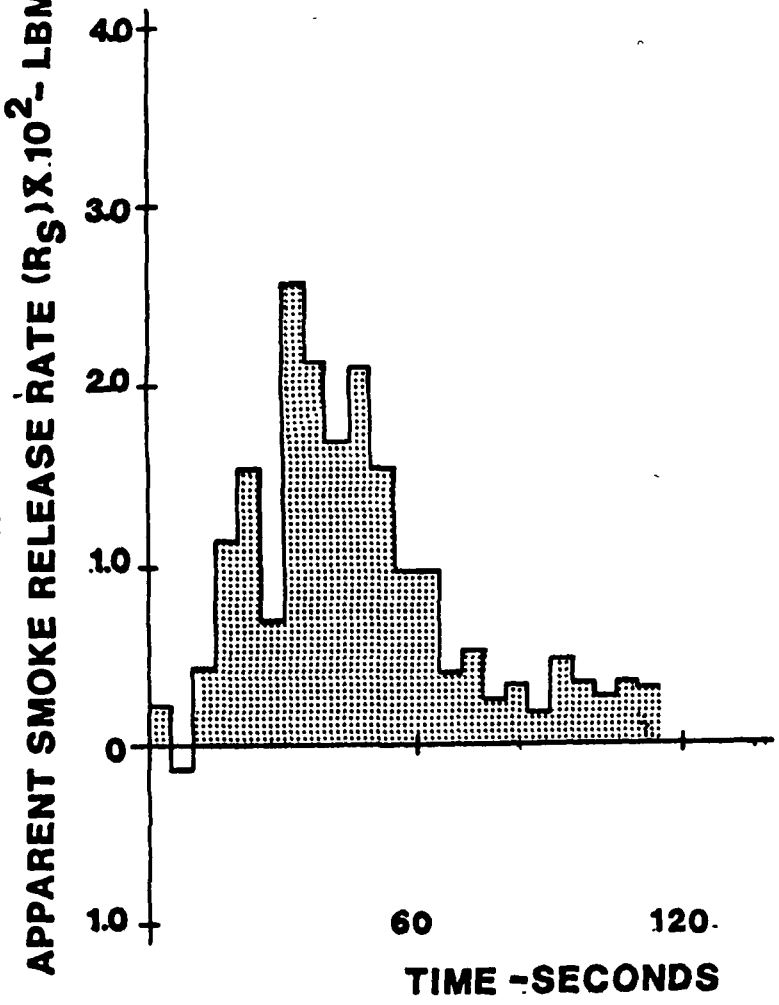
NOTE: VALUES $\leq +10^{-5}/-10^{-5}$ = 0



— PVF/EPOXY/PHENOLIC POLYAMIDE HONEYCOMB CORE

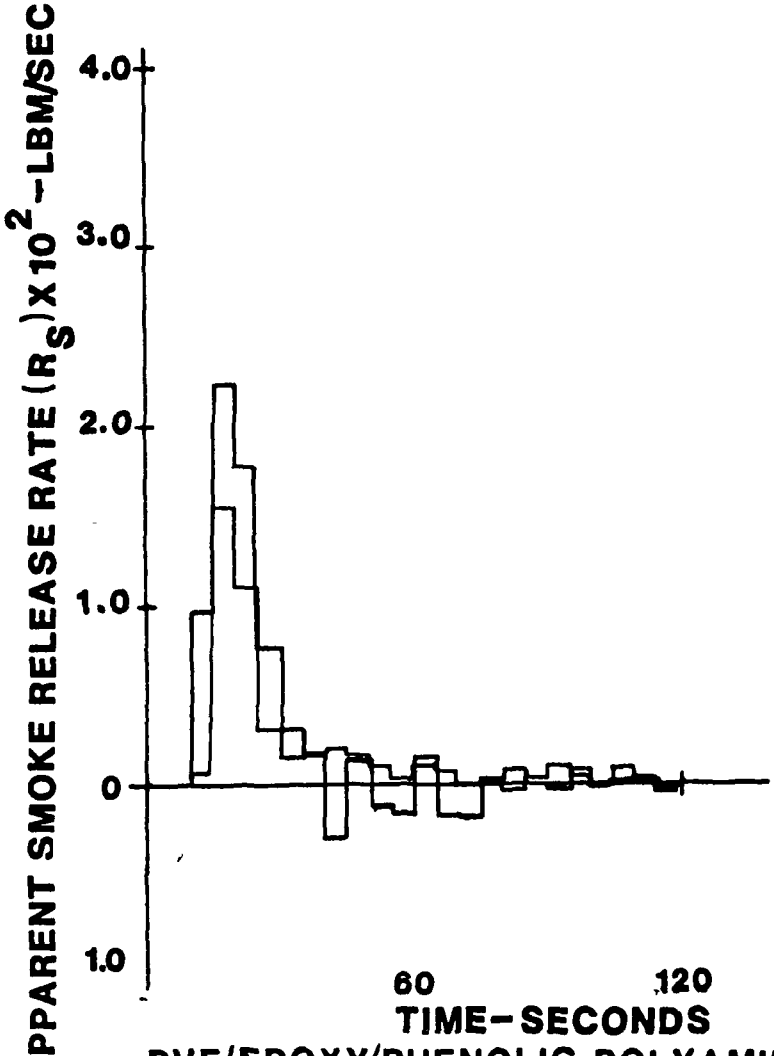
— PVF / PVC/ALUMINUM

SMOKE RELEASE RATES FOR POST-CRASH FIRE SOURCES



DESIGN POST - CRASH FIRE SOURCE

NOTE: VALUE $\leq +10^{-5} / -10^{-5} = 0$



ASSUMPTION FOR TRANSMISSION PREDICTIONS IN THE 737 FUSELAGE SECTION

PRESSURE = 2110.29 PSF.....THIS ASSUMES TEMP AMBIENT AND CABIN = 70° F (530° R) AT TIME = 0.

90

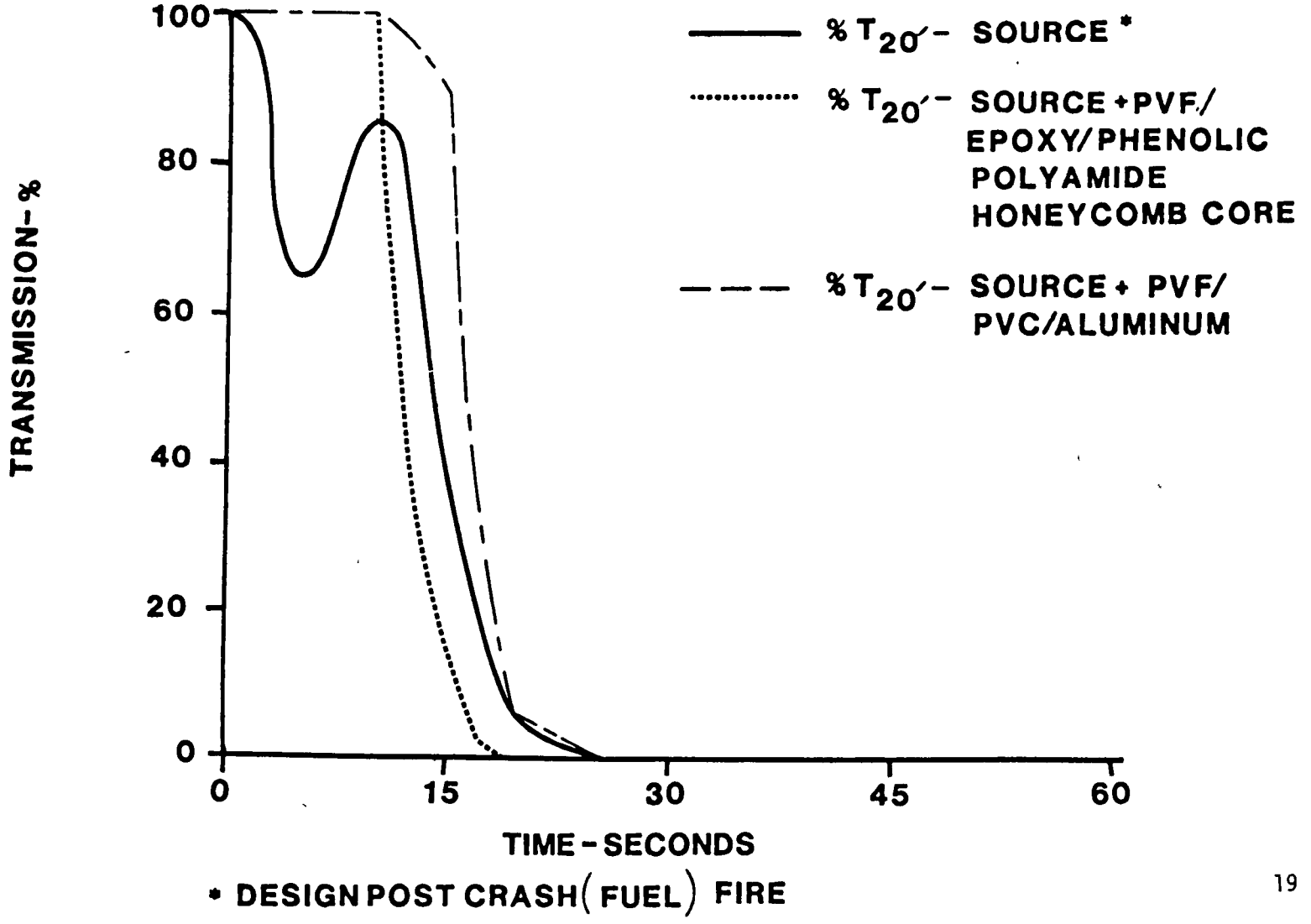
DESIGN TEMPERATURE =

1) DESIGN FIRE SOURE: TEMPERATURE OF DESIGN FIRE SOURCE ALONE.

2) MATERIAL/MATERIAL + DESIGN FIRE SOURCE TEMPERATURE PRODUCED BY BURNING OF MATERIAL WITH DESIGN FIRE SOURCE .

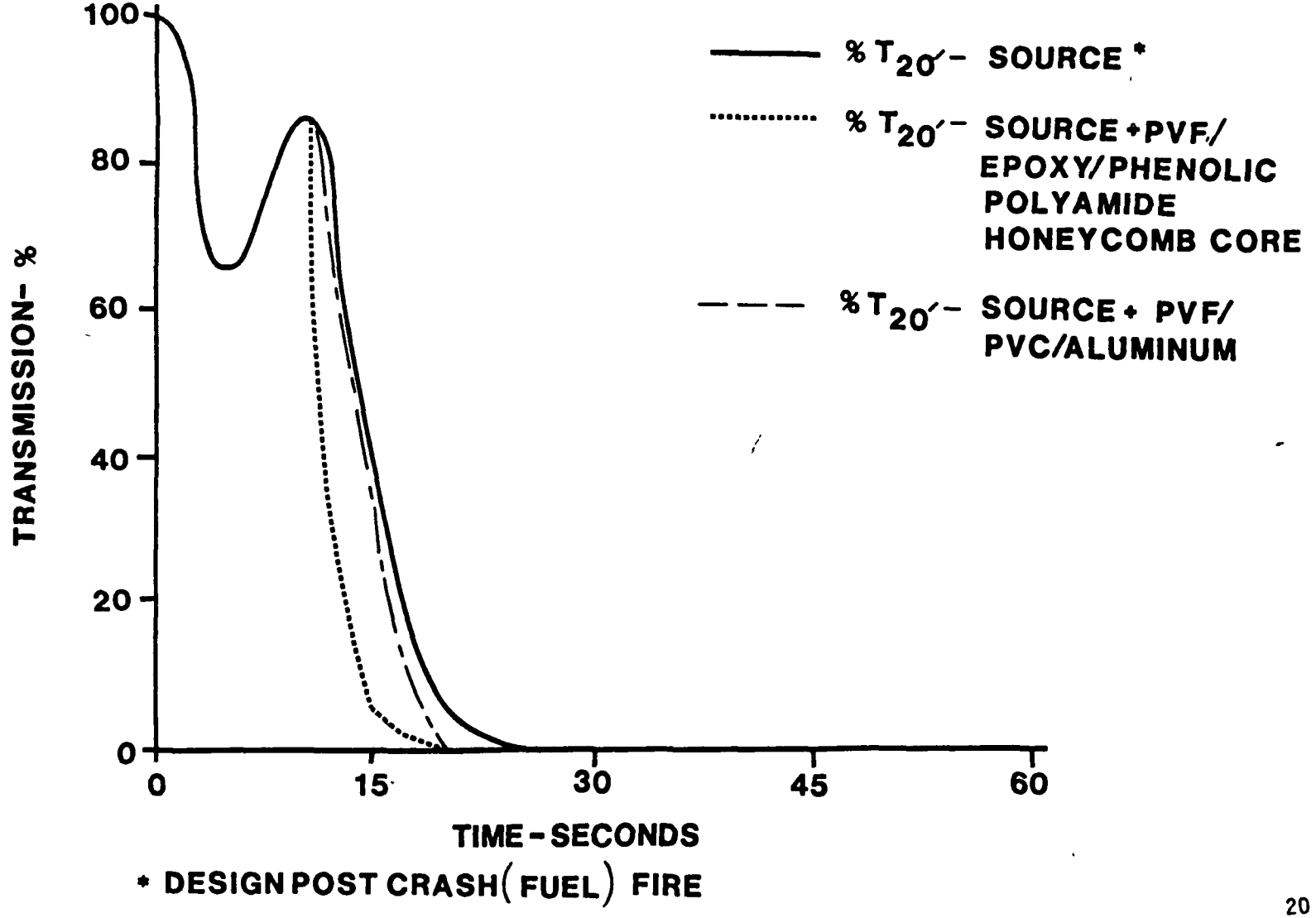
PREDICTED TRANSMISSION IN 737 SECTION

USING DESIGN POST-CRASH (FUEL) FIRE



* DESIGN POST CRASH (FUEL) FIRE

PREDICTED TRANSMISSION IN 737 SECTION
SUMMATION OF CONTRIBUTORS

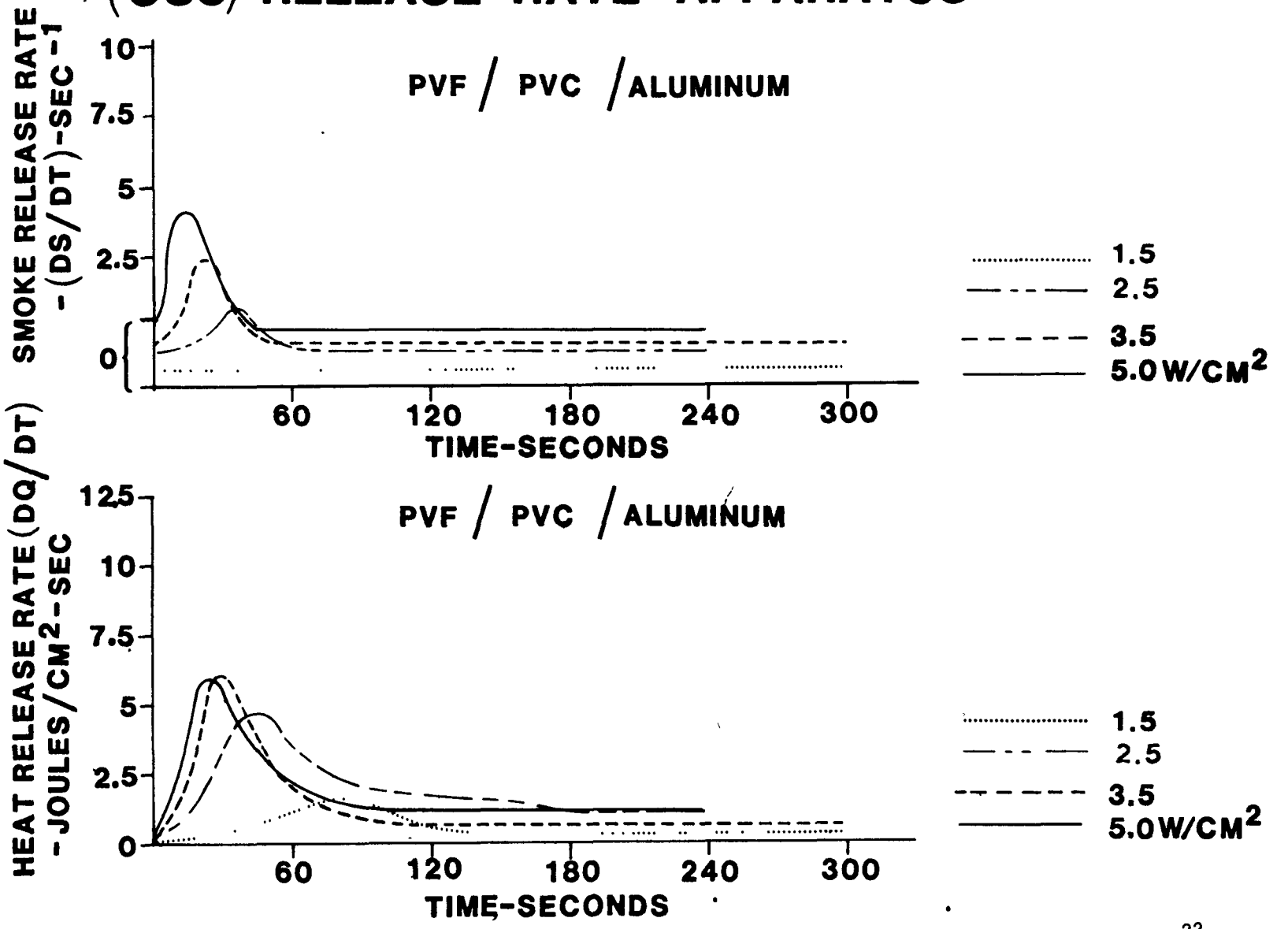


LABORATORY FIRE TESTS CONDUCTED AND PLANNED

BOEING IRAD	OSU	NBS	ASTME 162-67	FAR 25.853	METTLER	LOI
8 BASELINE MATERIALS	all positions W/CM^2 1.5 ✓ 2.5 ✓ 3.5 ✓ 5.0 ✓	W/CM^2 2.5 Flm ✓ 2.5 Smol ✓ 5.0 Flm ✓	✓	60Sec V ✓ 12 Sec V ✓ 15 Sec H ✓	✓	✓
4 NEW MATERIALS	2.5 ★ 5.0 ★	2.5 Flm ★ 5.0 Flm ★	★	Applicable test for in-service use ★	★	★
NAS 9-15168 2 BASELINE MATERIALS	all positions (W/CM^2) 1.5 ✓ 2.5 ✓ 3.5 ✓ 5.0 ✓	W/CM^2 2.5 Flm ✓ 2.5 Smol ✓ 5.0 Flm ✓	✓	60 Sec V ✓ 15 Sec H ✓	✓	✓
10 NEW MATERIALS	2.5 ✓ 5.0 ✓	2.5 Flm ✓ 5.0 Flm ✓	✓	Applicable test for in-service use ✓	✓	✓

✓ = Test Complete ★ = Test Planned Smol = Smoldering Flm = FLAMMING

DATA EXAMPLES-OHIO STATE UNIVERSITY (OSU) RELEASE RATE APPARATUS



NAS 9-15168 TEST METHOD SELECTION

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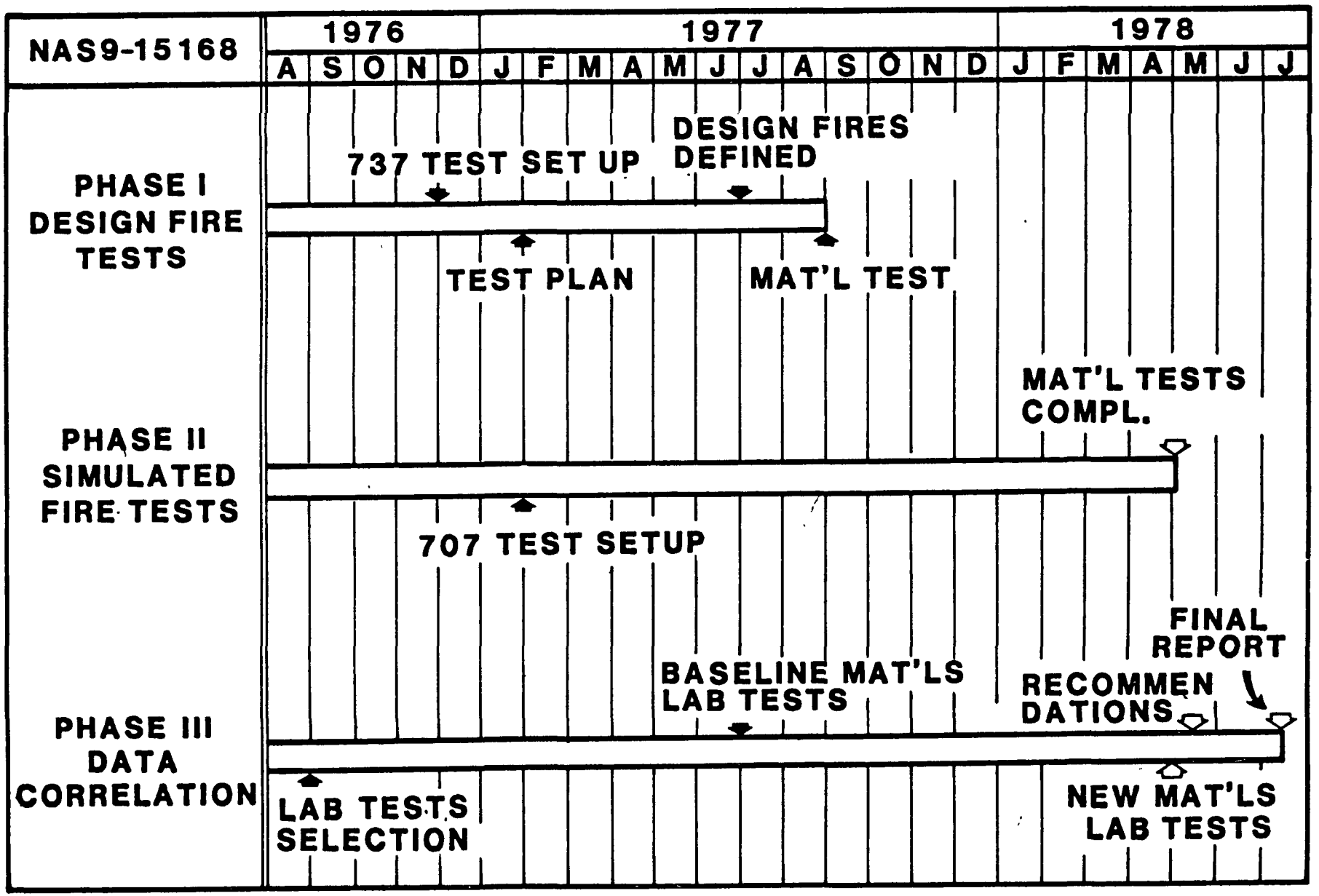
_____TEST(S)@ _____HEAT FLUX(ES)
WILL GIVE RESULTS APPROXIMATELY
RANKING MATERIALS IN THE SAME
ORDER AS PERFORMANCE IN
SIMULATED FUEL (INTERIOR FIRES)

_____ TEST(S) CAN EFFECTIVELY
SCREEN OUT MATERIALS NOT
WARRANTING EXTENSIVE TESTING
(ABOVE)

PROGRAM SCHEDULE



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DEVELOPMENT OF LIGHTWEIGHT, FIRE-RETARDANT, LOW SMOKE, HIGH STRENGTH, THERMALLY STABLE AIRCRAFT FLOOR PANELING

Roy A. Anderson and Richard J. Karch
Boeing Commercial Airplane Company
Seattle, Washington 98124

DEVELOPMENT OF LIGHTWEIGHT, FIRE-RETARDENT, LOW SMOKE, HIGH STRENGTH, THERMALLY STABLE AIRCRAFT FLOOR PANELING

By

Roy A. Anderson and Richard J. Karch

BOEING COMMERCIAL AIRPLANE COMPANY

P.O. Box 3707

Seattle, Washington 98124

ABSTRACT

This presentation describes Boeing's participation in a NASA-funded program (FIRMEN) to develop materials for use as floor panels possessing flammability, smoke and toxicity (FS&T) characteristics superior to current materials. The objectives of the program are to develop an aircraft floor paneling suitable for high traffic areas, e.g., aisle or galley and to install and certify the panel in a commercial aircraft for service evaluation.

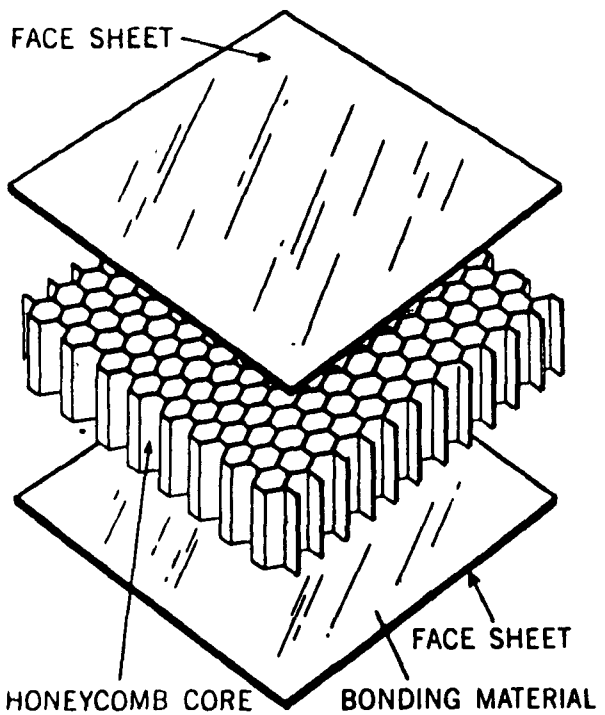
The development of a light weight, fire-retardent, low smoke, high strength, thermally stable aircraft floor panel has been completed. The service evaluation of a panel in a commercial aircraft is in progress and scheduled to be completed in March 1978.

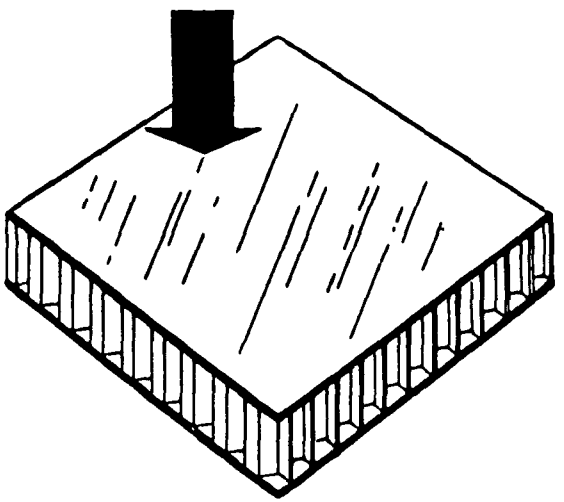
DEVELOPMENT OF LIGHTWEIGHT, FIRE-RETARDANT, LOW SMOKE, HIGH STRENGTH, THERMALLY STABLE AIRCRAFT FLOOR PANELING

NAS 9-15062

INTRODUCTION

- PRESENT AIRCRAFT FLOORING





COMPLETED SANDWICH STRUCTURE

INTRODUCTION

- PRESENT AIRCRAFT FLOORING
  - FACE SHEETS - Epoxy impregnated unidirectional fiberglass
  - ADHESIVE - Epoxy resin
  - CORE - Phenolic/nomex honeycomb core

INTRODUCTION

- CONTRACT NAS 9-14753 - PRIMARY OBJECTIVES
  - INCREASE FIRE RESISTANCE
  - LESS SMOKE AND TOXICANTS
  - INCREASE BURN THROUGH RESISTANCE
- CONTRACT NAS 9-15062 IS A FOLLOW ON TO NAS 9-14753

INTRODUCTION

- FLOOR PANEL EVALUATION
  - FLAMMABILITY, SMOKE AND TOXICITY TESTS (F, S&T)
  - MECHANICAL STRENGTH TESTS
  - HUMIDITY RESISTANCE TESTS

INTRODUCTION

- NAS 9-15062 PRIMARY OBJECTIVES
  - DEVELOP A HIGH-TRAFFIC PANEL
  - IMPROVE BURN THROUGH RESISTANCE
  - SERVICE TEST (Five year flight test)

INTRODUCTION

- NAS 9-15062 - STATUS
  - SERVICE EVALUATION PANEL HAS BEEN PROVIDED TO UNITED AIRLINES
  - PANELS HAVE BEEN PROVIDED FOR LARGE SCALE TESTING IN SUPPORT OF CONTRACT NAS 9-15168
  - LABORATORY TEST SPECIMENS HAVE BEEN PROVIDED IN SUPPORT OF CONTRACT NAS 9-15168

INTRODUCTION

- PRESENTATION OBJECTIVES
  - APPROACH USED TO DEVELOP THE SERVICE EVALUATION PANEL
  - SELECTED TEST RESULTS
  - CONCLUSIONS

INTRODUCTION

- APPROACH
  - SCREENING TESTS (14 candidates)
  - VERIFICATION TESTS (3 candidates)
  - END ITEM FABRICATION (1 system)

APPROACH

- SCREENING TESTS - FLAMMABILITY
  - VERTICAL BURN (12 & 60 second FAR 25-32)
  - BURN THROUGH (10 minute exposure)
  - SMOKE DENSITY (D_S at 1.5, 4 minutes and maximum)
  - TOXIC GAS EMISSION (HCN, HCL, HF, CO, SO_2, & NO_X)
  - OXYGEN INDEX TESTS (LOI)
  - CHEMICAL PROPERTIES (TGA)

APPROACH

- SCREENING TESTS - MECHANICAL STRENGTH/DURABILITY
  - IMPACT (flat point dart test)
  - FATIGUE (food roller cart)
  - WEIGHT
  - FLEXURE (long beam and short beam)

RESULTS

- SCREENING TEST RESULTS (3 MOST SATISFACTORY CANDIDATES)
  - NORDAM CONSTRUCTED
  - AIR LOGISTICS CONSTRUCTED
  - BOEING CONSTRUCTED

APPROACH

- VERIFICATION TESTS - FLAMMABILITY
  - SCREENING TESTS
  - HORIZONTAL BURN
  - FLAMMABILITY PROPERTIES (Lennox oil burner)

INTRODUCTION

- NAS 9-14753 - CONCLUSIONS AND RECOMMENDATIONS

  - EXPERIMENTAL FACE SHEETS, ADHESIVES, AND CORE SYSTEMS CAN BE DEVELOPED INTO A SATISFACTORY FLOOR PANEL
  - ADDITIONAL FLAMMABILITY AND MECHANICAL TESTING IS REQUIRED
  - SERVICE EVALUATION IS REQUIRED

APPROACH

- VERIFICATION TESTS - MECHANICAL STRENGTH/DURABILITY
  - SCREENING TESTS
  - WARPAGE
  - PEEL (rolling drum)
  - INSERT PULL OUT
  - PANEL IN-PLANE SHEAR

APPROACH

- VERIFICATION TESTS - HUMIDITY EXPOSURE
  - WEIGHT GAIN
  - PEEL (rolling drum)
  - FLEXURE (long beam and short beam)

RESULTS

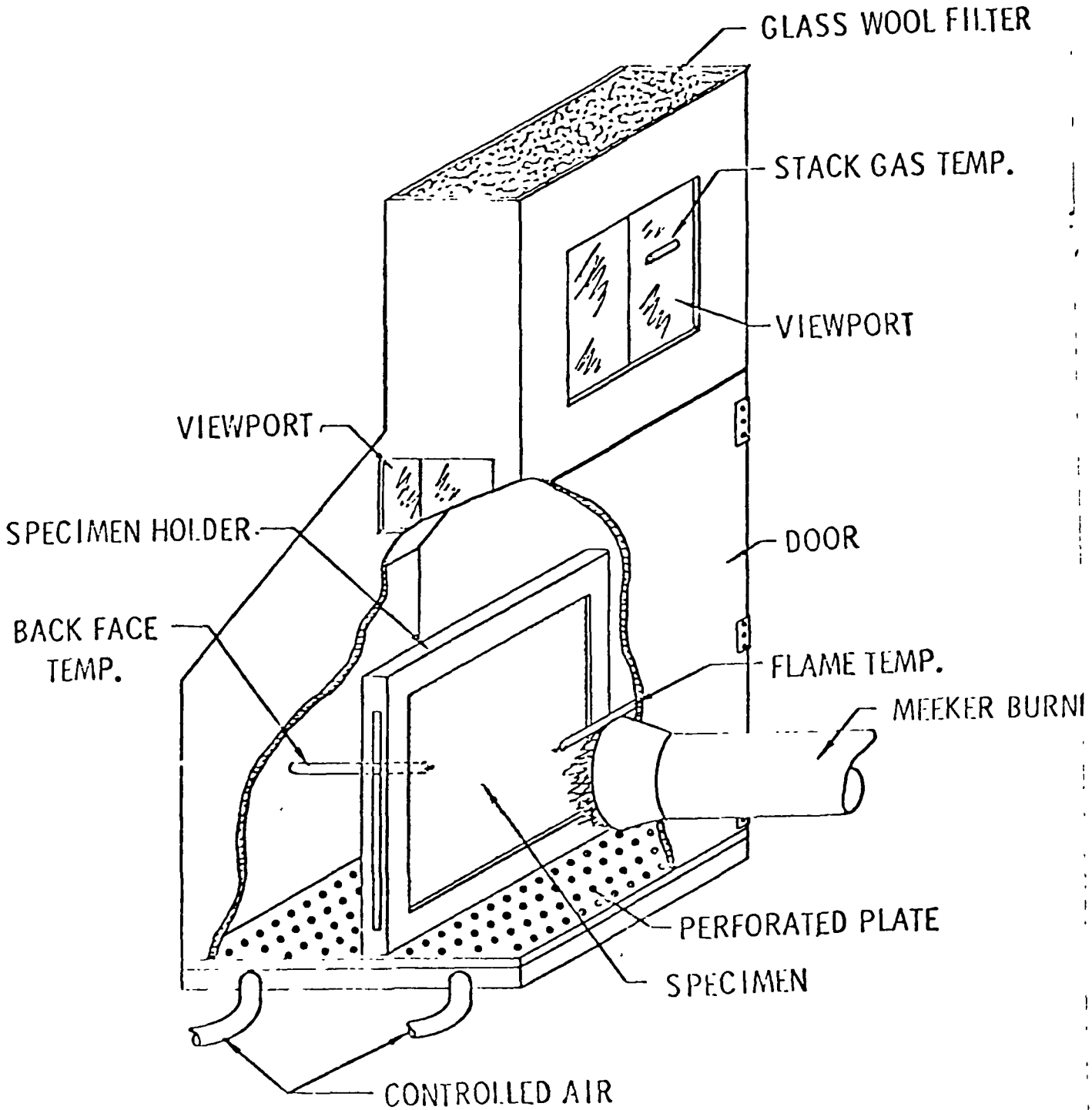
○ VERIFICATION TEST RESULTS (ONE PANEL FOR END ITEM FABRICATION)

● BOEING CONSTRUCTED

FACE SHEETS - Modified phenolic impregnated unidirectional S-glass (Deco XMP-100)

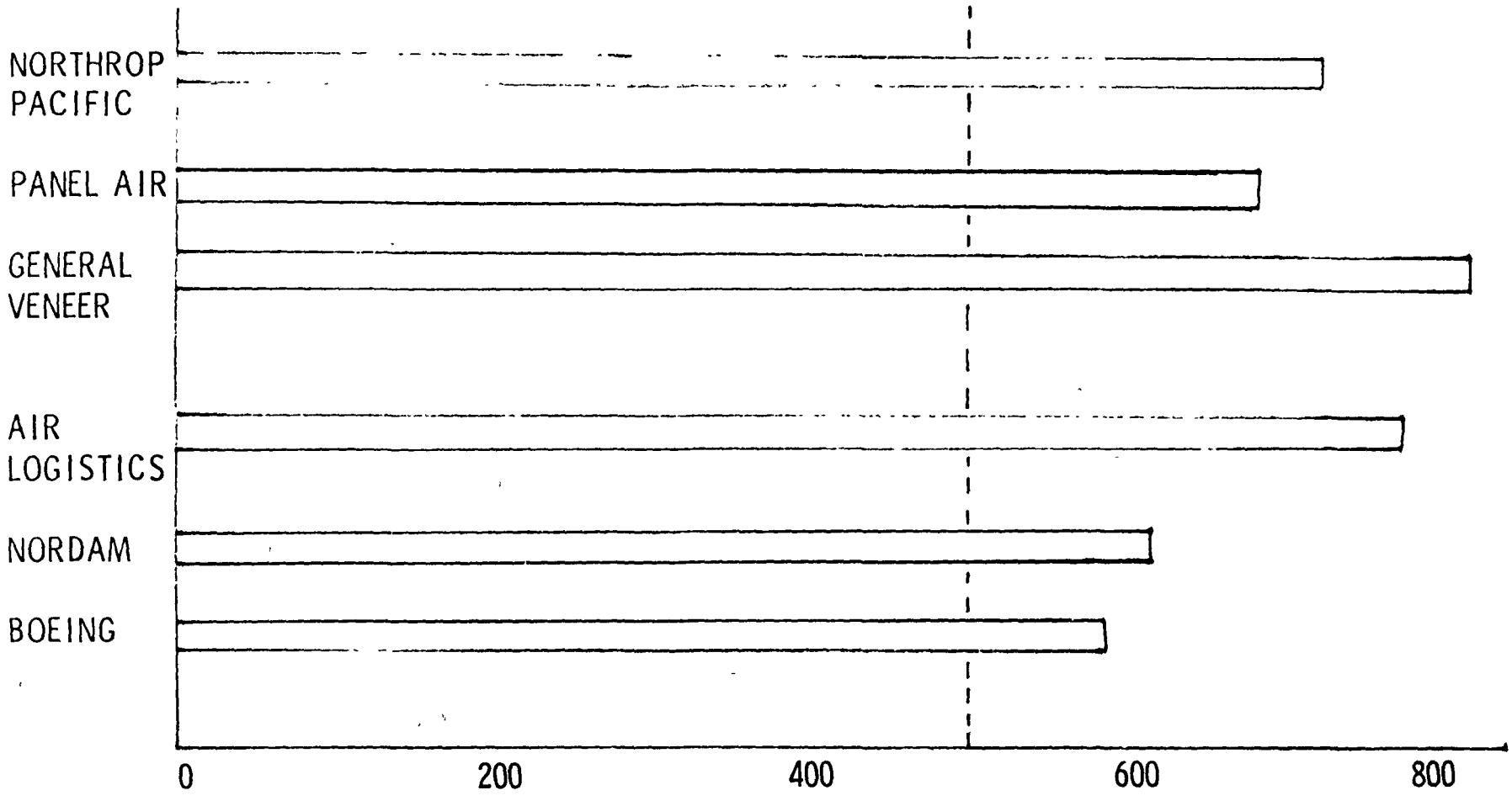
ADHESIVE - Modified phenolic film (Narmco 9252)

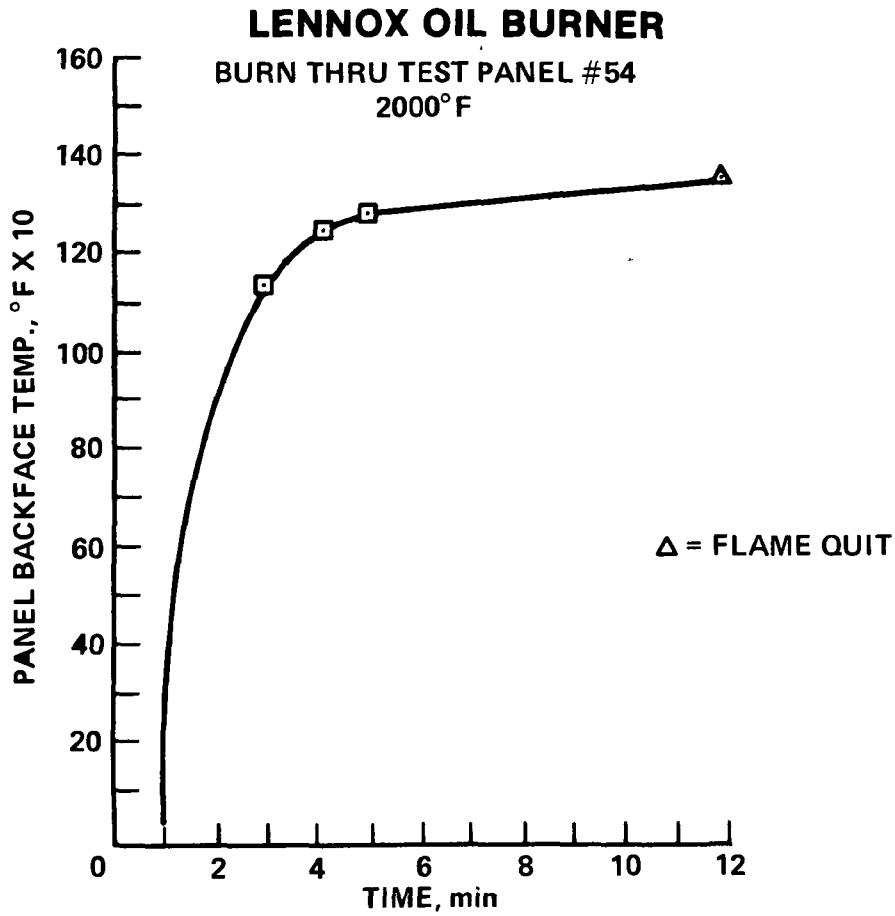
CORE - Phenolic/nomex honeycomb (Orbitex) filled with polyimide foam (Solar)



Boeing Burnthrough Apparatus

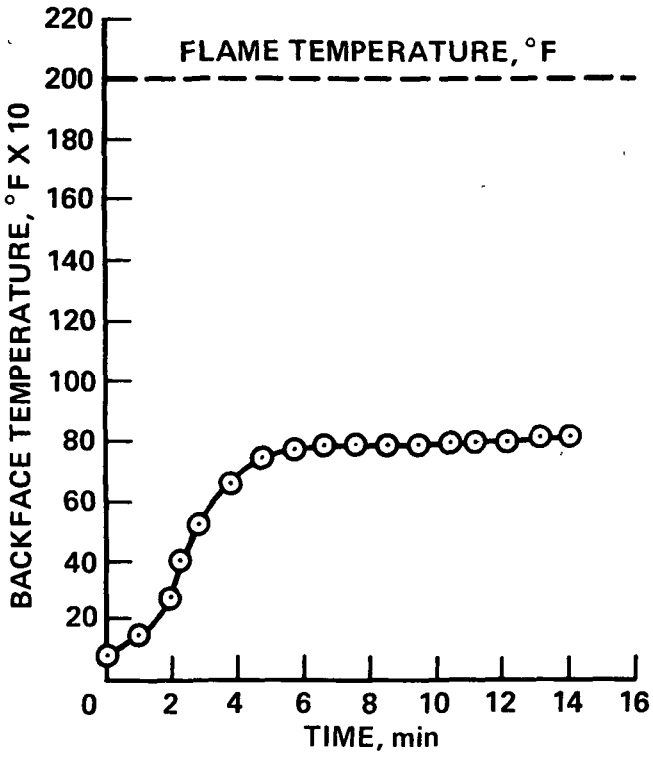
RESULTS


NORTHROP PACIFIC
PANEL AIR
GENERAL VENEER
AIR LOGISTICS
NORDAM
BOEING
0
200
400
600
800
TEMPERATURE AT 10 minutes (°F)
BOEING BURN THROUGH


LENNOX OIL BURNER
BURN THRU TEST PANEL #54
2000° F
PANEL BACKFACE TEMP., °F X 10
160
140
120
100
80
60
40
20
0
2
4
6
8
10
12
TIME, min
Δ = FLAME QUIT

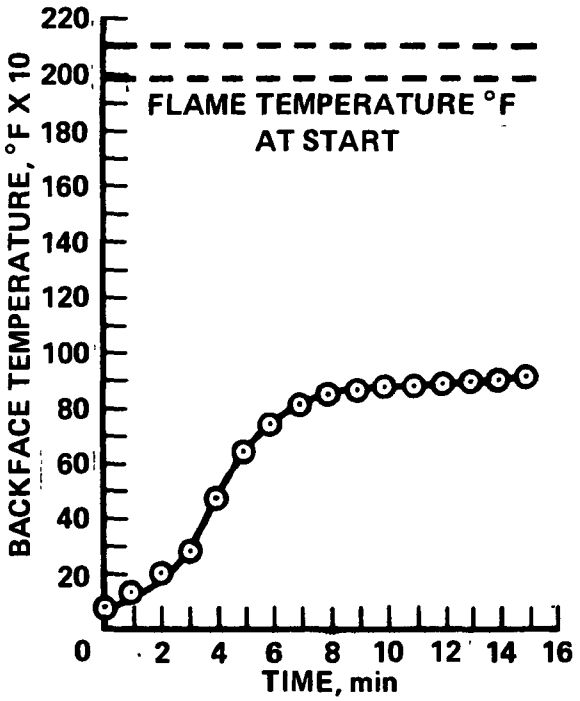
LENNOX OIL BURNER

BURN THRU TEST PANEL #76
2000°F OIL BURNER BLOWER

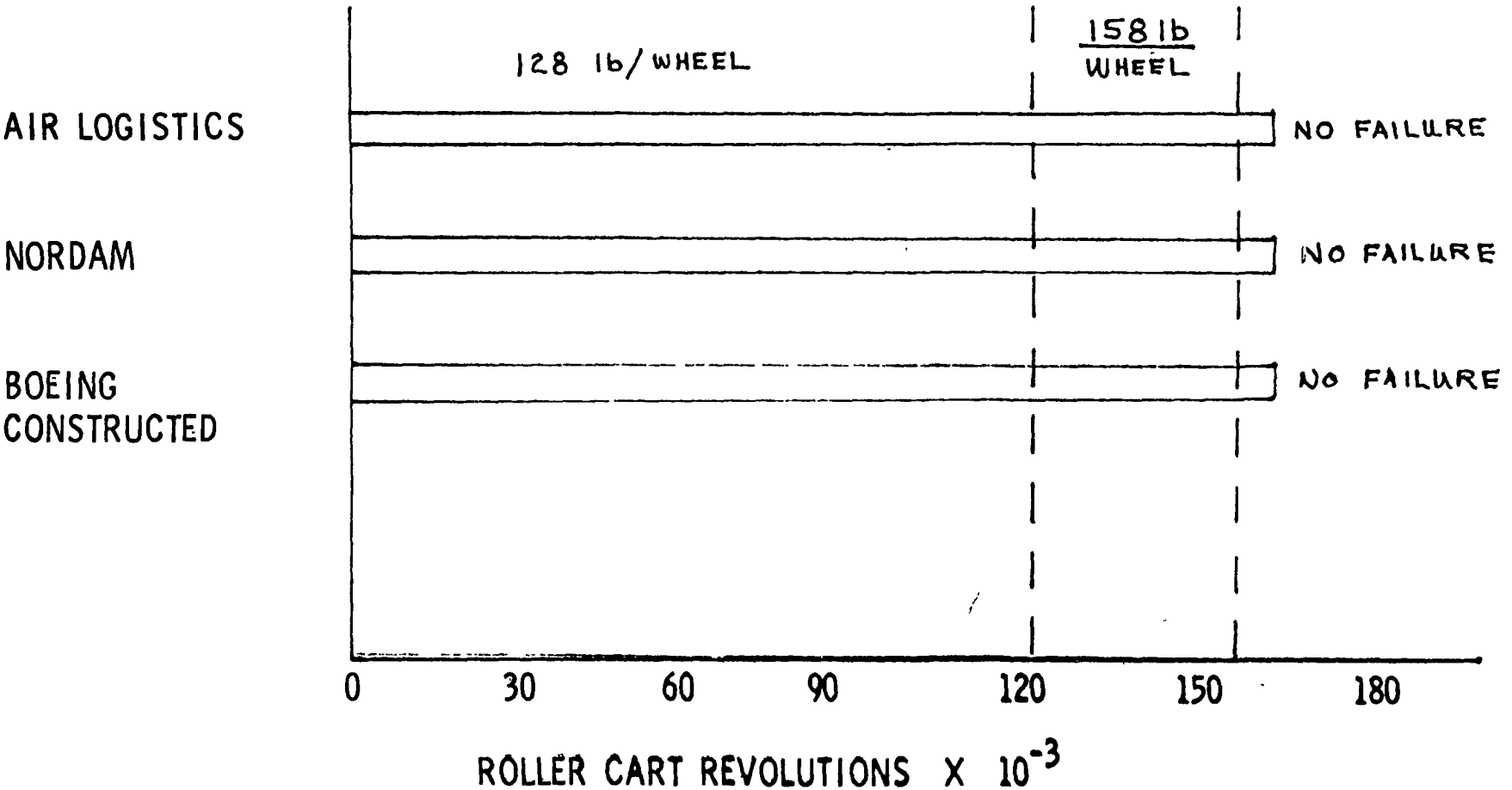


LENNOX OIL BURNER

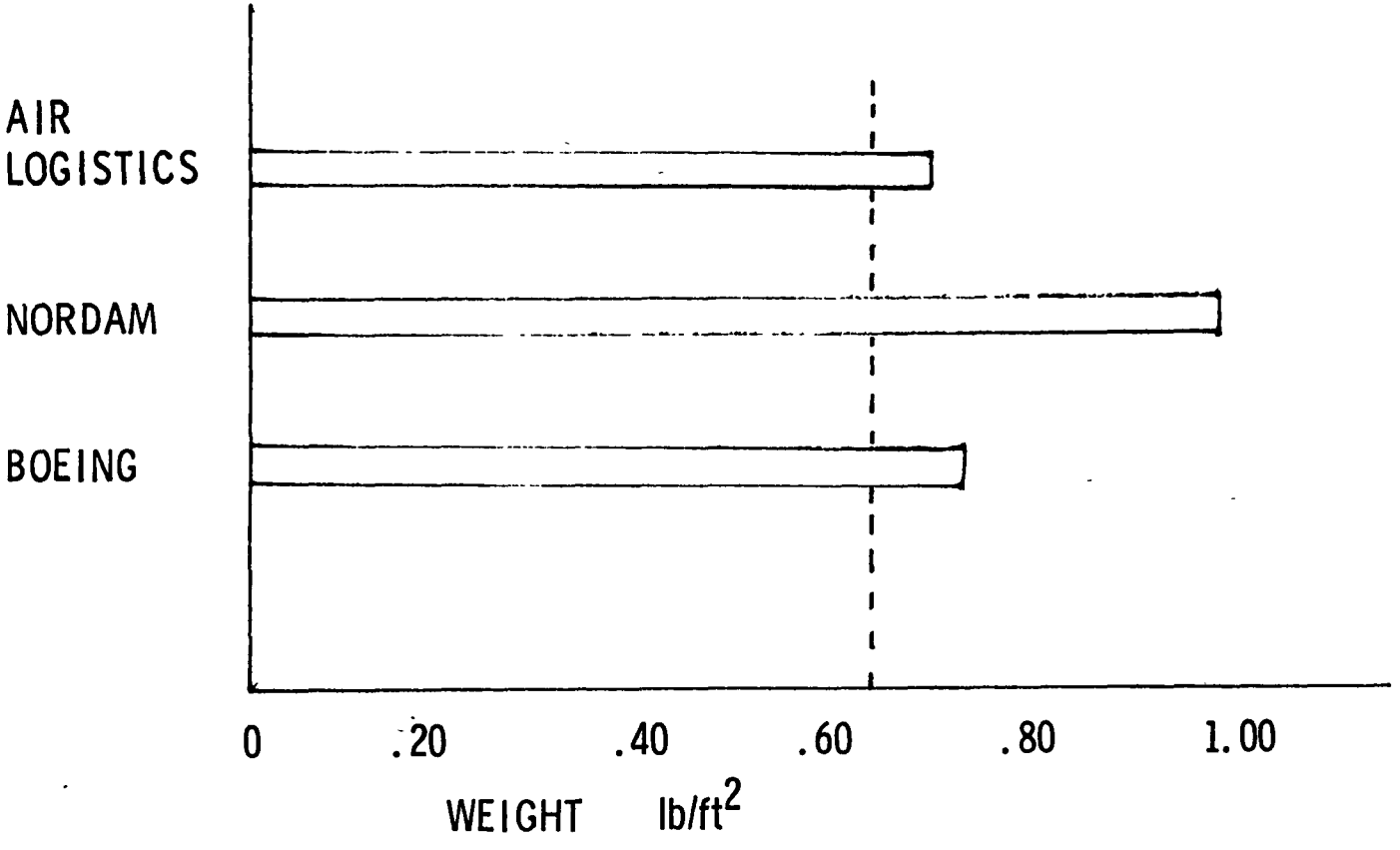
BURN THRU TEST PANEL #68
2000° F OIL BURNER BLOWER AT 3.5 INCHES FROM FACE



RESULTS


128 lb/WHEEL
158 lb/WHEEL
AIR LOGISTICS
NO FAILURE
NORDAM
NO FAILURE
BOEING CONSTRUCTED
NO FAILURE
0
30
60
90
120
150
180
ROLLER CART REVOLUTIONS X 10^{-3}

RESULTS



SUMMARY

○ CONCLUSION

- A LIGHTWEIGHT, FIRE-RETARDANT, LOW SMOKE, HIGH STRENGTH, THERMALLY STABLE AIRCRAFT FLOOR PANEL CAN BE CONSTRUCTED FOR UNDERSEAT AND HIGH TRAFFIC AREAS.

THERMOPLASTICS FOR AIRCRAFT INTERIORS

Bernard Silverman
Lockheed California Company
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DEVELOPMENT OF PROCESSES AND TECHNIQUES FOR MOLDING THERMALLY STABLE, FIRE RETARDANT, LOW SMOKE EMITTING POLYMERIC MATERIALS

Contract NAS 9-15406
NASA - LBJ
Houston, Texas
Technical Monitor -
D. E. Supkis

Contractor
Lockheed-California Company
Burbank, California
Project Leader -
B. Silverman

TYPICAL MOLDING TYPES

A. Compression Molding Materials

B. Injection Molding Materials

C. Thermoforming Sheet Materials

PROGRAM SCHEDULE

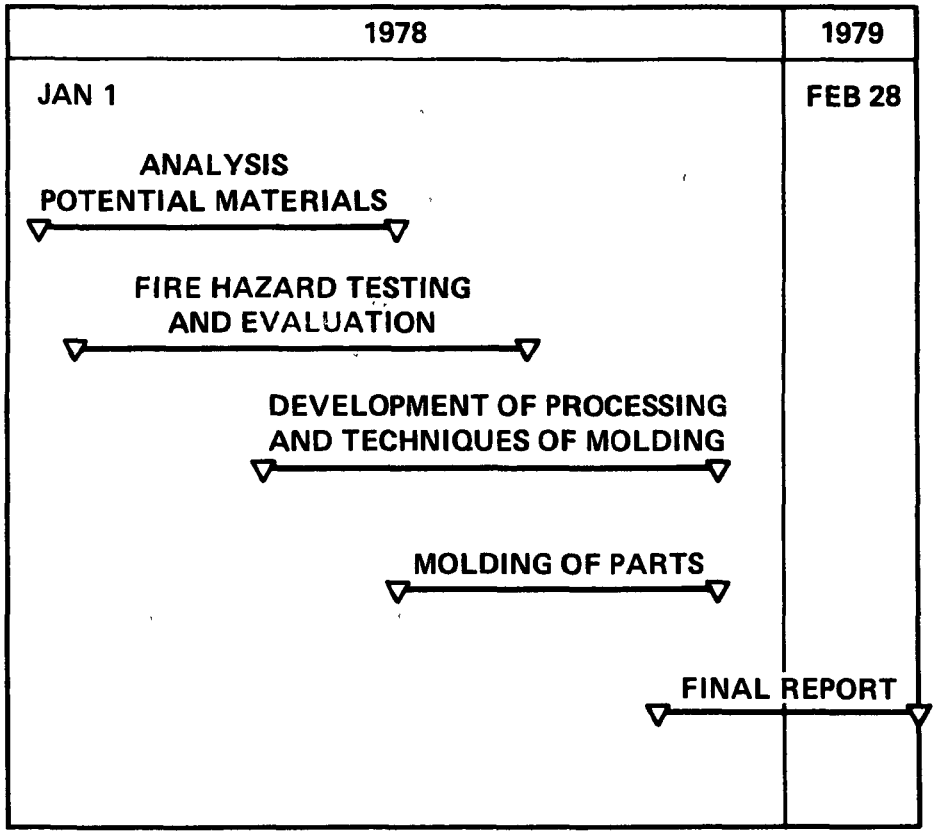

TABLE 4-1. PHYSICAL TECHNICAL PROPERTIES (Typical)

PHYSICAL PROPERTY	TYPE OF MOLDING			TEST METHOD FED. STD.-406, EXCEPT AS NOTED
	THERMOFORMED	INJECTION	COMPRESSION	
Tensile Strength psi min	6000	6000	8000	1011 Speed C
Impact Strength (notched Izod) ft lb/in of notch	3.0 min	3.0 min	3.0 min	1071
Flexural Strength psi-min	8000	8000	10,000	1031
Elongation % min at break	20	5	5	1011 Speed C
Mod of Elasticity, psi-min	300,000	300,000	300,000	1031
Specific Gravity max	1.40	1.30	1.30	5011
Heat of Deflect Temp °F min. @ 264 psi	250°F	250°F	300°F	ASTM D648
Color Fastness Fade-O-Meter	50 hr min	50 hr min	50 hr min	Fed. Std. 191 5060
Stress Cracking Resistance Solvent Test	No visible cracks	No visible cracks	No visible cracks	LAC C-22-1115 D Method 4.1.1.1
Oxygen Index (LOI) min	40	40	40	ASTM D-2863
Smoke Optical Density (DMS) max (6 minutes)	75	75	75	NBS Smoke Chamber AMINEO COT #4-5800
Thermal Stability (TGA) min	400	400	400	Thermogravimetric Analysis
Flammability Screening Test 60 sec vertical Test Method	5 sec extingh. max no drip	5 sec extingh. max no drip	5 sec extingh. max, no drip	FAA 25.853a Appendix F
Bondable Lap Shear psi min	500	500	500	1/2 in. overlap 1200-1400 psi/min.
180° Peel	8 ppi	8 ppi	8 ppi	2 in/min jaw sep.

Tentative Goals

INDIVIDUAL
(TYPICAL)

	PROPERTIES	MATERIAL
GENERAL	CHEMICAL NAME	POLYCARBONATE
	TRADE NAME	LEXAN
	VENDOR	GENERAL ELECTRIC
	FINISHED FORM	INJECTION MOLDING
	RAW MATERIAL COST, $/lb.	2.0
	COLORS AVAILABLE	CLEAR, BLACK, COLORS ON ORDER
	PAINT SYSTEMS	URETHANE + PRIMER
	ADHESIVE BONDING	URETHANE
	AVAILABILITY	FULL PRODUCTION
PRO-CESSING	DRYING REQUIREMENTS	YES, 4 HRS AT 100°C
	CURE CYCLE	INJECTION TEMP., MOLD TEMP.
	POST CURE CYCLE	NONE
	ANNEALING	NONE
PHYSI-CAL	DENSITY, G/cc^3, ($/in.^{3})	1.21
	WATER ABSORPTION, % IN 24 HOURS	0.15
	ROCKWELL HARDNESS	70 M, 1/8 R
MECHANICAL	TENSILE STRENGTH, (psi) MPa	58.6 MPa (8500 psi)
	TENSILE MODULUS, (psi x 10^5)	(3.25)
	TENSILE ELONGATION, %	.50
	FLEXURAL STRENGTH, (psi) MPa	82.7 (12,000)
	FLEXURAL MODULUS, (psi) MPa	2070 (3.0 x 10^5)
	COMPRESSIVE STRENGTH, (psi) MPa	(12,500)
	COMPRESSIVE MODULUS, (psi) MPa	87.2 (3.5 x 10^5)
	IZOD IMPACT, NOTCHED, ft-lb/in.	12.0
THERMAL AND FIRE SAFETY	HEAT DEFLECTION, °F (264 psi) 182°C MPa	(270°F)
	MAXIMUM SERVICE USE, (°F) °C	(230°F)
	OXYGEN INDEX	35
	FLAMMABILITY RESISTANCE	GOOD
	FAR 12 sec-IGNITION (60-sec IGNITION)	PASSES 12, & 60 sec
	FLAME-OUT	5
	GLOW TIME	0
	BURN LENGTH cm	5 DRIPS (NO FLAME)
	SMOKE IGNITION D_S - 6 min (D_M)	105
	TGA	
	TOXIC GAS EMISSIONS	
SERVICEABILITY	SOLVENT RESISTANCE	POOR
	HUMIDITY STABILITY	GOOD
	STRESS CRACK RESISTANCE	GOOD
	CLEANABILITY	FAIR
	COMMON MAINTENANCE	FAIR
	COMMERCIAL CLEANERS WITH AMMONIA	FAIR
	TRICHLOROETHANE	POOR
	ULTRA-VIOLET LIGHT RESISTANCE	GOOD 60 HRS
	ABRASION RESISTANCE	FAIR
MISC.	COST OF PROCESSING/lb MATERIAL	EQUAL TO PRESENT TYPE POLYCARBONATE
REMARKS		

INJECTION MOLDING MATERIALS

PROPERTIES

		POLYCARBONATE	POLYETKERSULFONE	POLYPHENYLSULFONE
GENERAL	CHEMICAL NAME			
	TRADE NAME	Lexan 940	200P	Radel
	VENDOR	General Electric	ICI (USA)	Union Carbide
	FINISHED FORM	Small Rellets	Small Pellets	Small Pllets
	RAW MATERIAL COST	$2 50	$8.00	* $15 00
	COLORS AVAILABLE	Clear & All Colors	Transp. & All Colors	All Colors
	PAINT SYSTEMS	PES-Urethane	Possible-Devel	?
	ADHESIVE BONDING	PES-Urethane	7-Devel	?
	AVAILABILITY	In Production	Limited Production	Limited Production
PROCESSING	DRYING REQUIREMENTS	4 Hrs @ 100°C	4 Hrs. 150°C	3 Hrs 150°C
	CURE CYCLE INJECTION TEMP °C	300°C-R.T.	* 350°C I.T.-170°C M.T.	375°C I T.-165°C M.T.
	POST CURE CYCLE °C	None	None	None
	ANNEALING °C	None	Required For Larger Pants	None
PHYSICAL	DENSITY, g/cc^3,(lb/in^3)	1 21	1 37	1.27
	WATER ABSORPTION,% IN 24 HOURS	0.15	0.43	
	ROCKWELL HARDNESS	70 M	88 M	
MECHANICAL	TENSILE STRENTH MPa (psi)	58.6 (8500)	82 7 (12,000)	71 7 (10,400)
	TENSILE ELONGATION %	50	8	60
	FLEXURAL STRENGTH, MPa (psi)	82.7(12,000)	113(16,000)	85 5 (12,400)
	FLEXURAL MODULUS, MPa (psi)	2070(3 0x10^5)	2415(3 5x10^5)	2280 (3.3x10^5)
	COMPRESSIVE STRENGTH, MPa (psi)	87 2(12,500)	82 7(12,000)	
	IZOD IMPACT, NOTCHEN, ft-lb/in	12	1.6	12.0
THERMAL AND FIRE SAFLTY	HEAT DEFLECTION, °C 1820 KPa (264 psi)	132°C(270°F)	203°C	240°C (400°F)
	MAXIMUM SERVICE USE, °C	110°C(230°F)	175°C	290°C
	OXYGEN INDEX	35	37	39
	FLAMMABILITY RESISTANCE - ASTM F501-77	(030) Passes	Passes (030)	.039) Passes
	FAR 853-60 SEE VERTICAL TEST -			0
	FLAME OUT	5	3	0
	GLOW TIME	0	0	1.5 cm
	BURN LENGTH	8cm	3cm	5
	SMOKE IGNITION D_s-6min (D_m)	(060) 110	20	500°C
	TGA °C		440°C	Minimal
	TOXIC GAS EMISSIONS	Very Low	Fair	
SERVICEABILITY	SOLVENT RESISTANCE	Poor	Poor	Good
	HUMIDITY STABILITY	Good	Good	Excellent
	STRESS CRACK RESISTANCE	Good	Fair	Good
	CLEANABILITY			Good
	Common Maintenance	Fair	Good	Good
	Commercial Cleaners With Annomia	Fair	Fair	Good
	Tricacoraethane	Poor	Fair	Good
	Ultra Violet Light Resistance	Good	Good	?
	ABRASION RESISTANCE	Fair	?	
MISC.	COST OF PROCESSING	Equal To Present Type Polycarbonate		
REMARKS		May Be Substituted Directly In System A Impact Resistance Greatly Improved	*Impact Strength Very Low	*May Be Prohibitive But Offers Other Good Features With Respect to Fire Safety Does Not Drip

	POLYAMIDE-IMIDE	POLYVINYLIDINE FLUORIDE	POLYIMIDE ALLOY (PPS)	POLYARYL
E-200 32 Monsanto Small Pellets $8 00 One Light Color ? ? Developmental	Torlon 4203 Amoco Chemical Small Pellets $4 00 Dark Brown ? Epoxy Limited Production	Kynar Pennwalt Small Pellets Black No No Limited Production	Tribolon XT-1211 Fluorocarbon Small Pellets $12.50 Dark Brown ? Possible ? Possible Limit Small Parts	Sulfone Asteel # 360
None 350°C I T -100°C M T. None None	8 Hrs at 120°C 360°C I.T.-260°C M.T. * 96 Hrs(130°C To 260°C)	None 200°C- R.T None None	2 Hrs 130°C 370°C I.T.-180°C M.T. 12 Hrs 20°C To 260°C	
1 19 0 15	1 40 0 28	180 109	1 45	
(10,000) 66 (2 9x10^5)	(27,000) 12 (30,000) (2 5x10^5)	(6000) 51-200 (2 0x10^5)	(7000) 8 (10,500) (6 1x10^5)	
3 0	(40,000) 2.5	(8600) 5	(12,500) * 1.1 To 2.5	
172°C 160°C 34 (030) Passes 80 Minimal	274°C 250°C 41 (030) Passes 0 0 *1 2 cm* 10 450°C Minimal	82°C(180°F) 70°C 45 Passes 0 0 *2 cm* 350°C High	250°C 225°C Passes 0 0 *1 cm* 3 450°C Minimal	
Fair Good ? Good Good Fair ? ?	Excellent Good Good Depends on Paints " " " "	Good Good Good Depends on Paints " " " "	Excellent Good Good Depends On Paint " " " "	
	*Processing Costs For Stress Relief Would Be Prohibitive	High Material & Processing Costs	High Malerial & Processing Costs	
		*Prohibitive Weight Cost * Is not Bondable	*Low Impact Strength *Higher Density	*Too Costly To Be Considered

PRELIMINARY MATERIAL SELECTION

Compression	Injection	Thermoforming
Phenolic/Glass	Polycarbonate (Lexan 940)	Polycarbonate (Lexan EF-6000)
Modified Phenolic-glass	Polyphenyl Sulfone (Radel)	Modified Kel-F
Polyimide/glass	Aromatic Polymer	?

SESSION B: FIRE TOXICOLOGY

Session Chairman: Henry A. Leon
Ames Research Center

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FIRE TOXICOLOGY FROM THE NATIONAL ACADEMY OF SCIENCES (NAS) POINT OF VIEW

David L. Winter
NASA Headquarters
Washington, D.C.

FIRE TOXICOLOGY FROM THE NATIONAL ACADEMY OF SCIENCES (NAS) POINT OF VIEW

The Subcommittee on Fire Toxicology of the Committee on Toxicology is now an element of the recently established Board on Toxicology and Environmental Health Hazards of the National Academy of Sciences. At the request of NASA, the Subcommittee on Fire Toxicology undertook the tasks of evaluating the state-of-knowledge in fire toxicology and recommending guidelines for establishing standard approaches for testing the toxicity of polymeric materials in fires.

The Subcommittee published its recommendations in the August 1977 NRC report, Fire Toxicology: Methods for Evaluation of Toxicity of Pyrolysis and Combustion Products, Report No. 2. Method guidelines included recommended pyrolysis/combustion conditions, animal exposure conditions, and end points to be measured. The subcommittee concluded that acceptable screening tests to evaluate the relative toxicities of the pyrolysis/combustion products of materials are not currently available, and more research is needed in this area. It did, however, recommend the following guidelines for developing the needed methodology.

"A. Materials should be evaluated under both pyrolysis and flaming conditions. Both gaseous and particulate combustion products should be mixed uniformly in the chamber atmosphere without being unduly subjected to surface condensation. Therefore, it is highly desirable to use one chamber for both pyrolysis and animal exposure.

B. Small rodent species such as rats or mice should be used as the animal model. Enough animals to give statistically valid results must be used at each exposure condition. The time of exposure should be in the range of 15 to 30 minutes, preferably 30 minutes. The temperature in the animal exposure chamber should not exceed 35°C and the oxygen level should be maintained above 16%.

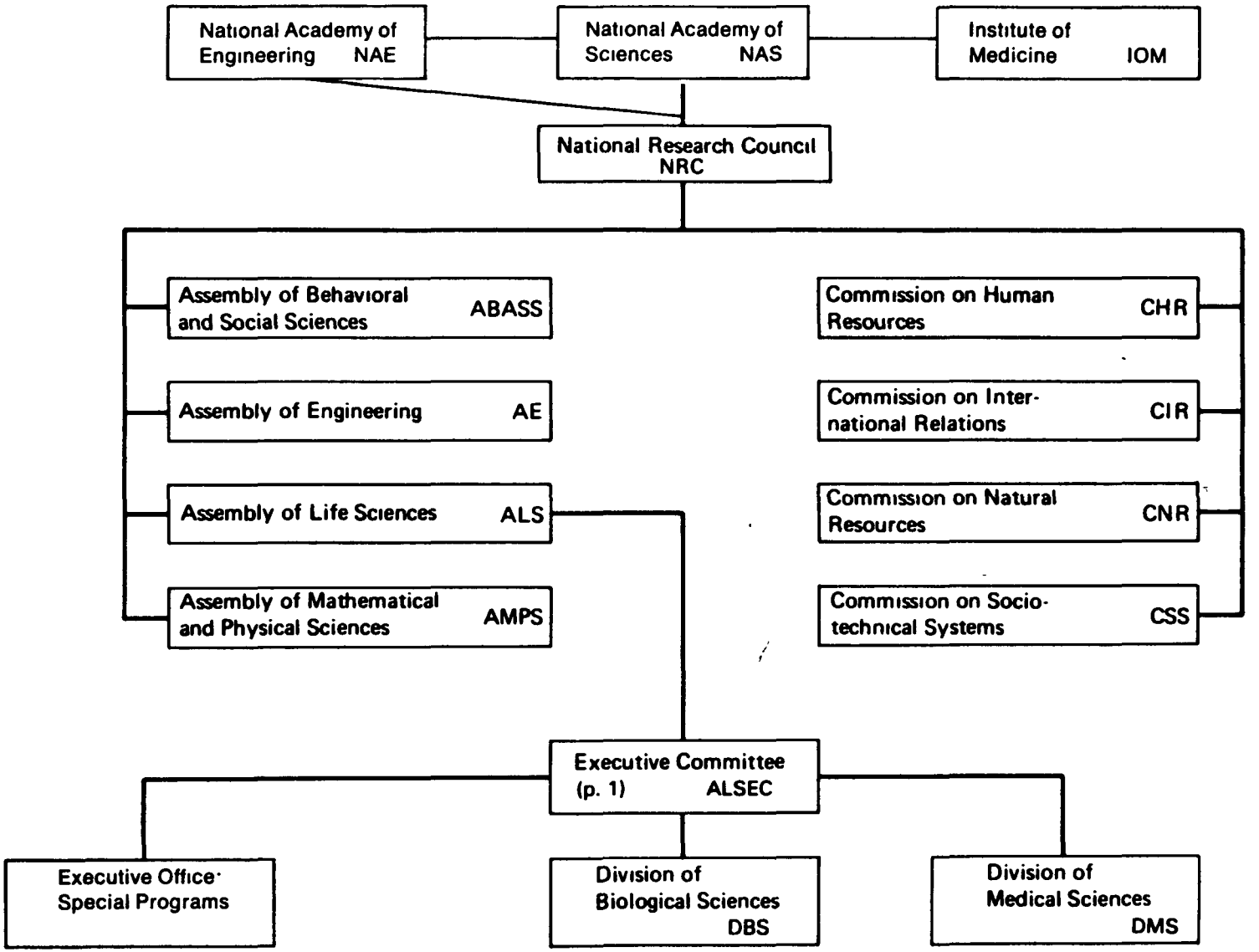
C. Incapacitation is considered to be the most important end point since it should be directly related to escape capability. Laboratory animals should be held for 2 weeks postexposure and observed for behavioral and physical changes as a measure of latent effects.

D. As a minimum set of parameters, temperature, carbon monoxide, carbon dioxide, and humidity should be monitored in the chamber during exposure of animals. Other toxic degradation

products such as hydrogen chloride or hydrogen cyanide, which could be anticipated because of the type of polymer under test, should also be monitored. Further, the smoke density in the animal chamber should be measured as a function of time following initiation of pyrolysis/combustion of the material.

E. Relative toxicity of material should be determined by comparing test materials with reference materials, either those currently in use or candidate materials, rather than attempting to make absolute toxicity evaluations."

1977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Commission on International Relations CIR
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Division of Biological Sciences DBS
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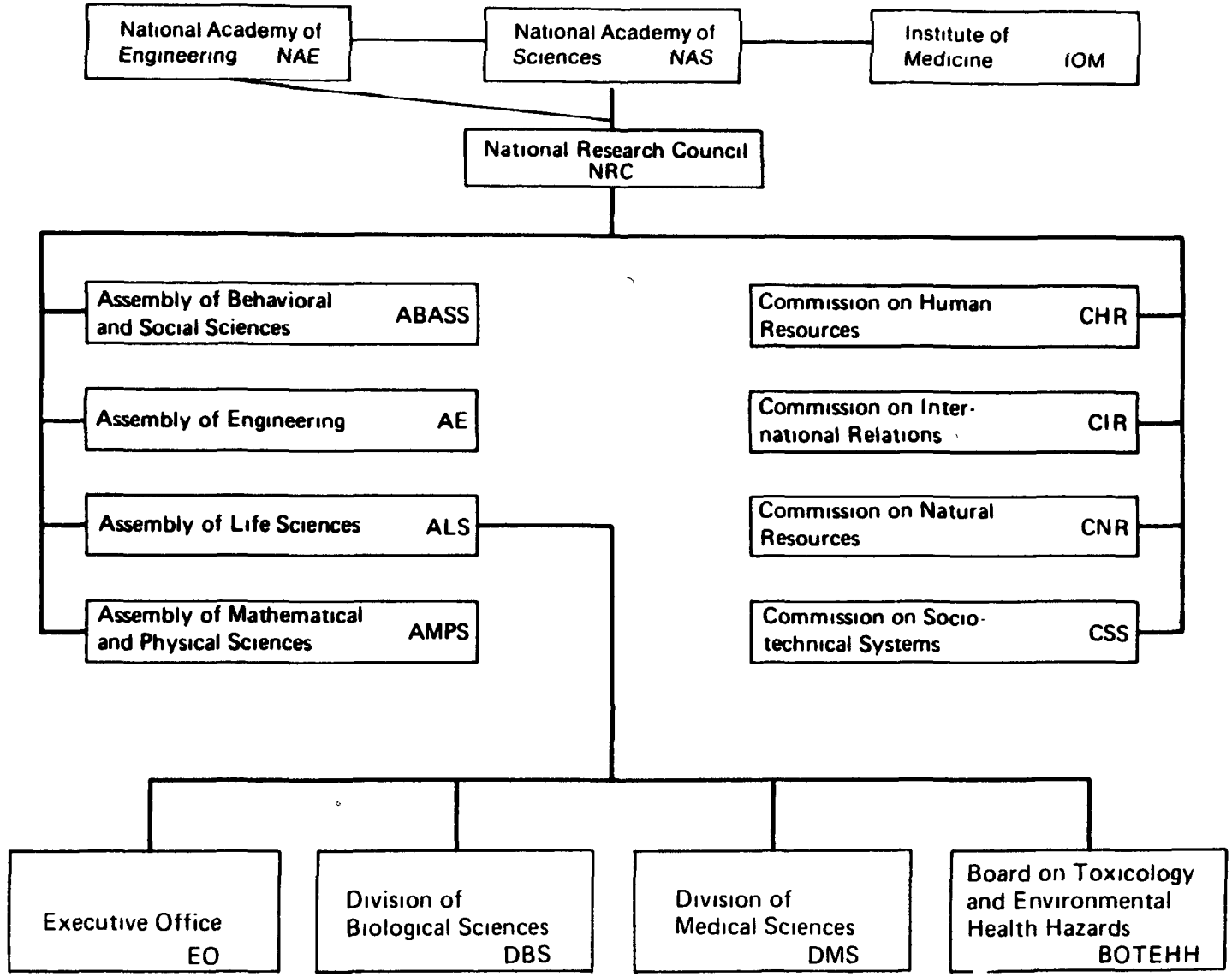
1978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Institute of Medicine IOM
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Assembly of Engineering AE
Assembly of Life Sciences ALS
Assembly of Mathematical and Physical Sciences AMPS
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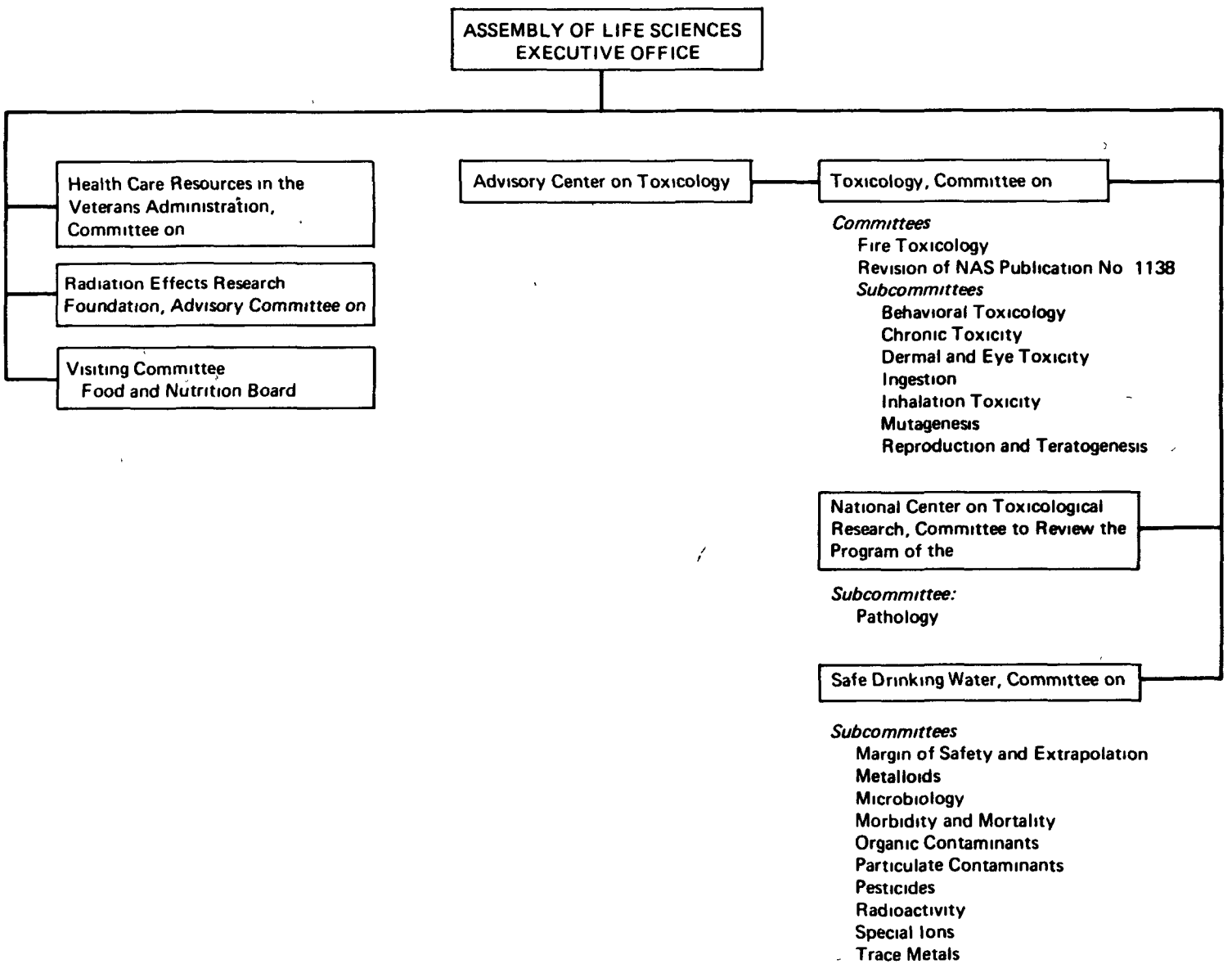
Commission on International Relations CIR
Commission on Natural Resources CNR
Commission on Sociotechnical Systems CSS
Executive Office EO
Division of Biological Sciences DBS
Division of Medical Sciences DMS
Board on Toxicology and Environmental Health Hazards BOTEHH

1977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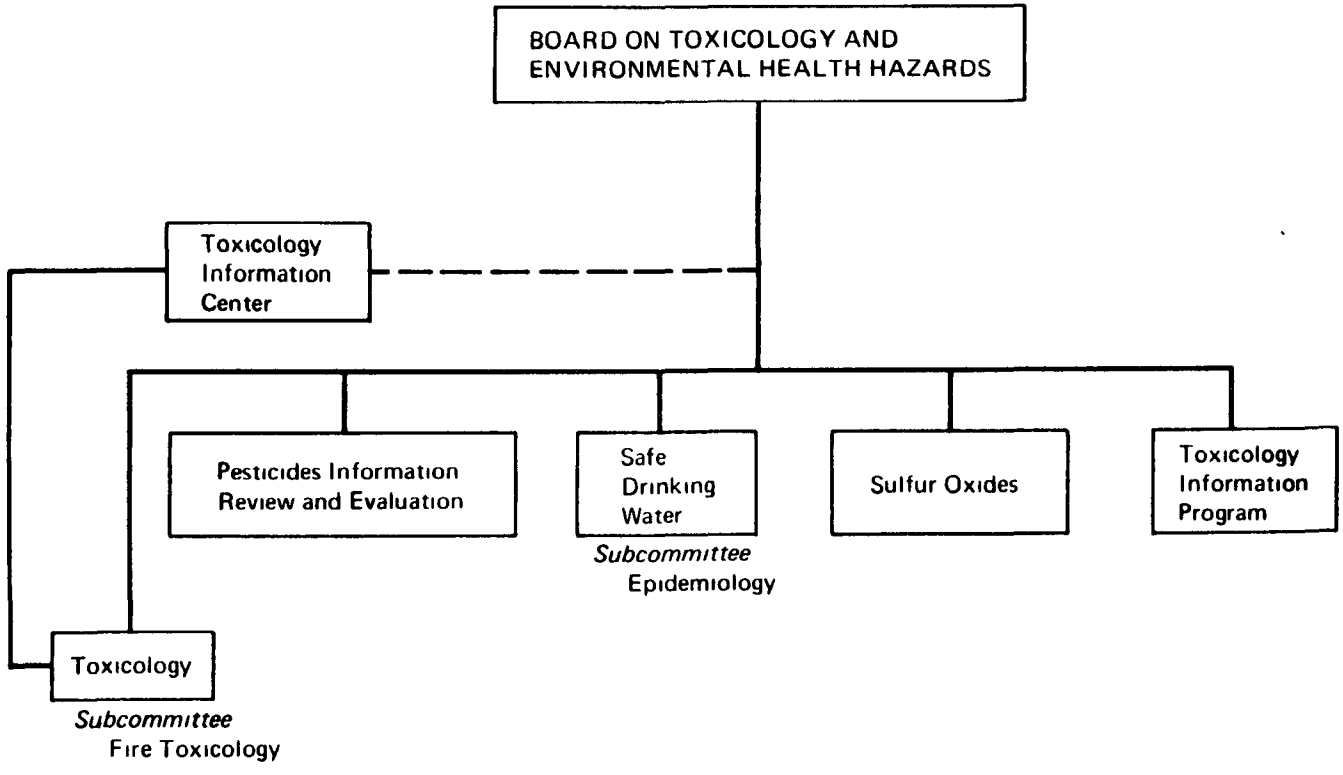
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CHARGE TO THE COMMITTEE ON FIRE TOXICOLOGY

1. REVIEW THE CURRENT STATE OF KNOWLEDGE AND METHODOLOGY FOR TESTING THE TOXICITY OF MATERIALS INVOLVED IN FIRES ON AIRCRAFT, SPACECRAFT, AND OTHER TRANSPORTATION SYSTEMS AND IDENTIFY ONE OR MORE "BEST AVAILABLE" TECHNIQUES.

2. TO CHARACTERIZE IDEAL TEST METHODS AND RECOMMEND RESEARCH TOWARD THEIR DEVELOPMENT.

3. EVALUATE CURRENT DATA ON SELECTED MATERIALS FOR THEIR TOXICOLOGICAL CHARACTERISTICS IN FIRE.

FIRE TOXICOLOGY

METHODS FOR EVALUATION OF TOXICITY OF PYROLYSIS AND COMBUSTION PRODUCTS

RECOMMENDED GUIDELINES ON METHODOLOGY

THE COMMITTEE HAS DEVELOPED GUIDELINES FOR A SCREENING PROCEDURE TO EVALUATE THE TOXICITY OF THE PYROLYSIS/COMBUSTION PRODUCTS OF POLYMERIC MATERIALS. ITS OBJECTIVES ARE TO SUGGEST A STANDARD METHOD FOR PYROLYZING OR BURNING SAMPLES THAT WILL SIMULATE THE NOXIOUS ATMOSPHERES THAT COULD BE ENCOUNTERED IN "REAL" FIRES AND TO SPECIFY STANDARDIZED EXPOSURE CONDITIONS AND END POINTS FOR FIRST-LEVEL SCREENING OF MATERIALS.

RECOMMENDED END POINTS

OBSERVATION

INCAPACITATION

MORTALITY

CARBOXYHEMOGLOBIN DETERMINATION

Attendees

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FIRE TOXICOLOGY PROGRAM: JSC METHODOLOGY

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FIRE TOXICOLOGY PROGRAM: JSC METHODOLOGY

H. SCHNEIDER, D. BAFUS

Toxicological testing of spacecraft materials was initiated at the Johnson Space Center in 1965. Toxicological evaluations of the pyrolysis/combustion products of candidate spacecraft materials were performed using a modified 142 liter Bethlehem Chamber equipped with a Lindberg Model 55031 furnace external to the chamber. In all of the toxicological assessments lethality was chosen as the endpoint. A new pyrolysis/combustion chamber with an internal furnace has been developed for toxicological testing and ranking of both spacecraft and aircraft materials. The pyrolysis/combustion chamber has a relatively small volume (75 liters) and permits the use of both behavioral and physiological measurements as indicators of incapacitation. Methods have been developed which employ high resolution gas chromatography/mass spectrometery to generate chamber atmospheric profiles which indicate the reproducibility of pyrolysate concentrations. The atmospheric volatile profiles in combination with CO, CO_2 and O_2 analysis indicates that a small chamber equipped with an internal furnace will give reproducible results.

The data presented is generated from a chamber designed from guidelines set forth by The National Research Council's Committee on Fire Toxicology.

JSC METHODOLOGY (CONT'D)

- CAGE TYPES WITHIN CHAMBER
  - BEHAVIORAL CAGES INTERFACED WITH COMPUTER
  - PHYSIOLOGICAL CAGES INTERFACED WITH APPROPRIATE INSTRUMENTATION (EKG, RESPIRATION, ETC.)
  - OBSERVATIONAL CAGE (NO MEASUREMENTS RECORDED BY INSTRUMENTS). SUBJECTS USED FOR HISTOPATHOLOGY STUDIES AND FOR LETHALITY
  - ALL CAGES LOCATED EQUAL DISTANCE FROM PYROLYSIS/ COMBUSTION SITE

- SUPPORTING INSTRUMENTATION
  - GAS CHROMATOGRAPHS
    CO, CO_2, O_2, NO_x, SO_x AND ORGANIC VOLATILES
  - GAS CHROMATOGRAPH/MASS SPECTROMETER IDENTIFICATION OF ORGANIC VOLATILES
  - CO-OXIMETER
    CARBOXYHEMOGLOBIN IN BLOOD
  - SCAT - PDP8/E SYSTEM
    MEASUREMENT OF BEHAVIORAL INCAPACITATION
  - INORGANIC GASES (WET CHEMISTRY

JSC METHODOLOGY

- PYROLYSIS/COMBUSTION
  - CHAMBER RELATIVELY SMALL IN SIZE (75 LITERS)
    - ALLOWS SMALL SAMPLE
    - ACCESSIBLE FOR CLEANING
    - ALLOWS RELIABLE OBSERVATIONS
    - LESS GAS STRATIFICATION
  - CHAMBER SIDES CONSTRUCTED OF PLEXIGLASS
    - RELATIVELY INERT TO SAMPLE
    - ALLOWS EXCELLENT VISUAL OBSERVATION
  - FURNACE IS CONDUCTIVE TYPE
    - FURNACE IS LOCATED INSIDE CHAMBER
    - TEMPERATURE RANGE TO 1000° C
    - CAPABLE OF INTRODUCING O_2 OR N_2 AT PYROLYSIS/COMBUSTION SITE
    - EXCELLENT TEMPERATURE STABILITY

Figure 1.

Gas Chromatographic Mass Spectrometric profile of Linear Polyethylene pyrolyzed at 600°C as sampled by a grab sample from the JSC pyrolysis/ combusion chamber.

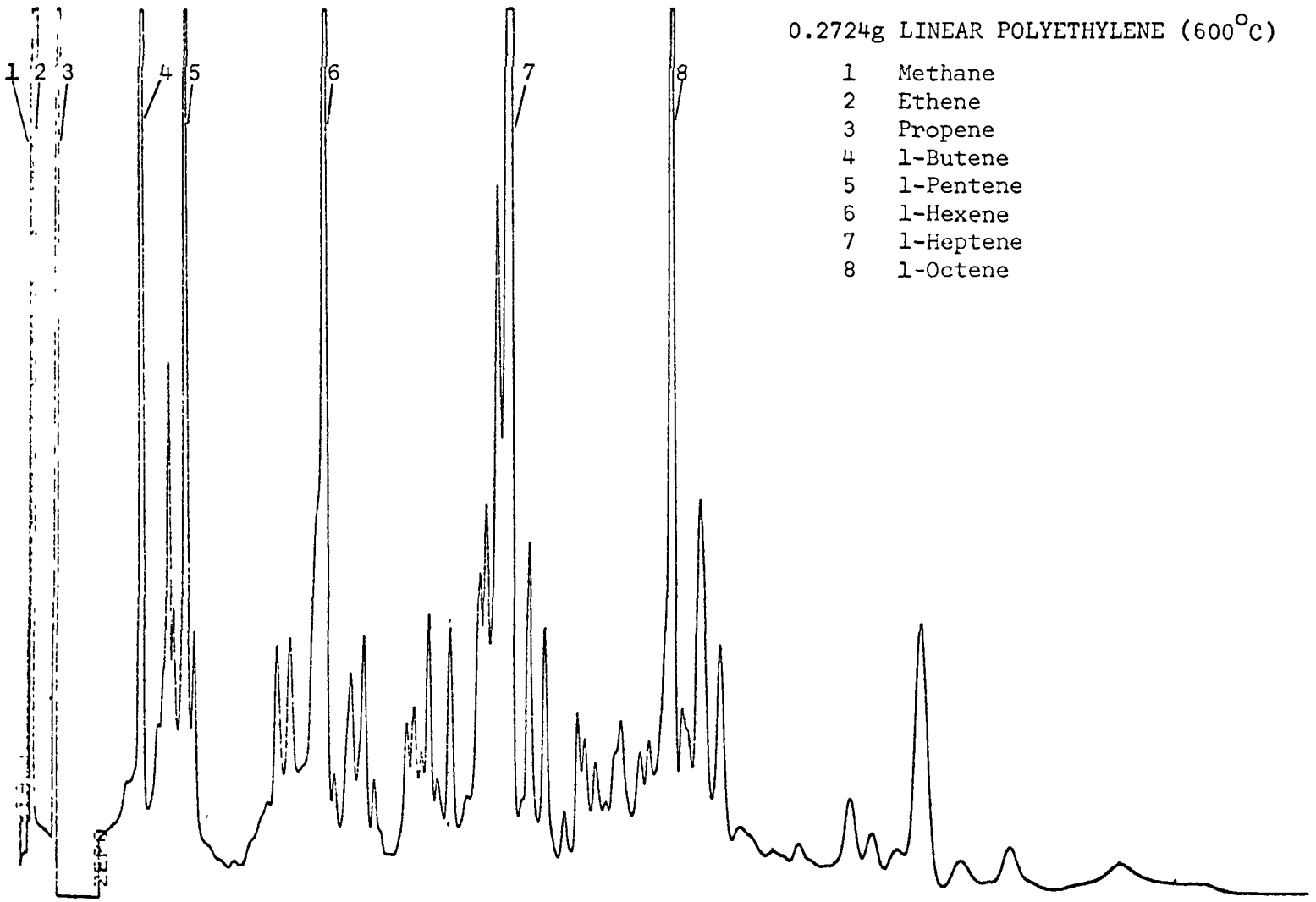
0.2724g LINEAR POLYETHYLENE (600°C)
1 Methane
2 Ethene
3 Propene
4 1-Butene
5 1-Pentene
6 1-Hexene
7 1-Heptene
8 1-Octene
1
2
3
4
5
6
7
8

Fig. 1

Figure 2.

Three different gas chromatographic profiles of linear polyethylene pyrolyzed at 600°C. All samples were collected by the grab method to avoid moving the chamber atmosphere through an online instrument. The profiles are essentially identical for three different burns using the same number of test animals and weight of materials.

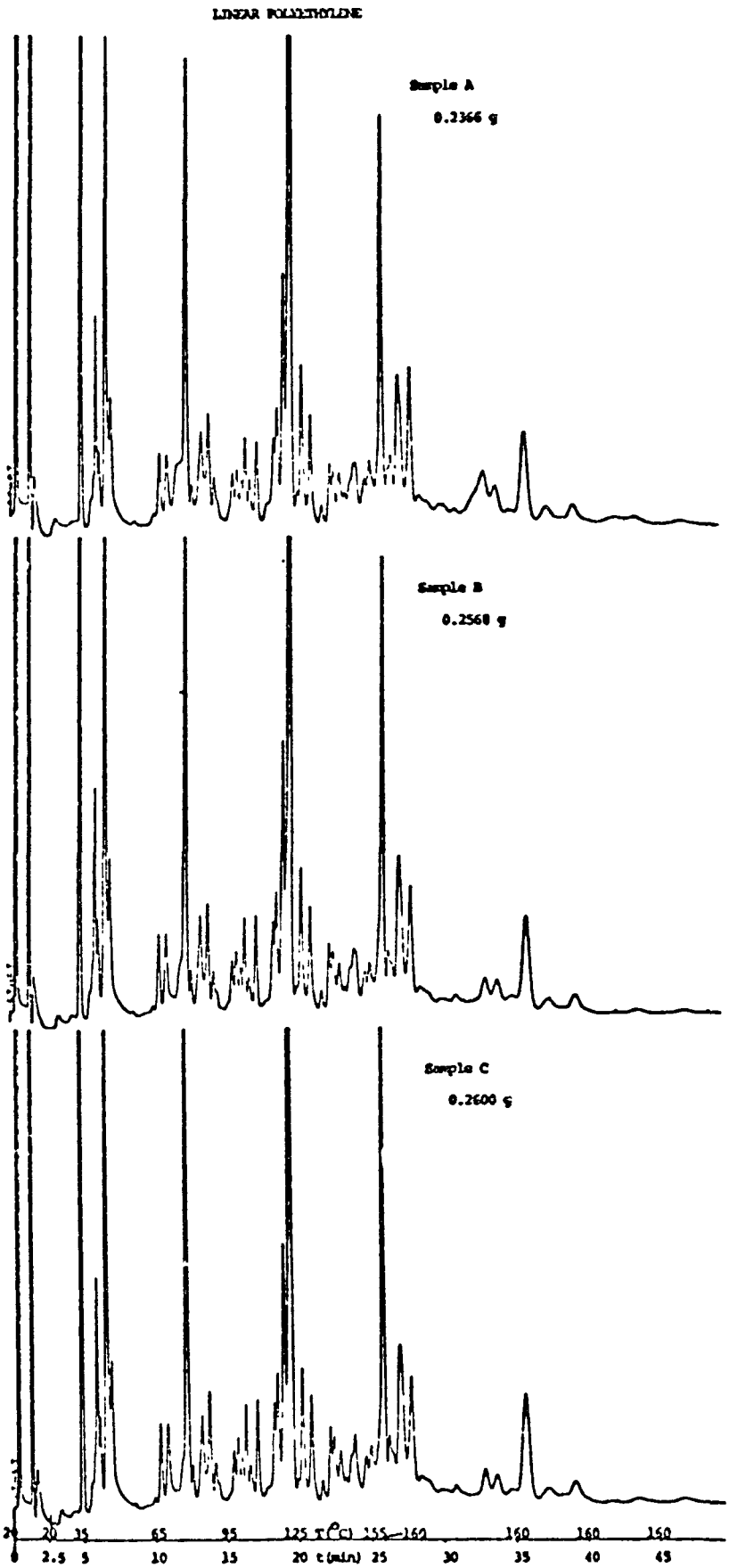
LINEAR POLYETHYLENE
Sample A
0.2366 g
Sample B
0.2568 g
Sample C
0.2600 g
20 20 35 65 95 125 T(°C) 155 160 160 160 160
0 2.5 5 10 15 20 t(min) 25 30 35 40 45

Fig. 2

Figure 3.

Oxygen, carbon monoxide and carbon dioxide data for linear polyethylene pyrolysis at 600^{0} C. The data is representative of multiple runs at each quantity of material.

OXYGEN, CARBON MONOXIDE AND CARBON DIOXIDE DATA

FOR LINEAR POLYETHYLENE PYROLYSIS AT 600°C

	0.2707g Sample			0.7417g Sample		
t(min)	% O_2	ppm CO/g	% CO_2	% O_2	ppm CO/g	% CO_2
0			0.11			0.10
5		801	0.28		926	0.38
10			0.47			0.52
15		838	0.62		921	0.69
20			0.70			0.80
25			0.87			0.96
30	19.59	823	1.04	19.76	934	1.08

Fig. 3

BEHAVIORAL TECHNOLOGY AND ITS APPLICATION TO FIRE TOXICOLOGY RESEARCH

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BEHAVIORAL TECHNOLOGY AND ITS APPLICATION TO FIRE TOXICOLOGY RESEARCH

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ABSTRACT

The application of behavioral technology to the toxicity testing of pyrolysis/combustion (P/C) products is discussed and two categories of behavioral tests commonly employed in fire toxicology programs are reviewed. Data are presented from a comparison of carbon monoxide (CO) induced incapacitation in rats performing in a rotating wheel or under a Sidmon free-operant schedule of shock avoidance. Rats performing in the rotating wheel were behaviorally incapacitated at CO concentrations and carboxyhemoglobin levels significantly lower than those which incapacitated operant avoidance animals. It is concluded that different measures of behavioral incapacitation may vary since incapacitation is a function of the particular toxic mechanism at work and the behavioral requirements of the specific task employed in the test procedure.

The National Research Council's Committee on Fire Toxicology recently suggested that traditional toxicity measures of lethality and organ pathology are necessary, but not sufficient for the toxicological evaluation of the pyrolysis and combustion (P/C) products of commonly employed construction materials.[1] Certainly any material whose P/C products are highly lethal or seriously damaging to bodily organs or tissue would be less desirable than one whose products were less toxic in terms of such effects. However, it is possible that the P/C products of a candidate material may be relatively safe in terms of these traditional measures of toxicity, yet at the same time, be behaviorally disabling, and, therefore, potentially dangerous in the event of fire. The relevance of behavioral measurements in toxicity evaluation procedures is further emphasized by recent statistics which show that impairment of escape capability due to smoke inhalation is a significant factor in a majority of fire-related deaths.[2] The logical conclusion is that the effects of P/C products on escape behavior and, therefore, on survival capability, must be an integral part of any complete fire toxicology evaluation.

In accordance with such reasoning, a number of different measures of behavioral incapacitation has been employed in the toxicity evaluations of P/C products during the past decade. One category of behavioral techniques involves simple visual monitoring of animal subjects during exposure to the P/C products of materials.

One such test is the USF/NASA procedure involving visual observation of free-moving mice with incapacitation defined as loss of equilibrium, prostration, collapse, or convulsions. Another test method in this same category employs performance in a motorized wheel with incapacitation defined as an inability to keep pace with the rotating wheel. Both of these procedures are relatively simple in terms of required test equipment and pre-test training time, with the USF/NASA procedure requiring no training of test subjects prior to P/C product exposure. However, each of the tasks requires visual observations and each employs admittedly subjective reports in determining incapacitation time.

On the other hand, a second category of behavioral techniques utilizes objective measurement of shock escape and avoidance behavior as a measure of incapacitation. Tasks of this type involve the leg-flexion response, performance on a rotorod, or the use of a pull rod or lever for operant manipulation. These latter techniques require more elaborate equipment and varying amounts of animal training prior to test exposure. However, none of these latter techniques depends upon subjective visual reporting and all permit a dichotomy of behavior into escape and avoidance components.

Despite the usage of this variety of behavioral techniques, little research has been conducted which allows a comparison of different behavioral end points. Hilado, Cumming, and Packram[3] report a comparison of end point measurements using two different

species of subjects (mice and rats), two different behavioral techniques (the USF/NASA and leg-flexion methods), and the pyrolysis effluents of two different test materials (polycarbonate and wool). The results indicated a close correlation between end point measurements of the two methodologies in both species and materials tested.The investigators concluded that much of the differences seen in the literature between various combustion toxicological methods may be due to differences in pyrolysis techniques rather than differences in behavioral methodologies.

These findings are in contrast to those of Fitzgerald, Mitchell, & Packam[4] who reported significant differences between rotorod and leg-flexion incapacitation induced by carbon monoxide. While average CO concentration was 1947 ppm, animals performing the rotorod task displayed behavioral incapacitation after shorter exposure times and at lower carboxyhemoglobin levels than animals performing the leg-flexion task.

The contrasting results of these two studies point out the need for further investigation into the relative contribution of different behavioral methodologies to the variability of findings in fire toxicology. Furthermore, comparisons such as these can provide useful information about the susceptibility of different behaviors to toxic incapacitation, supply further knowledge about specific mechanisms of incapacitation, and ultimately provide a guideline by which appropriate behavioral end points may be chosen.

One aspect of the fire toxicology program at the Johnson Space Center has been an assessment of the applicability of two different behavioral methodologies to the toxicological evaluation of P/C products. The following experiment, as part of this assessment process, was designed to compare the course of changes in two behaviors in animals exposed to increasing concentrations of CO. Specifically, the experiment was designed to compare CO-induced incapacitation of simple motor behavior in a rotating wheel with CO-induced changes in a more complex operant avoidance behavior. Behavior in the rotating wheel was selected for this study because of its history of frequent usage in fire toxicology evaluations while Sidman avoidance behavior was chosen because the many measurable parameters of this behavior allow multiple points of comparison and because its suitability for toxicity evaluations has yet to be tested. CO was selected as the incapacitating agent because it is a universal pyrolysis product and its quantity in the blood, in the form of carboxyhemoglobin (COHb), can be measured and correlated with overt behavior.

METHOD

ANIMALS. Sixteen naive, Sprague-Dawley rats ranging in age from 60-120 days old and in weight from 340-460 gms served as subjects. Throughout the course of the experiment, the subjects were housed individually or in groups of 2-3 in 30.5 cm x 35.6 cm lucite cages and given free access to food and water.

APPARATUS. Ten subjects were exposed to CO in an enclosed wire mesh wheel, measuring 27.9 cm in diameter and 8.9 cm in width, which rotated at a rate of 8 rev/min. The remaining 6 subjects were trained and exposed to CO in a 20.33 x 20.33 x 18.36 cm operant chamber equipped with a grid floor through which 70-80 volt AC shock could be delivered.

TRAINING. Prior to CO exposure all subjects were trained until a stable baseline performance was achieved. Operant subjects were trained on a Sidman avoidance schedule with a response-shock interval of 20 sec, a shock-shock interval of 5 sec, and shock duration of 1 sec.

CO EXPOSURE. CO was supplied to either the wheel or operant chamber through a flow regulator from a pressurized cylinder containing 3430 ppm CO mixed with air. On days of exposure, samples were drawn from the chambers at the end of each 5 min of exposure. Exposure duration was 20, 25, 30, 35, or 45 min for operant subjects and lasted until

incapacitation was evident for wheel subjects. At end end of each exposure session, the subject was removed from the apparatus and a venous tail sample of blood was obtained for COHb determination. CO concentrations were derermined by standard gas chromatographic techniques and COHb determinations were performed on an Instrumentation Laboratories Model 182 CO-oximeter precalibrated for rat blood.

RESULTS AND DISCUSSION

Figure 1 illustrates the concentration of CO in the rotating wheel as a function of increasing exposure time. Each point on the curve represents the mean and standard error of 10 samples taken from the wheel at each of the indicated exposure times and at the incapacitation end point. The mean concentration of CO in the wheel was 1407 ± 54 ppm at incapacitation.

Figure 2 shows the level of CO in the blood as % COHb under control conditions, at the point of incapacitation, and as a function of time since incapacitation after exposure on the rotating wheel. The mean level of COHb under home cage control conditions was 2.6 ± .6% compared to 48.6 ± 1.4% at incapacitation. As the slide illustrates, the exponential decay of COHb blood levels depicts a first order rate of CO elimination.

Figure 3 presents the mean CO concentration at the end of each 5 min. of exposure and mean blood COHb level after 20, 25, 30, 35, and 45 min. of exposure in the operant chamber. The decreasing increments which occurred in these two measures as a function of time can best be described by exponential functions. For instance, though mean COHb level rose to 58% during the first 25 minutes of exposure, the mean level increased only from 58% to 66% during the last 20 minutes of exposure.

It is important to note that after 20 minutes of exposure in the operant chamber, both mean CO concentration and blood COHb

levels were higher than the corresponding concentrations and levels present at the point of incapacitation in the wheel. After 20 minutes of exposure, mean COHb level in operant Ss was 50% at a CO concentration of 1761 ppm. At incapacitation in the wheel, mean CO concentration and COHb levels were 1407 ppm and 48.6%, respectively. These comparisons assume significance when the course of CO-induced changes in avoidance and escape behavior is evaluated.

AVOIDANCE BEHAVIOR - Figure 4 illustrates the inverse relationship between mean avoidance response rate and average inter-response time as a function of CO concentration. Average inter-response time was significantly increased as CO concentration reached 2208 ppm and blood COHb levels rose above 60%. This increase in average inter-response time is due almost exclusively to a significant decrease in avoidance response rates since escape response rates were not significantly affected at this concentration. Both the decrements in avoidance behavior and the increments in inter-response times remained statistically significant at all concentrations of CO greater than 2200 ppm.

It is interesting to note the temporary but significant decline in avoidance response rates which occurred during the first 5 minutes of exposure when CO concentration remained below 600 ppm. This initial decrement in avoidance behavior was not due to any incapacitating effect of CO since avoidance responding quickly returned to control levels and remained stable until the CO concentration rose above 2200 ppm.

ESCAPE BEHAVIOR. Figure 5 depicts the changes occurring in escape response and shock rates as a function of CO concentration. The significant increase in shock rate during the first 5 minutes of exposure (resulting from the previously discussed decline in avoidance response rates) was paralleled by a significant increase in escape response rate. Since escape impairment would be reflected by the failure of escape response rates to increase directly with any increase in shock rates, no impairment in escape functioning is evident at CO concentrations below 2000 ppm. However, at CO concentrations between 2100 and 2900 ppm and at COHb levels above 60%, significant increases in shock rate were not paralleled by any significant change in escape responding. At CO concentrations above 2900 ppm, as shock rate continued to increase, a significant decrease occurred in escape response rates. Thus, the impairment of escape functioning which was first evident as CO concentration rose above 2000 ppm was clearly established at 2900 ppm.

The consistence in the results of Experiment 2 is apparent in Table 1 which summarizes the CO-induced changes in operant performance. With the exception of the temporary decrement in avoidance responding during the first 5 minutes of exposure, other measures of performance show that significant behavioral impairment began as CO concentration rose above 2200 ppm and as COHb levels rose to 63%. These results are in contrast to the findings of Experiment 1 which demonstrated that behavioral impairment in the rotating wheel occurred at concentrations of CO below 1500 ppm and at COHb levels below 50%.

The present experiment demonstrates that considerable variability in measurements of time to behavioral incapacitation may occur if different behavioral tasks are employed in toxicological evaluations of pyrolysis and combustion products. Thus, caution is warranted in interpretating the incapacitation measures of any single behavioral task. For instance, to conclude from the wheel performance data that all escape functioning is impaired at CO concentrations of 1500 ppm and COHb levels of 50% would be inconsistent with the operant results which demonstrate that animals are capable of maintaining baseline rates of escape/avoidance behavior in the presence of CO concentrations up to 2000 ppm and at COHb levels up to 60%.

It is clear from the contrasting results of this experiment that behavioral incapacitation in any pyrolysis product evaluation procedure will be a function of two interacting factors: (1) the particular mechanism of incapacitation of the pyrolysis products, and (2) the behavioral requirements of the specific task employed in the test procedure. Marked differences in end point measurements due to these two factors are possible whenever different behavioral screening tasks are employed. For example, impairment in the rotating wheel appears to be due primarily to a loss of motor function. Performance of this task is particularly susceptible to the incapacitating effects of CO because of the continuous muscular activity required by the task. Data from preliminary studies indicate less susceptibility to CO-induced impairment in the rotating wheel when

motor requirements are reduced. In contrast, the pressing of a lever in an operant avoidance task requires considerably less muscular activity and possibly more involvement of higher CNS functions. This contrast in task requirements probably contributes significantly to the differences in the end point measurements of this experiment.

In conclusion, these results indicate that the factors which determine time of useful function are specific to the incapacitating agent and to the behavioral task employed and that these factors may cause considerable variability whenever different end point measurements are used. The selection of a particular behavioral task for the toxicological screening of pyrolysis and combustion products requires a careful consideration of these factors as well as a concern for the degree of relevance which any particular behavioral task may have for human fire escape and survival capabilities.

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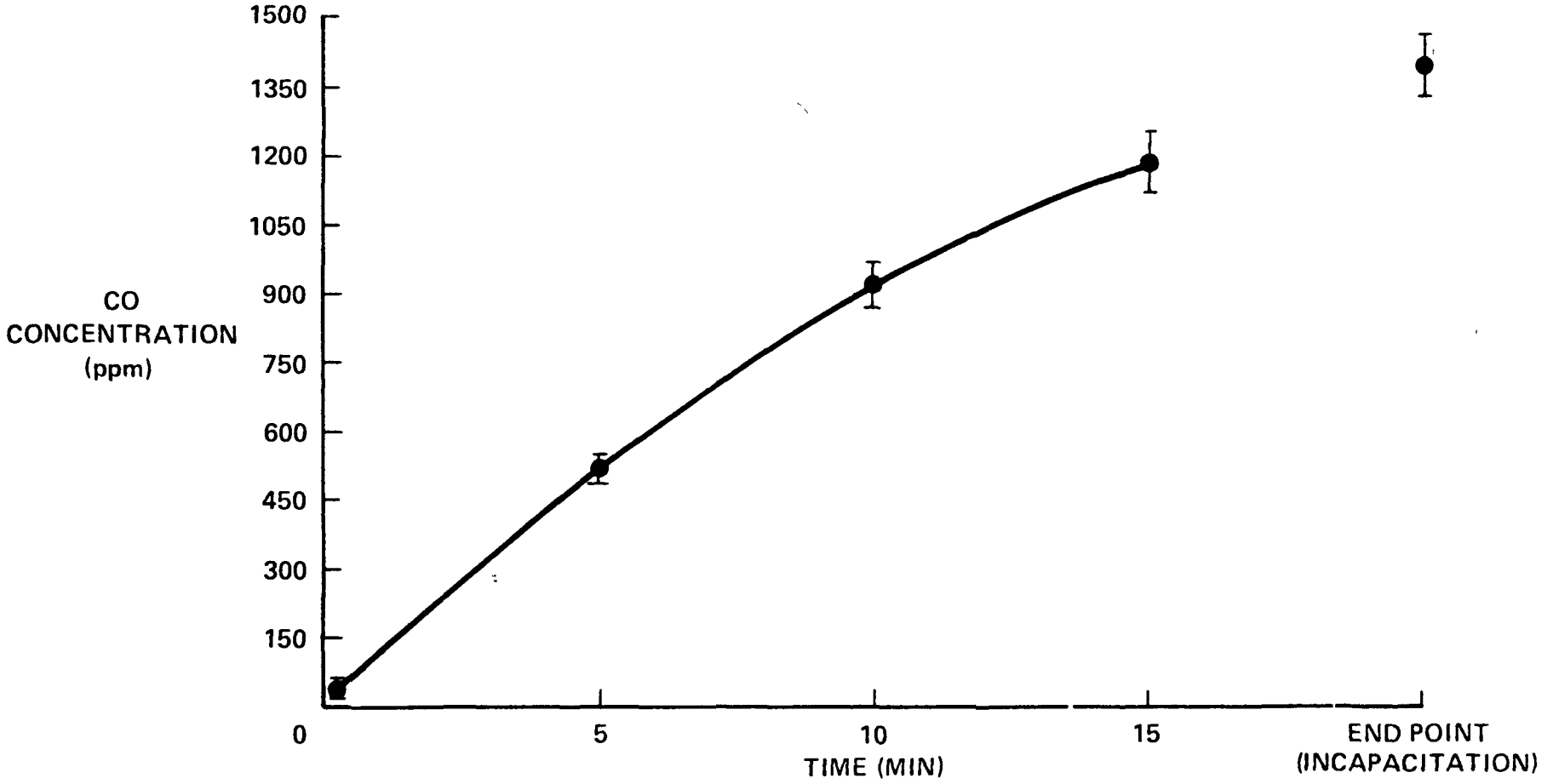

FIGURE 1.- CO CONCENTRATIONS IN THE ROTATING WHEEL AS A FUNCTION OF EXPOSURE TIME. EACH POINT REPRESENTS THE MEAN OF 10 EXPOSURE SESSIONS ± 1 SE.

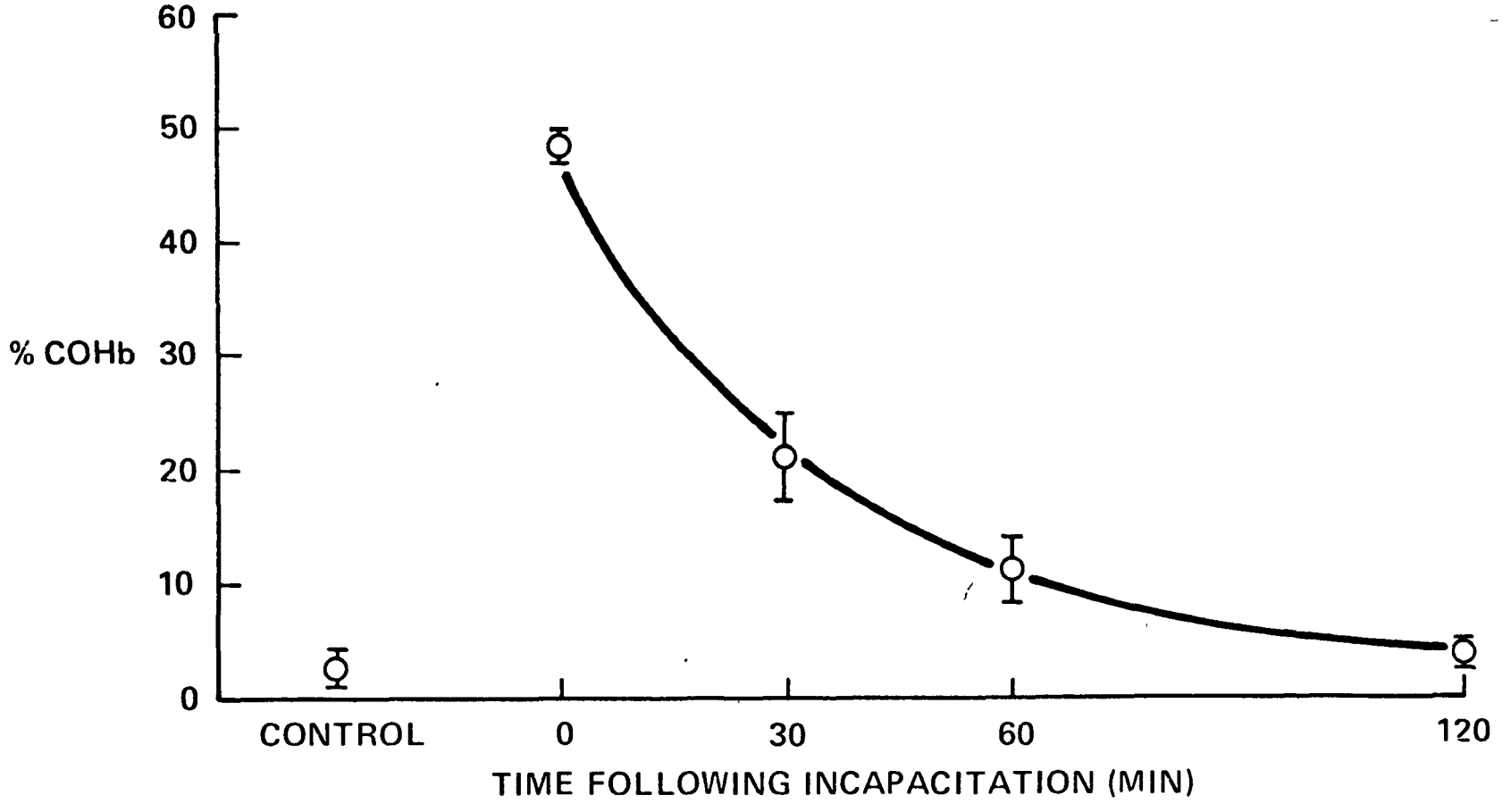

FIGURE 2.- BLOOD COHb CONCENTRATIONS OF CONTROL RATS AND RATS EXPOSED TO CO IN THE ROTATING WHEEL. COHb CONCENTRATIONS OF EXPOSED ANIMALS WERE MEASURED AT INCAPACITATION AND 30, 60, AND 120 MIN FOLLOWING INCAPACITATION. EACH POINT REPRESENTS THE SAMPLE MEAN (N = 7–9) ± SE.

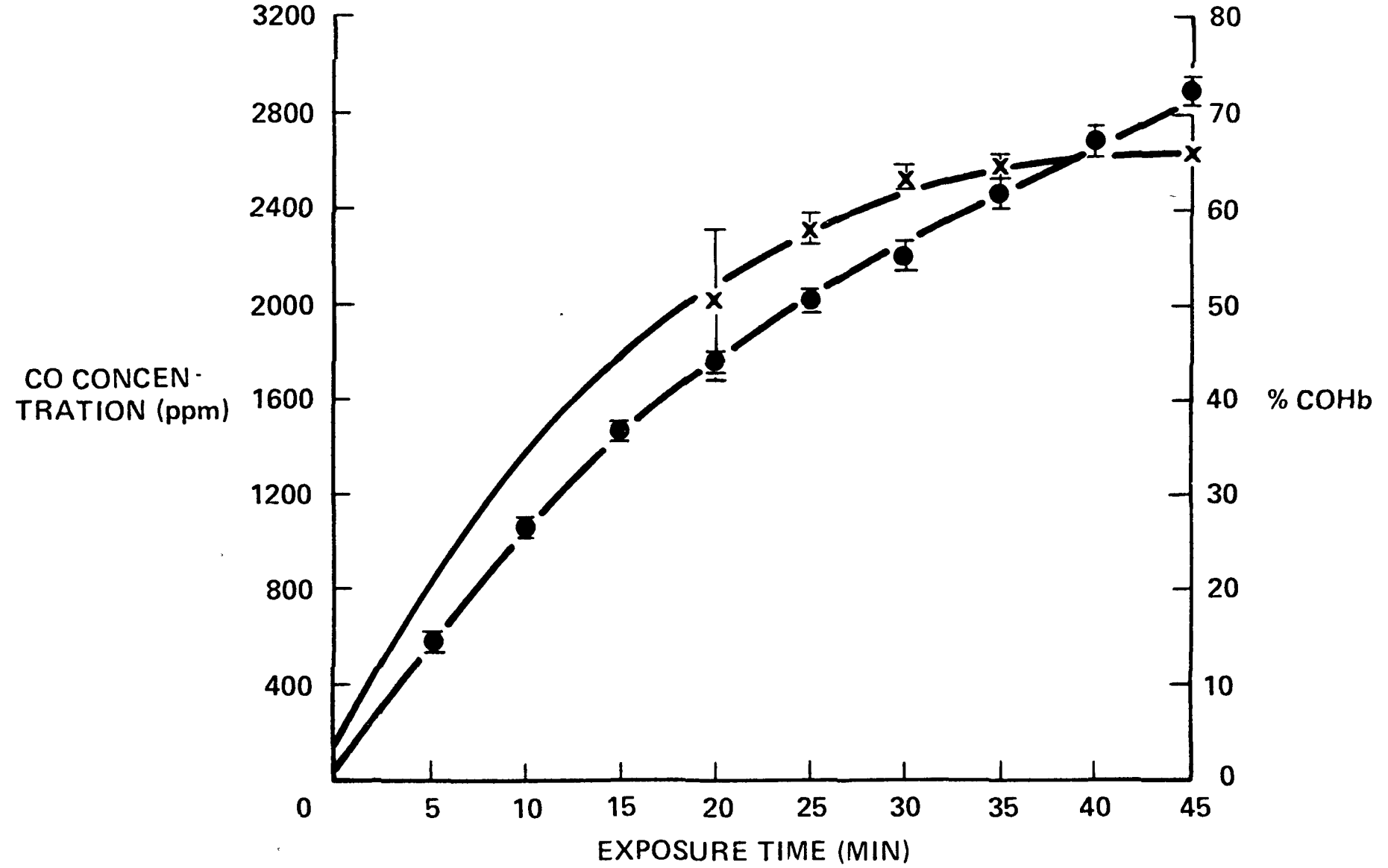

FIGURE 3.- CHAMBER CO CONCENTRATIONS (●) AND ANIMAL BLOOD COHb LEVELS (x) AS A FUNCTION OF EXPOSURE TIME IN THE OPERANT CHAMBER. EACH POINT REPRESENTS THE SAMPLE MEAN (N = 1-17) ±SE.

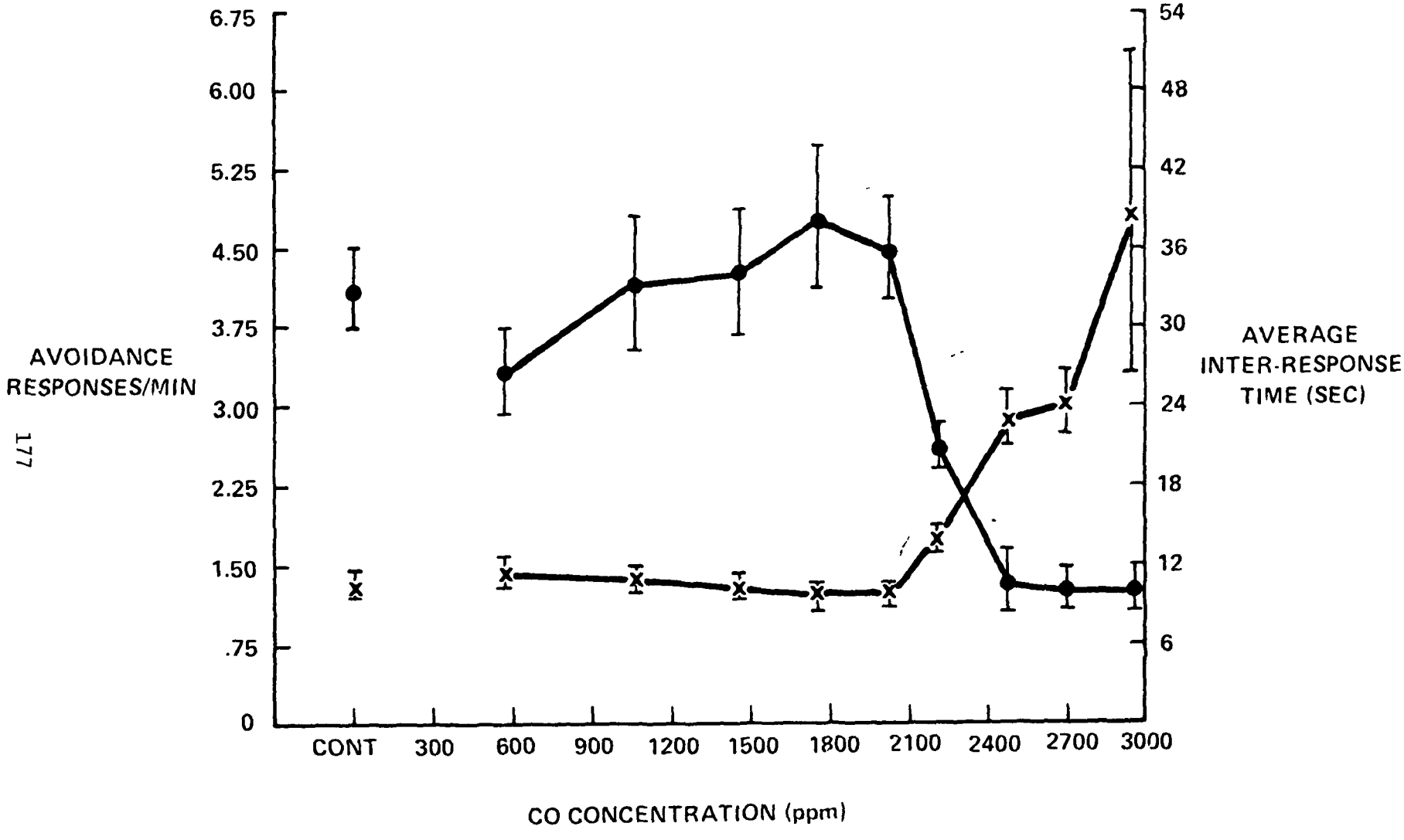

FIGURE 4.- EFFECT OF CO CONCENTRATION ON AVOIDANCE RESPONSE RATE (●) AND AVERAGE INTER-RESPONSE TIME (x). EACH POINT REPRESENTS THE SAMPLE MEAN (N = 5 – 18) ± SE.

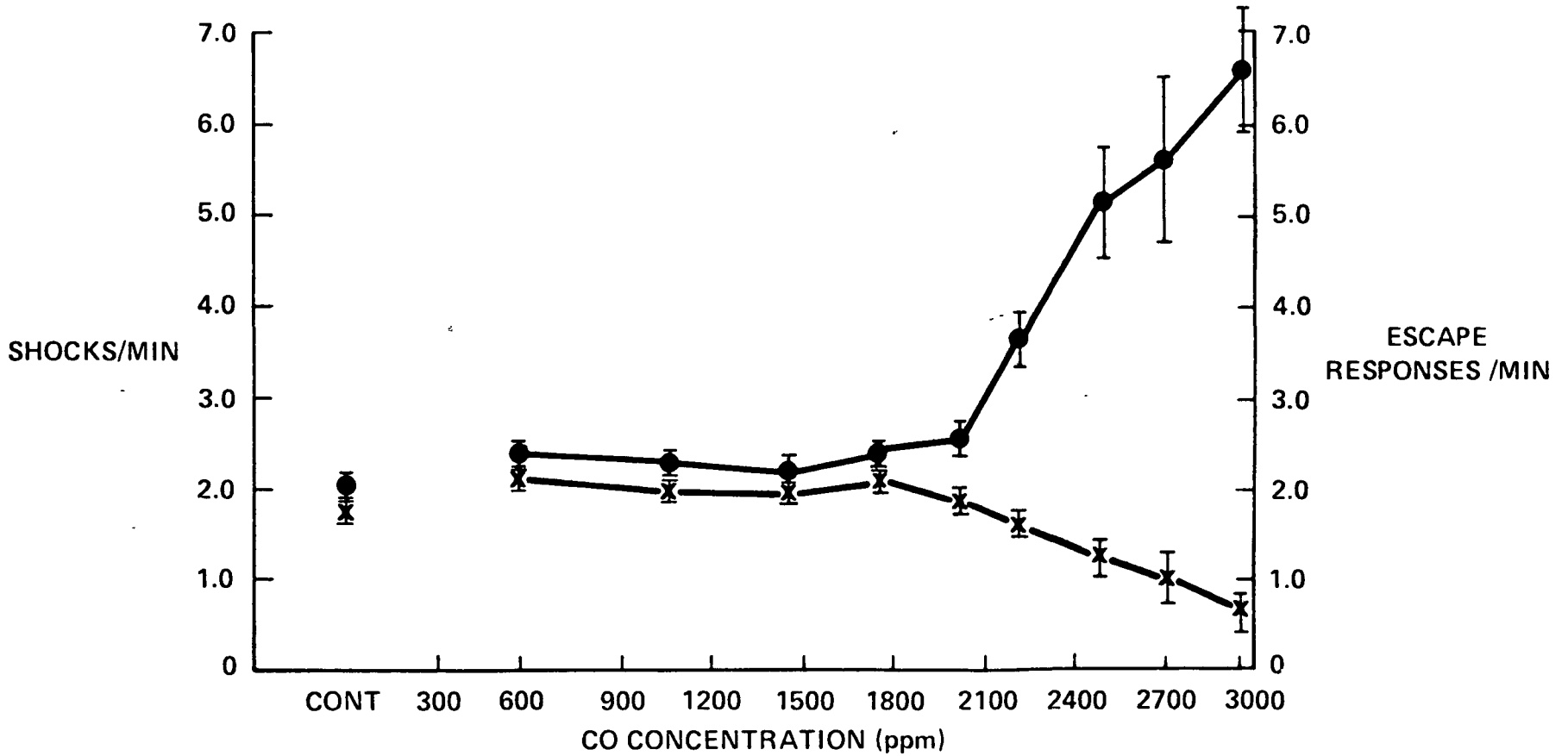

FIGURE 5.- EFFECT OF CO CONCENTRATION ON SHOCK RATE (●) AND ESCAPE RESPONSE RATE (x). EACH POINT REPRESENTS THE SAMPLE MEAN (N = 5 –18) ± SE.

CO CONCENTRATION (ppm): COHb :	571	1063	1460	1761 50%	2014 58%	2208 63%	2478 64%	2706	2938 66%
INTER-RESPONSE TIME	NS	NS	NS	NS	NS	↑	↑	↑	↑
AVOIDANCE RESPONSE RATE	↓	NS	NS	NS	NS	↓	↓	↓	↓
SHOCK RATE	↑	NS	NS	↑	↑	↑	↑	↑	↑
ESCAPE RESPONSE RATE	↑	NS	NS	↑	NS	NS	NS	NS	↓
UNESCAPED SHOCK RATE	NS	NS	NS	NS	NS	↑	↑	↑	↑
SHOCK TIME/SHOCK	NS	NS	NS	NS	NS	↑	↑	↑	↑
PERCENT ESCAPE	NS	NS	NS	NS	NS	↓	↓	↓	↓

TABLE I. CO INDUCED CHANGES IN OPERANT PERFORMANCE. EACH CELL INDICATES THE RESULTS OF A PAIRED T-TEST AS FOLLOWS:

NS: NO SIGNIFICANT CHANGE ($P>.05$)

↑: A SIGNIFICANT INCREASE ($P<.05$)

↓: A SIGNIFICANT DECREASE ($P<.05$)

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SMOKE TOXICITY METHODOLOGY

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INTRODUCTION

New generations of aircraft interior material will have to meet new and more rigid standards for flammability and thermal stability. In addition, the toxicity of their pyrolysis products must be within some reasonable limits. To address this latter point, NASA has asked SRI International to evaluate the toxicity of the pyrolysis products from five candidate aircraft materials. (Candidate material #5 was found to be completely resistant to pyrolysis and was therefore replaced by material #6.) Perhaps the most important part of this study was to demonstrate that we could do controlled pyrolysis of material and produce reproducible biological end points.

MATERIALS AND METHODS

Six materials were supplied by NASA, the Lyndon B. Johnson Space Center. For purposes of discussion, these materials (listed in Table 1) have been arbitrarily assigned numbers 1 to 6 according to the order in which they arrived in the laboratory.

Animals

Young adult male Fisher 344 rats were used for these studies. The animals were acclimated for approximately one week prior to exposure. Those used for the behavioral testing were housed individually in hanging wire cages. Those used for toxicity studies were housed in plastic cages, 5 per cage, on hardwood bedding. All animals were provided with food and water *ad libitum*. All animals were fasted overnight prior to exposure.

Table 1

MATERIALS IDENTIFICATION

Material No.	Description
1	Laminated polyimid foam and fiberglass sheets
2	Rigid polyimid foam sheets
3	Resin beads
4	Polyphenylene sulfide beads
5	Dixie cups filled with a white solid material
6	Polyphenyl sulfone molded pods

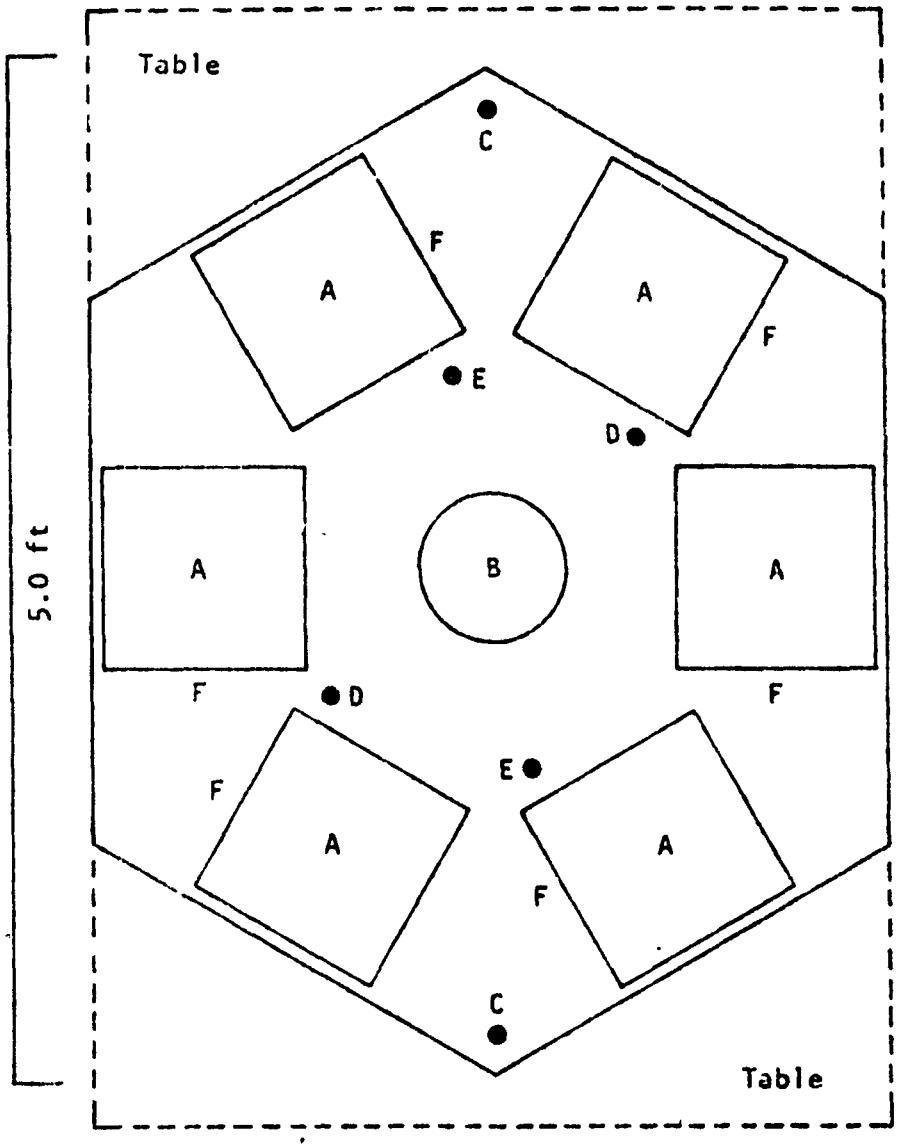
Exposure/Pyrolysis Facility

The animal exposure chamber is constructed on top of a 4 ft x 6 ft table. The chamber is hexagonal in shape and is approximately 24 in. high. It can accommodate six stainless-steel behavioral cages or several wire cages. Figure 1 is a diagram of the chamber arrangement. The cages (A) are arranged around the entry port for the smoke/pyrolysis products (B). On two opposite sides of the chamber are exhaust ports (C) for evacuating the chamber. There are two sampling ports (D) for continuous monitoring of CO, CO_2, and O_2. Two multiple thermocouple arrangements (E) are located on opposite sides of the smoke entry port. These thermocouples indicate whether temperature layering, and consequently pyrolysis product layering, is occurring in the chamber. In addition, individual thermocouples (F) next the each animal exposure chamber measure the temperature to which the animals are being exposed.

Figure 2 shows the arrangement beneath the chamber that permits continuous monitoring of CO, CO_2, and O_2. The atmospheric sample is drawn through a filter to remove particulate matter and through a moisture trap to protect the instruments from damage. The sample passes through the O_2, CO, and CO_2 monitors, through a flow meter and pump, and then is returned to the chamber so that no volume is lost from the chamber.

Figure 3 shows the multiple thermocouple arrangement that is located at each of two positions (E) in Figure 1. The thermocouples are 15 cm apart and the top one is 15 cm from the chamber top.

Figure 4 is a diagram of the pyrolysis apparatus, which is located beneath the chamber. Mounted on top of a laboratory jack so that it can be moved in and out, the apparatus is sealed against the bottom of the smoke entry port (B in Figure 1) when operating. The pyrolysis/combustion chamber is a Pyrex glass cylinder 17 cm in diameter. It sits on an aluminum base that contains a load cell, which measures the weight loss of the sample during pyrolysis. Two air-inlet ports are also located in the base so that the atmosphere in which pyrolysis and/or combustion occurs can be regulated. The atmospheres enter through



A = Behavioral chambers or animal cages
B = Entry port for smoke/pyrolysis products
C = Venting ports
D = Sampling ports
E = Multiple thermocouples to measure temperature layering
F = Individual thermocouples at each cage

FIGURE 1 DIAGRAM LOOKING DOWN ON THE TOP OF THE EXPOSURE CHAMBER

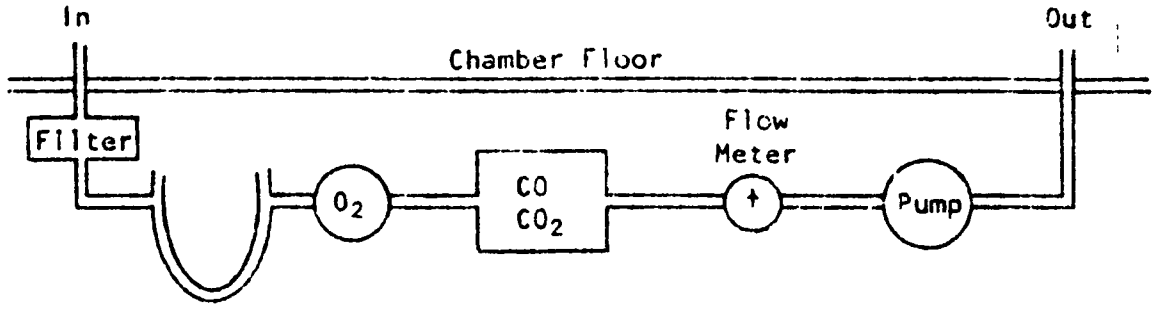


FIGURE 2 ARRANGEMENT FOR CONTINUOUS MONITORING OF O_2, CO, AND CO_2

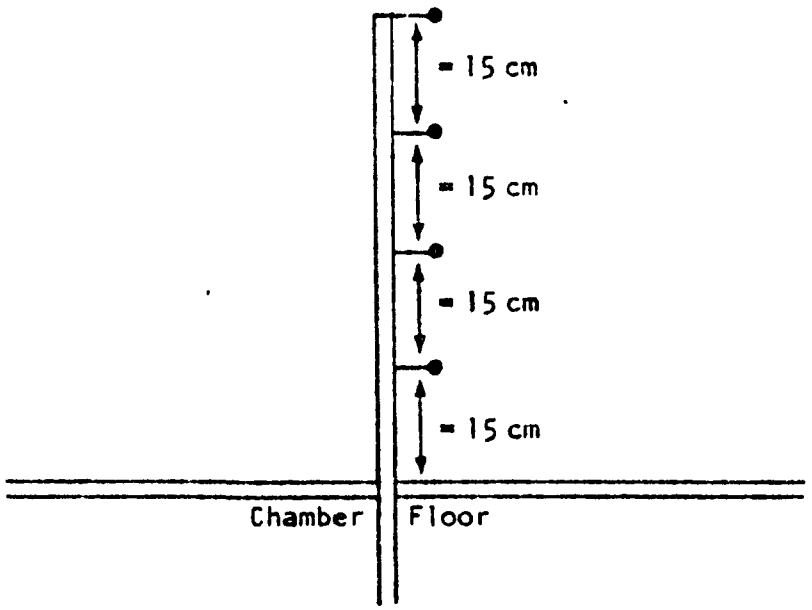


FIGURE 3 MULTIPLE THERMOCOUPLE PROBES

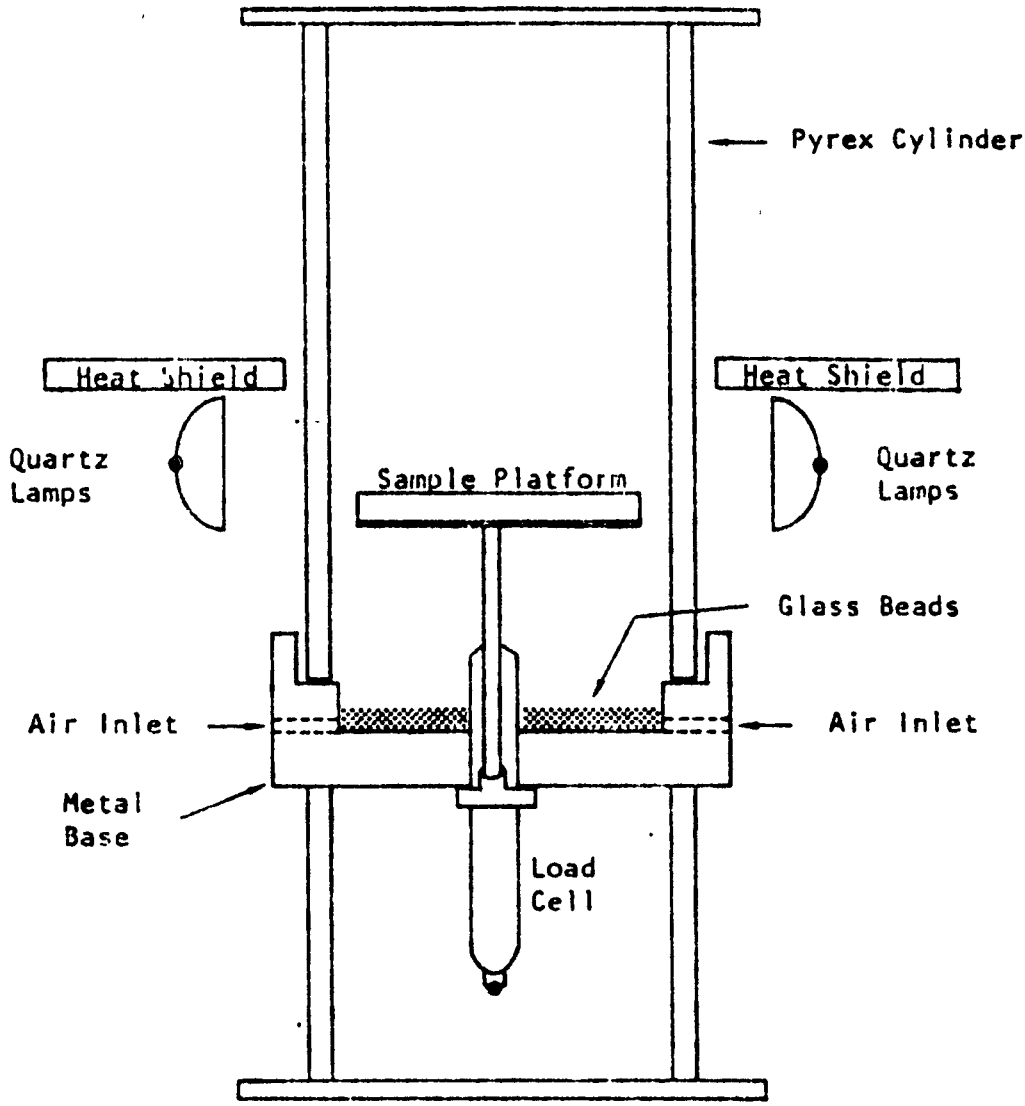


FIGURE 4 DIAGRAM OF PYROLYSIS APPARATUS

the base and pass through glass beads that disperse and mix the atmospheres. The mixture then passes up around the sample area and along the inner surface of the glass and into the chamber. Three banks of quartz lamps are arranged around the pyrolysis/combustion chamber to provide a heat source for pyrolysis. By varying the number of quartz lamps in each bank and their distance from the sample, a wide range of energies of radiant flux is available. The banks of quartz lamps are shielded from the bottom of the chamber by an asbestos heat shield so that they contribute no heat to the animal exposure chamber.

Acute Toxicity Studies

During the acute toxicity exposures, rats are housed two per cage in five open mesh (9.6 mm x 9.6 mm) wire cages, each measuring 22.3 cm x 22.9 cm x 27.9 cm. Additional rats can be placed in the sixth cage for blood-gas analysis upon completion of the exposure. Usually 30 minutes after the time the pyrolysis has begun, the chamber is purged with fresh air. During the exposure, the animals are observed through two viewing ports until the smoke density makes this impracticable.

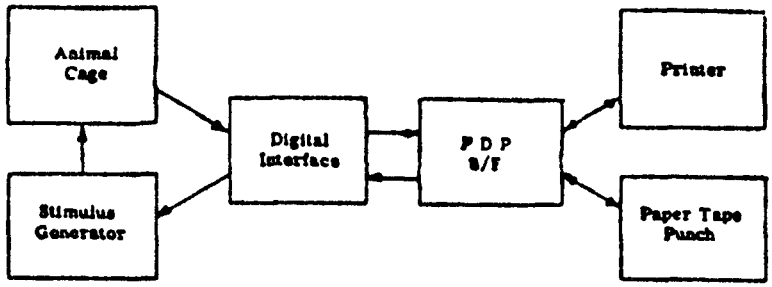
Animals sacrificed for blood-gas analysis are injected with sodium pentobarbital, and blood is taken by syringe from either the inferior vena cava or the descending aorta just inferior to the branching of the renal arteries. Sampling times are 5 to 7 minutes and 30 minutes after termination of the exposure. Carboxyhemoglobin, oxyhemoglobin, and total hemoglobin are determined with an Instrumentation Laboratories Model 182 co-oximeter calibrated for rat blood. Blood gases are determined with an Instrumentation Laboratories Model 713 blood-gas analyzer.

Incapacitation Studies

Apparatus

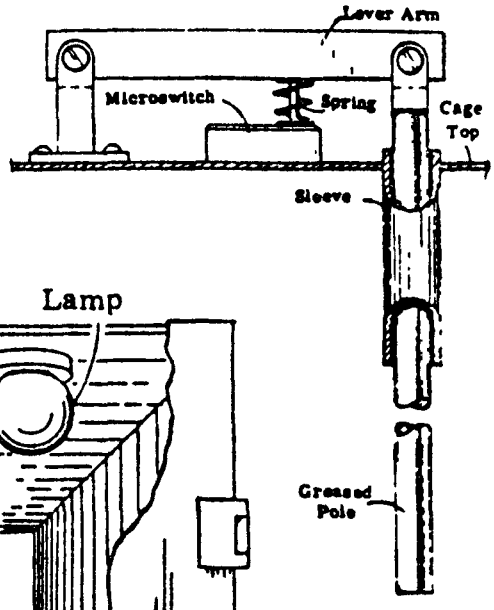
Each test chamber measures 30.2 cm x 30.2 cm x 35.6 cm and is constructed of stainless-steel (see Figure 5). Brass rods (3 mm diameter) spaced 1.27 cm apart serve as the floor. The rods can be electrified

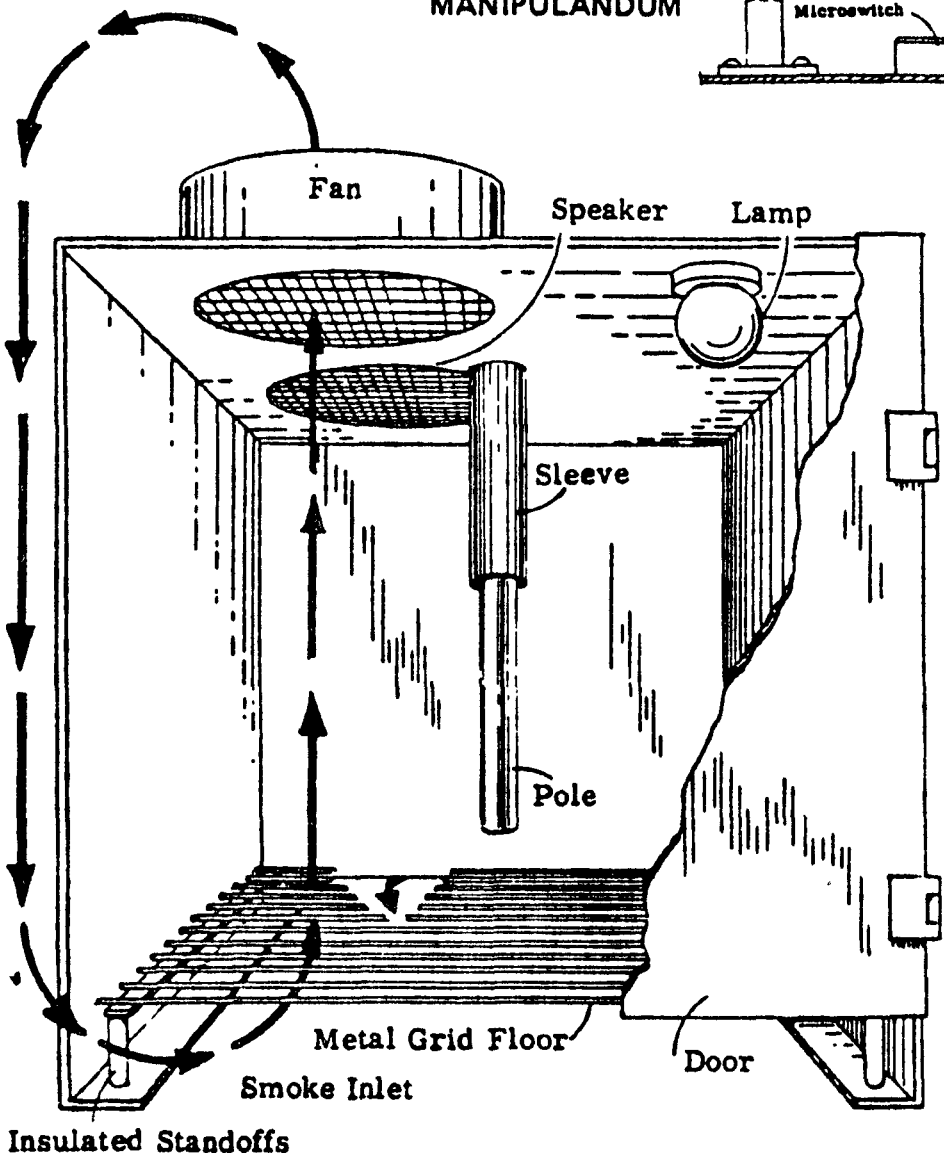
FIGURE 5 CONDITIONED AVOIDANCE RESPONSE APPARATUS



(a) SYSTEM COMPONENTS AND INTERFACES

(b) ANIMAL RESPONSE MANIPULANDUM





(c) C.A.R. CAGE

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with scrambled, constant-current shock. A 19.4-cm aluminum pole (1.27 cm in diameter) is suspended from the center of the ceiling. The pole is lubricated with Vaseline to discourage the rat from remaining on it. Downward displacement of the pole closes a microswitch that signals a response. A 7-watt light, a whisper fan, and an 8-Ω, 10.2-cm loudspeaker are also mounted in the ceiling. The light provides ambient illumination. The fan provides air and smoke circulation by drawing from the open floor, through the chamber, and out the top. Six such chambers are positioned around the table above the smoke generation system. A single hood encloses all the chambers. The test chambers are interfaced with a DEC PDP 8/F computer that provides automatic stimulus presentation and data collection. Data are recorded on a teletype and punched paper tape for offline processing.

CAR Training

Fischer 344 rats are trained to perform the conditioned avoidance response (CAR) in an apparatus similar to the one described above but located in another section of the building. They are first given 30 trials to learn to escape a 1-mA footshock by climbing a 20-cm pole. On each trial, the footshock remains on for 30 seconds unless the rat responds sooner, in which case the trial is terminated. The trials are presented randomly, but once every 1.5 minutes on the average. The rats are then given three daily 60-trial sessions to learn to avoid the footshock by climbing a 13-cm pole in the presence of each of three conditioned stimuli (CS) that precede the 1-mA footshock by 10 seconds. If the rat responds during this interval, the trial is terminated and an avoidance response is recorded. If no response occurs, the 1-mA footshock is initiated and, along with the CS, remains on for 20 seconds. A response during this interval also terminates the trial but is scored as an escape. The three CS consist of an increase in the intensity of the light or a 4-kHz tone or the presence of a 120-μA current on the floor. Each CS is pulsed at the rate of 2.5/second. The three CS are presented randomly 20 times each during each session. The time between

trials is also random, but averages 2 minutes. At the end of this training phase, most rats perform the CAR on 80% or more of the trials. Rats that fail to learn the escape response or the CAR are not used in tests for acute toxicity.

CAR Testing

Six animals are exposed and tested at a time. They are given several warm-up trials to ensure that the response is intact and that the equipment is functioning properly. Then the hood is secured, and an additional few trials are given. The "burn" is initiated and continued until a predetermined chamber concentration of CO or weight loss is reached, or for a predetermined time. At the end of the burn, a static condition is instituted and maintained for the remainder of a 30-minute, or longer, exposure time. The chamber is then vented, and recovery is monitored for an additional 30 minutes while fresh air is drawn through the animal chamber. During the exposure and recovery periods, trials are presented at the rate of about one per minute. The order of presentation of the three CS is random.

RESULTS

Chamber Operation

Figures 6 through 10 are representative of the data collected during a typical exposure. Figure 6 illustrates the weight loss and optical density resulting from a 4- to 5-minute pyrolysis of material #1. Once the pyrolysis is stopped, the smoke density decreases and the weight loss, of course, comes to a stop. Figures 7 and 8 show the vertical temperature profiles on each side of the chamber, from top to bottom. The thermistors on each side are spaced at 15-cm intervals, with the bottom thermistor being 15 cm from the floor of the chamber. The temperature profile reaches its highest point just at the end of the pyrolysis and then stabilizes at a lower temperature immediately. The vertical temperatures are very close to one another at each measurement period, indicating a lack of "layering" in the chamber. In other words, there is an apparent good mixing of the pyrolysis products in the chambers. Figure 9 shows the temperature at each animal cage location on the floor of the chamber. The purpose of these measurements is to ensure that the test animals are not being heat-stressed. Figure 10 shows the O_2, CO_2, and CO profiles during the 30-minute exposure to the pyrolysis products of material #1. As might be expected, there is an initial rapid loss of O_2 during the pyrolysis period (first 5 minutes) and then a much slower decrease in O_2 for the remainder of the 30-minute exposure period. The CO concentration climbed rapidly during the pyrolysis period and then stabilized and remained constant during the remainder of the exposure. The CO_2 concentration similarly increased rapidly during pyrolysis. However, it continued to increase, but at a much slower rate after the pyrolysis had stopped.

Acute Toxicity Studies

The acute toxicity of the candidate aircraft materials is shown in Table 2. The LC50 is given in terms of both weight loss of the sample

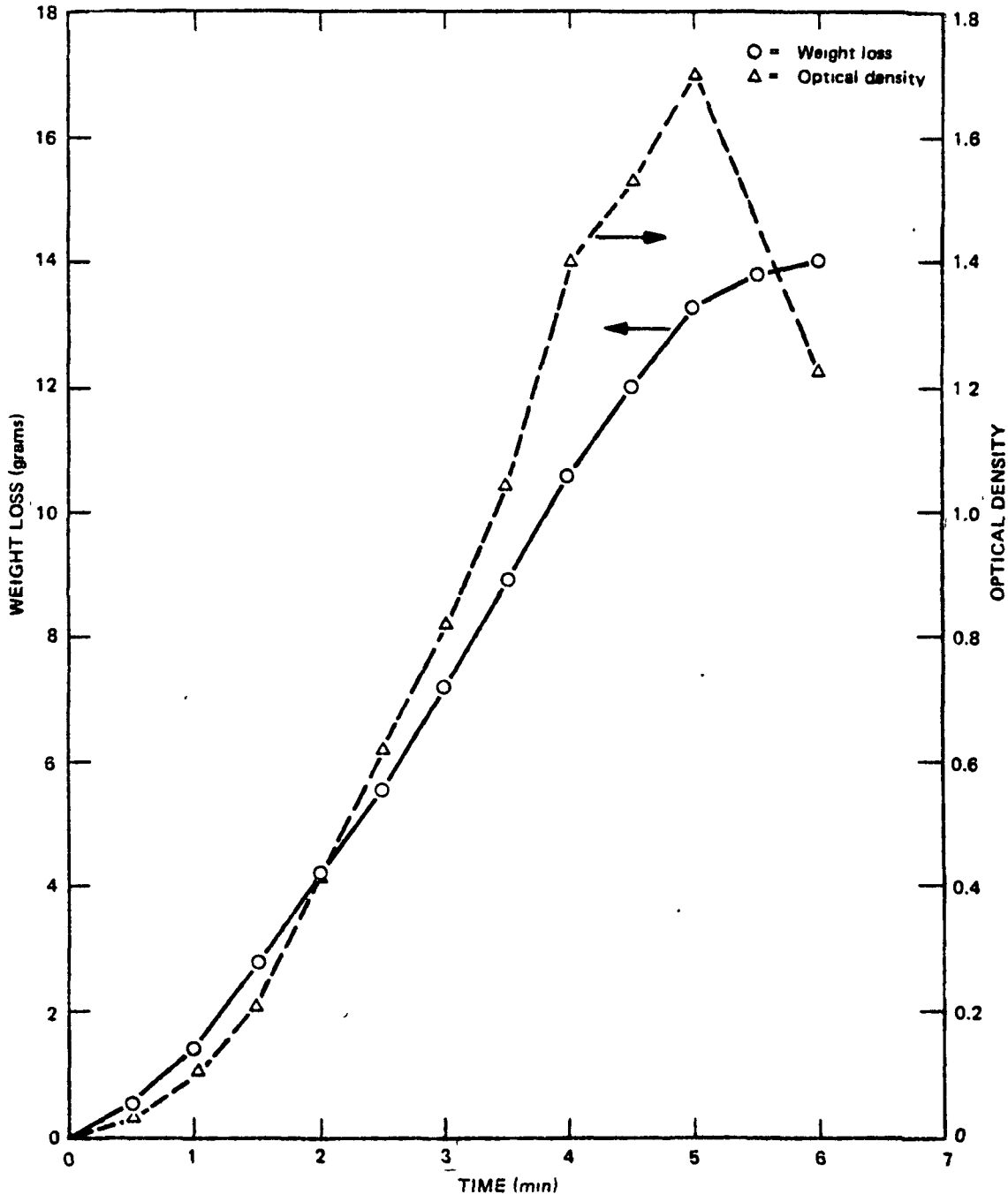

FIGURE 6 WEIGHT LOSS OF SAMPLE (MATERIAL #1) AND SMOKE DENSITY IN THE CHAMBER AS A FUNCTION OF BURN TIME

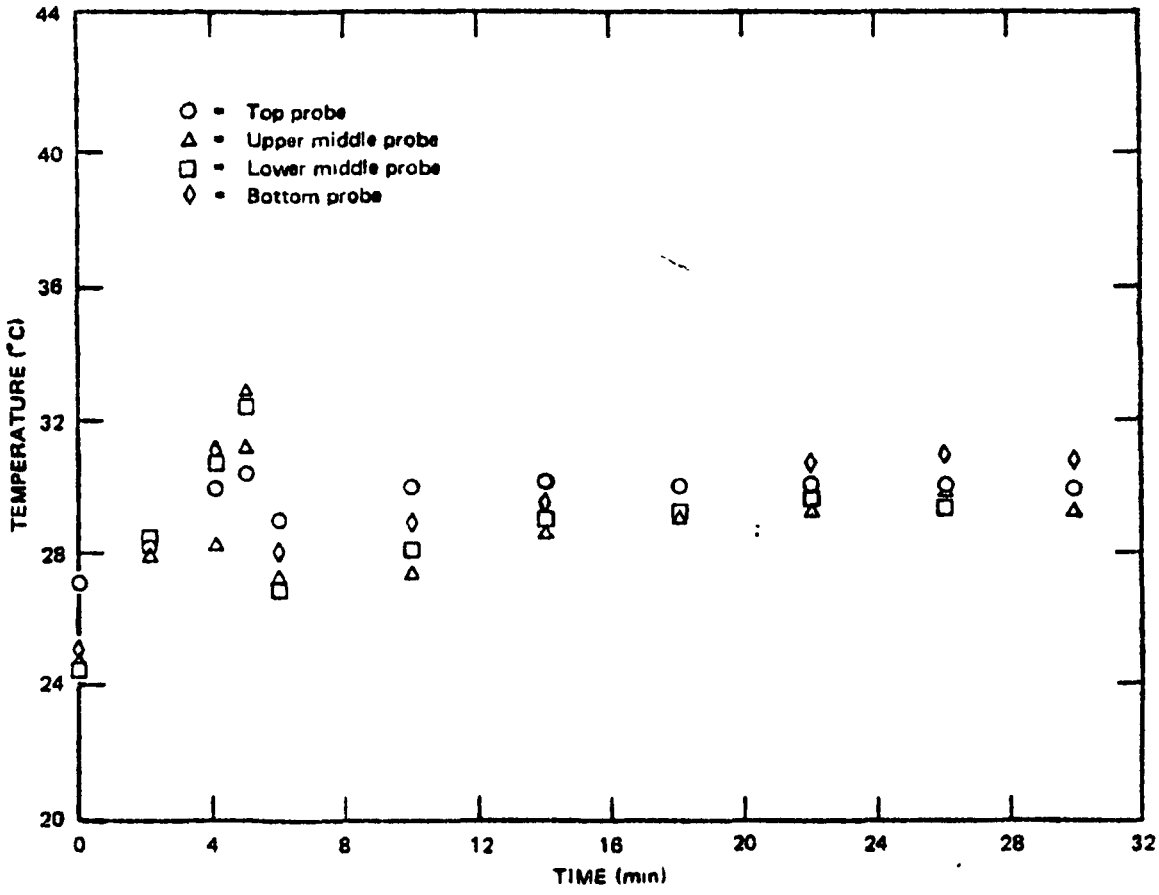

FIGURE 7 VERTICAL TEMPERATURE PROFILES NEAR ONE SIDE OF THE CHAMBER (MATERIAL #1)

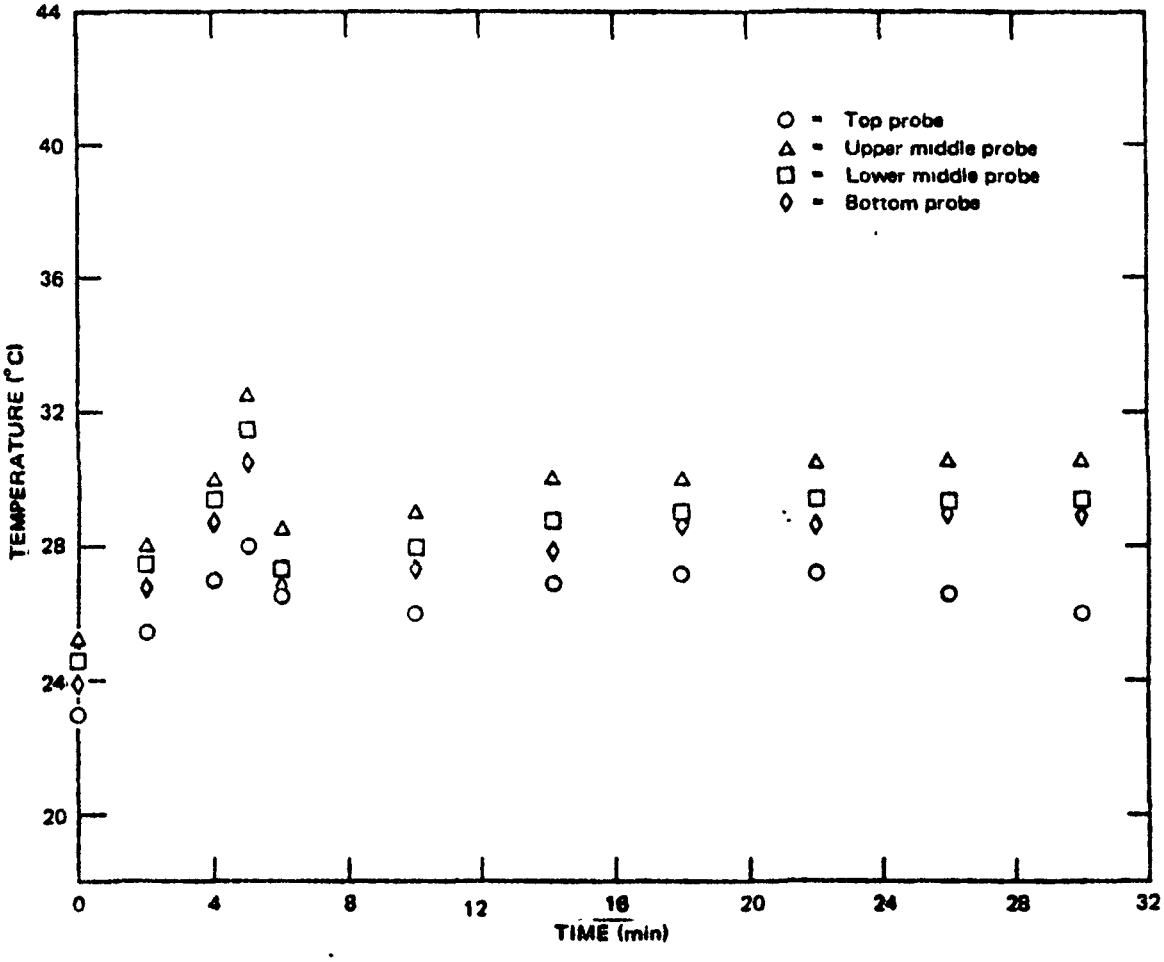

FIGURE 8 VERTICAL TEMPERATURE PROFILES AT OPPOSITE SIDE OF THE CHAMBER (MATERIAL #1)

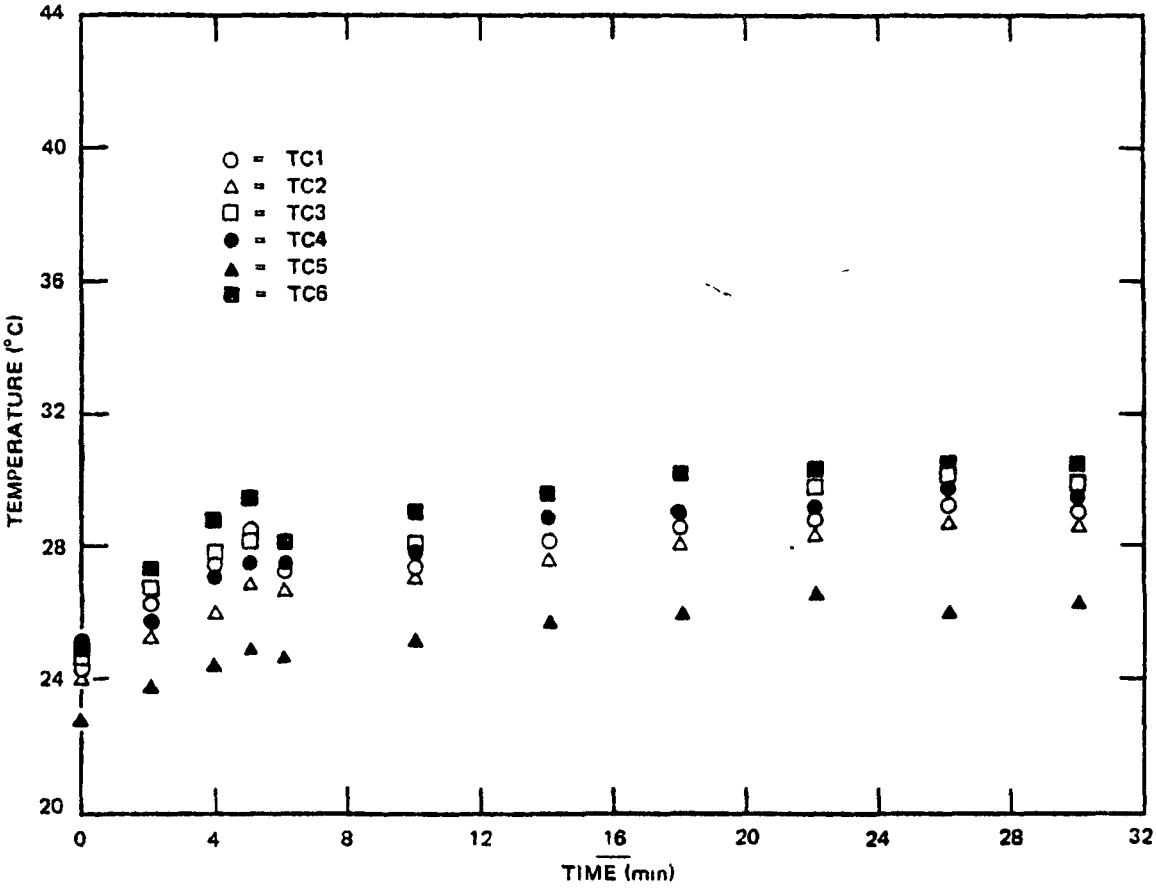

FIGURE 9 TEMPERATURE AT THE SIX CAGE POSITIONS DURING 30-MINUTE EXPOSURE TO MATERIAL # 1

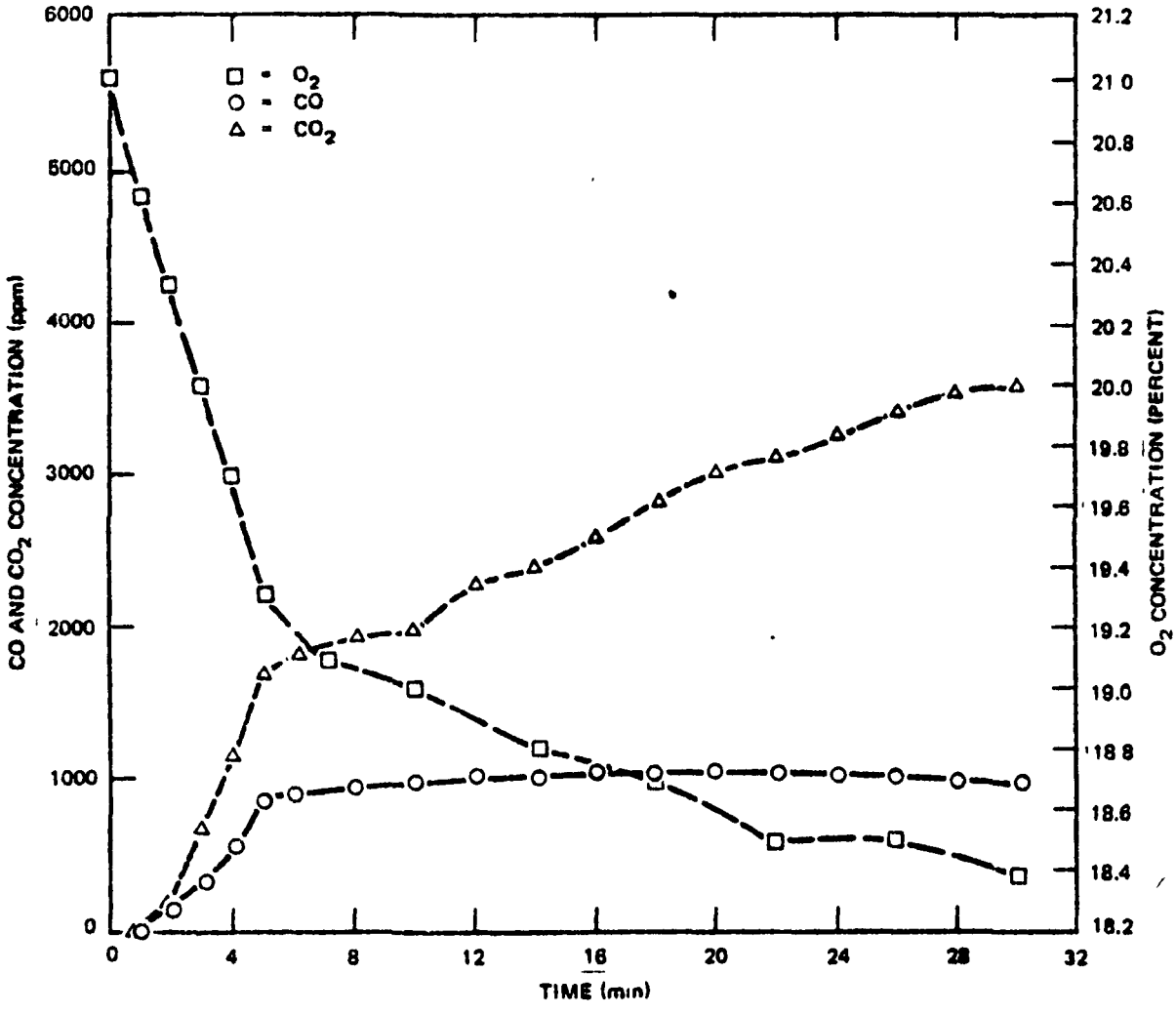

FIGURE 10 O_2, CO, AND CO_2 PROFILES DURING 30-MINUTE EXPOSURE TO PYROLYSIS PRODUCTS OF MATERIAL # 1

and CO concentration. The $LC_{t_{50}}$, the concentration of CO (in ppm) multiplied by the minutes of exposure, is also shown. The $LC_{t_{50}}$ permits a comparison of values when the exposure time varies.

The sample of material #1 tested consisted of a combination of two dissimilar samples of that material received in two different shipments. It is a foam laminated between two layers of fiberglass. The variables included not only the foam-to-fiberglass surface ratio, but also the amount of adhesive material. In addition, the color intensity and shade varied within samples so that energy absorption rates (fluxes) were different. We were unable to produce mortality with a 30-minute exposure to the pyrolysis products of material #1, so we exposed the animals for 60 minutes. All other exposures were for 30 minutes. We could not produce mortality with material #5 since it would not pyrolyze.

Table 2

ACUTE TOXICITY OF THE PYROLYSIS PRODUCTS FROM CANDIDATE AIRCRAFT MATERIALS AFTER A 30-MINUTE EXPOSURE*

Material Number	LC50 By Weight Loss (g/m^3)	LC50 By CO Concentration (ppm)	$LC_{t_{50}}$†
1	28.00	2280	135,800
2	9.43 (9.04-9.98)	3157 (2986-3310)	94,710
3	35.43 (34.11-36.16)	3683 (3625-3715)	110,490
4	7.95 (6.42-12.12)	520 (459-571)	15,600
5	Much greater than 60 grams	--	--
6	24.00 (21.00-28.00)	1525 (1381-1683)	45,750
CO alone	6.99 mg	6112 (5799-6347)	183,510

* Exposure for material #1 was 60 minutes.

† Expressed as the CO concentration in ppm multiplied by the minutes of exposure.

Ranking of the materials from the most toxic to the least toxic on either a weight-loss or a CO basis was practically the same except for material #2. On a weight-loss basis, the ranking is 4, 2, 6, 1, 3 (and 5); ranking on the basis of CO is 4, 6, 1, 2, and 3.

During the expsoure periods, the animals usually displayed an initial period (2-3 minutes) of varying degrees of excitement, followed by lying very quietly for the remainder of the exposure period. The 2-week recovery period indicated some residual toxicity in those animals that survived the exposures. Table 3 lists the body weights of survivors from exposures in the lethal range of concentrations of pyrolysis products of each material. Whereas rats exposed to materials #1, #2, and #3 generally gained weight in a normal fashion, those exposed to materials #4 and #6 not only had a decrease in weight gain but a moderate to severe weight loss during the recovery period. Mortality usually occurred in the chamber during exposure or within a few hours after exposure. Material #6 was an exception in that mortality occurred over a period of days after exposure.

Gross pathology of those animals that died or were sacrificed at 2 weeks post-exposure was confined to the lungs and spleen. The changes seen in the spleen were rough surfaces, which may be explained by the stress of the exposure. The lungs were heavy and edematous. Total areas of atalectasis and congestion were a frequent observation. Petecheal hemorrhages were often observed. Based on the gross pathology, there was little doubt that the lung was the primary target organ in all cases of toxicity.

Blood-gas analysis was performed on rats exposed to the pyrolysis products from each material at 5 and 30 minutes after exposure to the material. These data are summarized in Tables 4 through 8. In all cases, except for material #4 (Table 7), there was an initial elevated carboxy-hemoglobin level, which was readily reversible, as evidenced by the 30-minute post-exposure measurements. (It should be noted that the rat has a much more efficient carboxyhemoglobin-reducing system than

Table 3

INITIAL AND FINAL BODY WEIGHTS OF RATS
SURVIVING 14 DAYS AFTER EXPOSURE TO THE
PYROLYSIS PRODUCTS OF CANDIDATE AIRCRAFT MATERIALS

Material Number	Initial Body Wt* (grams)	Final Body Wt* (grams)	2-Week Gain
1	(10) 197 ± 11.8	(5) 259 ± 13	62
	(10) 220 ± 10.0	(10) 260 ± 11	40
	(10) 223 ± 12.0	(5) 249 ± 12	26
2	(10) 243 ± 4.7	(10) 303 ± 26.4	60
	(10) 249 ± 10.1	(8) 307 ± 13.9	58
	(10) 225 ± 27.2	(2) 307 ± 27.6	82
	(10) 227 ± 12.4	(1) 341	114
3	(10) 214 ± 13.2	(10) 249 ± 12.5	35
	(10) 203 ± 22.0	(6) 252 ± 13.2	49
	(10) 189 ± 16.4	(4) 211 ± 9.9	22
4	(10) 248 ± 17.3	(10) 265 ± 17.5	17
	(10) 259 ± 16.1	(8) 264 ± 23.2	5
	(10) 237 ± 12.3	(4) 214 ± 39.8	-23
6	(10) 269 ± 12.2	(10) 271 ± 14.1	2
	(10) 322 ± 18.7	(7) 273 ± 49.7	-49
	(10) 227 ± 19.0	(1) 189 ± --	-38
	(10) 328 ± 14.2	(1) 220 ± --	-108

* Body weights were taken just before exposure and just before sacrifice, 14 days later. Numbers in parentheses are the number of animals per group.

Table 4

BLOOD-GAS ANALYSIS OF MALE RATS*
5 AND 30 MINUTES AFTER A 30-MINUTE EXPOSURE
TO THE PYROLYSIS PRODUCTS OF MATERIAL #1

(CO concentration, 1100 ppm)

Measurement	Time After Exposure	
	5 Minutes	30 Minutes
Hemoglobin (g)	10.4-11.8	10.1-10.4
Carboxyhemoglobin (%)	27.6-28.3	18.2-18.6
pH	7.371-7.500	7.381-7.445
P_{CO_2} (mm Hg)	28.3-41.1	41.4-41.9
P_{O_2} (mm Hg)	82-130	30-44
HCO_3^- (mole %)	21.8-23.5	24.5-28.0
Total CO_2 (mole %)	22.6-24.8	25.8-29.3

* Two rats per group.

Table 5

BLOOD-GAS ANALYSIS OF MALE RATS*
5 AND 30 MINUTES AFTER 30-MINUTE EXPOSURES
TO THE PYROLYSIS PRODUCTS OF MATERIAL #2

	Time After Exposure			
	5 Min	30 Min	5 Min	30 Min
CO concentration (ppm)	2448	2448	1896	1896
Oxyhemoglobin (%)	37.2-40.6	59-75	23-34	38-49
Hemoglobin (g)	9.7-11.3	9.6-13.1	7.6-9.4	9.4-11.8
Carboxyhemoglobin (%)	49-50	24-27	33-34	13-19
pH	6.952-7.030	7.098-7.324	7.106-7.413	7.324-7.413
P_{CO_2} (mm Hg)	28-50	33-36	14-29	38-40
P_{O_2} (mm Hg)	22-26	55-57	42-143	33-38
Base excess	-19 to 21	-6 to 8	-23 to 17	-4 to 1
HCO_3^- (mole %)	7.2-10.8	10-18	4-9	20-24
Total CO_2 (mole %)	8.1-12.4	11-20	5-10	22-26

* Two rats per group.

Table 6

BLOOD-GAS ANALYSIS OF MALE RATS*
5, 15, AND 30 MINUTES AFTER A 30-MINUTE EXPOSURE
TO THE PYROLYSIS PRODUCTS OF MATERIAL #3

(CO concentration, 3678 ppm)

Measurement	5 Minutes	15 Minutes	30 Minutes
Hemoglobin (g)	8.2-12.4	9.2-11.7	8.9-11.8
Carboxyhemoglobin (%)	43.6-59.2	36.3-42.3	30.0-35.2
pH	6.786-6.934	6.957-7.117	7.075-7.204
P_{CO_2} (mm Hg)	43.9-81.4	39.8-60.1	44.6-65.2
P_{O_2} (mm Hg)	6-88	6-13	4-32
HCO_3^- (mole %)	8.3-12.0	11.2-18.3	14.9-22.3
Total CO_2 (mole %)	9.8-14.5	12.4-20.1	15.6-24.1

* Five rats per group. Rats anesthetized with pentobarbital before bleeding.

Table 7

BLOOD-GAS ANALYSIS OF MALE RATS
5 AND 30 MINUTES AFTER A 30-MINUTE EXPOSURE
TO THE PYROLYSIS PRODUCTS OF MATERIAL #4

(CO concentration, 310 ppm)

Measurement	Time After Exposure	
	5 Minutes*	30 Minutes†
Hemoglobin (g)	11.9-14.3	12.3-14.2
Carboxyhemoglobin (%)	0	0
pH	7.375-7.517	7.245-7.428
P_{CO_2} (mm Hg)	21-46	27-39
P_{O_2} (mm Hg)	73-111	64-98
Base Excess	-2.8 to 1.3	-12.1 to -3.0
HCO_3^- (mole %)	17.1-26.2	13.5-21.3
Total CO_2 (mole %)	17.7-27.7	14.5-22.5

* Four rats.

† Five rats.

Table 8

BLOOD-GAS ANALYSIS OF MALE RATS
5 AND 30 MINUTES AFTER A 30-MINUTE EXPOSURE
TO THE PYROLYSIS PRODUCTS OF MATERIAL #6

(CO concentration, 1440 ppm)

Measurement	Time After Exposure	
	5 Minutes*	30 Minutes†
Hemoglobin (g)	13.3-14.6	13.8
Carboxyhemoglobin (%)	25.6-37.8	22.5
pH	6.631-7.383	7.390
P_{CO_2} (mm Hg)	29-65	32
P_{O_2} (mm Hg)	15-84	46
Base Excess	-29 to 5.2	-3.8
HCO_3^- (mole %)	6.6-17.4	18.9
Total CO_2 (mole %)	8.5-18.0	19.9

* Five rats.

† One rat.

Table 9

SUMMARY OF THE BEHAVIORAL PERFORMANCE DATA FROM RATS EXPOSED TO THE PYROLYSIS PRODUCTS OF CANDIDATE AIRCRAFT MATERIALS*

Material Number	CC50	IC50	LC50
1	1229	1767	1787
2	1387	1964	1996
3	1615	2715	2257
4	121	176	124
6	1492	3043 (approx)	1430
CO alone	1600	3125	3650

* Values expressed as ppm of CO. Each value was determined from several trials by regression analysis. Each exposure was done with six animals.

man has.) Materials #2, #3, and #6 produced a moderate to severe acidosis, with partial depletion of the bicarbonate reserve, but this was also reversible in surviving animals at 30 minutes after exposure even though recovery may not have been complete. The partial pressures of O_2 and CO_2 (from venous blood) probably reflect a normal condition to slight hyperventilation. However, these samples were taken 5 minutes after the rats were removed to room air. Had the blood been drawn in the chamber at the end of the exposure period, there probably would have been much high P_{CO_2} values (evidence of breath-holding, or hypoventilation).

No blood gases were done on Material #5 since nothing could be pyrolyzed from this material.

Behavioral Studies

The results of the behavioral studies are summarized in Table 9. The loss of the Conditioned Avoidance Response (CC50), incapacitation (IC50), and lethality (LC50) are expressed in terms of the CO concentration. First, note that the LC50 values are lower for the animals in the behavioral chambers. This is probably because these animals are required to expend more energy in task performance and therefore have a higher respiratory minute volume than those allowed to rest in the exposure chamber. Consider, for example, the LC50 of CO alone. In the acute toxicity studies this was 6112 ppm, whereas in the behavioral chamber this was reduced to 3650 ppm, or nearly half the "resting" LC50 that was obtained in the wire cages.

Next, note that the incapacitating concentration of each material is the same (#1 and #2) or greater (#3, #4, and #6) than the LC50, in contrast to CO, for which the IC50 is about 85% of the LC50. (The IC50 for Material #6 is an approximation since CO concentrations that high could not be reached.) Materials #3 and #6 present an interesting phenomenon since the pyrolysis products apparently contain some substance that is antagonistic to CO incapacitation.

Inhibition of the conditioned avoidance response (CC50) was the most sensitive measure with Materials #1, #2, and #3, but was approximately the same as the LC50 for Materials #4 and #6.

Recovery of behavioral activity was complete within 24 hours in all animals except those exposed to the pyrolysis products of Material #6. These animals took up to 7 days to regain their pre-exposure level of performance.

DISCUSSION

This study was initiated to evaluate the toxicity (i.e., safety) of candidate aircraft materials since they may become involved in situations of thermal decomposition. This requires test methodology for evaluating not only the toxicity of the thermal decomposition products, but also the incapacitating effects of the decomposition products and the thermal stability of the initial product. First, an exposure chamber was built that allowed the controlled pyrolysis of material by external heat fluxes. The flux rates are adjustable over a wide range so that pyrolysis or flaming mode is easily achieved. This capability also allows us to complete the pyrolysis of a sample in a short time relative to the animal exposure time.

The exposure chamber is designed so that the pyrolysis area and animal exposure area are essentially one chamber. This design avoids large losses of combustion products on the walls of any transfer apparatus. At the same time, the animals are protected from direct exposure to the burning material. Thus, even a relatively long pyrolysis time does not cause a temperature rise of more than a few degrees at the animal locations in the chamber. Continuous monitoring of sample weight loss and the chamber concentrations of CO, CO_2, and O_2 gave us good control of the pyrolysis and permitted us to reproduce any desired exposure. We found that using the CO concentration produced by the pyrolysis of each material provided us with a satisfactory "internal standard" to determine our median effective doses.

In summary, the chamber and methodologies used in these studies generally meet or exceed those recommended by the National Academy of Sciences (Fire Toxicology: Methods for Evaluation of Toxicity of Pyrolysis and Combustion Products, Report No. 2, NAS Committee on Fire Toxicology, August 1977). Specifically, (1) we cannot do testing in both the flaming and the pyrolysis mode; (2) the pyrolysis time is short (1 to 4

minutes) with respect to the animal exposure time; (3) the animal chamber and pyrolysis unit are essentially one chamber and the sample is pyrolyzed in that chamber, whereas the energy (heat) source is located outside the chamber; (4) we use small animals and expose six to twelve at one time; (5) we use 30-minute exposures but can expose for longer or shorter times, as necessary; (6) the temperature in the exposure chamber never exceeds 35° C; (7) we measure incapacitation and avoidance as well as mortality; (8) we monitor CO, CO_2, and O_2 continuously during exposure, and the O_2 concentration is never below 17%.

The toxicity studies have been expressed in terms of CO concentrations because that has been a convenient and consistent measurement. However, we do not mean to imply that CO is the only--or even the main--factor contributing to the toxicity of the pyrolysis products of the various materials. This is evident from both the blood-gas data and the variable rate of body weight recovery seen after exposure. For example, the survivors after exposure to materials #4 and #6 lost weight during the 2-week postexposure period. After exposure to material #3, weight gain was reduced somewhat.

Gross pathology was confined to the lungs and, to a lesser degree, the spleen. The lungs were generally edematous and atalectatic, and occasionally petechial hemorrhages were seen. This is not characteristic of CO but, rather, was probably induced by the myriad of other compounds in the pyrolysate. For example, materials #3, #4, and #6 contained a great deal of SO_2.

The behavioral performance of the animals was somewhat surprising in that the decrement of CAR performance and/or incapacitation often occurred at concentrations that were about the same as or higher than the LC50. This seems to point out the need for doing both tests for incapacitation and those based on mortality data when evaluating these compounds.

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ANIMAL EXPOSURE DURING BURN TESTS

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4 Title and Subtitle

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FINAL REPORT

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Abstract

An animal exposure test system (AETS) has been designed and fabricated for the purpose of collecting physiological and environmental (temperature) data from animal subjects exposed to combustion gases in large scale fire tests. The AETS consists of an open wire mesh, two-compartment cage, one containing an exercise wheel for small rodents, and the other containing one rat instrumented externally for electrocardiogram (ECG) and respiration. Cage temperature is measured by a thermistor located in the upper portion of the rat compartment. Temperature range recorded is 0°C to 100°C. The ECG and respiration sensors are located in a belt placed around the torso of the subject, electrode wires forming an umbilical to a connector in the top of the compartment. A cable extends from the connector to the power supply and signal conditioning electronics. These are connected to a dual-beam oscilloscope for real-time monitoring and a magnetic tape recorder having three or more channels. After the burn test, the data on the tape is reproduced in the laboratory on an 8-channel Beckman Type SII Dynagraph for analysis. Endpoints observed are bradycardia, cardiac arrhythmias, changes in respiratory pattern, respiratory arrest and cardiac arrest. The ECG record also appears to be a good method of monitoring of animal activity as indicated by an increase in EMG (electromyograph) noise superimposed on the record during increased activity of the torso musculature. Examples of the recordings are presented and discussed as to their significance regarding toxicity of fire gases and specific events occurring during the test.

The AETS has been shown to be a useful test tool in screening materials for the relative toxicity of their outgassing products during pyrolysis and combustion. Recommendations for future effort include (1) improvement of the system effectiveness, (2) utilization of the system to enlarge the data bank of physiological responses to fire gases, (3) investigation in the laboratory of the responses to selected fire gases and extinguishing agents, singly and in combination.

OBJECTIVES

The objectives of this program have been:

1. To develop an animal exposure test system (AETS) for utilizing small animals as subjects (S_S) in large-scale burn tests. The AETS should be capable of being standardized so that any investigator, following the specifications set forth, can build and utilize the system and achieve results which can be accurately compared with those of another investigator using the same system.

2. To utilize the AETS in large-scale burn tests to collect physiological (cardiac and respiratory), environmental (temperature), and physical activity data to enable the relative toxic threat assessment of burning materials, in single or multiple speciments. The system should also be applicable to various laboratory-scale experiments without or with minor modifications.

APPROACH

Douglas studied the NASA plans, protocols, schematics for the full-scale burn tests of an aircraft lavatory to be conducted in 1975 at the test facilities of the Boeing Company, Seattle, Washington (7) and of a simulated lavatory at the University of California at Berkeley (Richmond) (8). The design requirements and criteria for a standardizable animal exposure test system (AETS) were developed from this study. The AETS had to be compatible with the primary test facility and plan. The AETS was to be a separate system but integratable with the primary test facility. Design considerations included such parameters as type of material for the chamber, its size, number of subjects to be accommodated, placement of sensors and sample ports within or near the chamber, methods of monitoring subject's activity and gas concentrations as well as length of sampling lines, and methods of sampling.

The gas analysis methods used were to be the same as those used in the primary test facility and were to be performed by the same laboratories and by the same technicians. This procedure was necessary for accuracy in gas analysis, particularly when a sampling method is used. On-line continuous gas analysis for O_2 and CO would have required a separate set of analyzers, if a closed cage were used. Thus, unnecessary duplication of instrumentation and manpower was avoided.

A conceptual design for the AETS was developed based on these considerations, followed by final design and fabrication of the AETS. A test plan, integrated with and compatible with the primary test plan, was developed.

The AETS, including subjects and instrumentation, was transported and installed in the Boeing Company facility and in the UCB-Richmond Fire Test Facility at Richmond, California. Douglas participated in three large-scale burn tests of aircraft lavatories. Douglas operated the AETS, collected and analyzed the data resulting from the exposure of animals to evolving fire gases, and presented conclusions as to the relative toxicity of the combustion products as a function of the materials involved in the fire bases on the gas analysis data collected by the Boeing Company and NASA ARC.

The parameters analyzed included:

- Air temperature within the AETS cage.
- Activity of freely-moving subjects before and during exposure to evolved gases.
- Electrocardiographic and respiratory patterns before and during the test exposure on one instrumented subject.
- Correlation of the physiological and cage temperature date with the gas analysis data.

INSTRUMENTATION

It was found that a simple 1.9 cm (3/4 inch)-wide belt around the chest, containing two elastic sections, using velcro to fasten the ends, appeared to be retained by the subject with less apparent discomfort than some of the previous methods of fixation to the S.

Sensors

A piezo-electric respiratory transducer previously used for human subjects was incorporated into the center of the belt between the two elastic sections of equal length and two velcro sections distal to these. Figure 2 illustrates the structure of the electrode belt (E.B.).

Next, the design of the surface ECG electrodes was considered. Standard Beckman disposal Telectrodes were modified, tested, and found to be unsatisfactory. Loops of metal wire, through which the S's front legs were put were then fabricated. These were fastened to the outer ends of elastic sections. This technique showed promise but was temporarily rejected. The final electrode design, however, consisted of a rounded thumb tack drilled with four holes into which were soldered short sections of paper clips. These were filed a length suitable for penetration of the fur of the S, particularly after clipping. Figure 3 is a lateral view schematic of the ECG electrode.

The entire electrode was then gold-plated. To apply the electrode to the belt, the pin of the tack was pushed through the elastic section, one on either side of the respiration sensor after determining the proper placement in the belt after optimum stretching and fastening on the subject. Wires (teflon-coated) were then soldered to the pin, joined with the other wires from the other electrode, the respiration transducer, and the two ground wires from ECG and respiration, to form the umbilical cable to the plug at the ceiling of the cage. The length was sized to permit the subject free access to any portion of his compartment.

Cage Temperature

A non-linear thermistor, "400" Series, Yellow Springs Instrument Co., was used to sense cage temperature. The original design range was 10°C to 65°C. A constant d.c. current is passed through the thermistor, the resultant voltage is amplified and conditioned to be compatible with the FM magnetic tape recorder. A positive 1.4 vdc corresponds to 10°C and 65°C is indicated by a negative 1.4 vdc. A calibration curve of voltage vs temperature for use in data reduction in Figure 1 of the Appendix.

After the Boeing test in which the cage temperature reached approximately 92°C, the temperature range was expanded to record from 0°C to 100°C although the calibration record remained the same.

Electrocardiogarm

The ECG signal conditioner amplifies frequencies from 1.0 Hz to 2000 Hz in order to provide complete recording of the rat cardiac frequencies. The signals are amplified about 4000 times (72 dB) and adjusted to the tape recorder input levels (± 1.4 vdc).

The ECG pre-amplifier consists of a transistor differential input stage to achieve high input impedance and low noise. Operational amplifiers are used in the output to increase signal level.

Respiration

The frequency design range for respiration is from 0.5 Hz to 500 Hz. Figure 2 of the Appendix shows the circuit diagram for the respiratory electronics. Respiration is measured with a piezo-electric transducer mounted in the electrode belt. The transducer is responsive to expansion and contraction of the rib cage. Signal conditioning electronics consist of an impedance buffer which isolates the transducer from the low impedance recorder and signal amplification to provide proper signal level to the tape recorder. Figure 4 in the text illustrates typical laboratory recordings of ECG and respiration.

Subject Activity

The original concept for monitoring physical activity of the mice in the second compartment was simply to record their activity via cinematography or video-tape. In the Boeing test, an exercise wheel and a teeter-totter were provided. The wheel was used vigorously by the S_S, but the teeter-totter appeared to be of little value. One of the simplest methods was found to be observation of the S_S climbing to the top of the cage. S's inability to maintain the inverted position and falling to the cage floor appears to be an adequate endpoint for functionability. Videotape recording of this test was quite useful for monitoring activity.

During the development of the electrode belt and during the Boeing test, it was found that the ECG and respiratory records were very useful in indicating the relative level of physical activity of the rat by the noise level generated in the ECG by his movements. The noise shown in the recording is roughly proportional to the degree of activity. Indications are (unverified as yet) that terminal spasticity and convulsions can be identified also. Additional research will be needed for verification.

Recording

ECG, respiration and cage temperature are recorded on any standard multichannel magnetic tape recorder. In the Douglas Biomedical Laboratory, a Precision Instrument 7-channel 1.27 cm (1/2-inch) FM tape recorder at 19.05 cm/s (7-1/2 ips) is used. At Boeing a standard 2.54 cm (1-inch) FM tape recorder at 38.1 cm/s (15 ips) was used to be compatible with their data acquisition system. The tapes are returned to the Douglas Biomedical Laboratory, reproduced on the 8-channel strip chart of a Beckman Type SII Dynagraph Recorder utilizing 4 channels to record ECG, unfiltered respiration, filtered respiration, and cage temperature (Figure 6). The temperature channel is used to indicate various events, e.g., start of test, ignition and other physical events by utilizing the T° calibrate/operate switch on the electronics box and a code developed for this purpose.

Data Analysis

Physiological and temperature data are analyzed from the strip chart. Parameters examined and end-points observed include changes in heart rate (HR), such as bradycardia (slow HR), cardiac arrhythmias and arrest, respiratory pattern changes, changes in respiratory integration time and respiratory arrest. Physical activity of the instrumented subject is also observed as EMG noise in the ECG baseline and this has been observed as being roughly proportional to the level of activity.

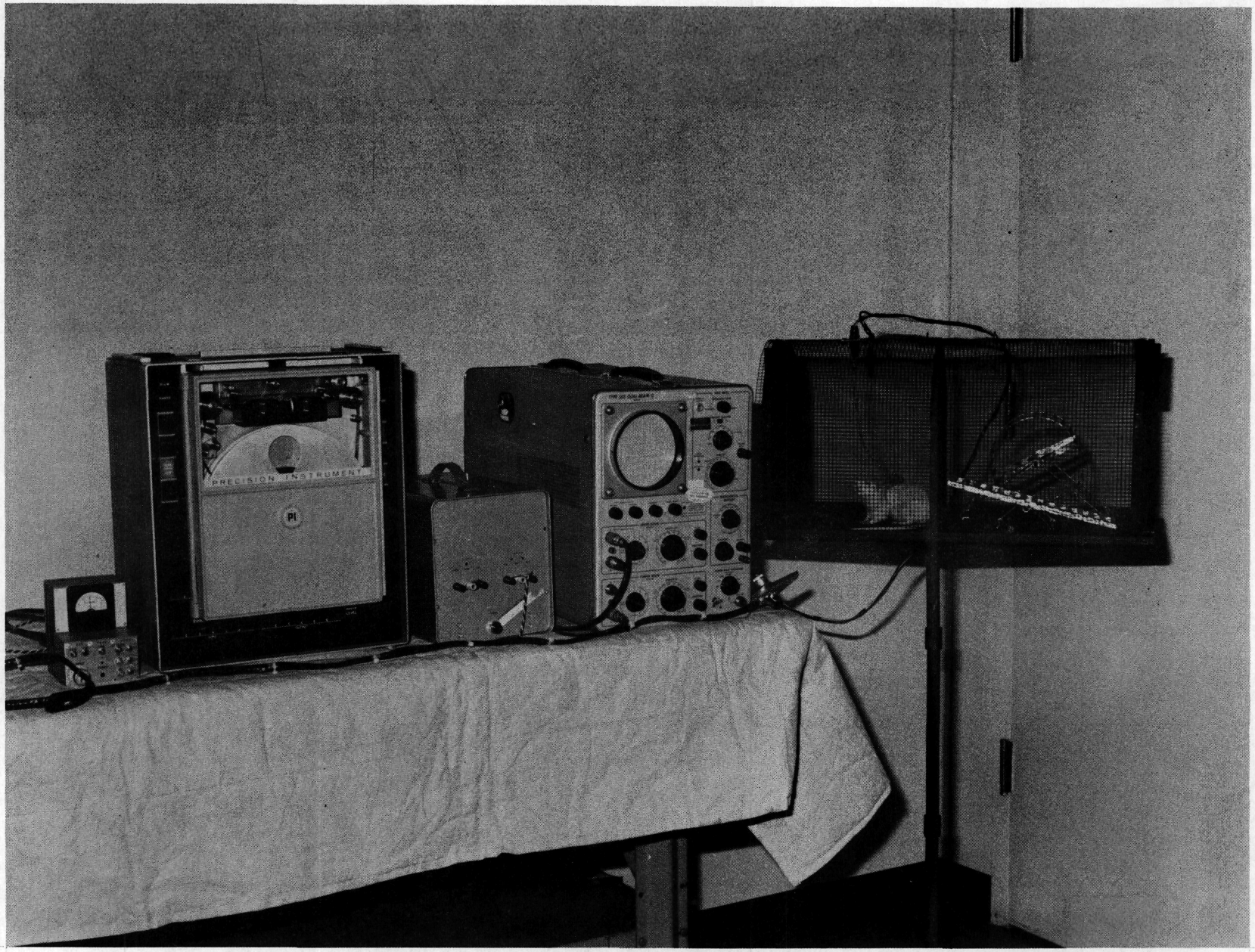

FIGURE 1. EXPOSURE CAGE ON ARTICULATED SUPPORT STAND.

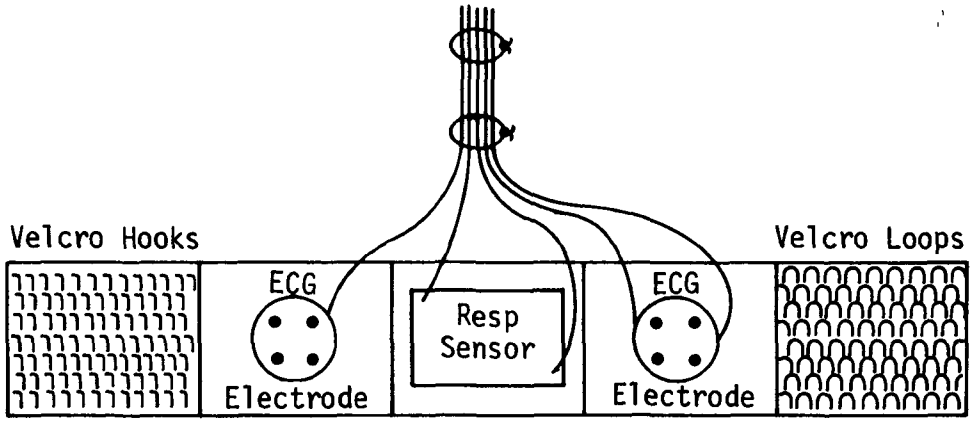

FIGURE 2. ELECTRODE BELT STRUCTURE

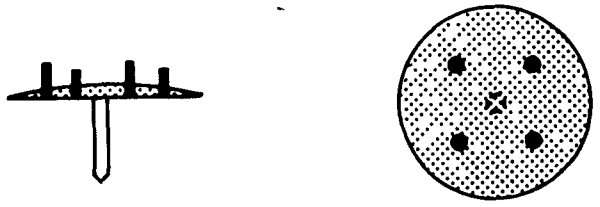

FIGURE 3. LATERAL AND TOP VIEW OF ECG ELECTRODE

COMMENTS ON THE BOEING TEST, JUNE 11, 1975

, in preparation for the Boeing test at Seattle, an AETS checkout test was run in the MDC Cabin Fire Simulator (CFS) facility at A3 (Huntington Beach). The fire source was 4.55 Kg (ten pounds) of shredded newspaper contained in two expanded metal baskets and ignited by means of a nichrome wire inserted into the basket located on the floor. The AETS was outside the simulated marsonite lavatory and connected with the lavatory enclosure by a 1.9 cm (3/4 inch) flexible hose approximately 38.1 cm (15 inches) long. The duct entered the AETS through a connector in the sealed plastic (polyethylene) covering of the cage, making it into a closed system for this test. The effluent duct discharged into the exhaust duct from the lavatory enclosure. The AETS air flow was regulated by the same exhaust pump and a control valve inserted into the effluent duct between the exposure cage and lavatory exhaust duct.

The AETS functioned as designed in this preliminary checkout test conducted in the MDC CFS.

The rat's responses to the fire gases are evident in 1.3 minutes after ignition. Cardiac arrhythmias continue for 4-5 minutes. At ten minutes into the test the fire was extinguished by flooding the compartment with nitrogen (N_2). Again, severe bradycardia and arrhythmias occurred in about one minute after N_2 was introduced. Hypoxia was undoubtedly a major factor in producing this effect. Cage temperature profile is shown in Figure 5. Table 2 summarizes the physiological effects and sequence.

The AETS was packed and transported to Boeing, Seattle , and the system prepared for the burn test. Checkout went smoothly until the subject chewed some of the electrode wires in two on the day of the test. Repairs were quickly made, and the system was again checked out and found to be working satisfactorily.

The test began on schedule and burned for the full allotted 30 minutes, then was extinguished with CO_2. Both rat and mice (in the activity side of the cage) died at approximately the 18th minute. All subjects were obscured by smoke at 16 minutes and the instrumented S's record indicated death at approximately 18 minutes. However, at about 12 minutes the mice were fairly incapacitated as indicated by their falling behavior in the wheel and by their dropping to the floor from the top of the cage. Table 2 summarized the physiological effects in this burn test. Figures 6 through 13 show the span from normal ECG and respiration to cardiac arrest, as a function of time. Fire gases and O_2 are shown in Figures 14 through 17 (9). Figure 21 shows the enclosure temperature. Figure 22 illustrates the arrangement of the "airline" type waste used as an ignition source and Figure 17 depicts the position and general arrangement of the AETS. The correlation of the physiological effects and the gas analysis data was reported in a "Special Report of the Boeing Test , a copy of which is included in the Appendix of this report for sake of completeness.

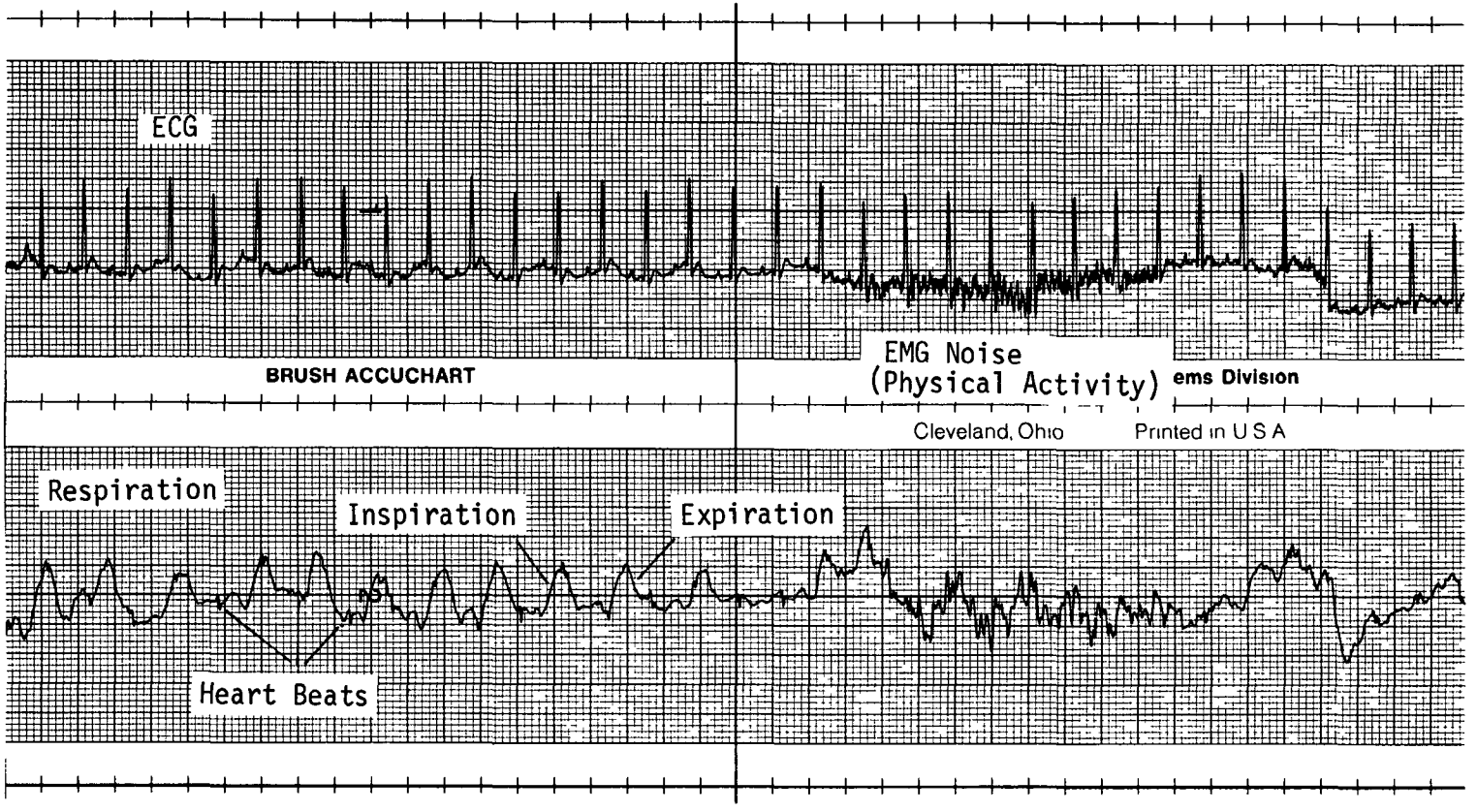

FIGURE 4. LABORATORY RECORDINGS OF ECG AND RESPIRATION ILLUSTRATING EMG

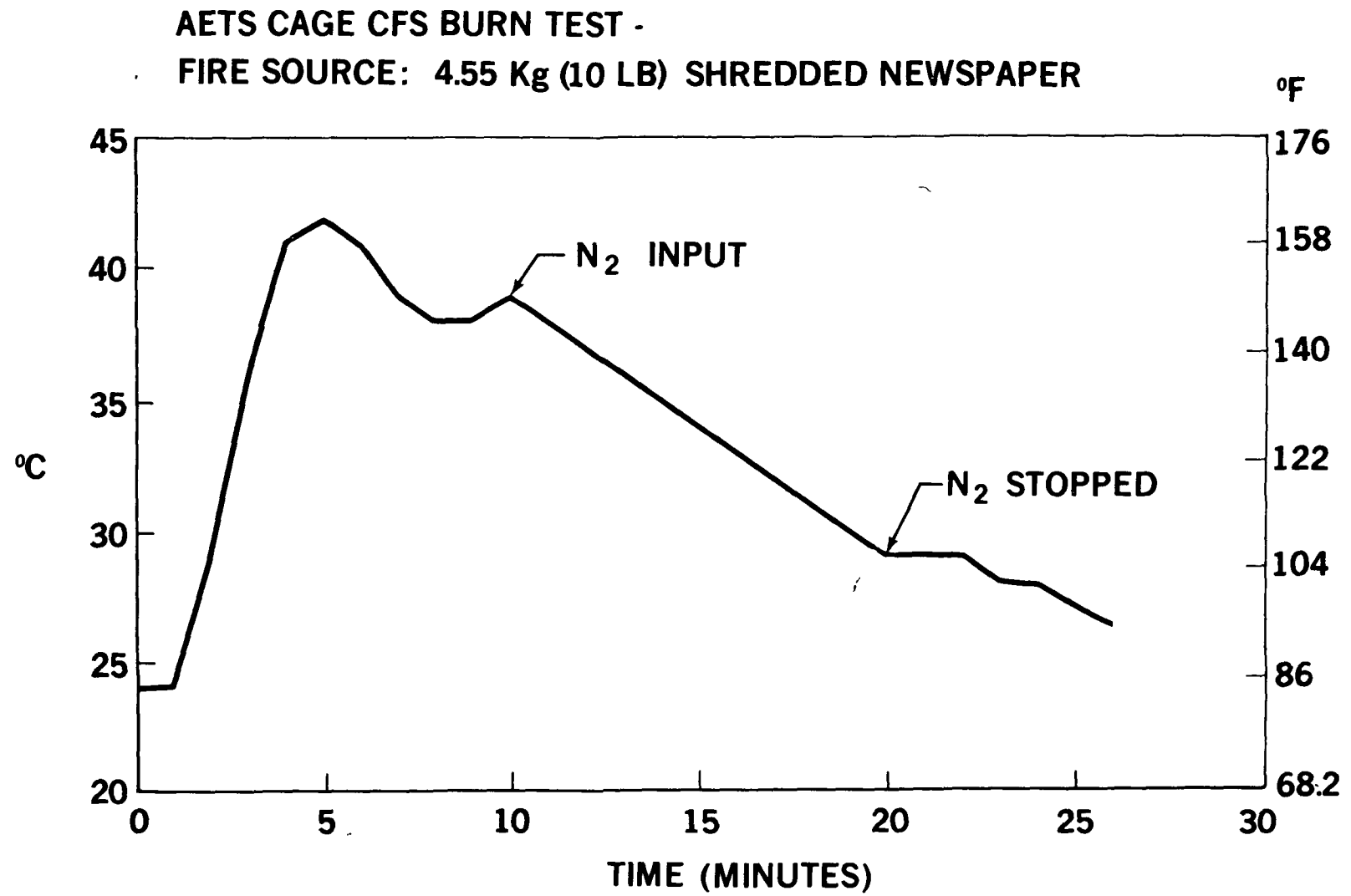

FIGURE 5. TEMPERATURE PROFILE, CFS TEST

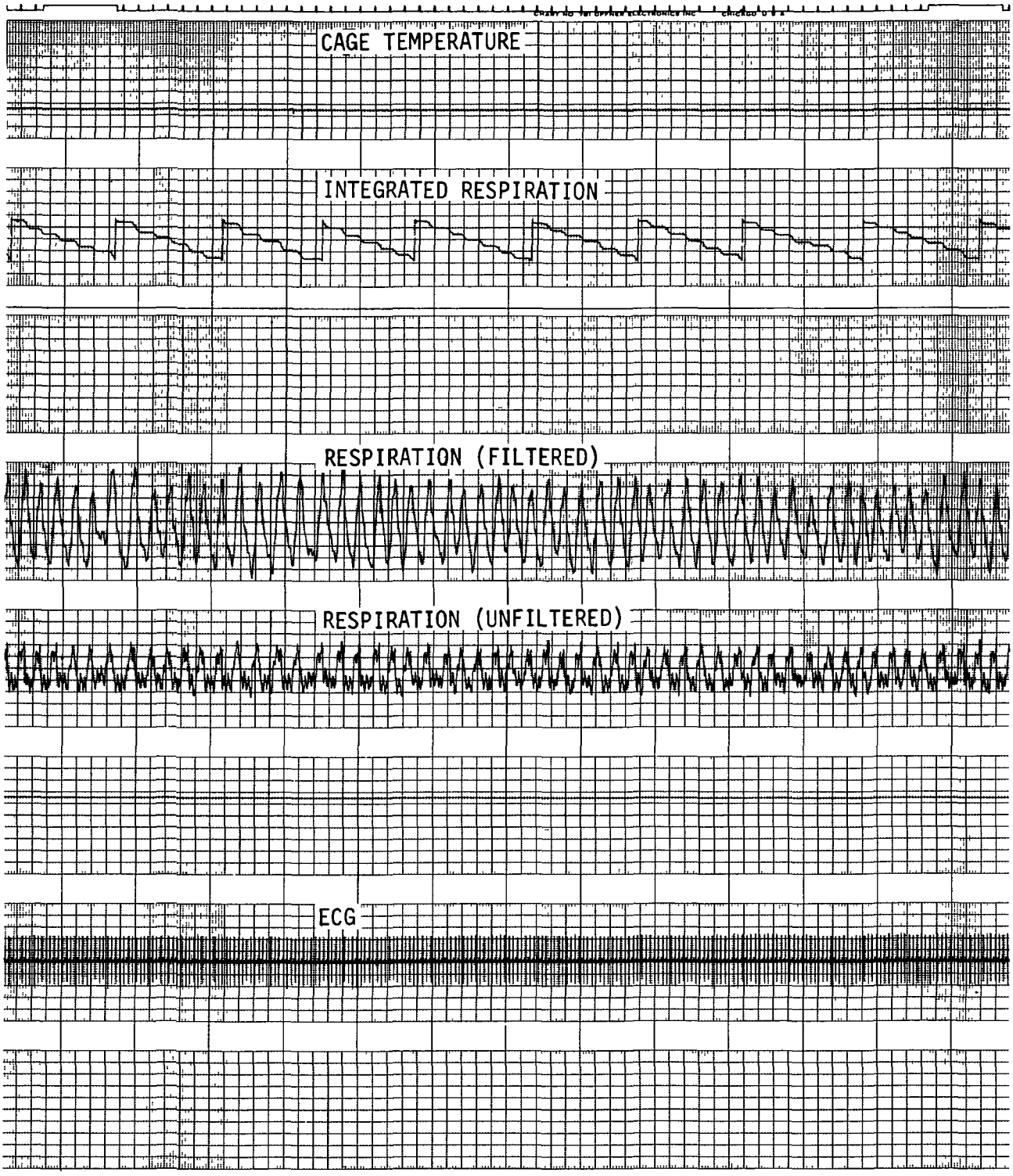

FIGURE 6. REPRODUCED BOEING TEST PHYSIOLOGICAL DATA

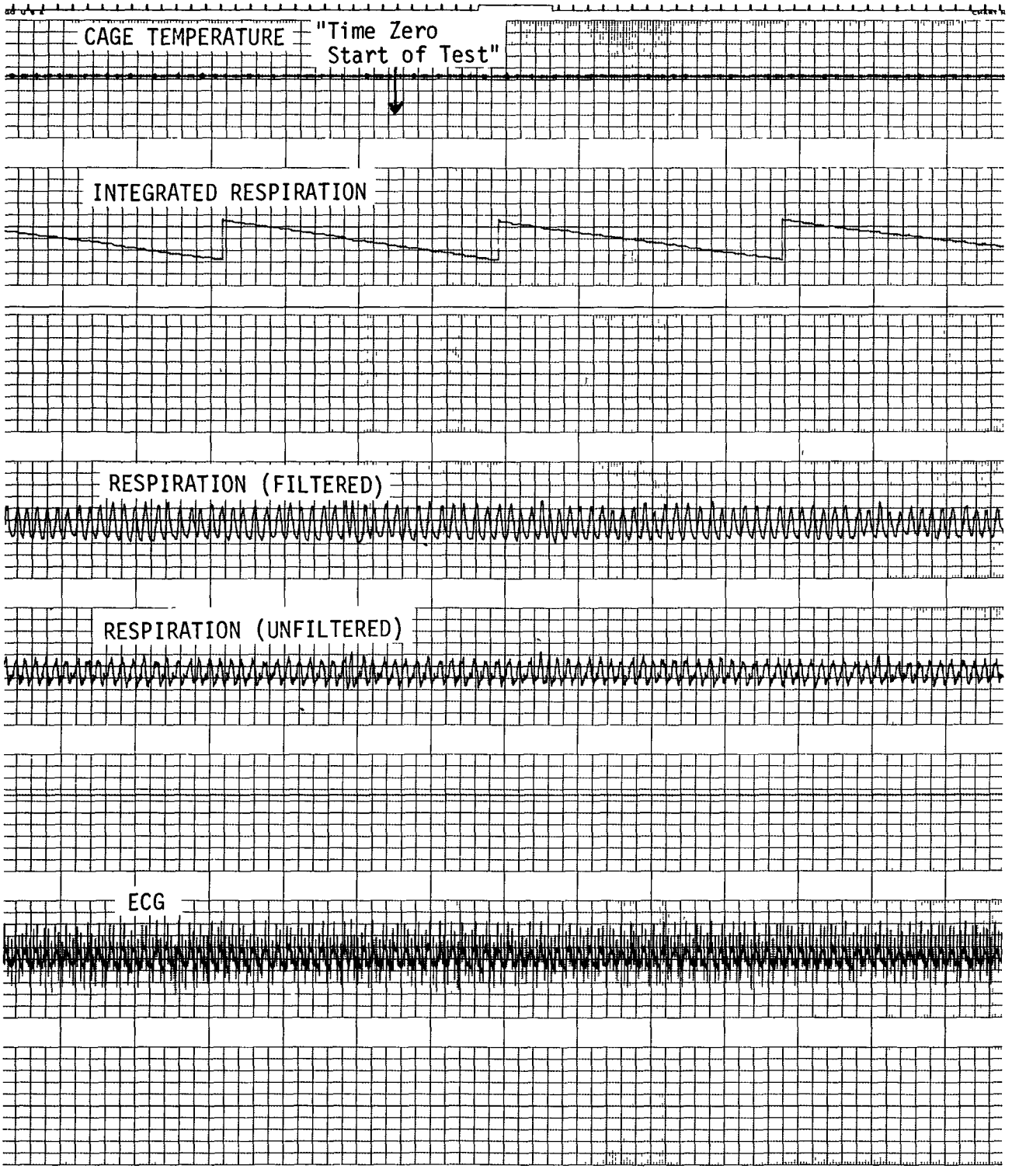

FIGURE 7. REPRODUCED BOEING TEST PHYSIOLOGICAL DATA

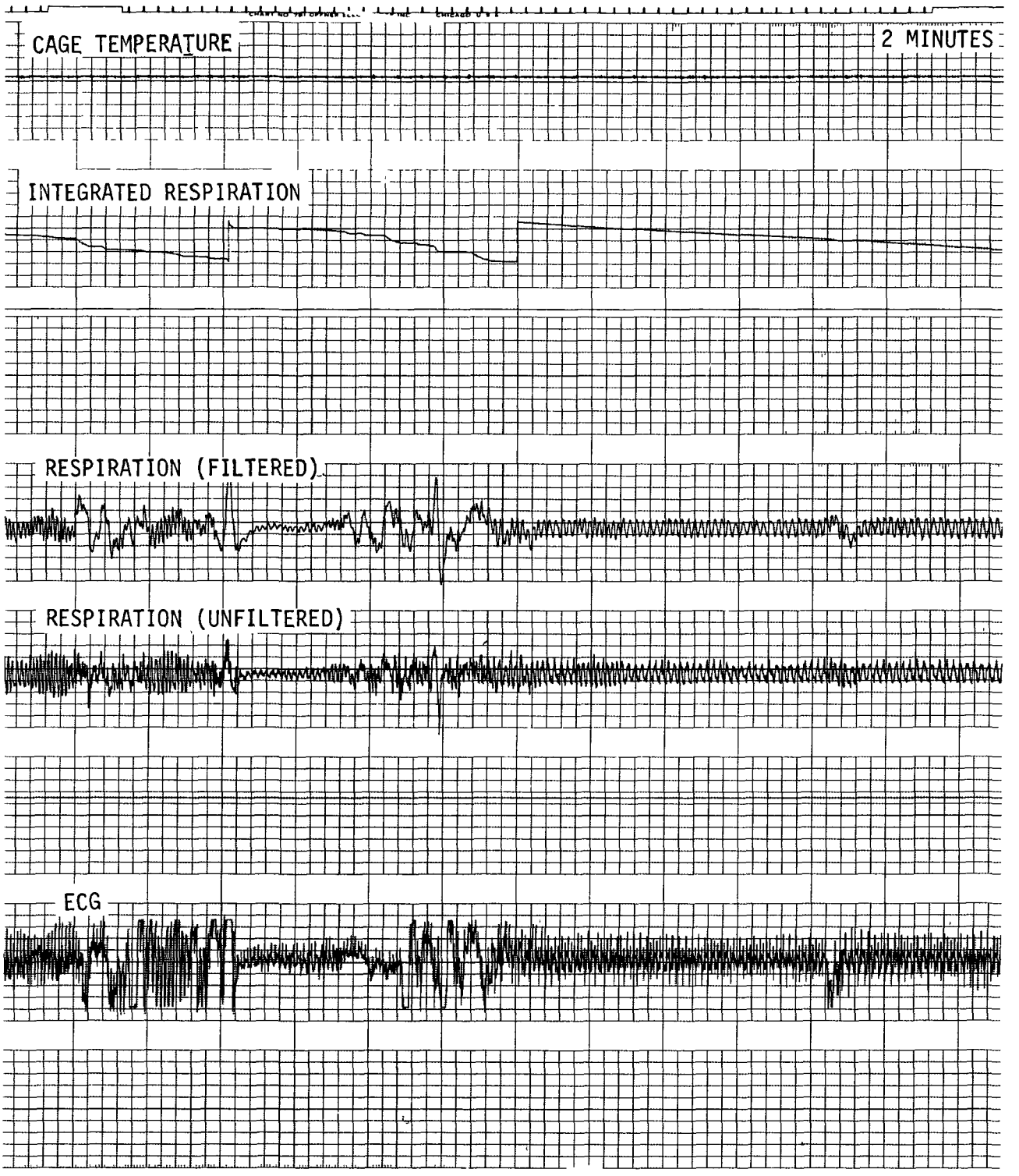

FIGURE 8. REPRODUCED BOEING TEST PHYSIOLOGICAL DATA

FIGURE 9. REPRODUCED BOEING TEST PHYSIOLOGICAL DATA

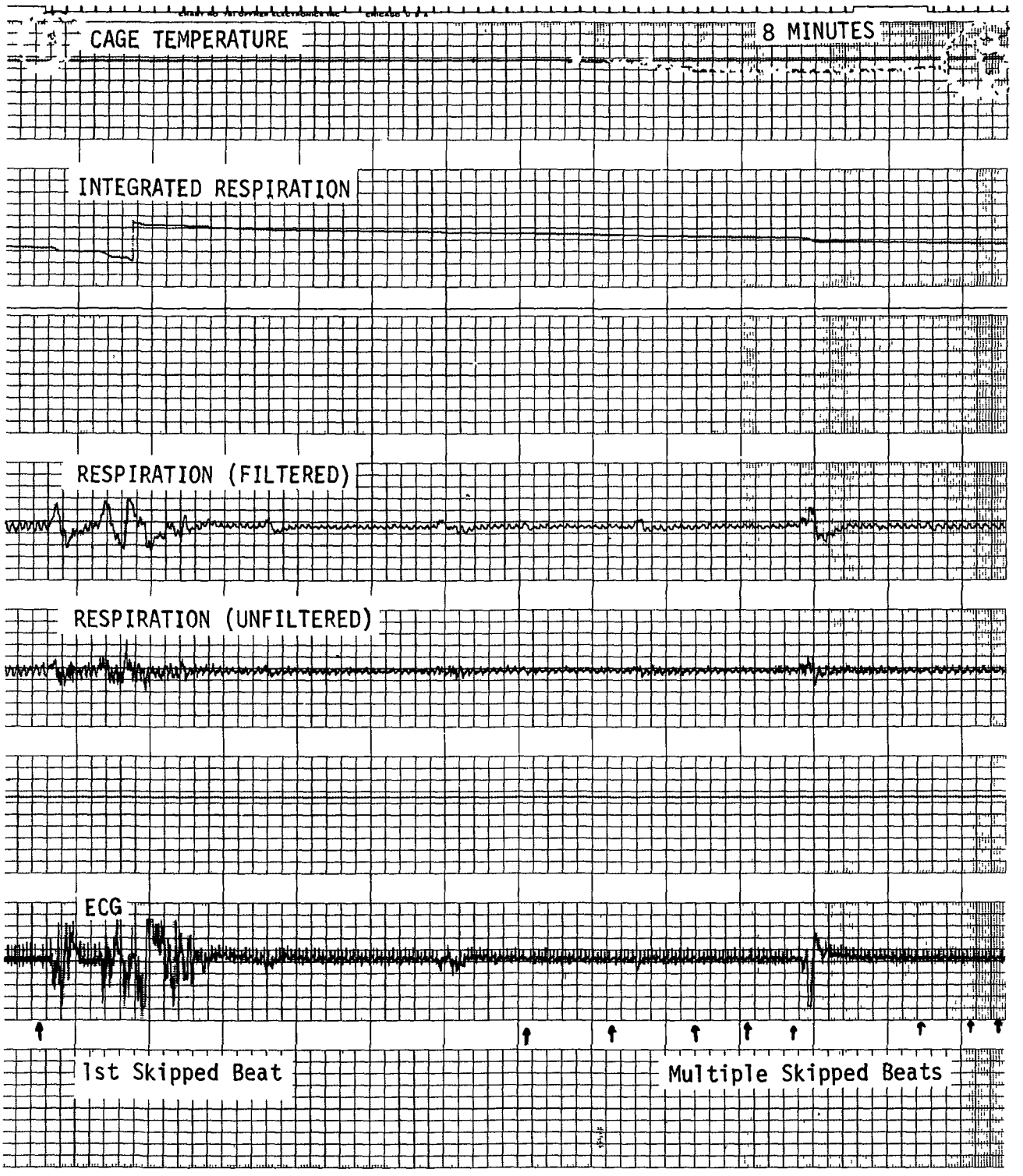

FIGURE 10. REPRODUCED BOEING TEST PHYSIOLOGICAL DATA

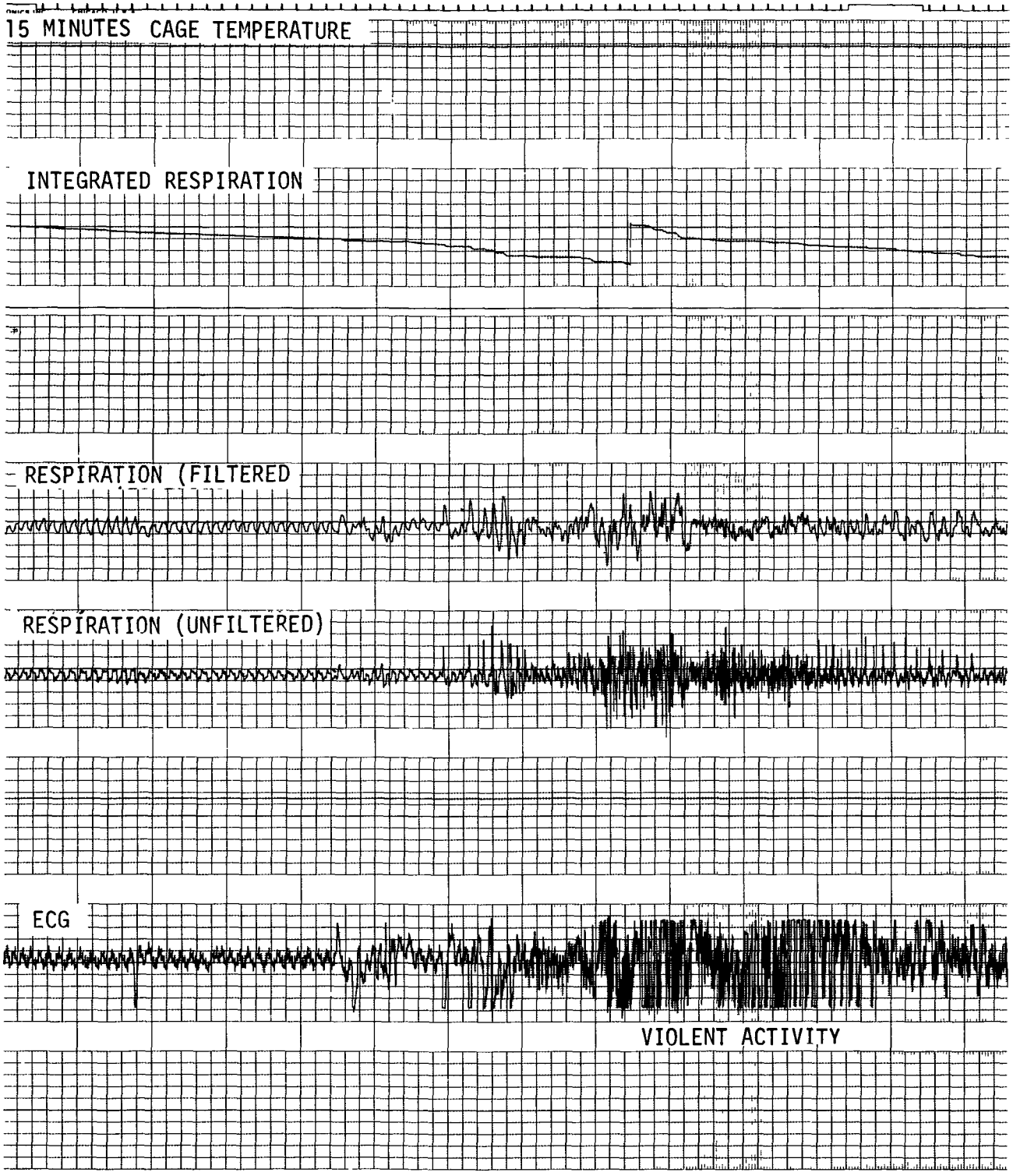

FIGURE 11. REPRODUCED BOEING TEST PHYSIOLOGICAL DATA

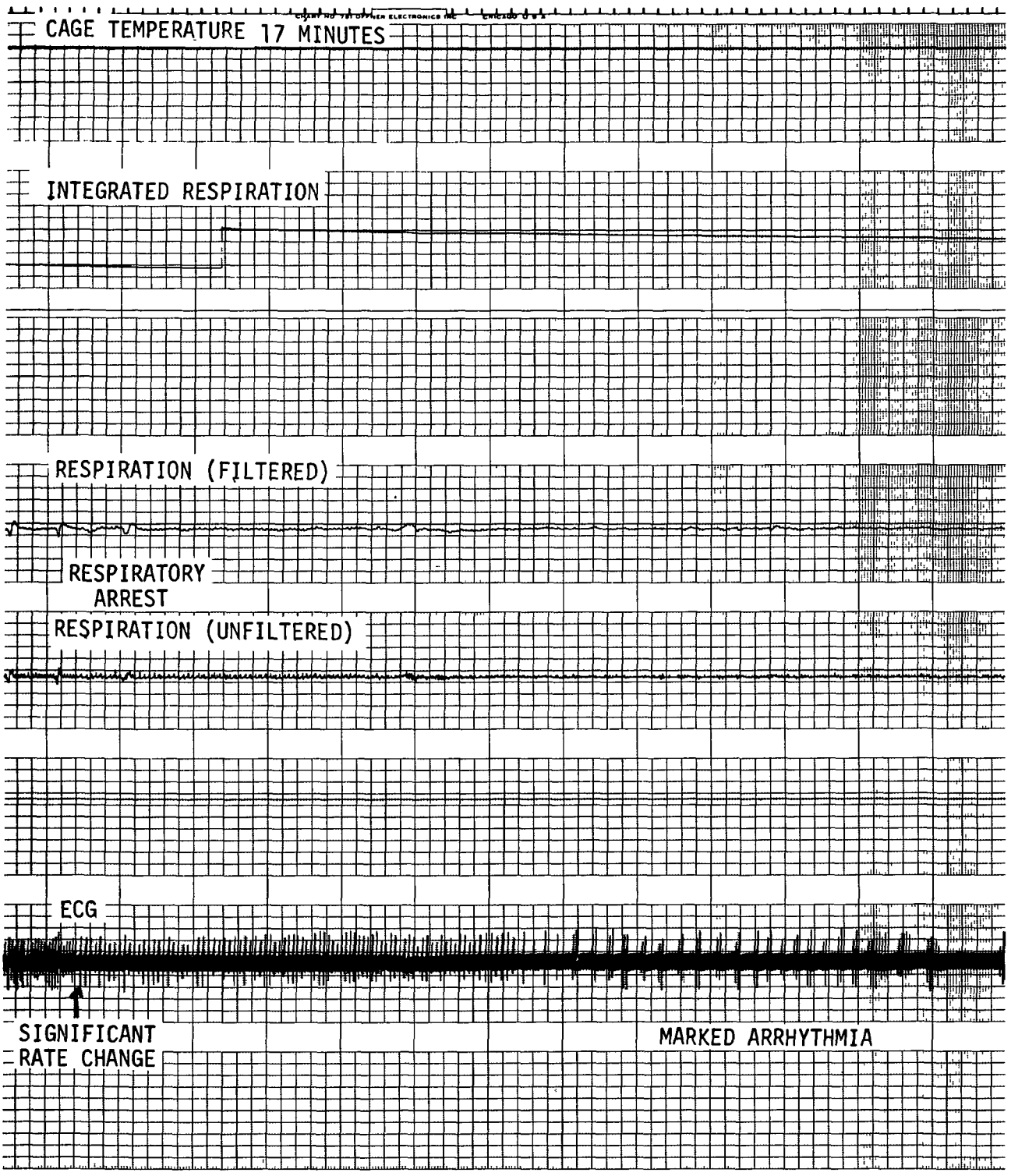

FIGURE 12. REPRODUCED BOEING TEST PHYSIOLOGICAL DATA

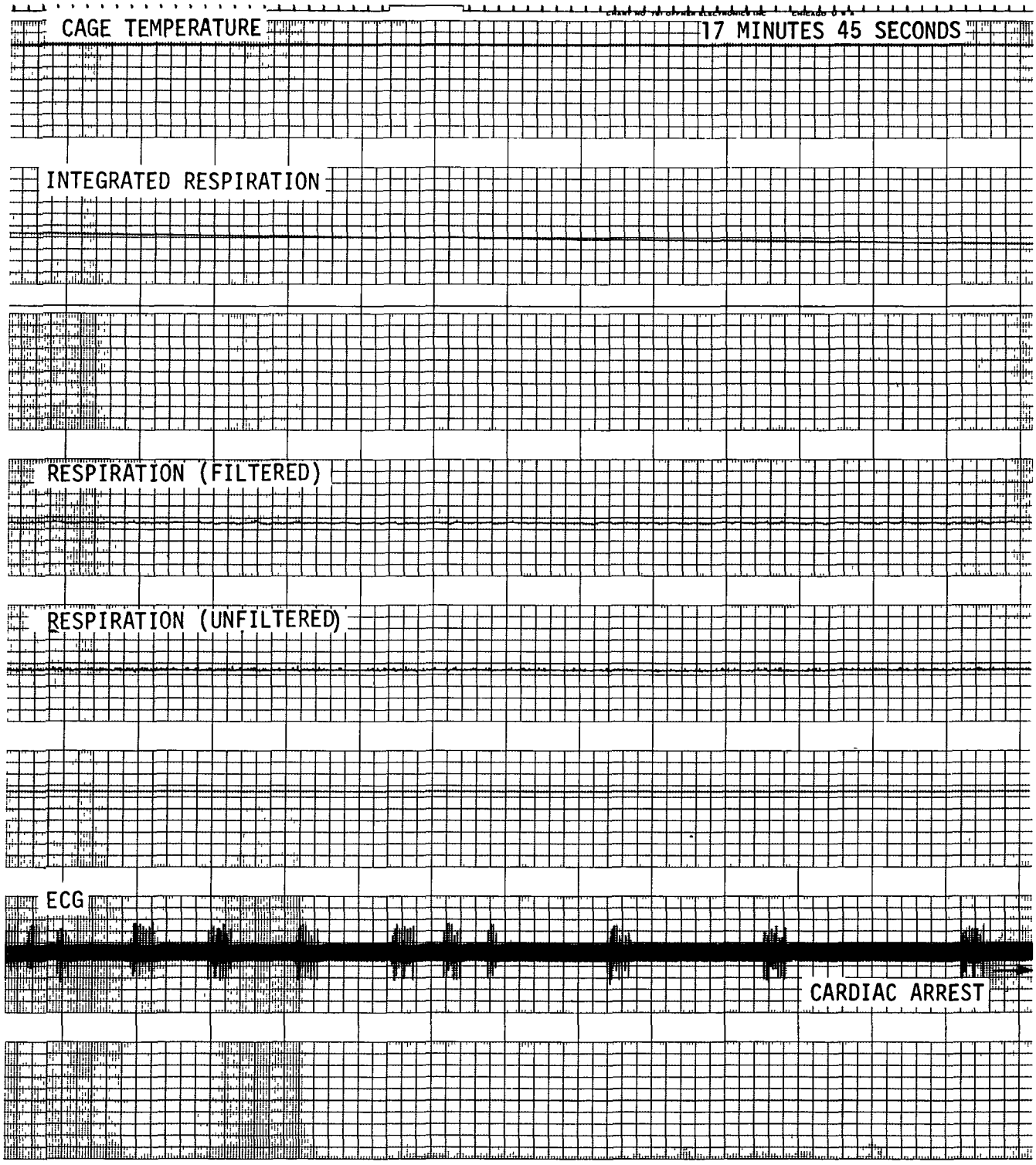

FIGURE 13. REPRODUCED BOEING TEST PHYSIOLOGICAL DATA

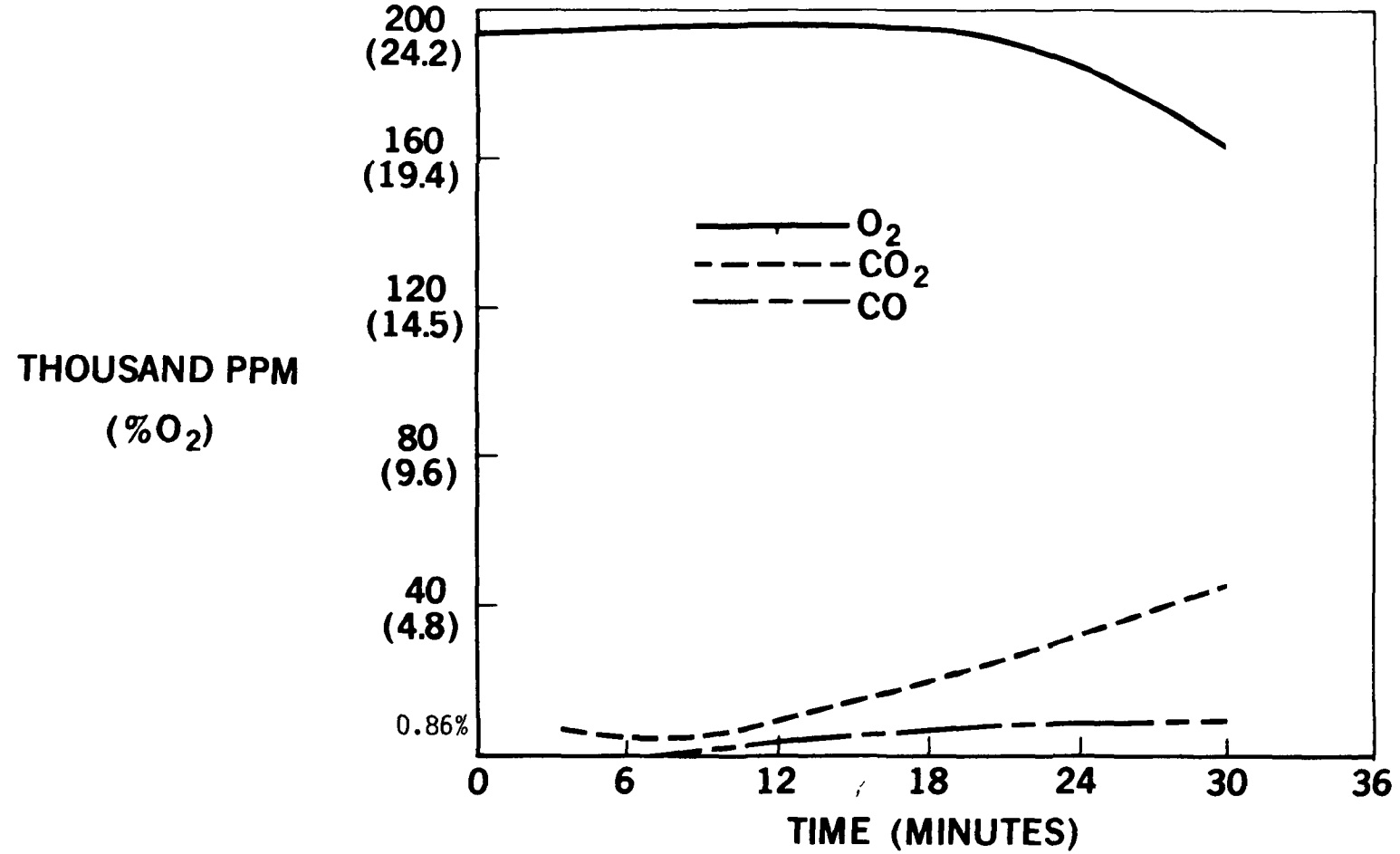

FIGURE 14. BOEING TEST DATA
MAJOR GASES IN
ENCLOSURE

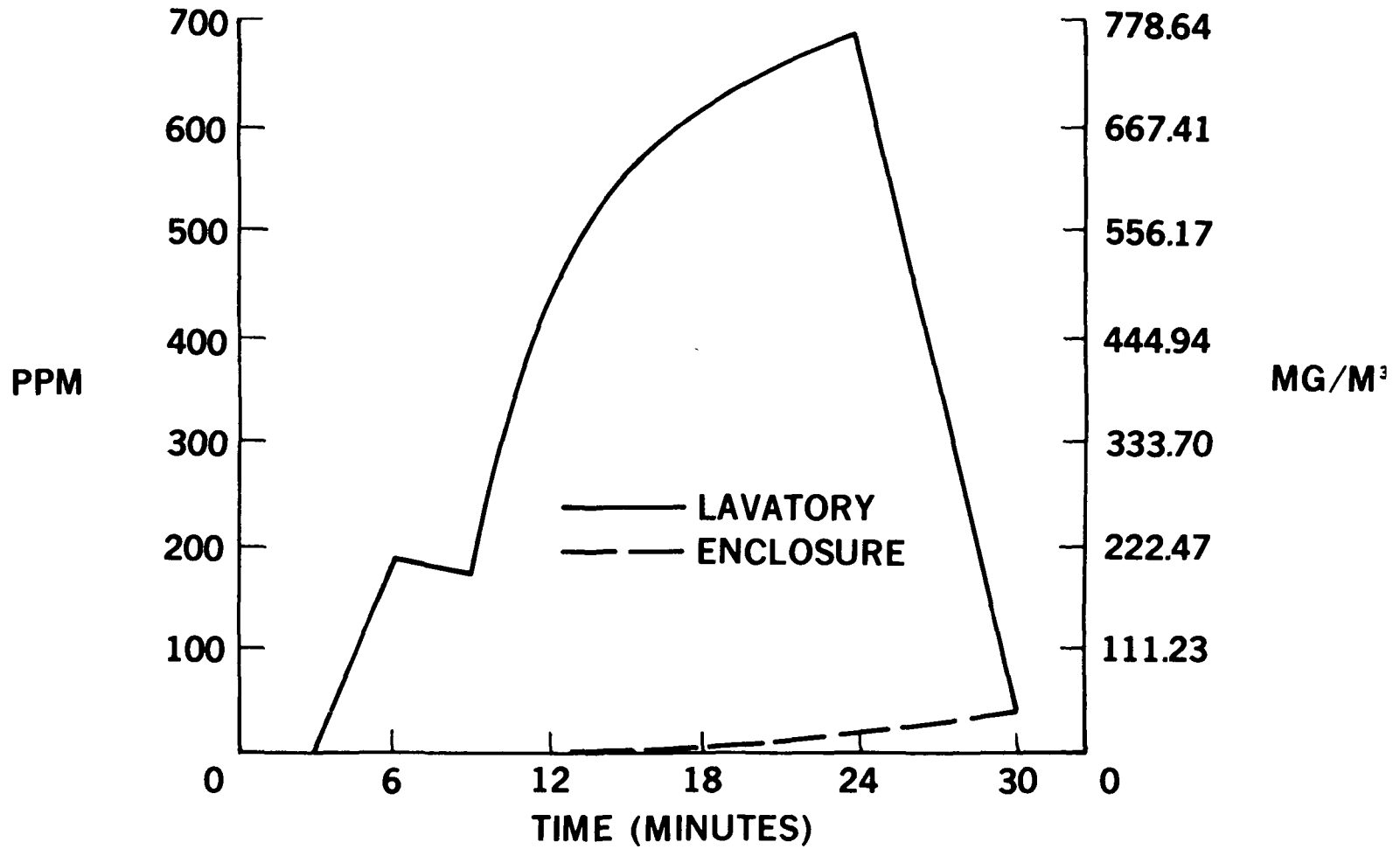

FIGURE 15. BOEING TEST DATA
CONCENTRATION OF HCN

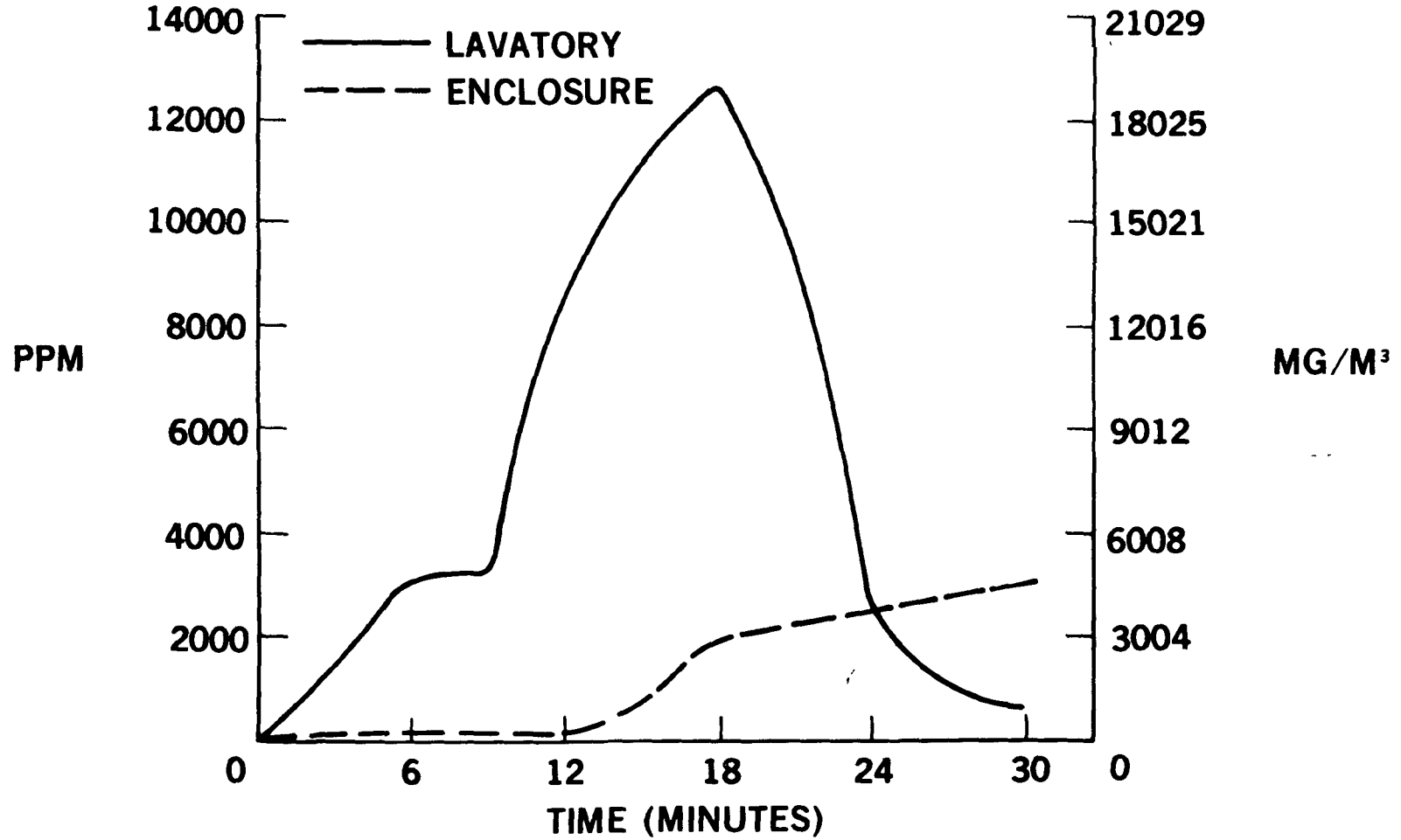

FIGURE 16. BOEING TEST DATA
CONCENTRATION OF HCI

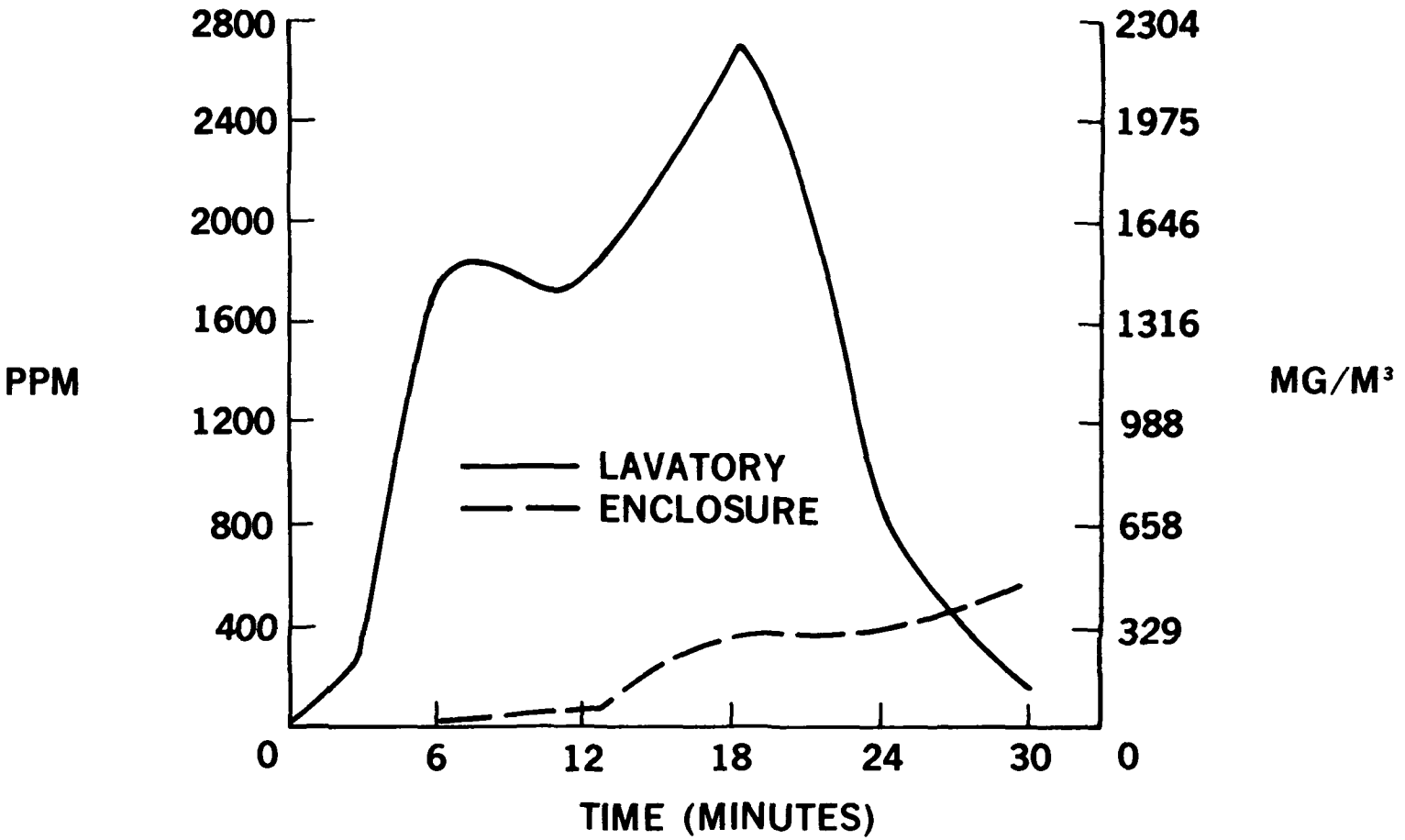

FIGURE 17. BOEING TEST DATA
CONCENTRATION OF HF

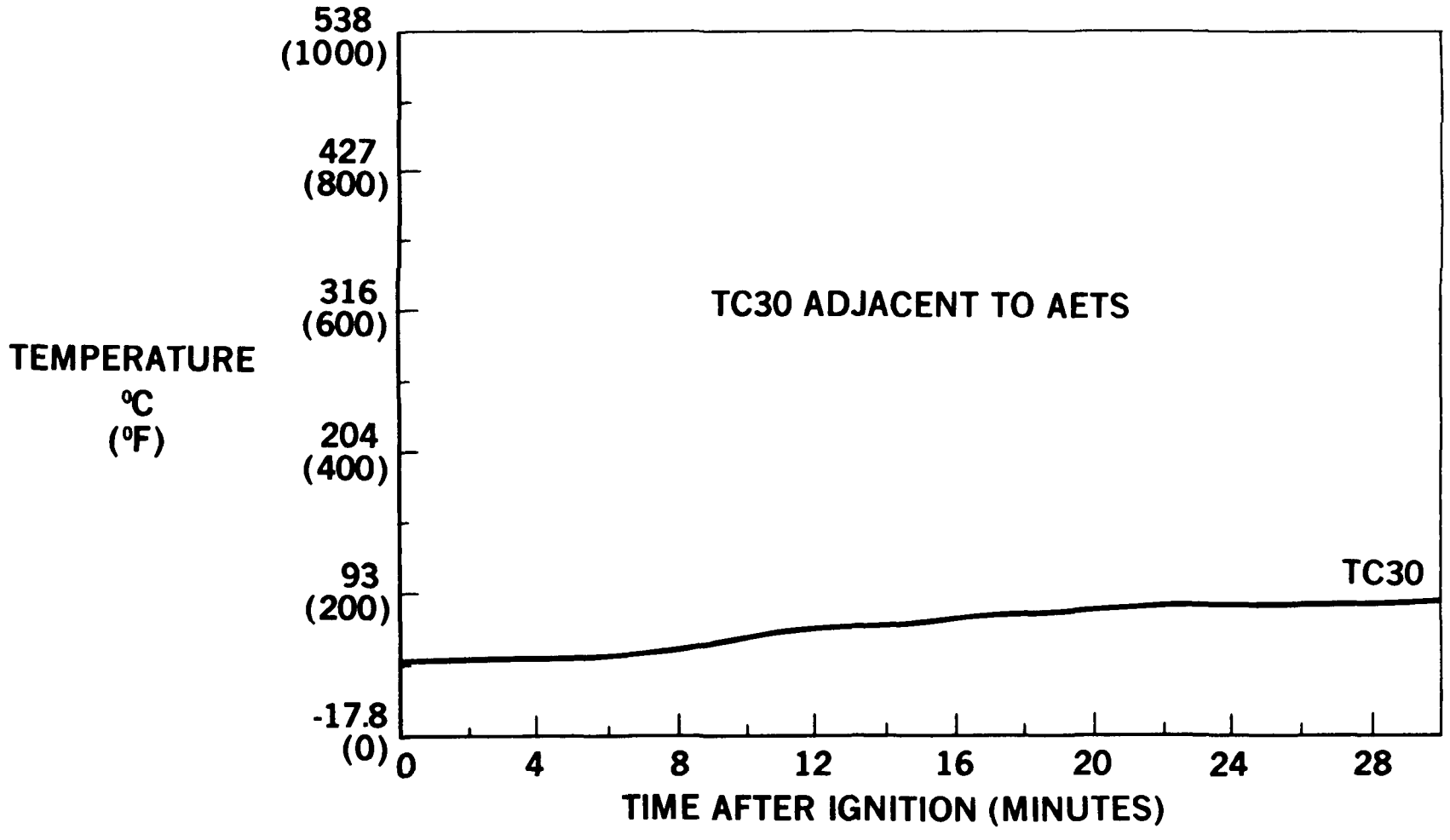

FIGURE 13. BOEING TEST DATA
AIR TEMPERATURE IN
ENCLOSURE

PHYSIOLOGICAL EFFECT	MINUTES INTO TEST
CARDIAC ARRHYTHMIA BEGAN AT	1.3
BRADYCARDIA (SLOWING OF HEART RATE) FROM 520 BPM TO 110 BPM NORMAL RATE ≈ 400-450	1.5
HEART RATE (H.R.) FASTER AND IRREGULAR	2.6
H.R. MORE REGULAR	5.5
TEST FIXTURE FLOODED WITH LIQUID N_2	10.0
MARKED BRADYCARDIA AND ARRHYTHMIA	11.0
HIGH RESPIRATORY AND PHYSICAL ACTIVITY	11.5
BRADYCARDIA AND ARRHYTHMIA	13.5
HIGH H.R. WITH ARRHYTHMIAS	17.0
STOPPED N_2 INFLOW	20.0
HIGH RESPIRATORY AMPLITUDE	20.5
CARDIAC RHYTHM RECOVERING	25.0
SUBJECT REMOVED. SURVIVED, IN FAIR CONDITION	27.0

TABLE 1 CFS PHYSIOLOGICAL DATA SUMMARY

ECG/RESPIRATION	MINUTES INTO TEST
FIRST ARRHYTHMIA (SKIPPED BEAT)	7.65
FOURTEEN MORE SKIPPED BEATS BY	9.0
TWO MORE SKIPPED BEATS BY	10.0
ECG AMPLITUDE DIMINISHED	10.0
BRADYCARDIA AND RESPIRATORY ARREST	17.0
CARDIAC ARRHYTHMIAS, MARKED BRADYCARDIA, SPORADIC ARREST FOR 2-7 SECONDS	17.25
PERMANENT CARDIAC ARREST	18.0

THE ECG AND RESPIRATORY RECORDS ALSO APPEARS TO REFLECT PHYSICAL ACTIVITY OF THE INSTRUMENTED SUBJECT.

* CAGE TEMPERATURE WENT OUT OF SCALE. MAXIMUM TEMPERATURE DESIGNED FOR WAS 65° C. BOEING RECORD SHOWED 196° F (91° C).

TABLE 2 BOEING TEST
PHYSIOLOGICAL DATA
SUMMARY

DISCUSSION

The physiological responses which have been observed in the instrumented subject in these tests, principally in the Boeing test and in the prior MDC CFS test, include:

1. Cardiac responses - bradycardia (slow heart rate), arrhythmias possibly of two or three types, and cardiac arrest.

2. Respiratory responses - reduction of amplitude, change of rate, reduction of minute volume.

3. Electromyographic responses (EMG) - of the torso. During physical activity of the subject, characteristic changes occur in the ECG baseline which have been related to muscle activity, in the laboratory and in the burn tests. Activity level can be estimated from the magnitude of EMG noise generated in the ECG record. It may be possible to identify convulsive activity, but this premise requires laboratory verification.

The activity responses observed in the mice in the second compartment of the Mark I cage were:

1. Vigorous activity, initially, on the exercise wheel and climbing the sides and under side of the cage mesh.

2. Stumbling and falling on the exercise wheel and riding up with the turning wheel nearly to the top of the turn. This effect was observed at approximately eleven minutes. This may be called the TUF.

3. Dropping from the underside of the cage top at approximately twelve minutes, apparently unable to muster the strength or coordination to hang on to the mesh as they had been doing. This may also be regarded as the TUF. Normally, these S_S were able to climb up, over and down again with ease.

4. Convulsive jumping at approximately fifteen minutes.

5. Collapse and sporadic convulsions at sixteen minutes (obscured after 16 minutes).

The behavior of the mice follows the pattern observed by most investigators, is a valid and useful method of monitoring, and little more needs to be said about this aspect. However, the physiological records when correlated with specific events of the test such as temperature increase, the time of appearance of the various fire gases (see Special Report, Appendix), and their rise in concentrations in time, give rise to certain questions regarding the physiological mechanisms of the recorded responses. Some questions are raised

regarding the mechanisms of similar cardiac responses when the S_S are exposed to fire gases, simple hypoxia, or various extinguishing agents such as nitrogen, CO_2, and the Halons. Why do all these different species produce cardiac effects that are so similar? Are the responses mediated by the same or different physiological mechanisms? And what are the mechanisms involved?

In the Boeing test the responses appeared to correlate with the build-up of HF and HCl in the enclosure. There was no O_2 deficit in the enclosure, so if hypoxia were the basic cause of cardiac effects, it probably was due to the presence of fire gases, or greatly diminished respiration from the irritating smoke, or both. Sporadic increases in respiratory rate and amplitude with or without an increase in physical activity, suggest that this may be the correct hypothesis. On the other hand, in the MDC CFS test, the rapidity of the onset of cardiac response, probably before hypoxia could have caused it, suggests that another mechanism may be in action. Other observations in MDC fire testing tends to support the latter hypothesis.

Other questions arise: Are the rats's cardio-respiratory responses similar to those expected in the human? Which is more responsive to these stimuli? Can the human response be scaled 1:1, or will it be different and in which direction?

1. There was no appreciable reduction of O_2 (20.+%) in the enclosure by the time of death (TOD) at 18 minutes.

2. There was no significant increase in CO_2 (2.0%) in the enclosure by the time of death at 18 minutes.

3. There was no significant increase in CO (0.33%) in the enclosure by the time of death at 18 minutes. CO first appeared in the enclosure at approximately 10 minutes and reached approximately 3300 ppm (0.33%) by 18 minutes (TOD) giving approximately 8 minutes of exposure at low concentrations. This undoubtedly made a minor contribution to the hypoxia.

4. HCN had barely made its appearance in the enclosure by 18 minutes (TOD). Therefore, HCN appears not to have been a significant factor.

5. HF appeared in enclosure at 6 minutes, slowly increased linearly, to approximately 65 ppm by 13 minutes, then rapidly increased to approximately 325 by TOD (18 minutes).

6. HCl was barely detected until 12 minutes when it rose sharply to nearly 2000 ppm by TOD (18 minutes).

7. Enclosure temperature remained fairly constant at approximately 100°F for 6 minutes, rose to 48.9°C (120°F) at 8 minutes, 60.°C (140°F) at 12 minutes and to 71.1°-73.8°C (160-165°F) at 18 minutes (TOD).

Discussion

Thus, three known factors appear to be the most significant in the death of the subjects.

1. Cage temperature increase to approximately 73.8°C (165°F)at 18 minutes (TOD).

2. Sudden increase in HCl concentration from near zero at 12 minutes to nearly 2000 ppm at 18 minutes (TOD).

3. Sudden increase in HF concentration from approximately 65 ppm at 12 minutes to approximately 350 ppm at 18 minutes (TOD).

It is very probable that these three factors exerted a synergistic effect to cause the expiration of subjects. The probable mechanism is most likely the onset of severe hypoxia, in spite of adequate O_2 present in the enclosure, produced by severe pulmonary edema and/or hemorrhage induced by the irritant and corrosive action of HCl and HF. High environmental temperature undoubtedly intensified the reactivity of HCl and HF. The possibility of other toxic gases which were not measured for, e.g., NO_2, SO_2, aldehydes, etc., should not be discounted. Also, the possibility of the "adrenalin effect" in the presence of halogenated hydrocarbons should be considered.

Conclusions

On the basis of the information available, and realizing that unknowns are involved, it can be tentatively concluded that the subjects expired from the combined hypoxic effects of primarily HCl, HF, and high temperature, with minor contributions to hypoxia being made by CO and possibly other unknown gases.

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SESSION C: POLYMERIC MATERIALS

Session Chairman: John A. Parker
Ames Research Center

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OVERVIEW OF FIREMEN PROGRAM AT AMES RESEARCH CENTER

Demetrius A. Kourtides
Chemical Research Projects Office
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Moffett Field, California 94035

Overview of Firemen Program at Ames Research Center

Demetrius A. Kourtides

ABSTRACT

The Ames Firemen Program is described. The key elements of the program involve (a) the development and evalation of aircraft interior composite panels (b) the thermochemical and flammability characterization of thermoset and thermoplastic resins and (c) the evolution of fire resist aircraft seat components. The first two elements are described in this paper.

In the first area of interior panels, the processing and evaluation of composites fabricated from currently used resins and advanced fire resistant resins is described. Laboratory test methodology used to qualify candidate composite materials includes thermochemical characterization of the polymeric compounds and evalution of the completed composite assemblies for flammability, fire endurance and smoke evolution. The use of these test methods will be discussed in comparing advanced lamination resins and composites consisting of modified phenolics, bismaleimide and polyimide, with conventional baseline materials consisting of epoxy. Particular attention is given to the development of assessment criteria such as fire endurance, or fire containment capability, and smoke produced when these composites are subjected to a fire enviroment.

In the second area of thermoplastic resins, the thermochemical and flammability characteristics of some typical thermoplastic materials currently in use and others being considered for in aircraft interiors are described. The properties studied included (1) thermomechanical properties such as glass transition and melt temperature, (2) changes in polymer enthalpy, (3) thermogravimetric analysis in anaerobic and oxidative environments, (4) oxygen index, (5) smoke evolution, (6) relative toxicity of the volatile products of pyrolysis, and (7) selected physical properties. The generic polymers that were evaluated included: acrylonitrile butadiene styrene, bisphenol A polycarbonate, 9,9 bis (4-hydroxyphenyl) fluorene polycarbonate-poly (dimethylsiloxane) block polymer, phenolphtalein-bisphenol A polycarbonate, phenolphthalein polycarbonate, polyether sulfone, polyphenylene oxide, polyphenylene sulfide, polyaryl sulfone, chorinated polyvinyl chloride homopolymer, polyvinyl fluoride, and polyvinylidene fluoride. Processing paramenters, including molding characteristics of some of the advanced polymers, are described. Test results and relative rankings of some of the flammability, smoke, and toxicity properties are presented. Under these test conditions, some of the advanced polymers evaluated were significantly less flammable and toxic or equivalent to polymers in current use.

Overview of Firemen Program at Ames Research Center

Presented at the FIREMEN Program Review

by D. A. Kourtides

April 14, 1978

Figure 1. I will give a brief overview of the Firemen Program at Ames. Before I begin, I would like to acknowledge Boeing Commercial Airline Co. for providing some of the data to be presented here.

Figure 2. The objectives of the program as stated here are to provide an understanding and certain selection criteria for the development and use of fire-resistant materials for aircraft interiors. The primary objective is to resuce flame propagation, smoke, and toxicity in thd cabin and to increase fire containment capability in selected areas such as lavatories and cargo compartments. In this presentation I will summarize primarily 2 areas:

(a) Aircraft interior panels

(b) Thermoplastics--which would be useable either as moldings or films in aircraft interiors.

Figure 3. The present contractual activities are shown here. We have an ongoing program at Boeing for the development of fire-resistant films. A program has just been initiated also for the development of fire-resistant inks for possible replacement of the acrylic inks. The details of these programs will be described by Gerald Johnson. We are presently in phase II for the evaluation of fire-resistant aircraft seat components at Douglas. We are contemplating efforts for flashover laboratory tests for the decorative surface and we are initiating an effort for the evaluation of fire-resistant polyimide foam as an edge closeout for panels.

Figure 4. The program plan is shown here. Phase I and Phase II of the program involved the development and evaluation of composite panels. This program is essentially completed. We are presently in Phase III and Phase IV at Boeing for the development of fire-resistnat films and inks. These programs will be discussed in detail by Gerald Johnson. The program is supported by our R & T program for the development of phosphorylated epoxy adhesives (Dr. Bilow will be describing these), transperent films and edge closeouts.
In addition, we are conducting fire containment and flashover tests at the University of California. Boeing will be fabricating both baseline and advanced panels, which eventually will be tested by FAA-NAFEC in the C-133 aircraft.

Figure 5. The program on thermoplastics has been transfered to JSC. At the present time, we are in Phase II of the aircraft seat program.
We hope to start a program on the use of advanced materials for post-crash fire protection.

Figure 6. I will briefly discuss the aircraft interior panels work.

Figure 7. The purpose of this program was to assess the relative flammability and thermochemical properties of some typical state-of-the-art and candidate experimental aircraft interior composite panels, and to develop an understanding of the relationship of flammability and thermochemical properties of these systems. Specifically, aircraft interior composite panels were characterized as to their thermal stability, oxygen index of the composite components, smoke evolution from the panels, fire containment capability or fire endurance,

identification of the pyrolysis effluents, relative toxicity of the degradation products and mechnical properties.

Figure 8. The integration of the composite panel program is shown here. A panel has been selected jointly by ARC and Boeing and these panels will be tested by JSC at the Douglas Cabin Fire Simulator. Once the film and ink development work is completed, we hope to be able to develop materials and process specification for an advanced panel configuration which could be useable to all the airfram manufacturers. In addition, the information generated on the performance of these materials could be useful to FAA for consideration in the rule making process.

Figure 9. The composite panels used by most airframe manufacturers as interior paneling are sandwich panels that vary slightly in configuration, component composition, thickness, and density depending on the type of aircraft in which they are used and the specific application. In general, the panel consists of a clear polyvinyl fluoride film which is bonded to a polyvinyl fluoride decorative film bonded to a fiberglass epoxy resin laminate. The complete laminate is bonded to an aromatic polyamide honeycomb core either when the prepreg is uncured or with a suitable adhesive bond ply depending on the resin used in the prepreg. The current method of bonding the skins to the core consists of using an epoxy resin-impregnated bond ply over which is applied the 181 E glass cloth/polyvinyl fluoride decorative laminate. The resin in the bond ply provides the adhesives to bond the skin to the honey comb and the decorative laminate to the bond ply. Curing is accomplished at approximately 100°C with vacuum bag pressure. For panels requiring decorative laminates on one side

only, the bond ply provides the backside skin. The epoxy resin used in these panels is a fire-retardant bisphenol A type epoxy resin cured with methylene dianiline.

Figure 10. Three types of advanced resin systems were used for the fabrication of the laminates used in these composites: bismaleimide, polyimide and phenolic resins. Exact formulation for the polyimide and phenolic resins was not available from the manufacturers. The bismaleimide is an addition type polimide. The resin is producedby mixing a bismaleimide with a diamine at a specified ratio resulting in a resin with controlled crosslink density. The resin polymerizes thermally without loss of volatiles. The core of this panel was filled with a quinone dioxime or polyquinoxoline foam to provide additional fire containment capability. The polymide and phenolic panels were fabricated from commercially available resins. All composites fabricated were 2.54 cm thick. The laminates were adhered to the honeycomb structure using the various types of resin-fibergalss adhesive plys indicated. It can be seen that in general, longer processing times were required for the bismaleimide and polyimide panels than the phenolic panels. Density of the panels was approximately the same (90-100 Kg/m^3).

Figure 11. In this slide we compare the oxygen index of the laminating resins with their relative anaerobic char yield. Thermo analyses of the facesheet resins were conducted on a Dupont 950 thermogravimetric analyzer (TGA) using nitrogen atmosphere at a heating rate of 10^oC/min. The polyimide resin was the most thermally stable resin followed by the modified phenolic, bismaleimide. The char yield indicated is that of the resincured to an optimum condition. The oxygen indexes

(OI) of the components comprising the composites were determined in accordance with ASTM D-2863. The oxygen index was measured using one ply laminates consisting of the 181 glass with 30-47 resin. The OI indicated is calculated based in the fraction of the resin present in the fibergalss and the fiberglass having an LOI of 100%. The specimans again were cured to an optimum condition. It can be seen that the OI increases as the char yield of the laminating resin increases. The polyimide system had the highest oxygen index followed by the phenolic system, the bismaleimide system and the baseline epoxy syste.

Figure 12. The amount of heat released from the various panels was measured using the OSU heat release rate apparatus at Boeing run at heat fluxes of 2.5 to 5.0 W/cm^2 and with specimans mounted vertically. The total heat released from the facesheet laminates is plotted against the incident heat flux on the specimans. There was a significant difference between the epoxy and polymide systems at 5.0 W/cm^2. The differences are due to the chemical structure, char formation, and amount of resin consumed in the two systems. The differences in the total heat released are greater in the higher heat flux range than the lower heat flux range.

Figure 13. The smoke emission for the systems was measured in the NBS smoke chamber. In this slide the specific optical density at 4 minutes is plotted against the heat flux to the panels. The samples were tested at 1, 2.5, and 5.0 W/cm^2 under flaming conditions. It can be seen that the smoke release rate is increased as the

heat flux was increased. This increase is due to more material becoming involved in the combustion at the higher heat fluxes. The smoke release for the epoxy system was the greatest, followed in order by the bismaleimide, modified phenolic and polyimide. It is desirable to have a D_s value of less than 100 at 2.5 W/cm^2 for materials that are proposed for aircraft interiors.

Figure 14. The panels were tested in the Ames T-3 Fire Test Facility at a heat flux of approximately 10 W/cm^2. This test provided a comparison of the fire endurance capability of the composite panels. The backface temperature rise of the panel is plotted as a function of time when the samples are subjected to this type of fire. (This is shown by the solid lines and indicated on the left side of the slide.) It can be seen that the backface temperature of the conventional epoxy composite B reached 200°C in 2.5 minutes; whereas, it took as long as 8 minutes for the foam filled bismaleimide composite A to reach a comparable backface temperature. The other composite panels, C and D, were slightly better than A. The broken line represents the front face temperature of the sample exposed to the fire and is shown on the right side of the slide. Samples were 8" x 8" x 1" thick.

Figure 15. Based on processability, cost and flammability properties, the modified phenolic facesheets were selected as the optimum system to be used in the fabrication of the advanced panel. In this slide, the comparative flammability properties of the epoxy and phenolic facesheets are summarized. It can be seen that a significant

decrease in propensity to burn, smoke evolution and heat release was achieved by the use of the modified phenolic resin in the facesheet. In addition, the amount of hydrogen fluoride was decreased by the use of polyvinyl fluoride/polycarbonate decorative film.

Figure 16. I will briefly discuss the thermoplastics work. This task has been transferred to JSC but work is continuing at ARC in the development of transparent films based on some of the thermoplastics studied.

Figure 17. The thermoplastic polymers evaluated included both state-of-the-art and other high temperature polymers. The typical polymer structure of the polymers is shown here. Polymers were evaluated as injection molded or extruded sheets and as films. The polymers that were evaluated included: acrylonitrile butadiene styrene, bisphenol A polycarbonate, 9,9 bis (4-hydroxyphenyl) fluorene polycarbonate-poly (dimethylsiloxane) block polymer, phenolphthalein-bisphenol A poly-carbonate, and phenolphthalein polycarbonate.

Figure 18. Polyether sulfone, poly-phenylene oxide, polyphenylene sulfide, polyaryl sulfone, chlorinated polyvinyl chloride homopolymer, polyvinyl fluoride, and polyvinylidene fluoride are shown here. Processing parameters, including molding characteristics of some of the advanced polymers, were also studied.

Due to the shortness of time, I will only summarize some of the flammability properties of these polymers.

Figure 19. The char yield of the polymers was determined at 800°C in nitrogen and air. Vc is defined as the percent weight remaining at the temperature indicated. The anaerobic Vc is considered to be more relevant since it represents more likely the fire environment.

Figure 20. In this slide, we compare the relative anaerobic char yield of the polymers at 800°C with the oxygen index at 23°C. Parker and Winkler in 1968 and later in 1972 and 1975 with other coauthors have shown a direct relationship of OI of thermoset polymers to their anaerobic char yield. Van Krevelen has shown a similar relationship with other thermoplastic polymers such as polyethylene and polypropyline. The same relationship can be observed in this study. It can be seen that, in general, polymers with high char yield exhibit a high oxygen index. Chlorinated polyvinyl chloride homopolymer (samples 17 and 25) exhibit a high oxygen index and a relatively low char yield. The char yield shown here has been adjusted to include the equivalent of 0.539 g of HCl per 1.0 g of initial sample of polymer combusted. It is known (47) that HCl is a flame inhibitor and the high oxygen index is attributed to the quenching effect of the HCl during the test. The d relationship of rc and OI indicates that possibly rc is a key criterion for the selection of thermally stable polymers for critical applications such as aircraft interiors.

Figure 21. The relative flammability characteristics of these polymers are shown here. For comparative purposes, the values of the material properties are indicated in terms of percent, 100% indicating the most desirable fire-safe material properties.

The properties indicated are char yield, percent light transmittance at 4 minutes, oxygen index and relative toxicity as measured using the NASA-USF toxicity chamber.

To rank materials, it is desirable to develop a "fire safety equation" that would assign weight to specific measurements of each variable. That is, oxygen index, smoke evolution, toxicity and char yield of each polymer. Development of such an equation is dependent on the identification of the variables to be measured, determination of the importance of each variable to the real aircraft fire situation, selection of measurement techniques for each variable, and determination of the weight to be assigned to the measurement of each specific variable to reflect the real fire situation. This is an extremely difficult task and will be discussed later.

Figure 22. In this case we assumed equal weight assignment to each flammability parameter and used the percent values indicated previously for an over simplified relative ranking of the polymers. The relative fire resistance of the polymers is shown against their relative char yield. It is shown that polymers with high char yield possess high relative fire resistance.

Figure 23. In summary, we have completed jointly with Boeing the evaluation of 13 types of composite panels based on the following four laminating resins: epoxies, modified phenolics, polyimides and bismaleimides. Based on processing, cost and combined flammability porperties, the phenolic norolac resin has been selected as the optimum laminating resin for fabricating advanced panels. These advanced panels are

currently being constructed by Boeing into lavatory structure for testing at the Douglas Cabin Fire Simulator. The thermoplastics program is currently being sponsored by JSC. The screening of candidate seat materials has been completed.

Figure 24. Our plan is to complete the panel development in the area of:

(a) fire-resistant films which can be used either in combination or without PVF.

(b) Phosphorylated epoxy adhesive and

(c) fire resistant inks.

We anticipated to provide material and process specifications for these materials systems in addition to materials which can be tested under full scale conditions.

AERONAUTICAL MATERIALS AND STRUCTURES

SYSTEMS TECHNOLOGY

OVERVIEW

FIREMEN—FIRE RESISTANT MATERIALS

RTOP 510-56-01

D. A. KOURTIDES

FIREMEN PROGRAM REVIEW
NASA AMES RESEARCH CENTER
APRIL 13, 14, 1978

Fig. 1

PROGRAM OBJECTIVE: AERO MATERIALS & STRUCTURES SYSTEMS TECHNOLOGY
SPECIFIC OBJECTIVE: FIREMEN—FIRE RESISTANT MATERIALS

- **RTOP OBJECTIVE (510-56-01)**

  TO PROVIDE THE MATERIALS TECHNOLOGY REQUIRED TO MAKE FUTURE AIRCRAFT MATERIALS, STRUCTURES AND SUBSYSTEMS AS FIRE RESISTANT AS FEASIBLE, AND TO ACCELERATE THE TRANSFER OF THIS TECHNOLOGY TO AIRCRAFT MANUFACTURERS.

- **TARGETS**
  - PROVIDE MATERIALS TECHNOLOGY FOR REDUCING FLAME PROPAGATION, SMOKE, AND TOXICITY IN CABIN
  - INCREASE FIRE CONTAINMENT CAPABILITY IN SELECTED AREAS OF THE CABIN/CARGO
  - EVALUATE FIRE-RESISTANT TRANSPARENT DUST COVERINGS
  - DEVELOP ADVANCED SEAT CUSHION SYSTEMS
  - PROVIDE MATERIALS TECHNOLOGY FOR FIRE- RESISTANT FILMS, ADHESIVES AND INKS

Fig. 2

PROGRAM OBJECTIVE: AERO MATERIALS AND STRUCTURES SYSTEMS TECHNOLOGY
SPECIFIC OBJECTIVE: FIRE RESISTANT MATERIALS
RTOP: 510-56-01

PROGRAM PLAN, FY '78

NO.	ACTIVITY	NET R&D $K		DURATION
1.	NAS2-7978, MOD. NO. 3, "DEVELOPMENT AND EVALUATION OF INTERIOR PANEL COMPOSITES AND FILMS," BOEING.	99(PY77)		9/77-9/78
2.	RFP 2-27132, "DEVELOPMENT AND EVALUATION OF INKS," BOEING.	99		1/78-1/79
3.	NAS2-9337, "DEVELOPMENT OF FIRE-RESISTANT AIRCRAFT SEAT," DOUGLAS.	99		10/77-10/78
4.	RFP 2- , "FLAME PROPAGATION, FLASHOVER TESTS OF DECORATIVE FILMS/INKS," BOEING.	32		3/78-3/79
5.	NAS-2-7980, "EVALUATION OF FIRE-RESISTANT EDGE SEALS FOR PANELS," HITCO.	35		3/78-3/79

Fig. 3

PROGRAM OBJECTIVE: AERO MATERIALS & STRUCTURES SYSTEMS TECHNOLOGY
SPECIFIC OBJECTIVE: FIRE RESISTANT MATERIALS - FIREMEN

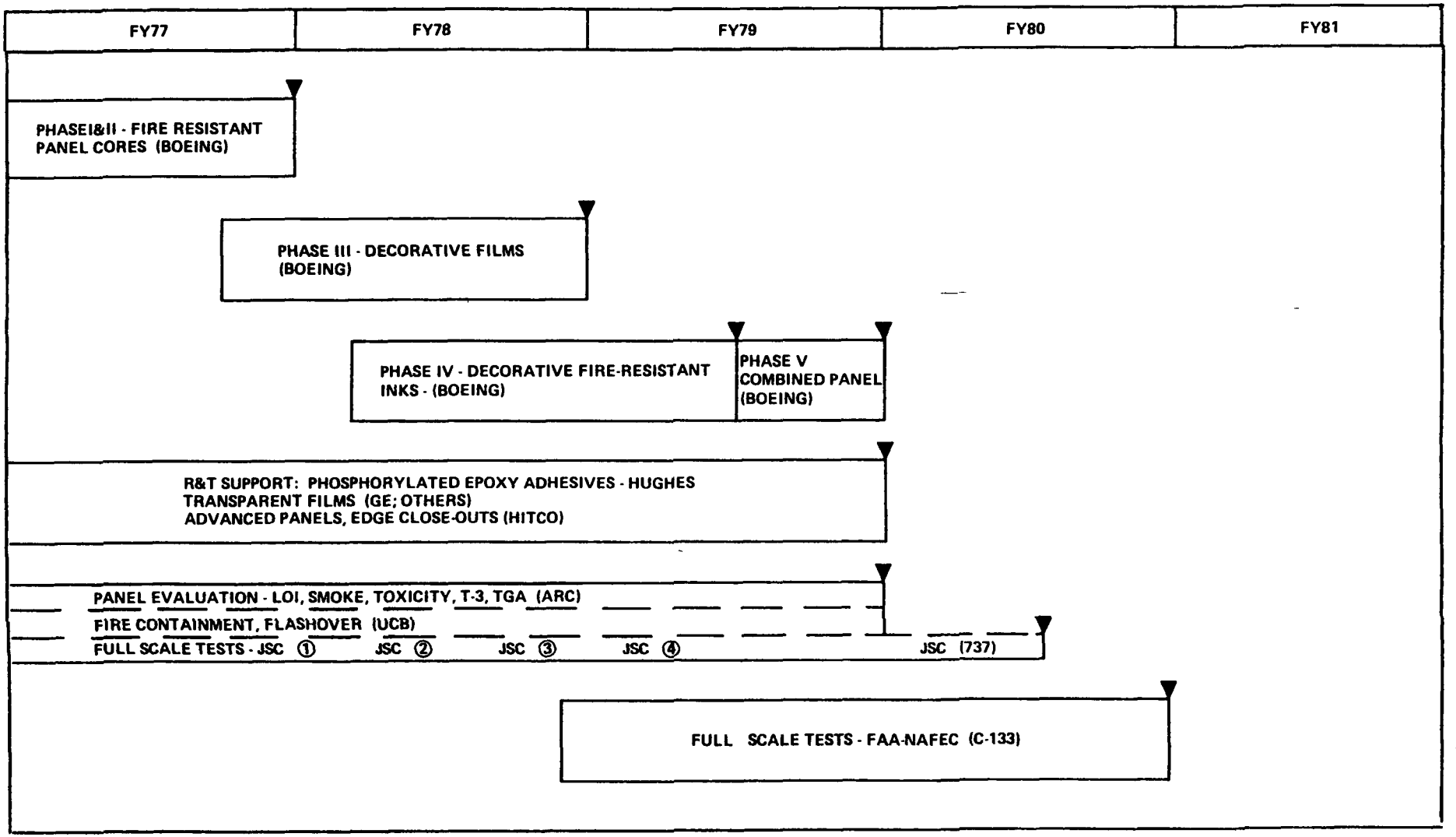


Fig. 4

PROGRAM OBJECTIVE: AERO MATERIALS & STRUCTURES SYSTEMS TECHNOLOGY
SPECIFIC OBJECTIVE. FIRE RESISTANT MATERIALS - FIREMEN

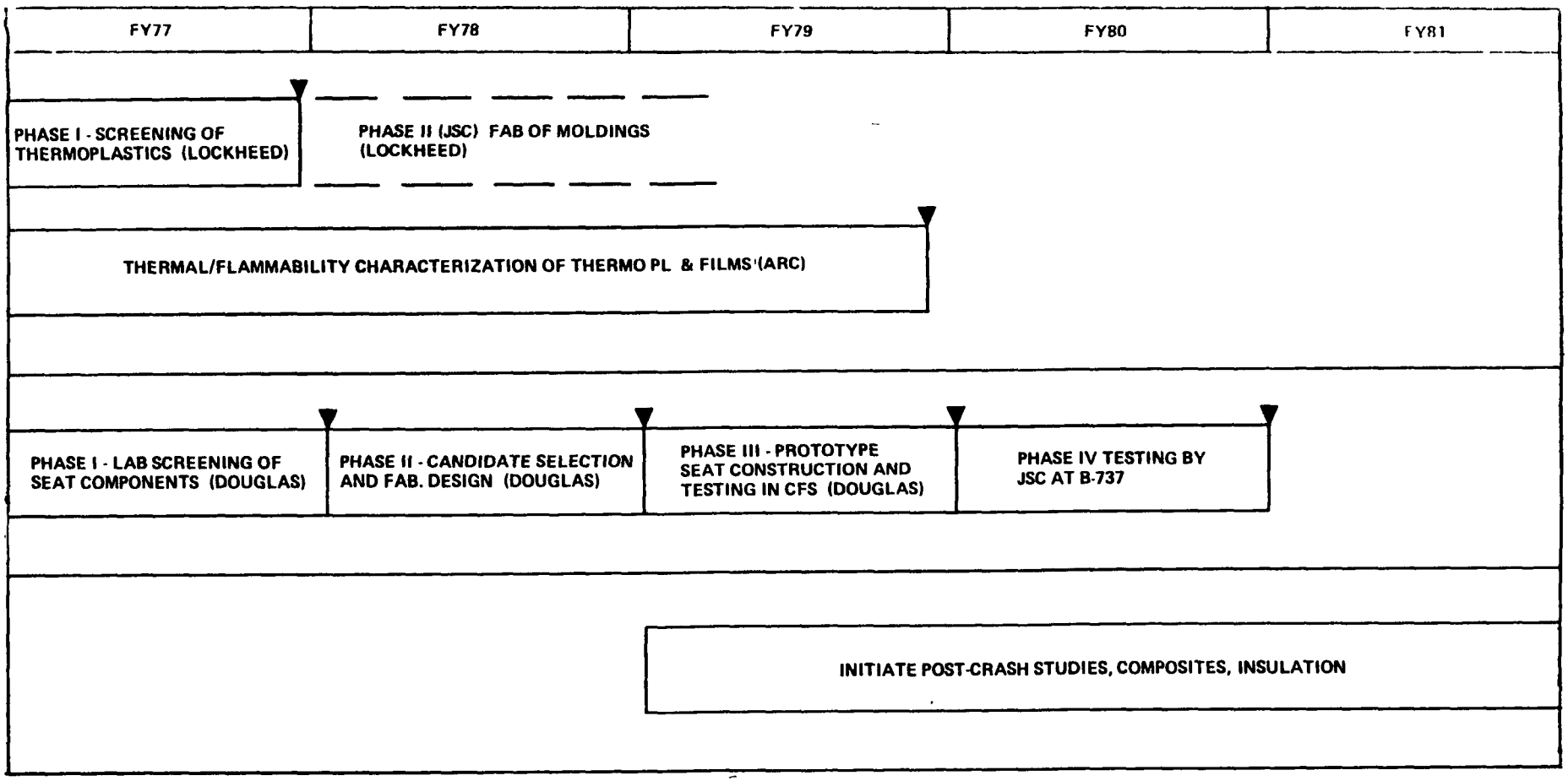


Fig. 5

AIRCRAFT PANELS

Fig. 6

PROGRAM OBJECTIVES

OBJECTIVE

DETERMINE THERMAL-CHEMICAL AND FLAMMABILITY PROPERTIES OF TYPICAL STATE-OF-THE-ART AND OTHER ADVANCED AIRCRAFT INTERIOR COMPOSITE PANELS IN ORDER TO ASSESS THEIR RELATIVE FIRE RESISTANCE.

SCOPE

- DETERMINE PROPERTIES OF PANEL COMPONENTS AND PANELS
- THERMOMECHANICAL

  THERMOGRAVIMETRIC ANALYSIS
  DIFFERENTIAL THERMAL ANALYSIS

- PROCESSING

  TEMPERATURE, PRESSURE (MOLDING) AND CURE PARAMETERS

- FLAMMABILITY

  OXYGEN INDEX
  SMOKE EVOLUTION (NBS AND OSU APPARATUS)

- PHYSICAL-MECHANICAL

  FLATWISE TENSION
  COMPRESSION
  WEAR
  PEEL STRENGTH
  ELONGATION

- THERMAL

  THERMAL EFFICIENCY
  HEAT RELEASE

- TOXICITY

  APPARENT LETHAL CONCENTRATION
  TOXIC GAS EVOLUTION

Fig. 7

INTEGRATION OF COMPOSITE PANEL PROGRAM

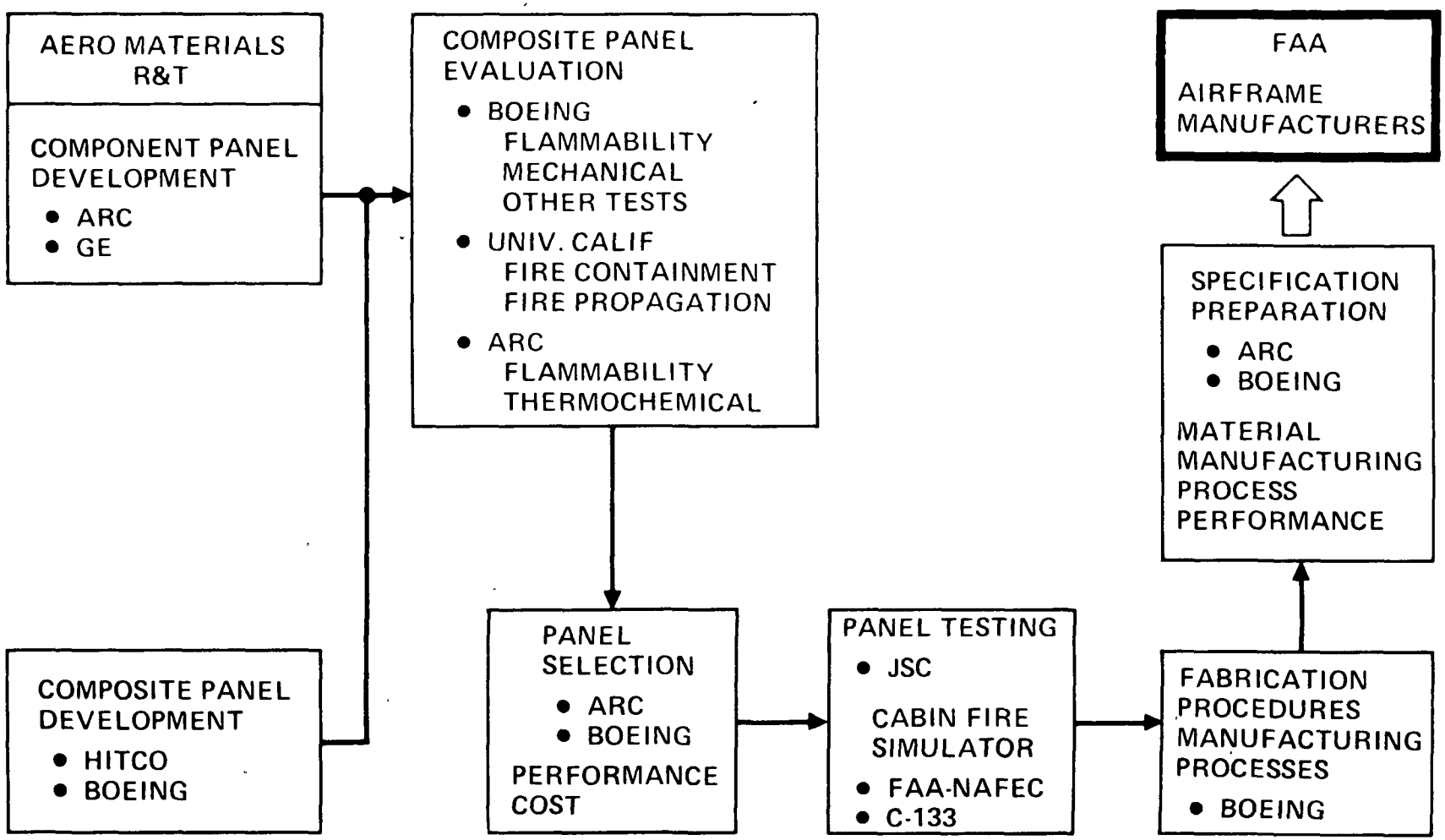


Fig. 8

BASELINE EPOXY PANEL CONFIGURATION

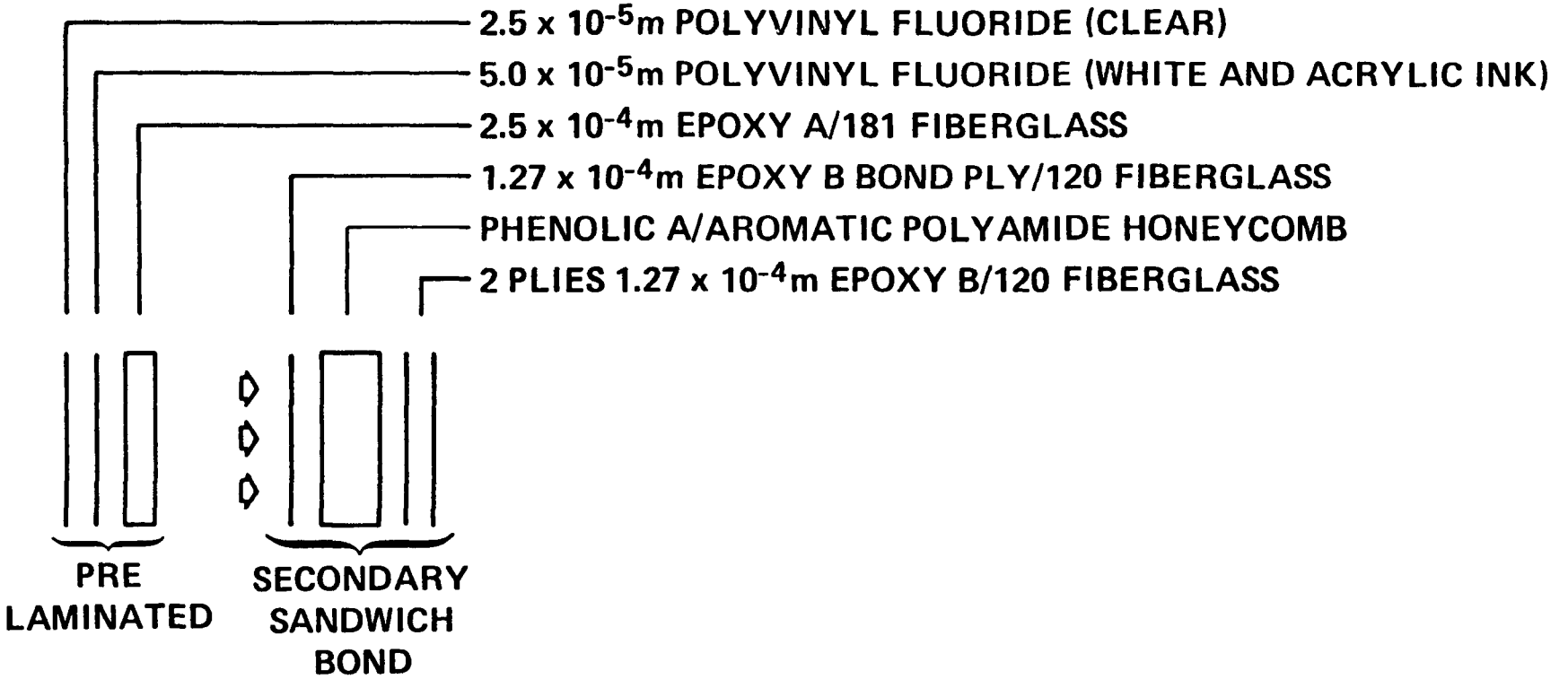
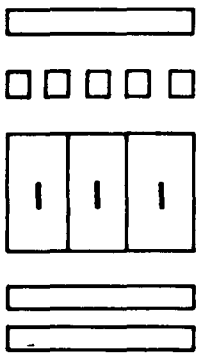


Fig. 9

ADVANCED PANEL CONFIGURATION



	BISMALEIMIDE	POLYIMIDE	PHENOLIC
	BISMALEIMIDE/181 FIBERGLASS BISMALEIMIDE/120 FIBERGLASS POLYIMIDE A ADHESIVE	POLYIMIDE B/181 FIBERGLASS POLYIMIDE B/120 FIBERGLASS POLYIMIDE C ADHESIVE	PHENOLIC B/181 FIBERGLASS PHENOLIC B/120 FIBERGLASS
	PHENOLIC A/ AROMATIC POLYAMIDE 29 kg/m^3 32 kg/m^3 QDO FOAM	POLYIMIDE C/ AROMATIC POLYAMIDE 48 kg/m^3	PHENOLIC A/ AROMATIC POLYAMIDE 48 kg/m^3
	POLYIMIDE A ADHESIVE	POLYIMIDE C ADHESIVE	
	2 PLIES BISMALEIMIDE/ 120 FIBERGLASS	2 PLIES POLYIMIDE B/ 120 FIBERGLASS	2 PLIES PHENOLIC B/ 120 FIBERGLASS
CURE CYCLE:			
PRESSURE	5.76 x 10^4 sec, 68.9 kN/m^2, 160°C	3.60 x 10^3 sec, 68.9 kN/m^2, 177°C	720 sec, 68.9 kN/m^2, 160°C
BOND	5.76 x 10^4 sec, 68.9 kN/m^2, 177°C	3.60 x 10^3 sec, 68.9 kN/m^2, 177°C	3.60 x 10^3 sec, 68.9 kN/m^2, 127°C

Fig. 10

EFFECT OF CHAR YIELD ON OXYGEN INDEX OF FACESHEET LAMINATING RESINS

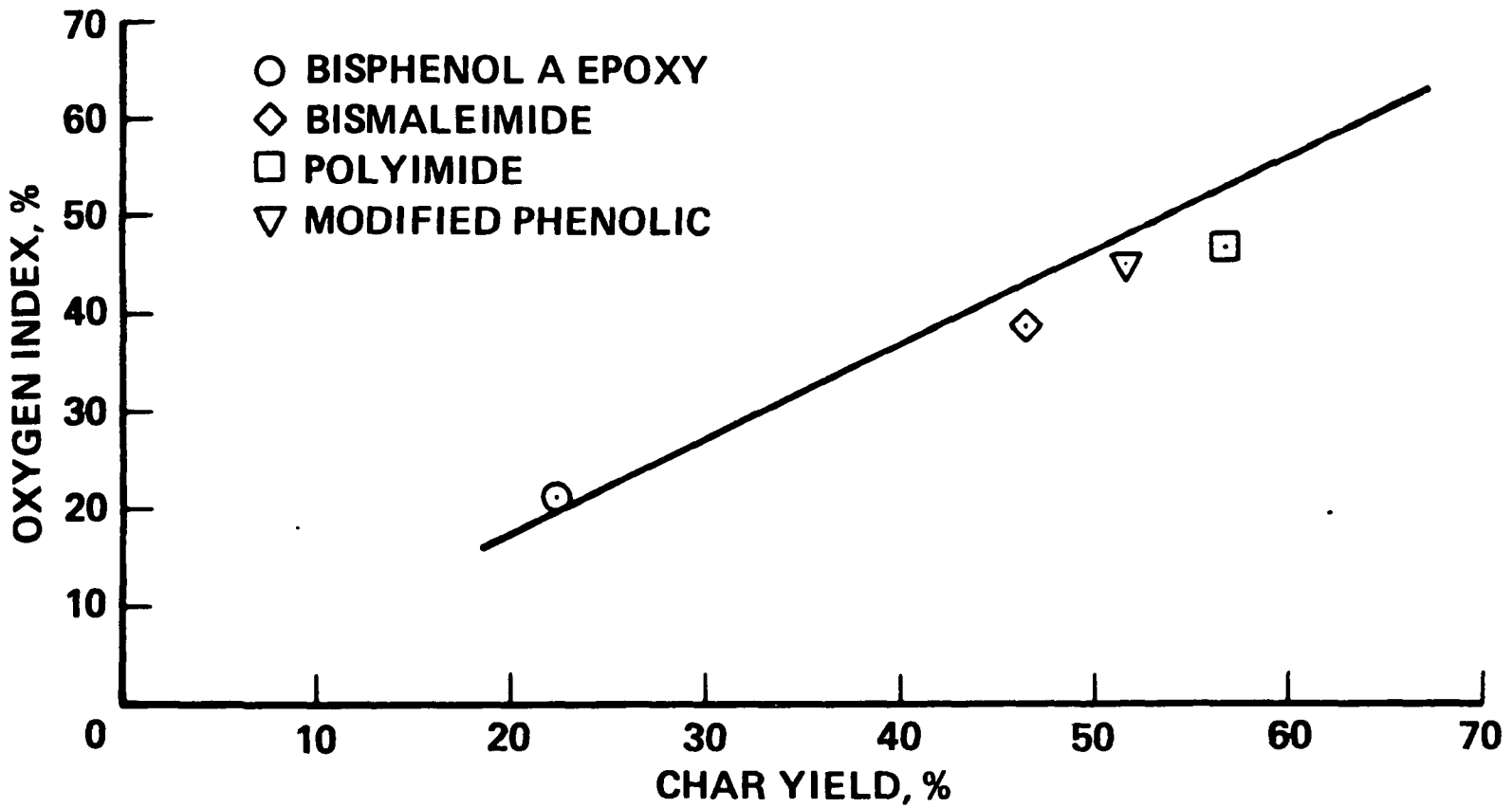


Fig. 11

EFFECT OF HEAT FLUX ON TOTAL HEAT RELEASED FROM PANELS

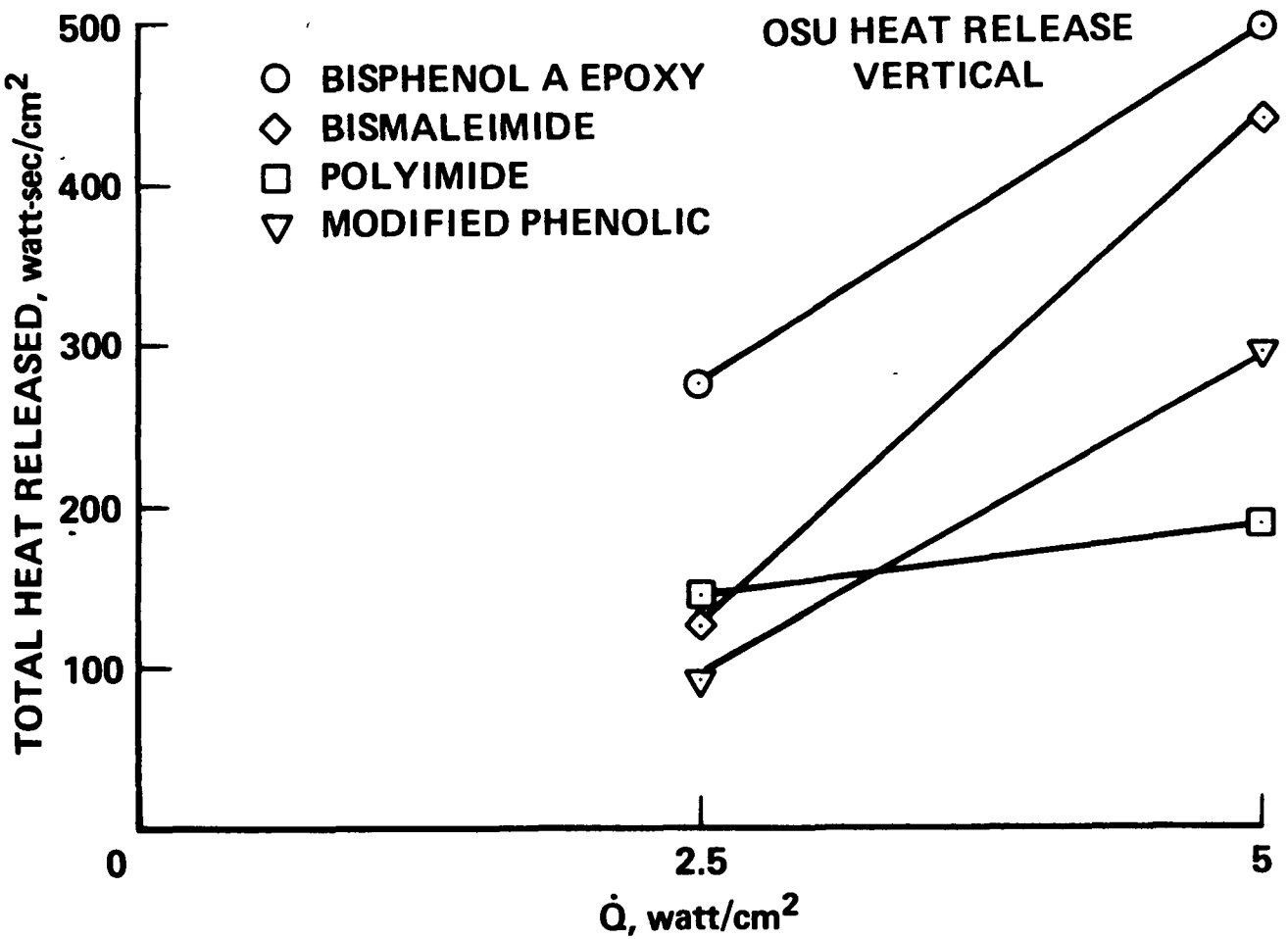


Fig. 12

EFFECT OF HEAT FLUX ON SMOKE DENSITY

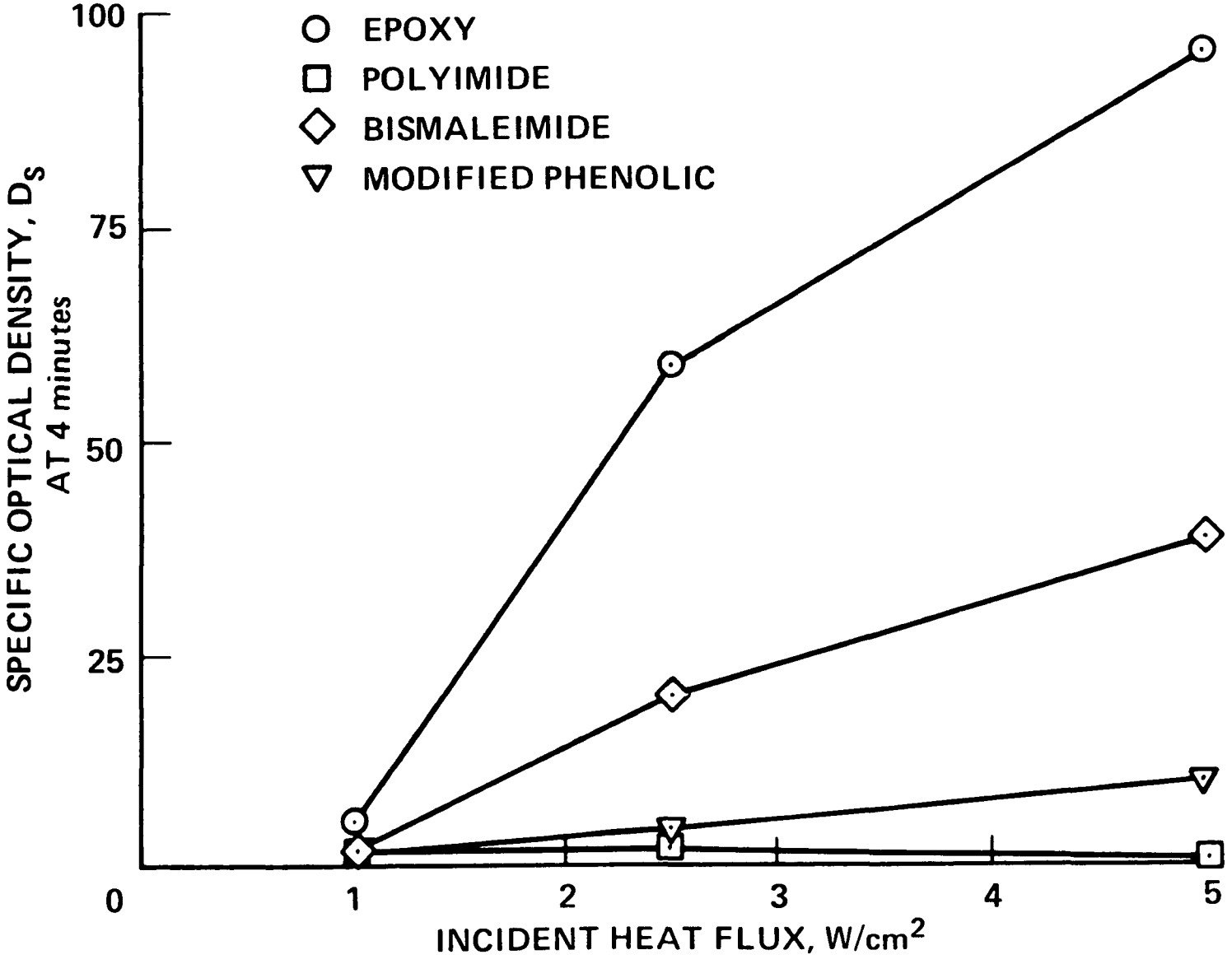


Fig. 13

THERMAL EFFICIENCY OF PANELS

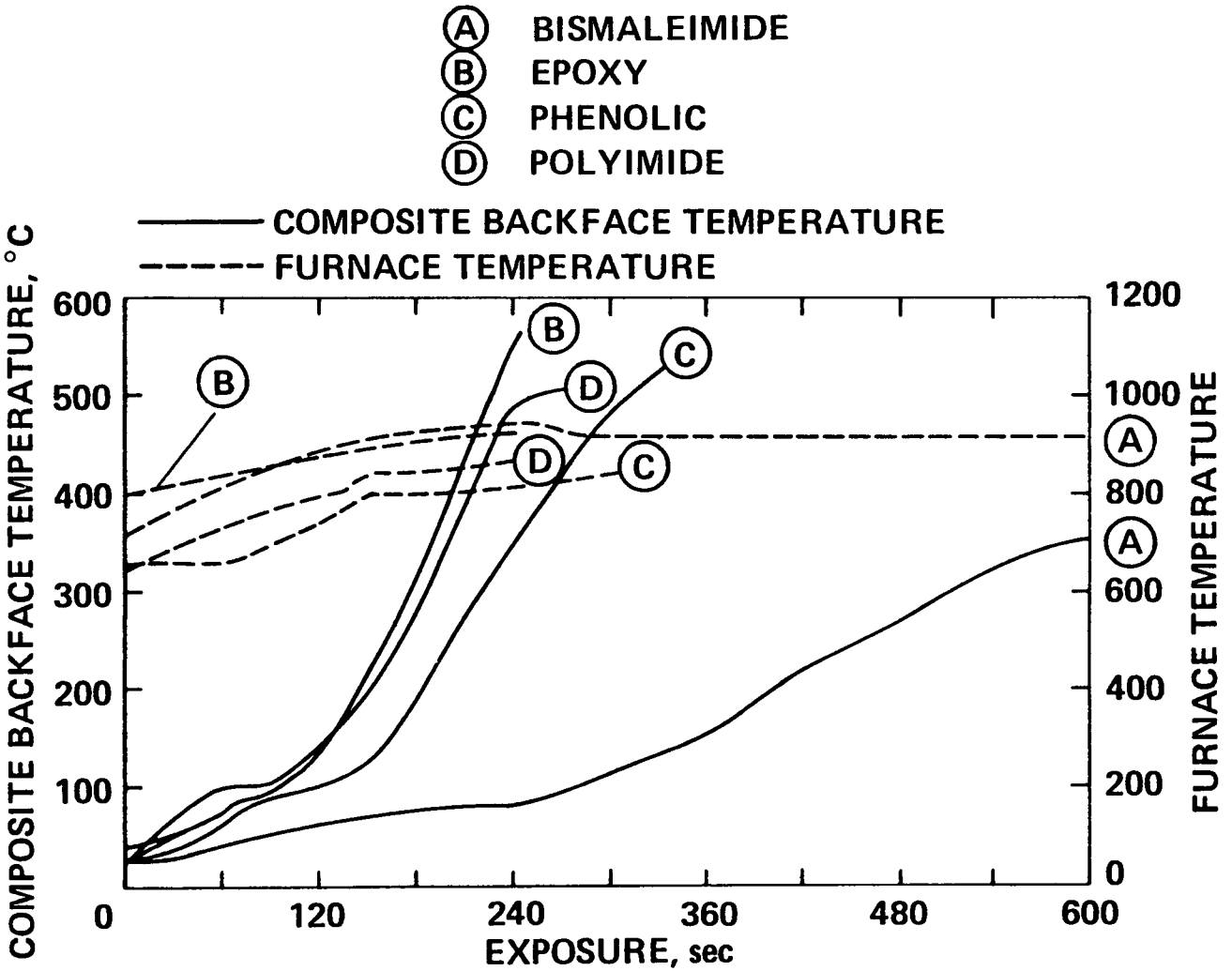


Fig. 14

COMPARATIVE FLAMMABILITY PROPERTIES OF EPOXY AND PHENOLIC FACE SHEETS

	EPOXY	PHENOLIC
PROPENSITY TO BURN (LOI)		
FACE SHEET	29.0	100
ADHESIVE	27.7	53.5
SMOKE EMISSION (D_s, 4 min), NBS		
2.5 W/cm^2	62.8	2.5
5.0 W/cm^2	96.5	8.4
HEAT RELEASE (W-sec/cm^2) OSU		
$\dot{Q}$ 2.5 W/cm^2	--	120
$\dot{Q}$ 5.0 W/cm^2	500	320
FILM	**PVF/PVF**	**PVF/PC**
GAS RELEASE (HF mg/g)		
MONEL TUBE PYROLYSIS	74.1	27.5

Fig. 15

THERMOPLASTICS

Fig. 16

TYPICAL CHEMICAL STRUCTURES OF POLYMERS

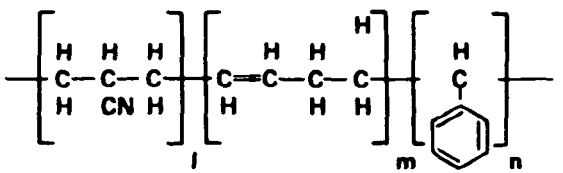
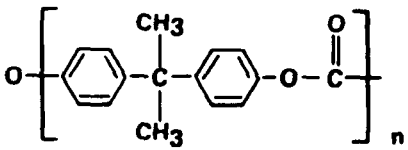
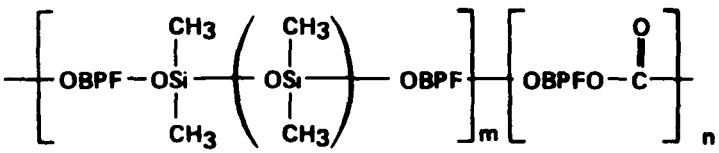
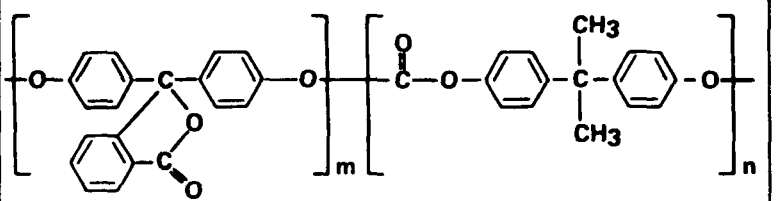
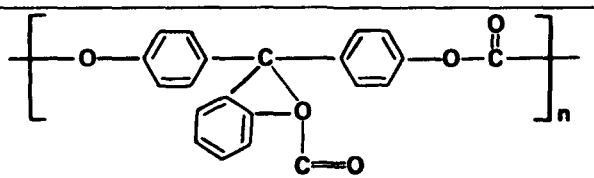
SAMPLE NUMBER	SAMPLE DESCRIPTION	POLYMER	POLYMER STRUCTURE
18	SHEET	ACRYLONITRILE BUTADIENE STYRENE (ABS)	
14	SHEET	BISPHENOL A POLY-CARBONATE (BPAPC)	
19	FIRE RETARDANT; SHEET		
21	FILM; SOLVENT CAST FROM CHLOROFORM, 21% DMS	9,9 BIS (4-HYDROXYPHENYL) FLUORENE POLYCARBONATE-POLY (DIMETHYLSILOXANE) BLOCK POLYMER (BPFC-DMS)	
23	INJECTION MOLDED DISCS, 10.16 cm. DIA. by 0.3175 cm, 15% DMS		
27	UNCURED, MOLDING POWDER		
28	MOLDING POWDER, CURED AT 315.56°C		
30	80% MOLE PHENOLPHTHALEIN, FILM	PHENOLPHTHALEIN-BISPHENOL A POLYCARBONATE COPOLYMER (PH-BPAPC)	
31	70% MOLE PHENOLPHTHALEIN, FILM		
55	FILLED WITH 10% Al_2O_3, 5% TiO_2; FILM	PHENOLPHTHALEIN POLY-CARBONATE (PHPC)	

Fig. 17

TYPICAL CHEMICAL STRUCTURES OF POLYMERS

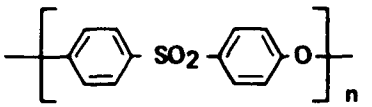
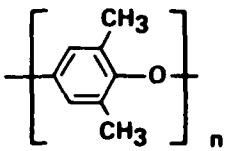
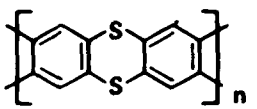
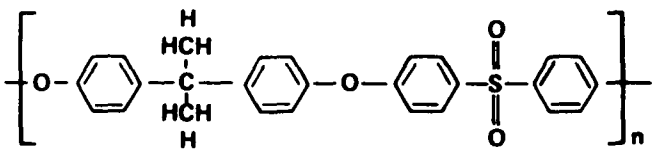
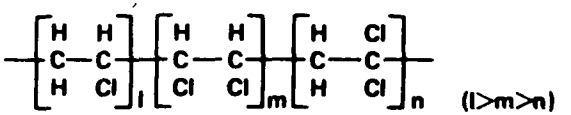
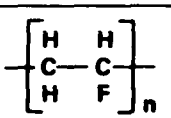
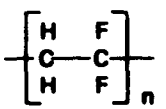
SAMPLE NUMBER	SAMPLE DESCRIPTION	POLYMER	POLYMER STRUCTURE
12 13 22	MOLDING PELLETS MOLDING PELLETS 0.0127 cm FILM	POLYETHER SULFONE (PES)	
16	MODIFIED; SHEET	POLYPHENYLENE OXIDE (PPO) (POLY-2,6-DIMETHYL-PHENYLENE OXIDE)	
11 20 24	MOLDING PELLETS MOLDED PART SECTION, 0.3175 cm THICK 0.3175 cm SHEET	POLYPHENYLENE SULFIDE (PPS)	
10 15	MOLDING PELLETS MODIFIED, SHEET	POLYARYLSULFONE (PAS)	
17 25	SHEET SHEET	CHLORINATED POLYVINYL CHLORIDE HOMOPOLYMER (CPVC)	
32	0.0051 cm FILM	POLYVINYL FLUORIDE (PVF)	
58	0.0127 cm FILM	POLYVINYLIDENE FLUORIDE (PVF_2)	

Fig. 18

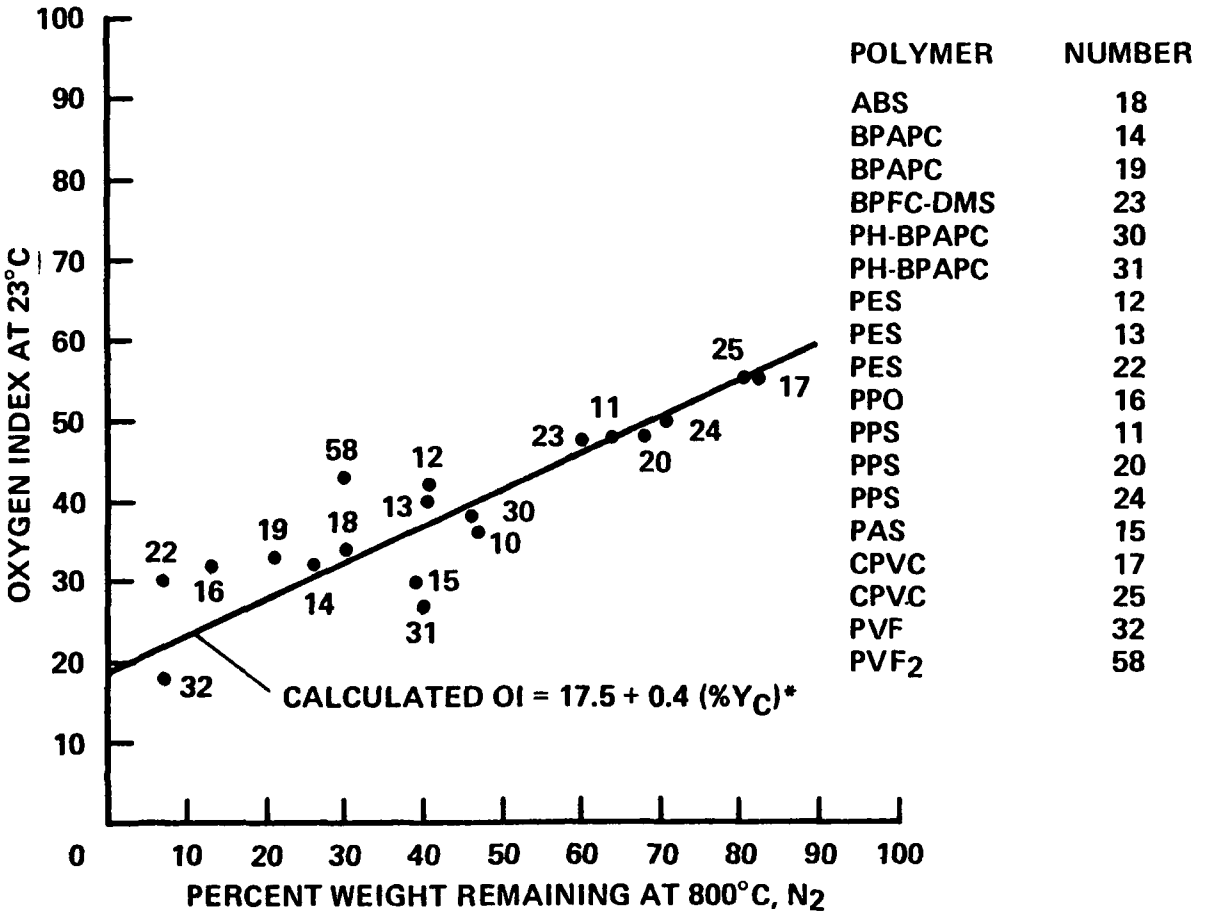
TABLE 5.- CHAR YIELD OF THERMOPLASTICS IN NITROGEN AND AIR

SAMPLE NO.	POLYMER	γ_c, 800°C, N_2	γ_c, 800°C, AIR
18	ABS	18	5
14	BPAPC	30	3
19	BPAPC	27	5
21	BPFC-DMS	58	*
23	BPFC-DMS	61	19
27	BPFC-DMS	58	19
30	PH-BPAPC	47	2
31	PH-BPAPC	43	2
55	PHPC	50	*
12	PES	44	10
13	PES	43	10
22	PES	9	0
16	PPO	17	17
11	PPS	66	42
20	PPS	68	47
24	PPS	72	47
10	PAS	50	5
15	PAS	42	10
17	CPVC	29	5
25	CPVC	28	5
32	PVF	8	3
58	PVF_2	30	5

*NOT DETERMINED

Fig. 19

EFFECT OF CHAR YIELD OF THERMOPLASTIC POLYMERS ON OXYGEN INDEX



*D.W. VAN KREVELEN, SOME BASIC ASPECTS OF FLAME RESISTANCE OF POLYMERIC MATERIALS, VOL. 6, POLYMER (AUG. 1975)

Fig. 20

Relative Flammability Characteristics of Thermoplastics.

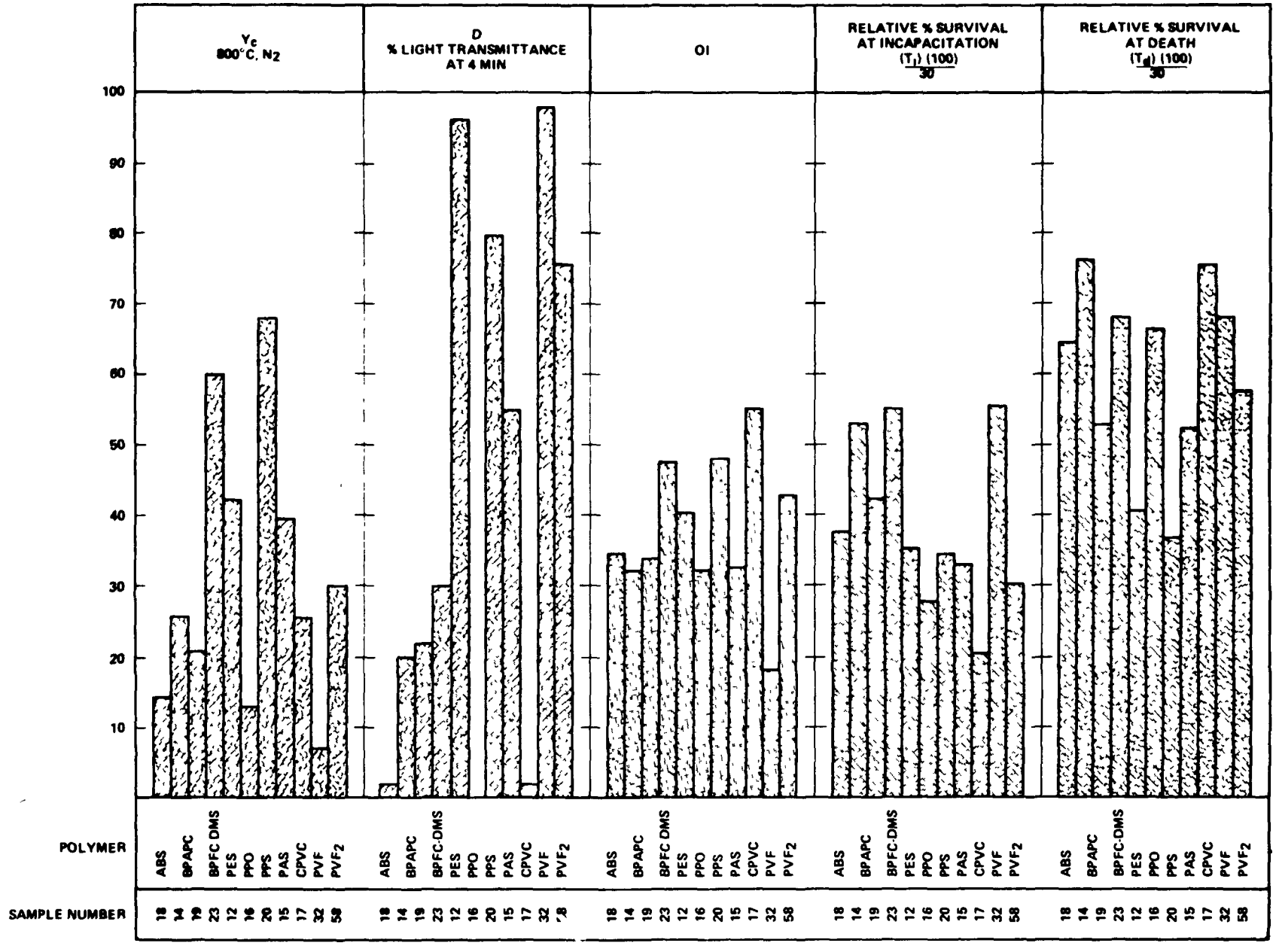
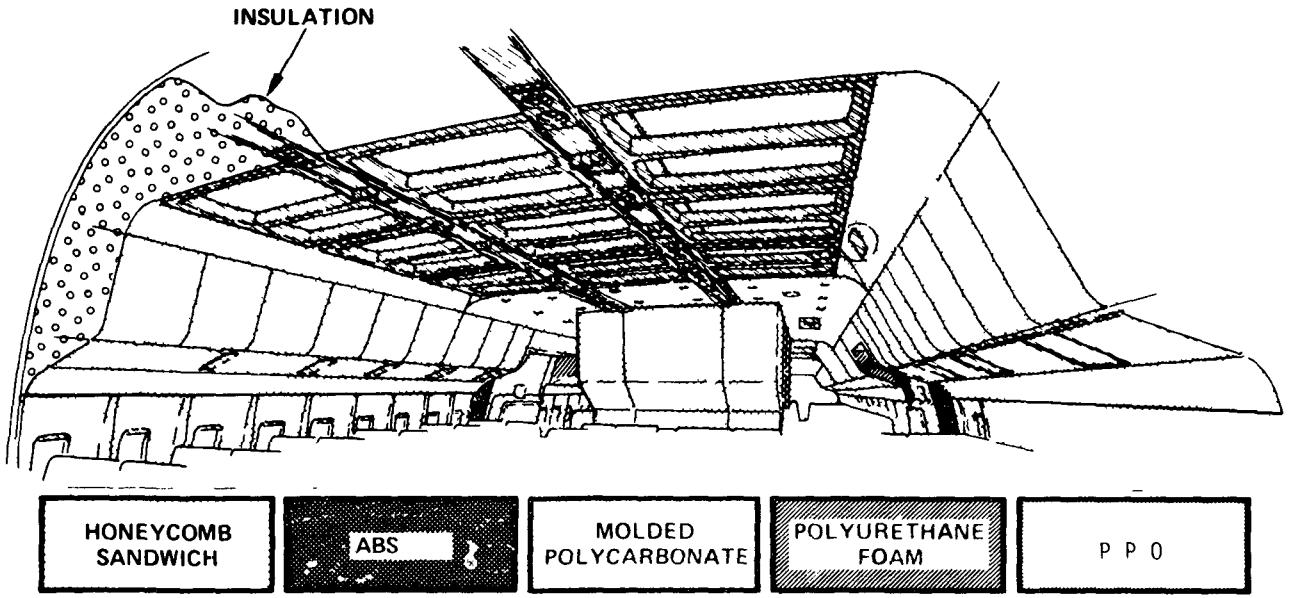


Fig. 21

RELATIVE FIRE RESISTANCE OF SOME THERMOPLASTIC POLYMERS



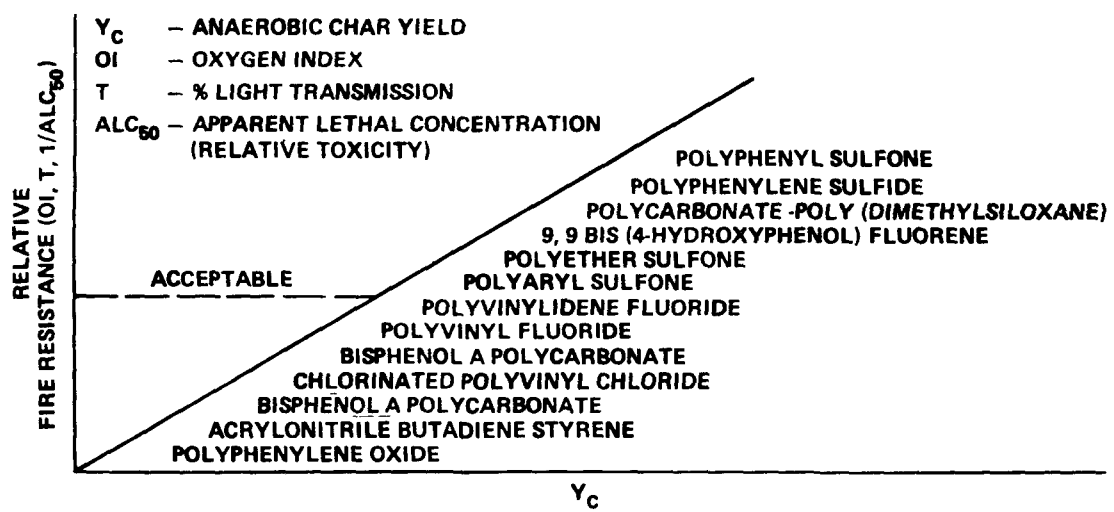


Fig. 22

FIREMEN
ACCOMPLISHMENTS
FY 1977-1978

- COMPOSITE PANELS
  - COMPLETED EVALUATION OF 13 TYPES OF COMPOSITE (CORE) PANELS FROM 4 LAMINATING RESINS
    - EPOXIES
    - PHENOLICS
    - POLYIMIDES
    - BISMALEIMIDE
  - SELECTED 2 CANDIDATE PANELS FOR LARGE SCALE TESTING BY JSC BASED ON PHENOLIC RESINS
  - THERMOPLASTICS
    - COMPLETED THERMOCHEMICAL/FLAMMABILITY CHARACTERIZATION
    - TRANSFER MOLDING TECHNOLOGY TO JSC
  - SEATS
    - COMPLETED LABORATORY SCREENING

Fig. 23

FIREMEN

PLANS
FY 1978, 1979

- COMPOSITE PANELS
  - DECORATIVE FILM - ON GOING DEVELOPMENT AND CANDIDATE SCREENING
  - ADHESIVES - PHOSPHORYLATED EPOXIES
  - INKS - PROGRAM INITIATED
- SEATS
  - FABRICATION DESIGN STUDIES OF ADVANCED SEATS INITIATED
  - TESTING IN CFS
- PROVIDE ADVANCED MATERIALS SYSTEMS TO JSC, & FAA-NAFEC FOR FULL-SCALE TESTING

Fig. 24

DEVELOPMENT OF AIRCRAFT LAVATORY COMPARTMENTS WITH IMPROVED FIRE RESISTANCE CHARACTERISTICS

Roy A. Anderson and Gerald A. Johnson
Boeing Commercial Airplane Company
Seattle, Washington 98124

DEVELOPMENT OF AIRCRAFT LAVATORY COMPARTMENTS WITH IMPROVED FIRE RESISTANCE CHARACTERISTICS

By

Roy A. Anderson and Gerald A. Johnson
Boeing Commercial Airplane Company
P. O. Box 3707
Seattle, Washington 98124

ABSTRACT

This presentation describes Boeing's participation in a NASA-funded program (FIREMEN) to develop materials for use as lavatory wall panels, sidewall panels, and ceiling panels possessing flammability, smoke, and toxicity (FS&T) characteristics superior to current materials of construction (i.e., epoxy resin, polyvinylfluoride film, and acrylic ink). The objective of the program was to develop a sandwich panel system (viz., impregnating resin, honeycomb core, decorative film, and printing ink) that possessed both improved FS&T characteristics and acceptable cost, processing requirements, aesthetic qualities, abrasion resistance, stain resistance, scuff resistance, and washability.

Development of an impregnating resin (viz., modified phenolic) has been completed, development of a decorative film is in progress, and screen printing ink development has just begun. The effort began in 1975 and is scheduled for completion in 1979.

All tests performed under this program were on a laboratory scale. Consequently, final verification of FS&T improvements will ultimately require full-scale testing.

PRESENTATION

Slide 1 - Title

A program to evaluate baseline and candidate materials for aircraft lavatory applications and funded by NASA-ARC began in 1975.

Slide 2 - Objectives

Overall objectives of the whole program.

Slide 3 - Materials Development Program

Whole program broken into four phases.

Slide 4 - Baseline Lavatory Burn

A burn test was conducted on a 747 lavatory in 1975. The results have been reported.

Slide 5 - Sandwich Panel Resin System Development

Slide 6 - Objectives

Objectives of the resin system development program.

Slide 7 - Sandwich Panel Development Program

Resin system development program broken down into five tasks.

Slide 8 - Resin System Program Schedule

Slide 9 - Task 1

Screening of phenolic prepregs resulted in peel strength failure of all candidates.

Slide 10 - Task 2

Laboratory testing of four resin systems.

Slide 11 - Materials Matrix - Task 2

Slide 12 - Assessment of Test Results

Slide 13 - Ranking Procedure

Slide 14 - Ranking Procedure

Slide 15 - Sandwich Panel Ranking

The ranking shown resulted from both arithmetic and geometric procedures.

Slide 16 - Fire Containment Considerations

Four foams evaluated to improve burn through characteristics.

Slide 17 - Foam Evaluation

Foam and core with no face sheets were tested. The weight distribution of each of the tests is shown on the slide.

Slide 18 - Foam Ranking

Equations similar to those on Slide 14 were utilized.

Slide 19 - Tasks 3 and 4

Results showed polycarbonate (Lexan) to be the only promising film. Unfortunately, embrittlement problems precluded its incorporation into Task 5.

Slide 20 - Materials Matrix - Task 5

Slide 21 - Limiting Oxygen Index Apparatus

Slide 22 - Propensity to Burn

Slide 23 - NASA Animal Exposure Chamber

Slide 24 - Panel Weight

Slide 25 - OSU Heat Release Apparatus

Slide 26 - Smoke Emission - OSU Chamber - Flaming

Slide 27 - Smoke Emission - OSU Chamber - Flaming

Slide 28 - Total Heat Release - OSU Apparatus - Flaming Vertical

Specimens with no decorative film and thin core were utilized to minimize their contribution to the heat release values.

Slide 29 - Total Heat Release - OSU Apparatus - Flaming Vertical

Specimens included decorative film and thick core.

Slide 30 - Heat Release Rate - OSU Apparatus - Flaming Vertical

Specimens with no decorative film and thin core were utilized to minimize their contribution to the heat release values.

Slide 31 - Heat Release Rate - OSU Apparatus - Flaming Vertical

Specimens included decorative film and thick core.

Slide 32 - Boeing Burn Through Apparatus

Slide 33 - Boeing Burn Through

Slide 34 - Mechanical Strength - 0.25 Inch Core

A value of 10 in-lb/3 in width is acceptable.

Slide 35 - Mechanical Strength

A value of 150 lb/in^2 is acceptable.

Slide 36 - FS&T Imrpovements

Slide 37 - Decorative Film Development

Slide 38 - Objectives

Objectives of the decorative film development program.

Slide 39 - Film Development Program

Program involved three tasks.

Slide 40 - Decorative Film Program Schedule

Slide 41 - Test Plan

Decorative film development test plan.

Slide 42 - Test Plan

Continuation of the decorative film development test plan.

Slide 43 - Task 1-A Films

List of candidate films.

Slide 44 - Task 1-A Films

Continuation of the candidate film list.

Slide 45 - Propensity to Burn

Limiting oxygen index.

Slide 46 - Propensity to Burn

Limiting oxygen index.

Slide 47 - Smoke Emission - NBS Chamber

Tests on unsupported films.

Slide 48 - Smoke Emission - NBS Chamber

Tests on unsupported films.

Slide 49 - Toxic Gas Emission - NBS Chamber

Slide 50 - Toxic Gas Data - NBS Chamber

Slide 51 - Toxic Gas Data - NBS Chamber

Slide 52 - Tensile Properties - Room Temperature

Test Method ASTM D882.

Slide 53 - Tensile Properties - Room Temperature

Test Method ASTM D882.

Slide 54 - Tensile Properties - Room Temperature

Test Method ASTM D882.

Slide 55 - Tensile Properties - Room Temperature

Test Method ASTM D882.

Slide 56 - Tensile Properties - Room Temperature

Test Method ASTM D882.

Slide 57 - Tensile Properties - Room Temperature

Test Method ASTM D882.

Slide 58 - Mechanical Test

Test set up to be used in conjunction with a Thermomechanical Analyzer for the determination of tensile properties of the candidate films at elevated temperatures.

Slide 59 - Materials Evaluation - Task 2

New resin system from France under evaluation.

Slide 60 - Problems

There are problems with the resin system from France including the four listed.

Slide 61 - Future Work

Tentative films for Task 1B - Testing.

Slide 62 - Future Work

Testing for the tentative films shown on Slide 61.

Slide 63 - Decorative Laminate Configurations

Various material configurations to be investigated.

Slide 64 - FS&T Specimens

Specimen configuration to be used for the four tests indicated.

Slide 65 - Screen Printing Ink Development

Slide 66 - Objectives

Objectives of the screen printing ink development.

Slide 67 - Screen Printing Ink Development Program

Program involved three tasks.

Slide 68 - Screen Printing Ink Program Schedule

Slide 69 - Test Plan

Screen printing ink development test plan.

Slide 70 - Test Plan

Continuation of the screen printing ink development test plan.

Slide 71 - Material Requirements - Task 1

Screening test requirements.

Slide 72 - Resin Systems

Potential candidate materials for consideration.

Slide 73 - Tasks 2 and 3

Five different panels will be made during ink evaluation studies. Testing will include those tests shown.

DEVELOPMENT OF AIRCRAFT LAVATORY COMPARTMENTS WITH IMPROVED FIRE RESISTANCE CHARACTERISTICS

R.A. ANDERSON AND G.A. JOHNSON
BOEING COMMERCIAL AIRPLANE COMPANY
APRIL 1978

OBJECTIVES

- SIDEWALL, CEILING, AND PARTITION PANEL DEVELOPMENT
  - RESIN SYSTEM
  - DECORATIVE FILM
  - DECORATIVE INK
- LOW SMOKE, FLAMMABILITY, AND TOXICITY
- AESTHETIC AND MECHANICAL PROPERTY RETENTION
- END ITEM DELIVERIES TO NASA-ARC

MATERIALS DEVELOPMENT PROGRAM

- BASELINE LAVATORY BURN
- RESIN SYSTEM DEVELOPMENT
- DECORATIVE FILM DEVELOPMENT
- DECORATIVE INK DEVELOPMENT

BASELINE LAVATORY BURN

PHASE I

NAS2-8700

SANDWICH PANEL RESIN SYSTEM DEVELOPMENT

PHASE II

NAS2-8700

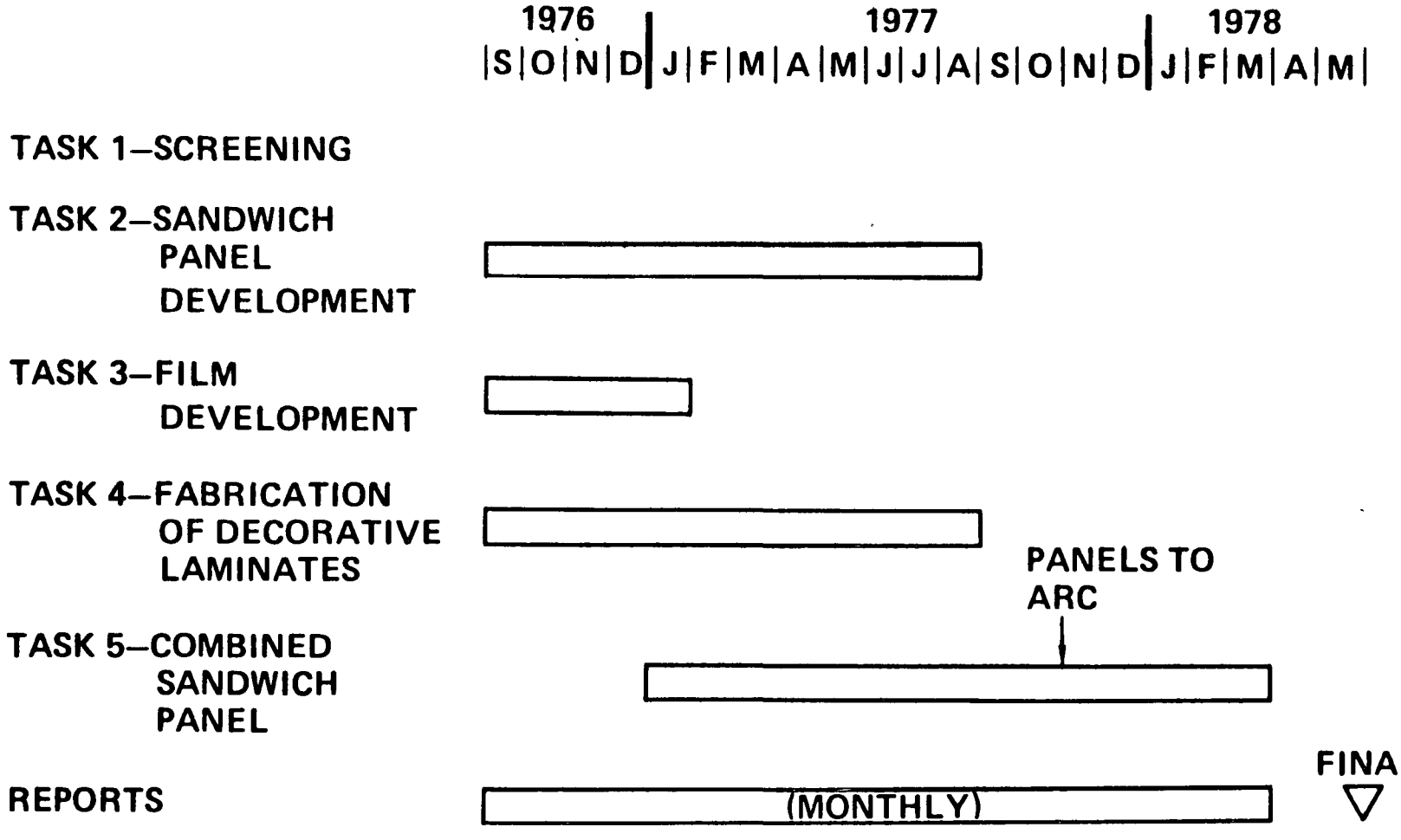
OBJECTIVES

- SIDEWALL, CEILING, AND PARTITION PANEL DEVELOPMENT
- RESIN AND DECORATIVE FILM DEVELOPMENT
- LOW SMOKE AND TOXIC GAS EMISSION
- RESISTANT TO HIGH HEAT FLUX
- PROCESS ASSESSMENT
- RANKING SYSTEM
- END ITEM DELIVERY TO NASA-ARC

SANDWICH PANEL DEVELOPMENT PROGRAM

- TASK 1—SCREENING
- TASK 2—SANDWICH PANEL DEVELOPMENT
- TASK 3—FILM EVALUATION
- TASK 4—FABRICATION OF DECORATIVE LAMINATES
- TASK 5—COMBINED SANDWICH PANEL

RESIN SYSTEM PROGRAM SCHEDULE



TASK 1

- PHENOLIC PREPREG SCREENING
  - FIBERITE
  - NARMCO
  - DUPONT
  - CIBA-GEIGY
- MECHANICAL STRENGTH PROBLEM
  - PHENOLIC–7.7 MAXIMUM
  - EPOXY–15 MAXIMUM
- NEW MATERIALS FOR TASK 2

TASK 2

- RESIN SYSTEM DEVELOPMENT
  - EPOXY (BASELINE)–FIBERITE
  - BISMALEIMIDE–HEXCEL AND HITCO
  - POLYIMIDE–DUPONT
  - PHENOLIC–NARMCO, FIBERITE, AND CIBA-GEIGY
- LABORATORY TESTING
  - FLAMMABILITY
  - SMOKE EMISSION
  - TOXIC GAS EMISSION
  - TOXICOLOGY (USF–DR. CARLOS HILADO)
  - HEAT RELEASE
  - MECHANICAL PROPERTIES
  - DURABILITY

MATERIALS MATRIX–TASK 2

SYST. NO.	FACESHEET	BOND PLY AND BACK SKIN	ADHESIVE	HONEYCOMB CORE	FOAM
1	EPOXY FIBERITE MXB-7203	EPOXY FIBERITE MXB-7251	NONE	PHENOLIC/ POLYAMIDE 3 PCF NOMEX	NONE
2	PHENOLIC NARMCO 8250	PHENOLIC NARMCO 9251	NONE	PHENOLIC/ POLYAMIDE 3 PCF NOMEX	NONE
3	BISMALEIMIDE HEXCEL 531	BISMALEIMIDE HEXCEL 532	NONE	PHENOLIC/ POLYAMIDE 3 PCF NOMEX	NONE
4	POLYIMIDE DUPONT PYRALIN 3002	POLYIMIDE DUPONT PYRALIN 3002	POLYIMIDE AM.CYANAMID BR-34	POLYIMIDE/ FIBERGLASS 4.5 PCF	NONE
5	PHENOLIC NARMCO 8250	PHENOLIC NARMCO 9251	NONE	PHENOLIC/ POLYAMIDE 3 PCF NOMEX	ICU 2 PCF
6	POLYIMIDE DUPONT PYRALIN 3002	POLYIMIDE DUPONT PYRALIN 3002	POLYIMIDE AM.CYANIMID BR-34	POLYIMIDE/ FIBERGLASS 4.5 PCF	PI/PU 2 PCF
7	BISMALEIMIDE RHODIA KERIMID 601	BISMALEIMIDE RHODIA KERIMID 601	POLYIMIDE AM.CYANAMID FM-34	PHENOLIC/ POLYAMIDE 1.8 PCF NOMEX	PQ 2 PCF
8	POLYIMIDE DUPONT PYRALIN 3002	POLYIMIDE DUPONT PYRALIN 3002	POLYIMIDE AM CYANAMID BR-34	POLYIMIDE/ POLYAMIDE 3.0 PCF PI-NOMEX	NONE
9	POLYIMIDE DUPONT PYRALIN 3002	POLYIMIDE DUPONT PYRALIN 3002	POLYIMIDE AM. CYANAMID BR-34	POLYIMIDE/ POLYAMIDE 3.0 PCF PI-NOMEX	PI/PU 2 PCF
10	PHENOLIC CIBA-GEIGY FIBREDUX 917G	PHENOLIC CIBA-GEIGY FIBREDUX 917G	NONE	PHENOLIC/ POLYAMIDE 3.0 PCF NOMEX	NONE
11	PHENOLIC FIBERITE MXB-6070	PHENOLIC FIBERITE MXB-7255	NONE	PHENOLIC/ POLYAMIDE 3.0 PCF NOMEX	ICU 2 PCF
12	PHENOLIC FIBERITE MXB-6070	PHENOLIC FIBERITE MXB-7255	NONE	PHENOLIC/ POLYAMIDE 3.0 PCF NOMEX	NONE
13	BISMALEIMIDE RHODIA KERIMID 601	BISMALEIMIDE RHODIA KERIMID 601	POLYIMIDE AM.CYANAMID FM-34	PHENOLIC/ POLYAMIDE 1.8 PCF NOMEX	ICU 2 PCF (PYROLYZED)

ASSESSMENT OF TEST RESULTS

- VISUAL EXAMINATION

- RANKING PROCEDURE

RANKING PROCEDURE

- LABORATORY TESTS–WEIGHT DISTRIBUTION
  - FLAMMABILITY–10%
  - SMOKE EMISSION–20%
  - TOXIC GAS EMISSION–10%
  - HEAT RELEASE–20%
  - HEAT RELEASE RATE–20%
  - THERMAL CONDUCTIVITY–4%
  - MECHANICAL STRENGTH–6%
  - DENSITY–10%

- MATERIAL AND FABRICATION
  - 15%
  - LABORATORY TESTS–85%

RANKING PROCEDURE

- METHOD 1—ARITHMETIC
  - $A_T = 0.85\ A_{LT} + 0.15\ A_{MF}$
  - $A_{LT} = 0.1\ (FLA) + 0.2\ (SMO) + 0.1\ (TOX) + 0.2\ (HEA) + 0.2\ (HER) + 0.04\ (BFT) + 0.06\ (MEC) + 0.1\ (DEN)$
- METHOD 2—GEOMETRIC
  - $G_T = (G_{LT})^{0.85}\ (G_{MF})^{0.15}$
  - $G_{LT} = (FLA)^{0.1}\ (SMO)^{0.2}\ (TOX)^{0.1}\ (HEA)^{0.2}(HER)^{0.2}\ (BFT)^{0.04}\ (MEC)^{0.06}\ (DEN)^{0.1}$

SANDWICH PANEL RANKING

1. CIBA-GEIGY FIBREDUX 917G/917G/NOMEX CORE

2. FIBERITE MXB 6070/MXB 7255/NOMEX CORE

3. NARMCO 8250/9251/NOMEX CORE

FIRE CONTAINMENT CONSIDERATIONS

- BACKFACE TEMPERATURE
- BURN-THROUGH
- FOAM IN CORE
  - POLYQUINOXALINE–HITCO
  - POLYIMIDE/POLYURETHANE–GENERAL PLASTICS
  - PYROLYZED POLYISOCYANURATE–HITCO
  - PHENOLIC–CIBA GEIGY

FOAM EVALUATION

- CORE + FOAM ONLY
- OSU APPARATUS (5.0 W/cm^2)
  - SMOKE EMISSION–10%
  - HEAT RELEASE–10%
  - HEAT RELEASE RATE–10%
- BOEING BURN-THROUGH
  - HEAT RELEASE–10%
  - HEAT RELEASE RATE–10%
  - THERMAL CONDUCTIVITY–50%
- MATERIAL
  - 7.5%
  - LABORATORY TESTS–92.5%

FOAM RANKING

- PROCEDURE
  - ARITHMETIC
  - GEOMETRIC

- RESULTS
  1. PHENOLIC
  2. PQ
  3. PYROLYZED ICU
  4. PI/PU

TASKS 3 AND 4

- DECORATIVE FILM EVALUATION
  - POLYVINYLFLUORIDE–DUPONT
  - FM POLYVINYLFLUORIDE–DUPONT
  - POLYVINYLIDENE FLUORIDE–REXHAM
  - POLYCARBONATE–GENERAL ELECTRIC
  - POLYETHERSULFONE–ICI AMERICAS
- RESULTS AND CONCLUSIONS
  - POLYCARBONATE
  - POLYVINYLFLUORIDE–FINAL TASK
  - FILM NEEDED–IMPROVED FS & T
  - FILM DEVELOPMENT PROGRAM

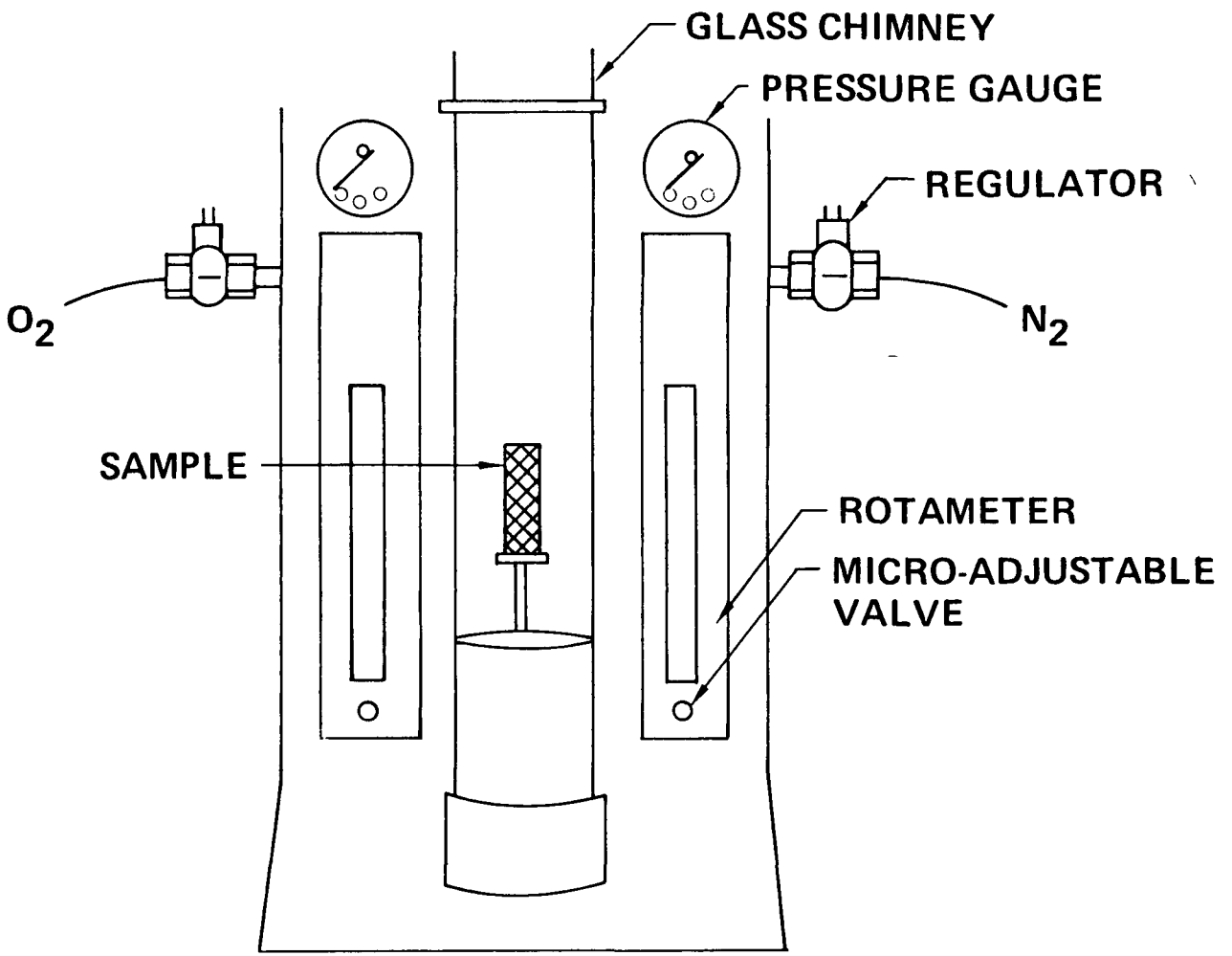
MATERIALS MATRIX–TASK 5

PANEL NO	DECORATIVE FILM	FACESHEET		BOND PLY		HONEYCOMB CORE		FOAM	
1	PVF*/ACRYLIC INK/PVF**	EPOXY	FIBERITE MXB-7203	EPOXY	FIBERITE MXB-7251	PHENOLIC/ POLYAMIDE	3 PCF NOMEX	NONE	
2	PVF*/ACRYLIC INK/PVF**	PHENOLIC	CIBA-GEIGY FIBREDUX 917G	PHENOLIC	CIBA-GEIGY FIBREDUX 917G	PHENOLIC/ POLYAMIDE	3 PCF NOMEX	NONE	
3	PVF*/ACRYLIC INK/PVF**	PHENOLIC	CIBA-GEIGY FIBREDUX 917G	PHENOLIC	CIBA-GEIGY FIBREDUX 917G	PHENOLIC/ POLYAMIDE	3 PCF NOMEX	PHENOLIC	2 5 PCF

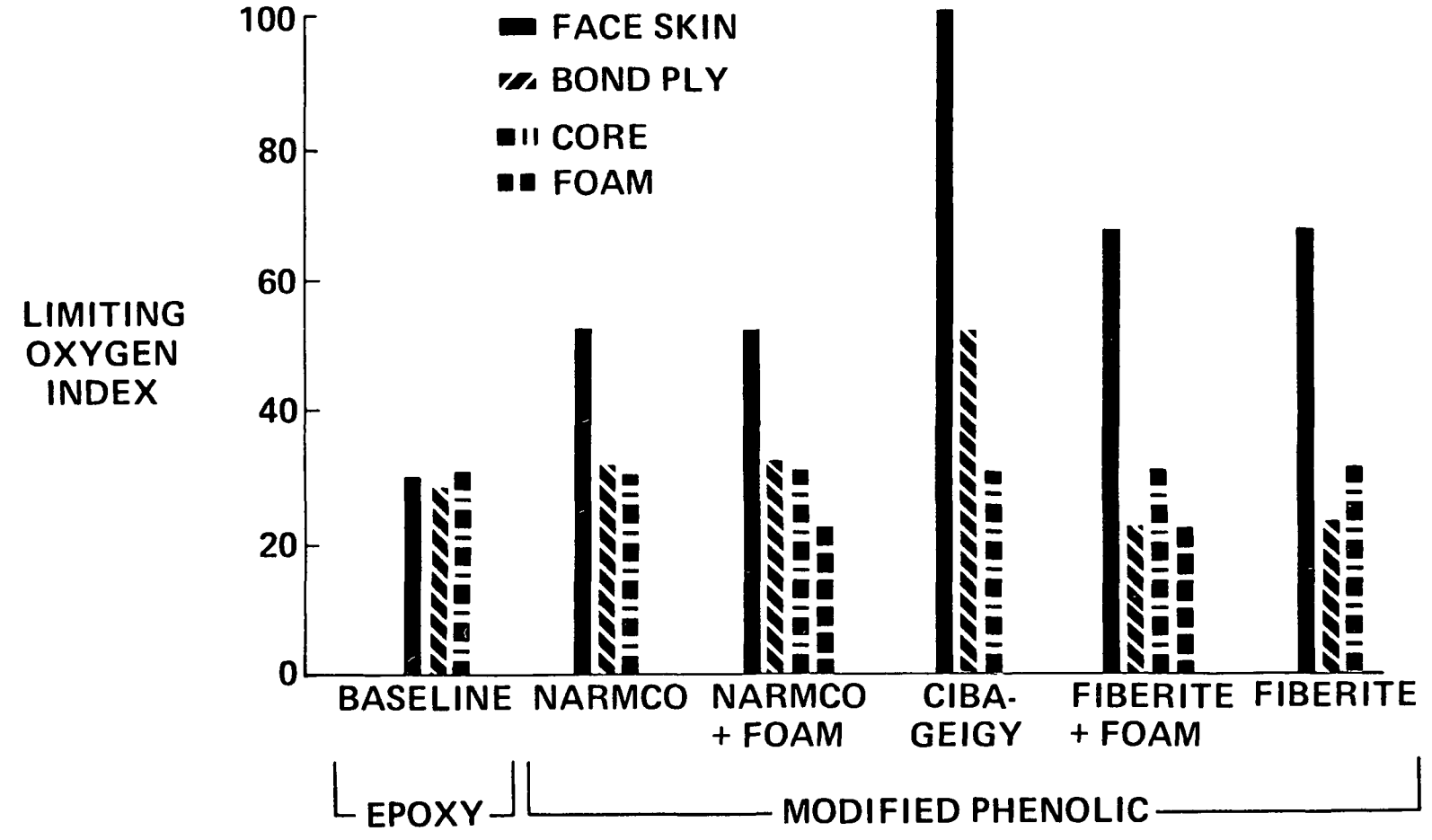
*0 025 mm (0 001 in) PVF TOP FILM

**0.051 mm (0 002 in.) PVF SUBSTRATE FILM

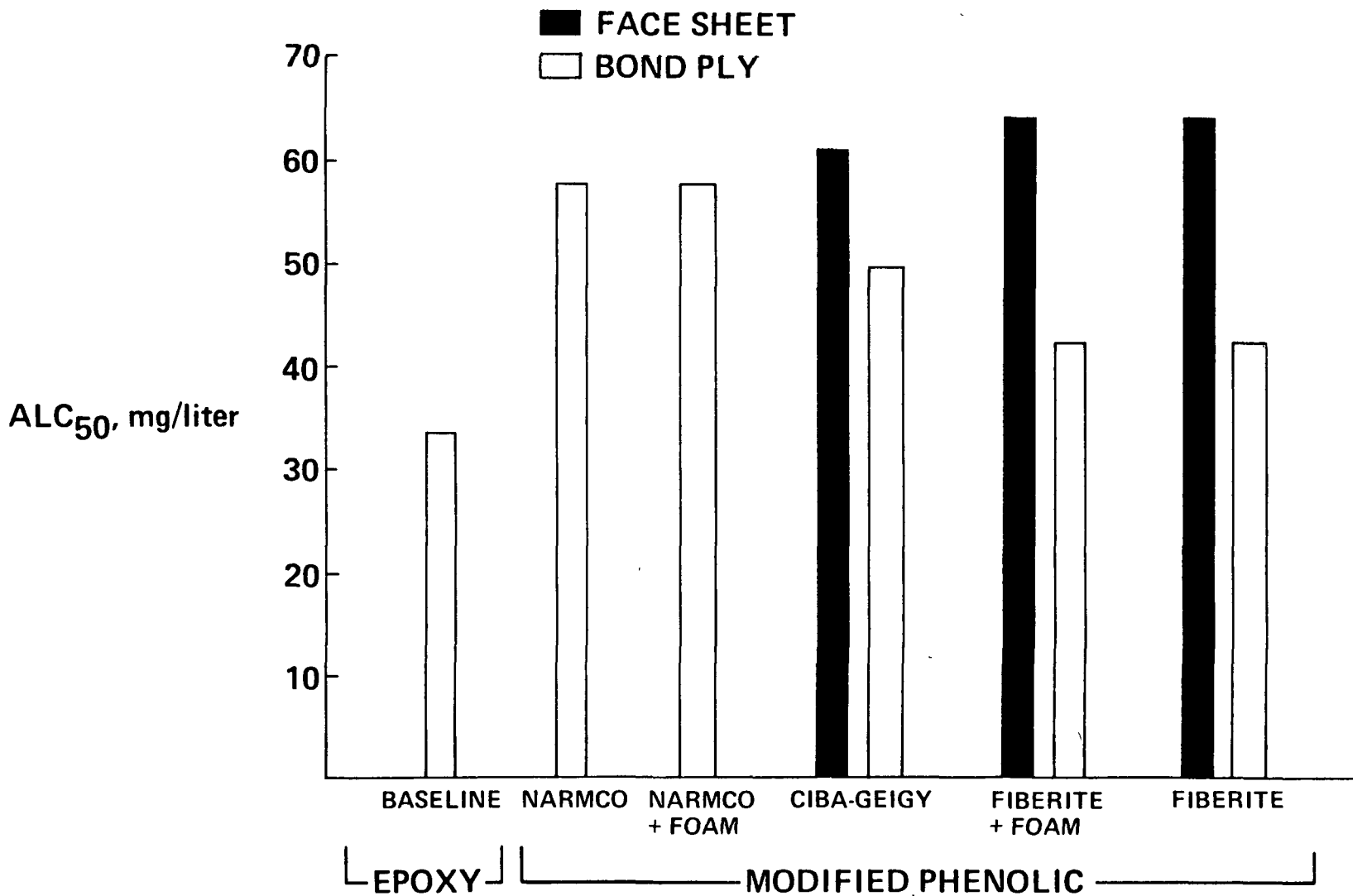
LIMITING OXYGEN INDEX APPARATUS



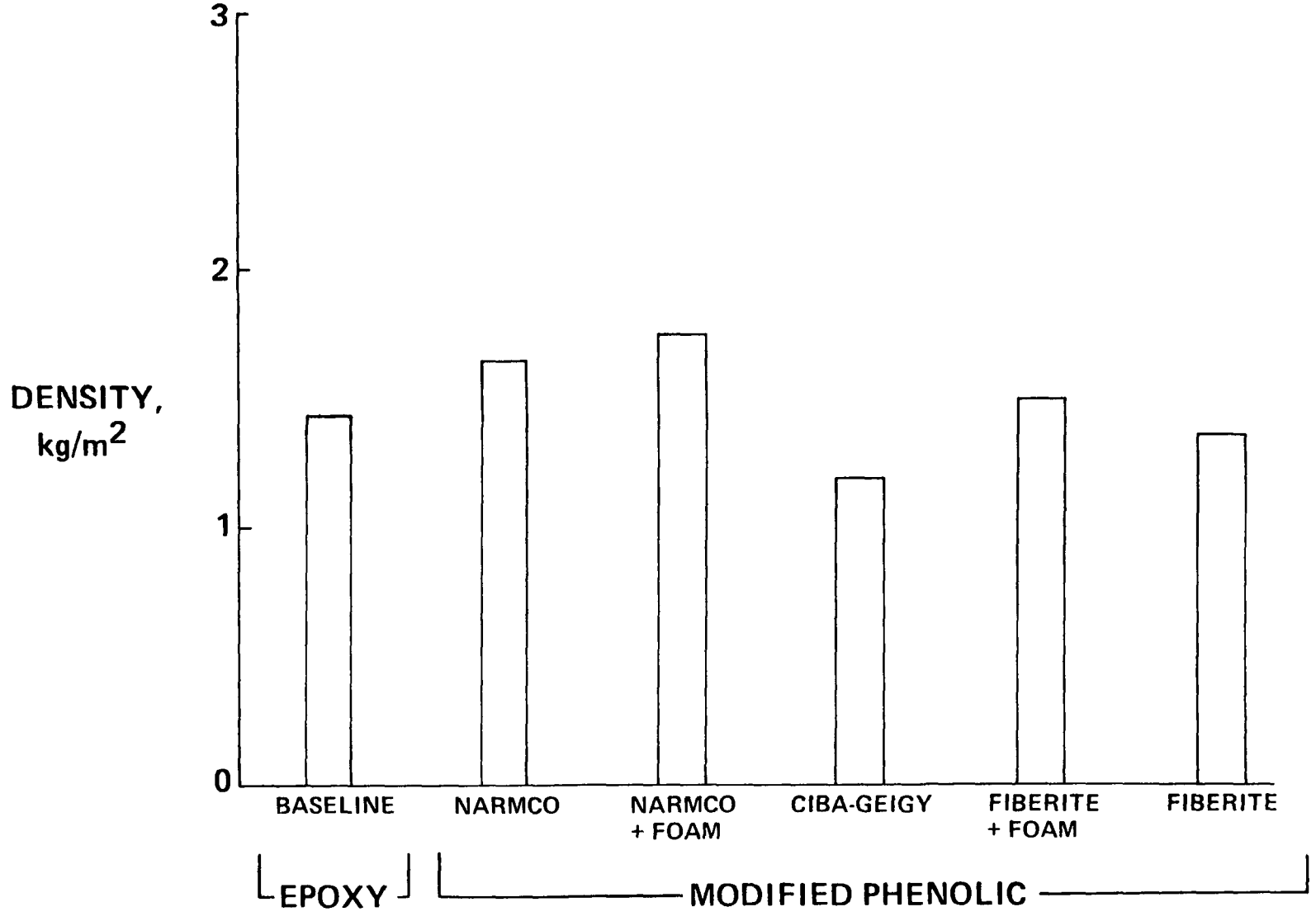
PROPENSITY TO BURN



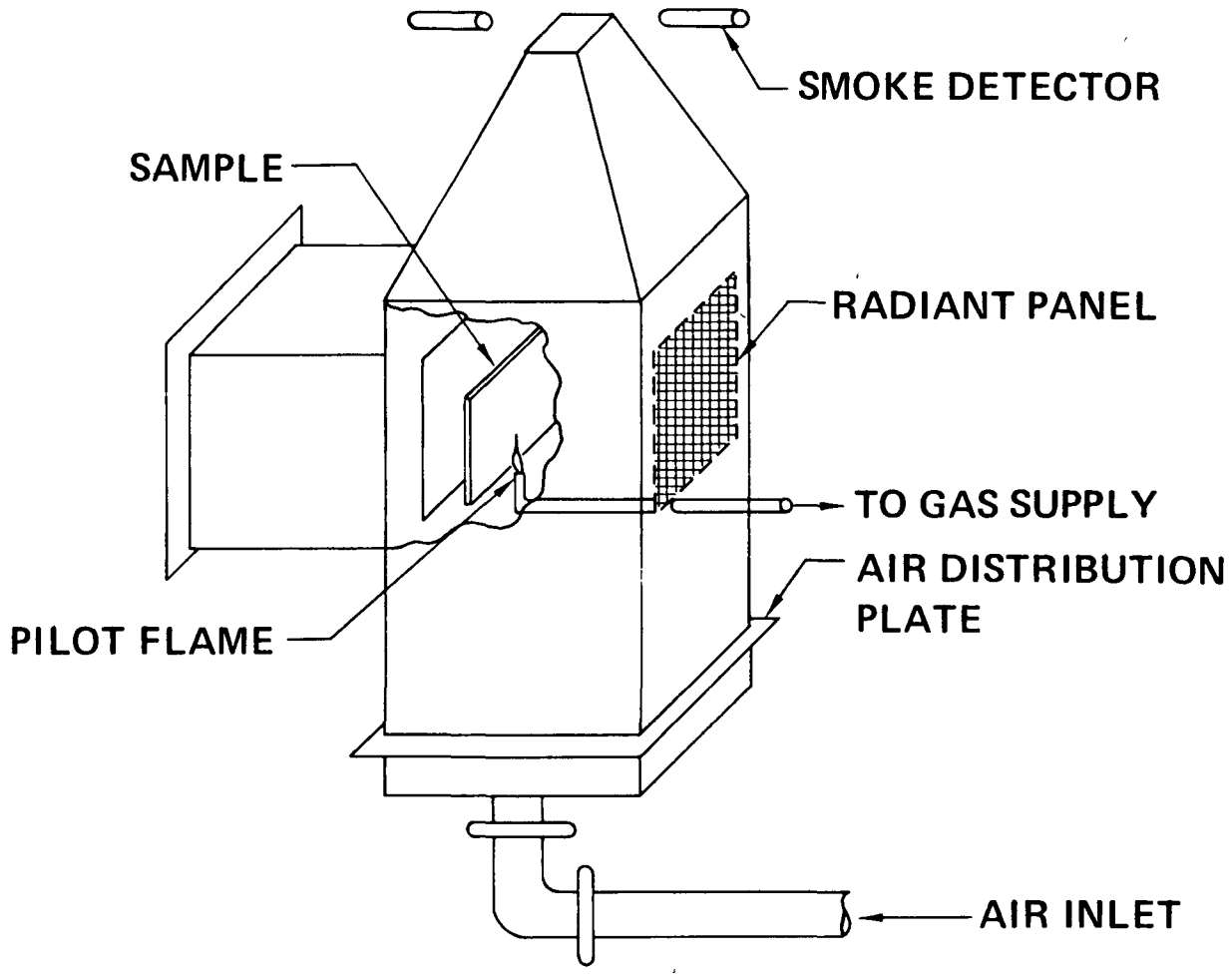
NASA ANIMAL EXPOSURE CHAMBER



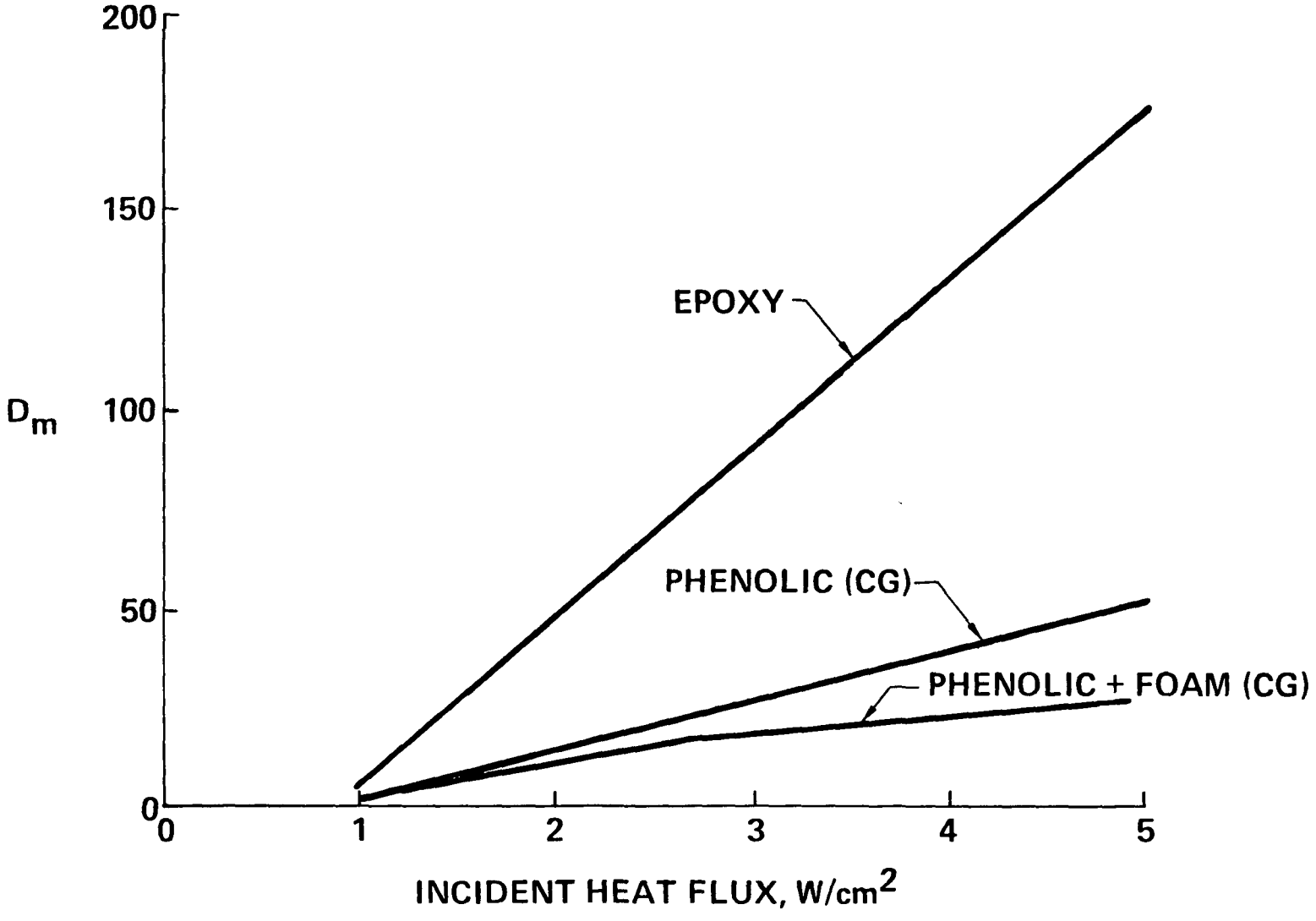
PANEL WEIGHT



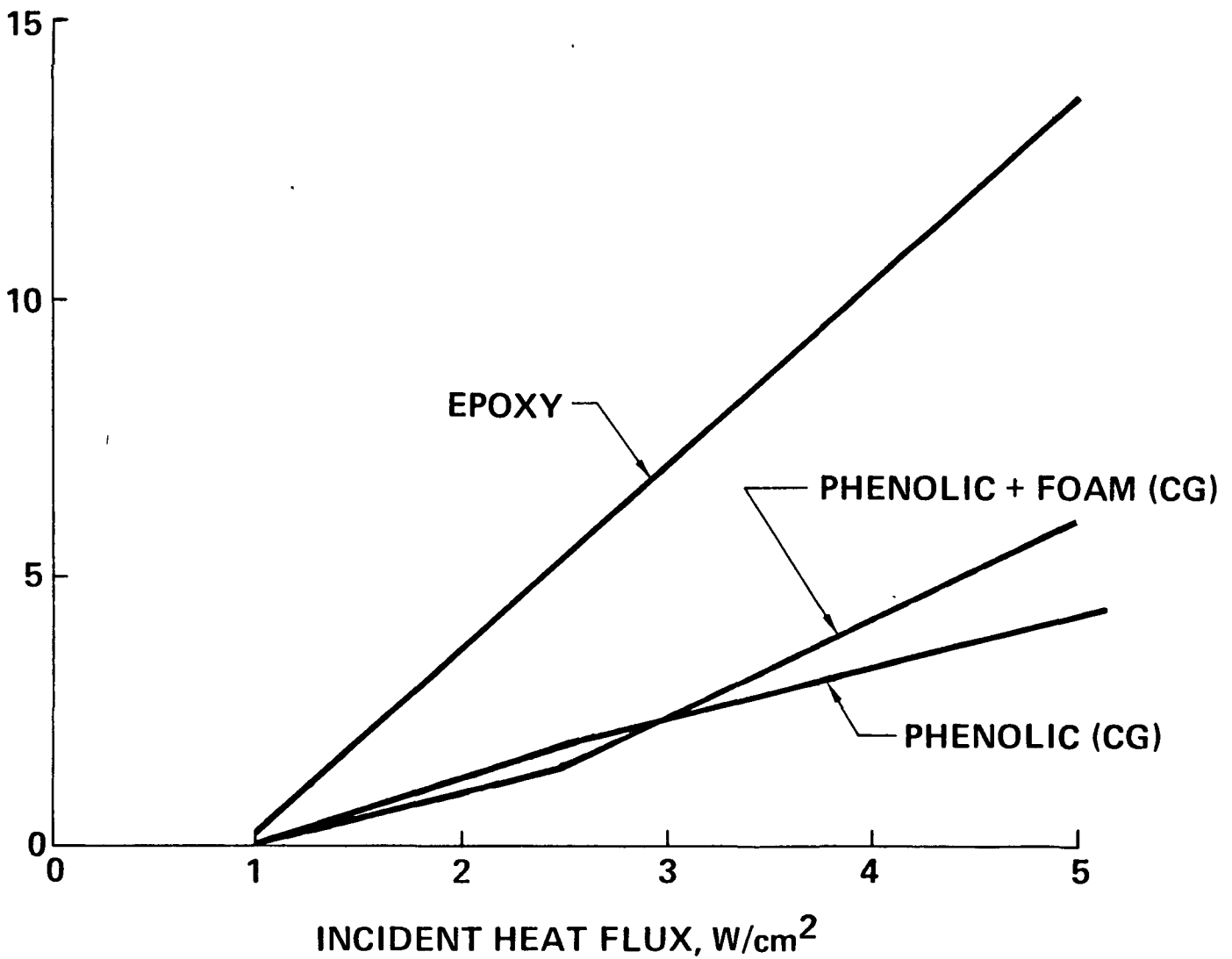
OSU HEAT RELEASE APPARATUS



SMOKE EMISSION–OSU CHAMBER–FLAMING

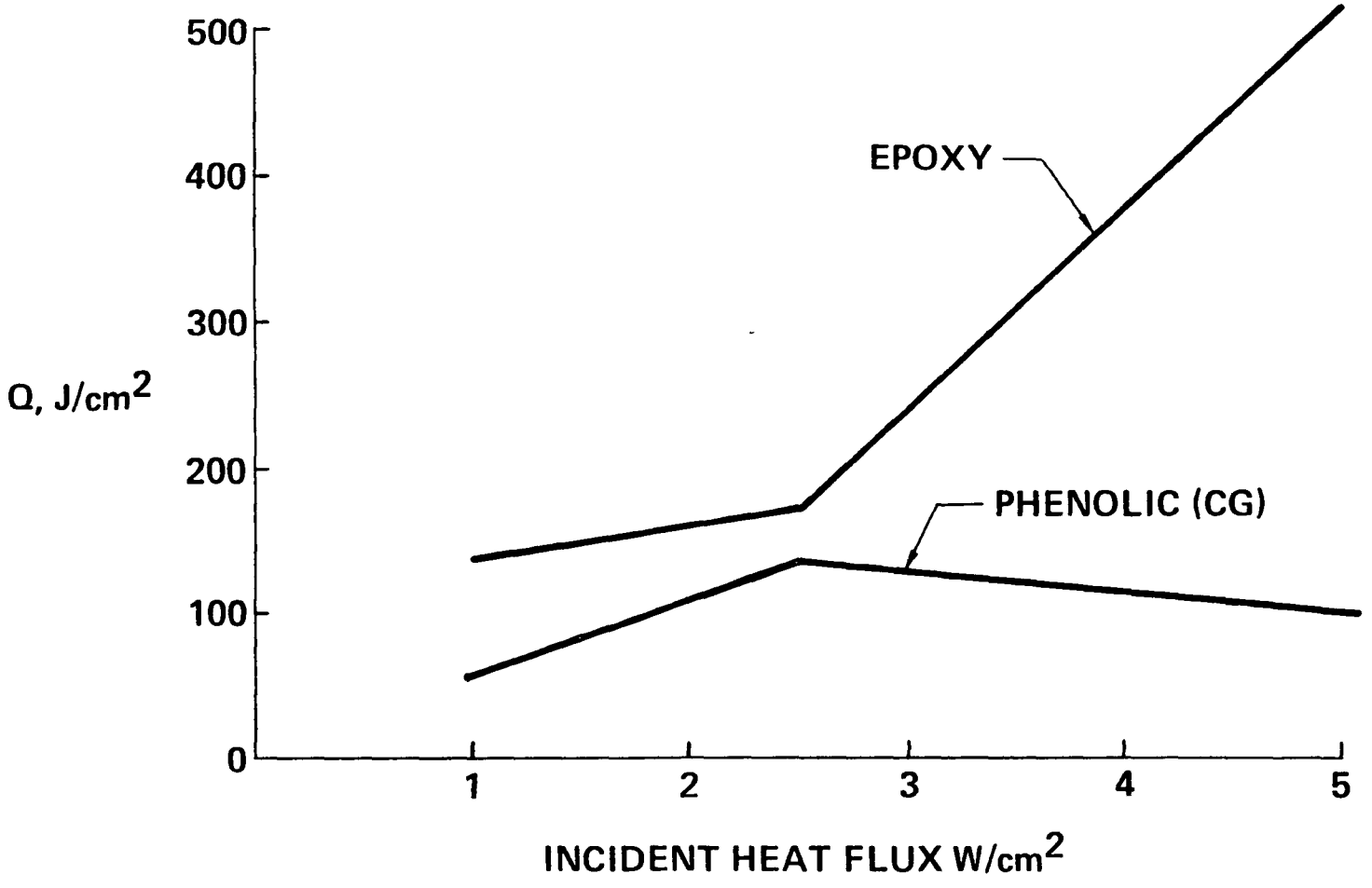


SMOKE EMISSION–OSU CHAMBER–FLAMING



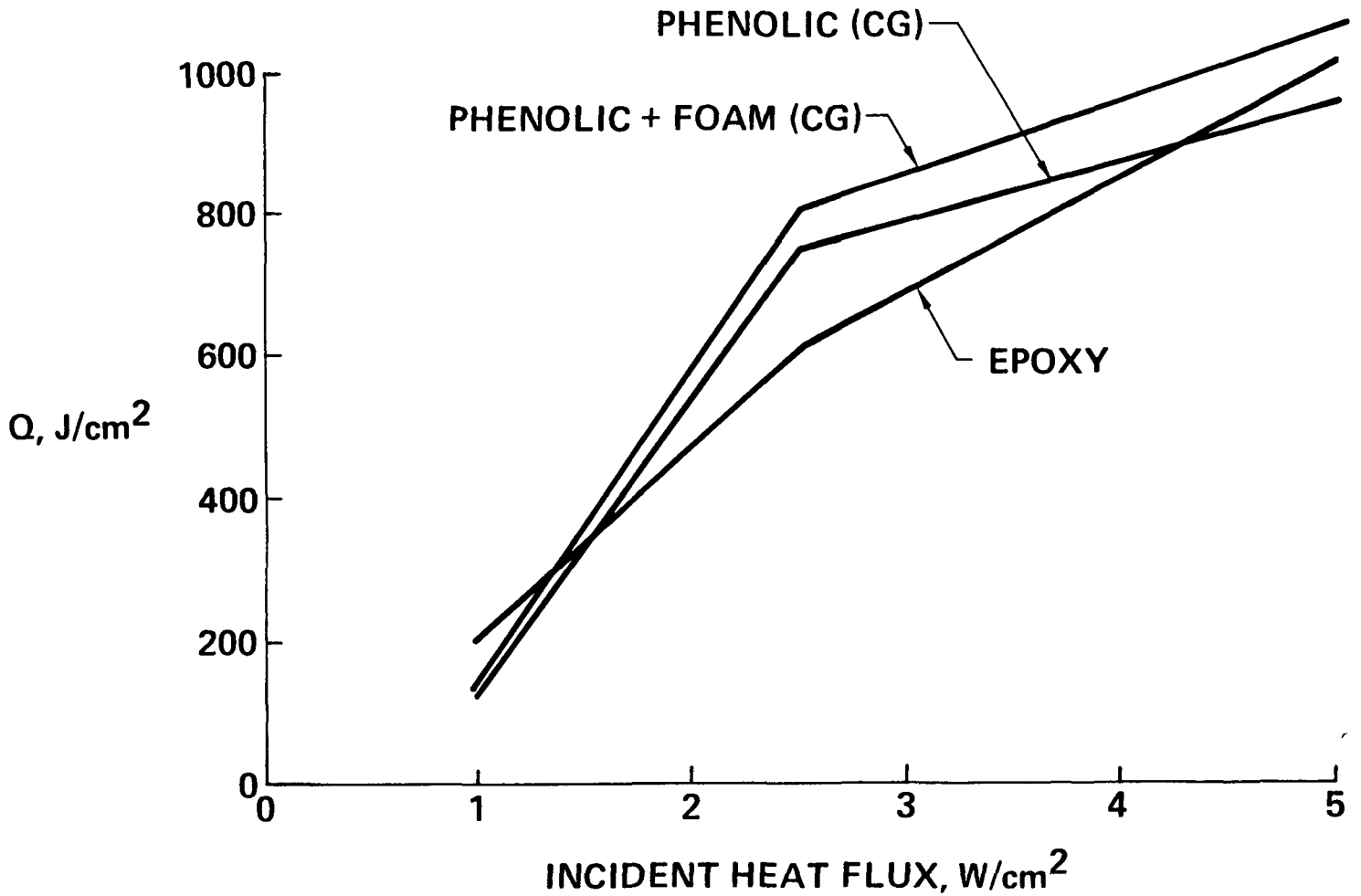
TOTAL HEAT RELEASE–OSU APPARATUS–FLAMING VERTICAL

0.25 INCH CORE

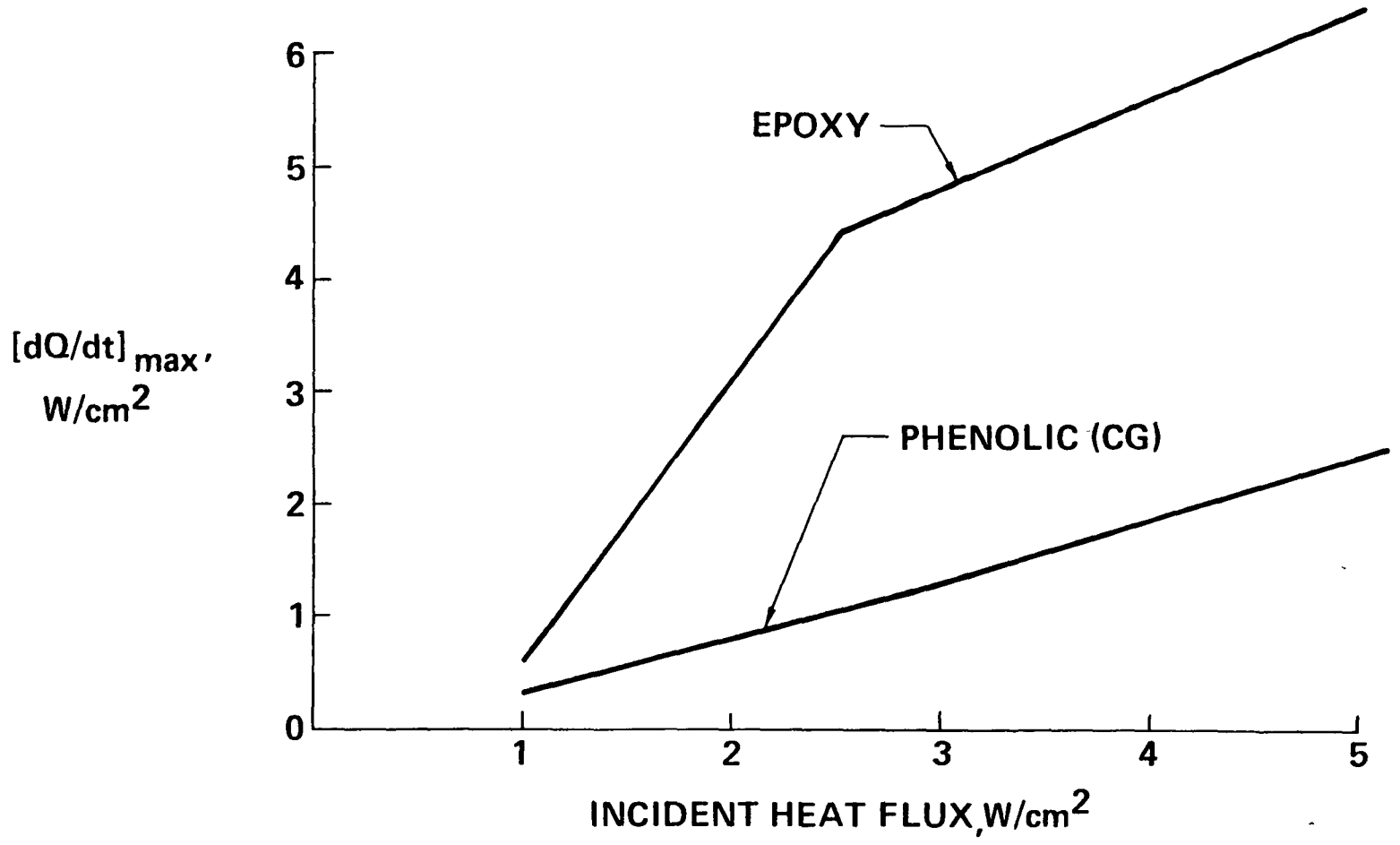


TOTAL HEAT RELEASE–OSU APPARATUS–FLAMING VERTICAL

0.95 INCH CORE

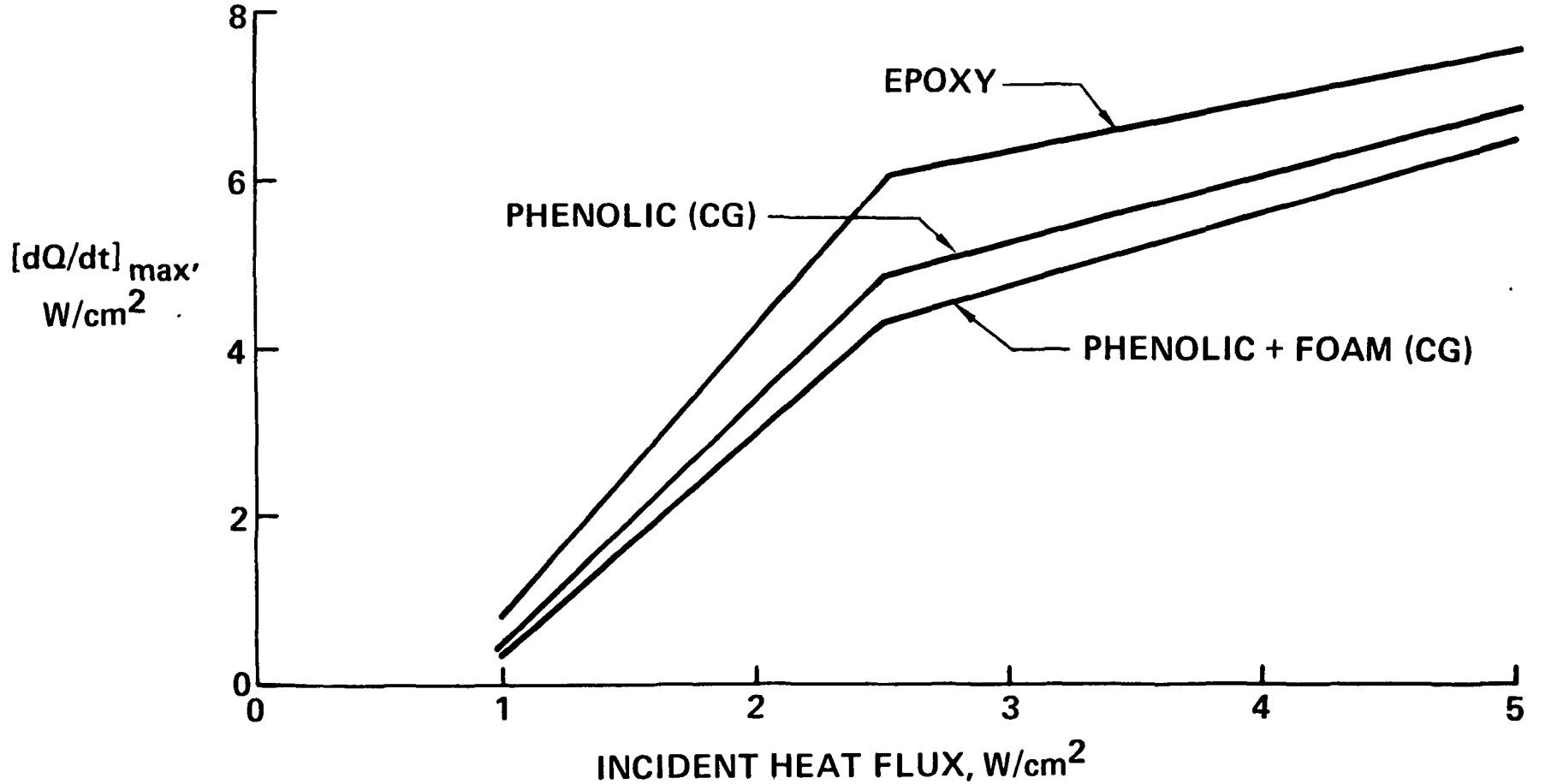


HEAT RELEASE RATE–OSU APPARATUS–FLAMING VERTICAL
0.25 INCH CORE

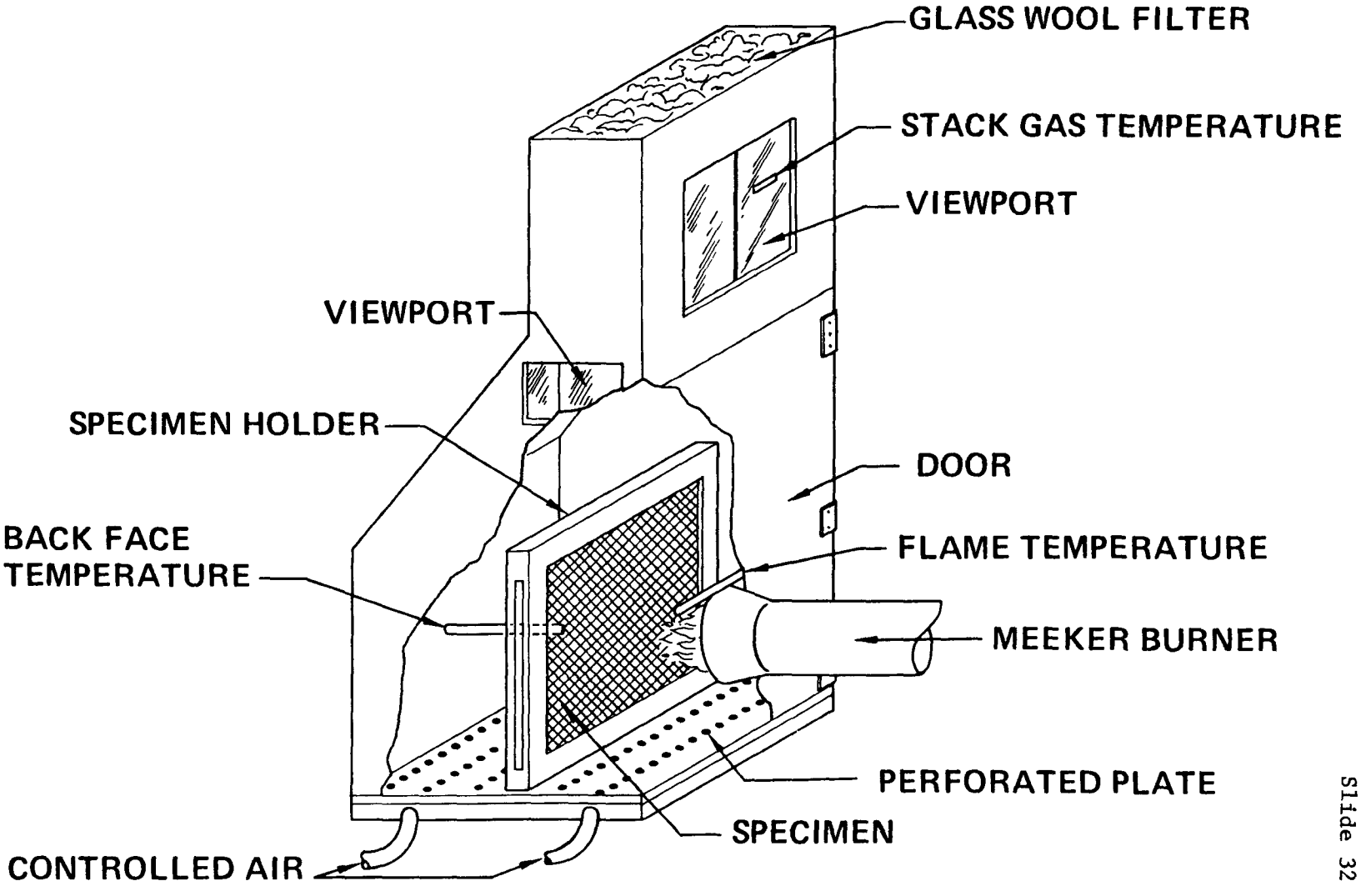


HEAT RELEASE RATE–OSU APPARATUS–FLAMING VERTICAL

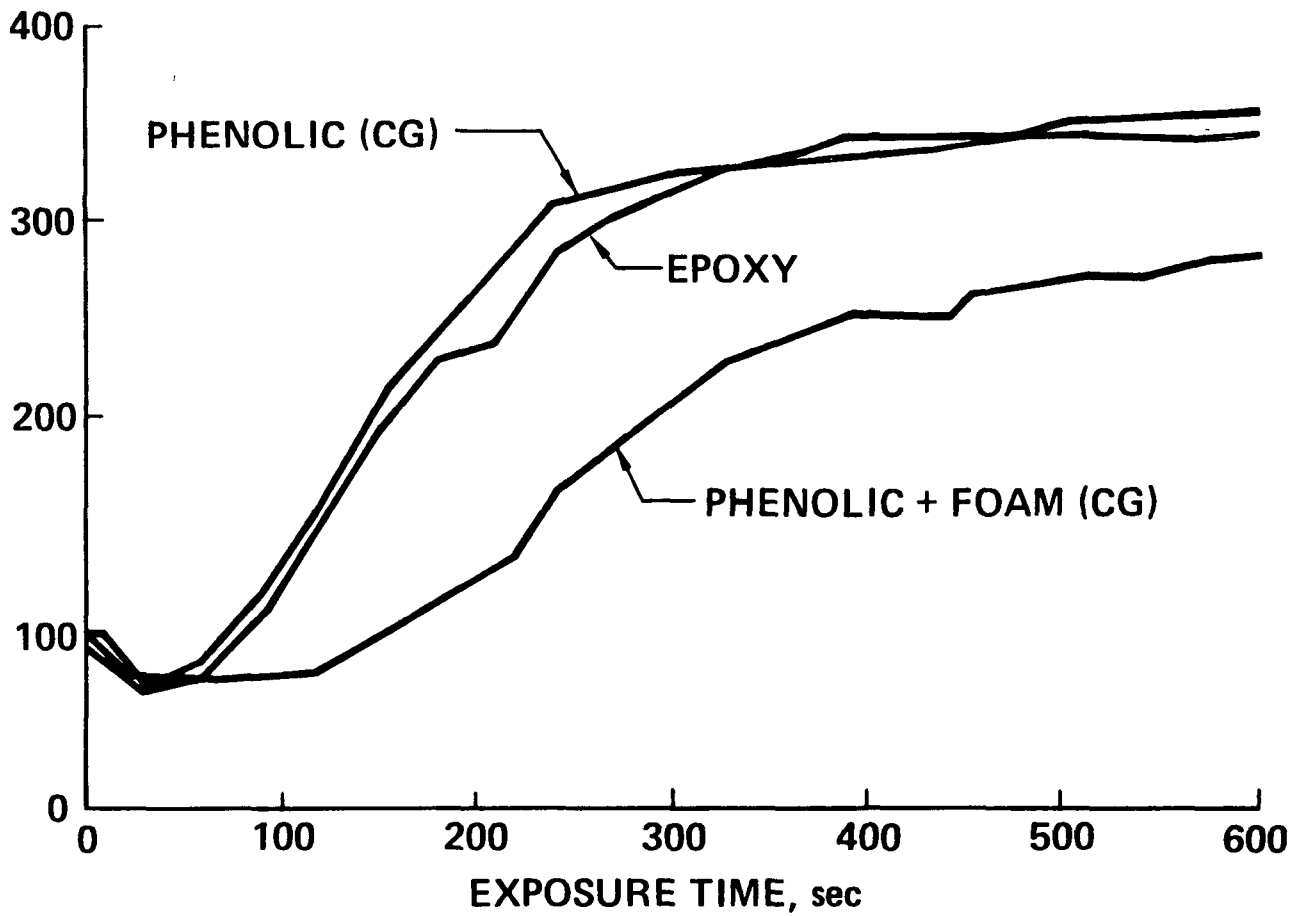
0.95 INCH CORE



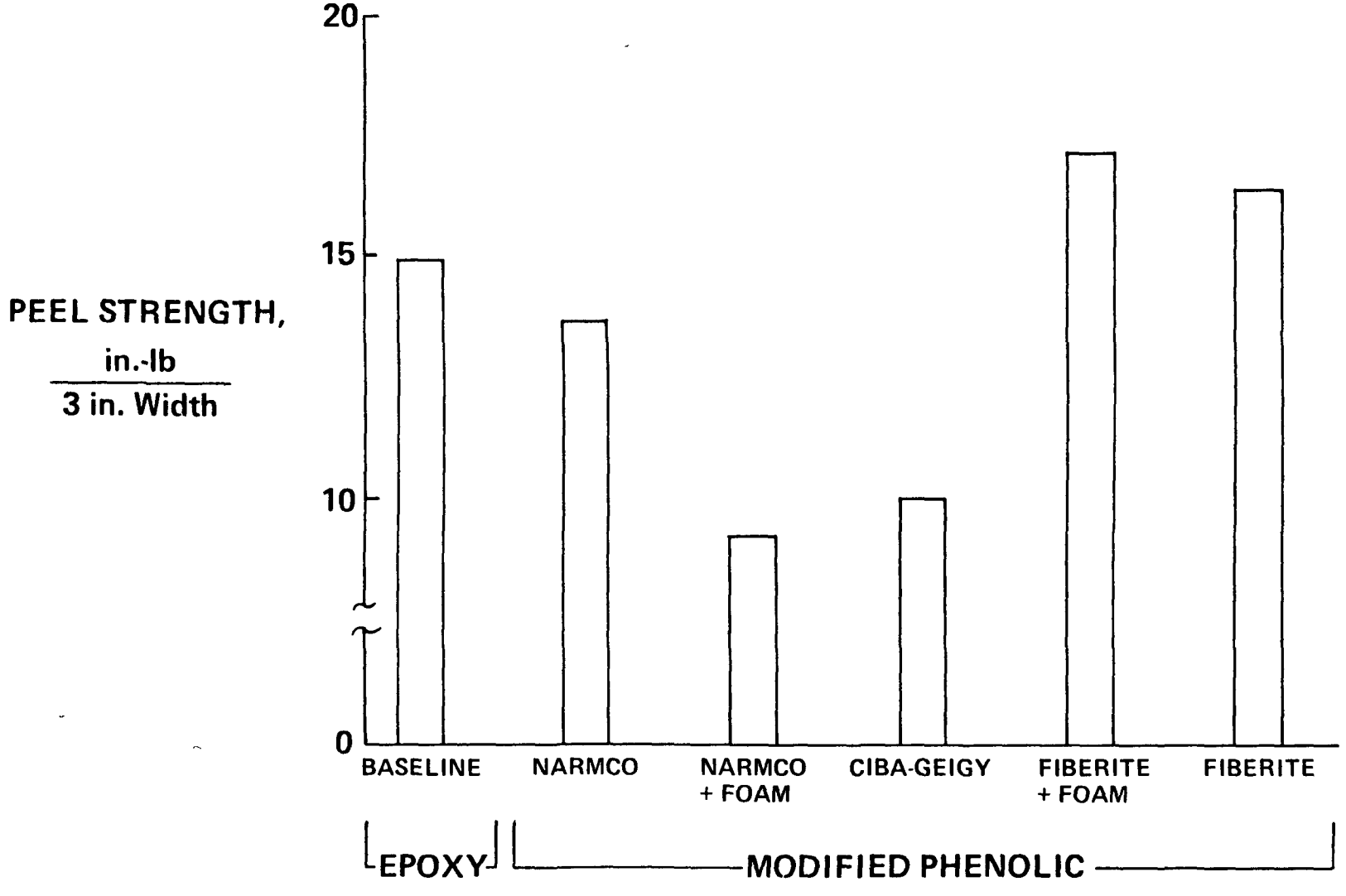
BOEING BURN-THROUGH APPARATUS



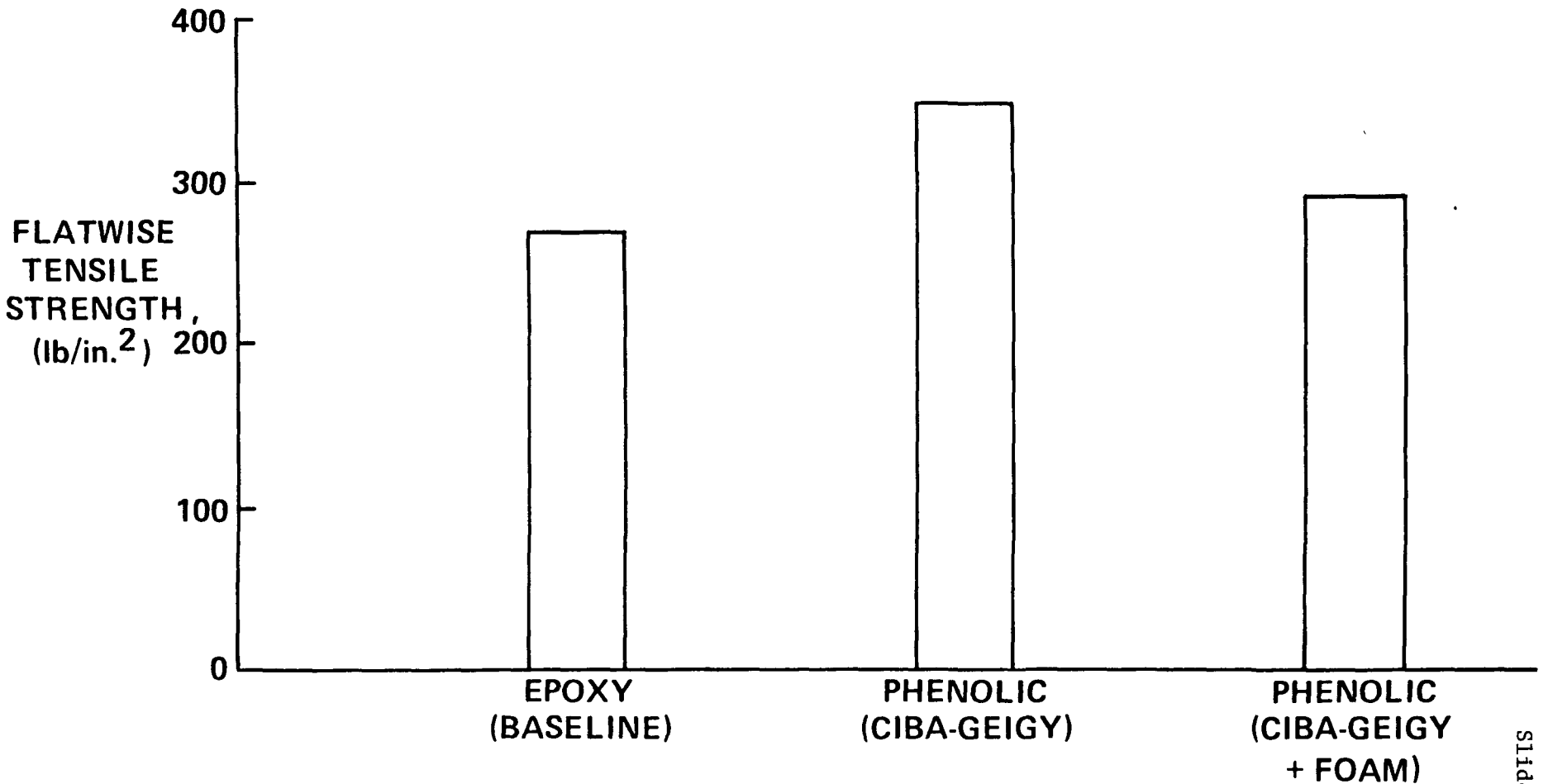
BOEING BURN-THROUGH



MECHANICAL STRENGTH–0.25 INCH CORE



MECHANICAL STRENGTH



FS & T IMPROVEMENTS

	BASELINE EPOXY	CIBA-GEIGY PHENOLIC
• PROPENSITY TO BURN (LOI)		
• FACE SHEET	29.0	100^{+}
• BOND PLY	27.7	53.5
• SMOKE EMISSION (D_s @ 4 min) NBS		
• 2.5 W/ cm^2	62.8	2.5
• 5.0 W/ cm^2	96.5	8.4
• HEAT RELEASE (J/cm^2) OSU		
• 2.5 W/ cm^2	177.2	126.0
• 5.0 W/ cm^2	512.4	96.3
• ALC_{50} (mg/liter) NASA CHAMBER		
• FACE SHEET	–	61.2
• BOND PLY	33.6	49.7

DECORATIVE FILM DEVELOPMENT

PHASE III

NAS2-8700

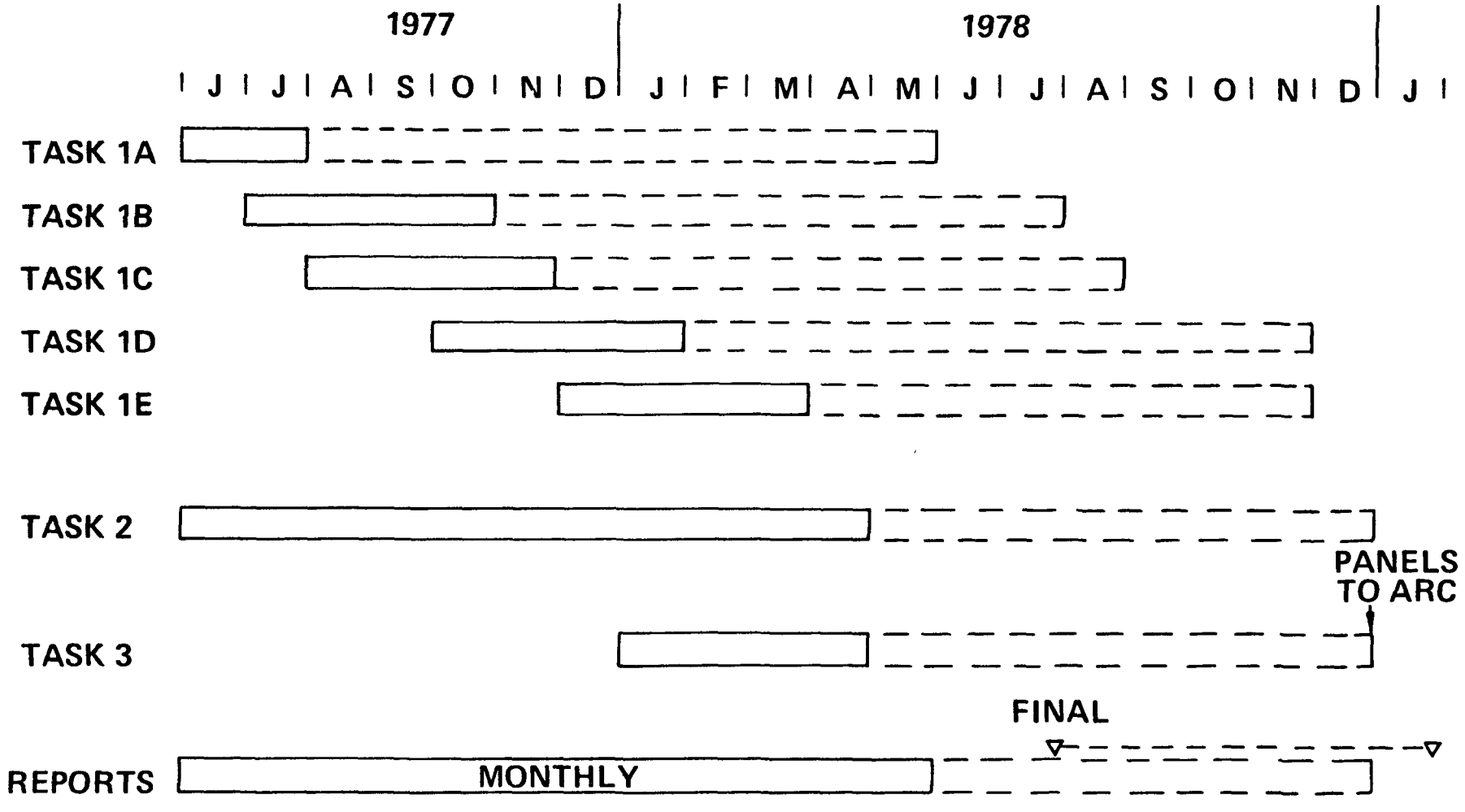
OBJECTIVES

- SIDEWALL, CEILING, AND PARTITION PANEL DEVELOPMENT
- DECORATIVE FILM DEVELOPMENT
- LOW SMOKE AND TOXIC GAS EMISSION
- RESISTANT TO HIGH HEAT FLUX
- PROCESS ASSESSMENT
- RANKING SYSTEM
- END ITEM DELIVERY TO NASA/ARC

FILM DEVELOPMENT PROGRAM

- TASK 1–DECORATIVE FILM DEVELOPMENT
  - TASK 1A–FILM SELECTION
  - TASK 1B–FILM SCREENING
  - TASK 1C–FILM PRINTABILITY
  - TASK 1D–COMPOSITE FILM TESTING
  - TASK 1E–FABRICATION OF DECORATIVE LAMINATES
- TASK 2–RESIN SYSTEM DEVELOPMENT
- TASK 3–COMBINED SANDWICH PANEL

DECORATIVE FILM PROGRAM SCHEDULE



TEST PLAN

	TASK					
	1-A	1-B	1-C	1-D	1-E	3
• FLAMMABILITY						
LOI (ASTM D2863)	X			X		
SMOKE (NBS CHAMBER)	X	X		X		X
TOXICITY (NBS CHAMBER)	X	X		X		X
HEAT RELEASE (OSU CHAMBER)		X				X
FLAME SPREAD (ASTM E-162)		X				
VERTICAL, 60 SECOND (FAR 25-32)				X		
BURN-THROUGH (BOEING)						X
T-3 THERMAL ENDURANCE (NASA)						X
TOXICITY (NASA)						X
• THERMOPHYSICAL						
TGA/DTA		X				
PYROLYSIS–600°C		X		X		

TEST PLAN

	TASK					
	1-A	1-B	1-C	1-D	1-E	3
• MECHANICAL						
TENSILE STRENGTH		X				
MODULUS		X				
ELONGATION		X		X		
SHRINKAGE		X				
HEAT DISTORTION TEMPERATURE		X				
PEEL STRENGTH				X	X	X
ABRASION RESISTANCE					X	X
BEAM FLEXURE						X
FLATWISE TENSION						X
IMPACT						X
• OTHER						
PRINTABILITY			X			
UV STABILITY				X		
STAIN RESISTANCE				X		
DECORATIVE CAPABILITY					X	
DENSITY						X

TASK 1-A FILMS

POLYVINYLFLUORIDE (PVF)

1. .002" WHITE TEDLAR (DUPONT)
2. .001" CLEAR DEGLOSSED TEDLAR + 6880 (DUPONT)
3. .002" WHITE FM TEDLAR (DUPONT)
4. .001" CLEAR TEDLAR + 6880 (DUPONT)

POLYVINYLIDENE FLUORIDE (PVF_2)

1. .003" WHITE FLUOREX H (REXHAM)
2. .002" CLEAR FLUOREX H (REXHAM)

POLYOLEFIN

1. .002" CLEAR BICOR 240B, POLYPROPYLENE (MOBIL)
2. .001" CLEAR BICOR 360B, POLYPROPYLENE (MOBIL)
3. .020" CLEAR TPX, POLYMETHYLPENTENE (MITSUI)
4. .008" WHITE APPLETON 61079, POLYETHYLENE (APPLETON)
5. .002" CLEAR WITCO, POLYBUTYLENE (WITCO)
6. .001" WHITE WITCO, POLYBUTYLENE (WITCO)

POLYIMIDE/POLYAMIDE

1. .001" BROWN KAPTON (DUPONT)
2. .002" BROWN KAPTON (DUPONT)
3. .002" CLEAR YELLOW DAPI-BTDA (CIBA-GEIGY)
4. .002" WHITE NOMEX PAPER (DUPONT)
5. .002" CLEAR ARAMID (DUPONT)

POLYPHENYLSULPHONE

1. .001" CREAM RADEL R-5010 (UNION CARBIDE)

POLYSULPHONE

1. .001" CLEAR UDEL (UNION CARBIDE)

POLYETHERSULPHONE

1. .001" POLYETHERSULPHONE 300P (ICI)

TASK 1-A FILMS

POLYESTER

1. .001" ISO-BPE AROMATIC (ISOVOLTA)
2. .002" WHITE MELINEX 334 (ICI-US)
3. .002" CLEAR MELINEX 442 (ICI-US)
4. .006" WHITE PERMACARE II HC (APPLETON)
5. .007" WHITE FR REEMAY (APPLETON)
6. .017" WHITE HY-PERMACARE-6 (APPLETON)
7. .008" WHITE PERMACARE IV (APPLETON)
8. .007" WHITE PERMALESCENT (APPLETON)
9. .006" COLORED PERMACARE (APPLETON)

POLYBENZIMIDAZOLE

1. .002" POLYBENZIMIDAZOLE 23856-30 #1 (CELANESE RESEARCH)

ACRYLIC

1. .002" CLEAR KORAD A-CU (KORAD)
2. .002" WHITE KORAD 63000 (KORAD)

POLYCARBONATE

1. .002" CLEAR LEXAN (GENERAL ELECTRIC)

POLYPARABANIC ACID

1. .002" CLEAR YELLOW TRADLON (EXXON)
2. .002" OPAQUE YELLOW TRADLON (EXXON)

IONOMER

1. .001" SURLYN 1652 (DUPONT)
2. .001" SURLYN 1601 (DUPONT)

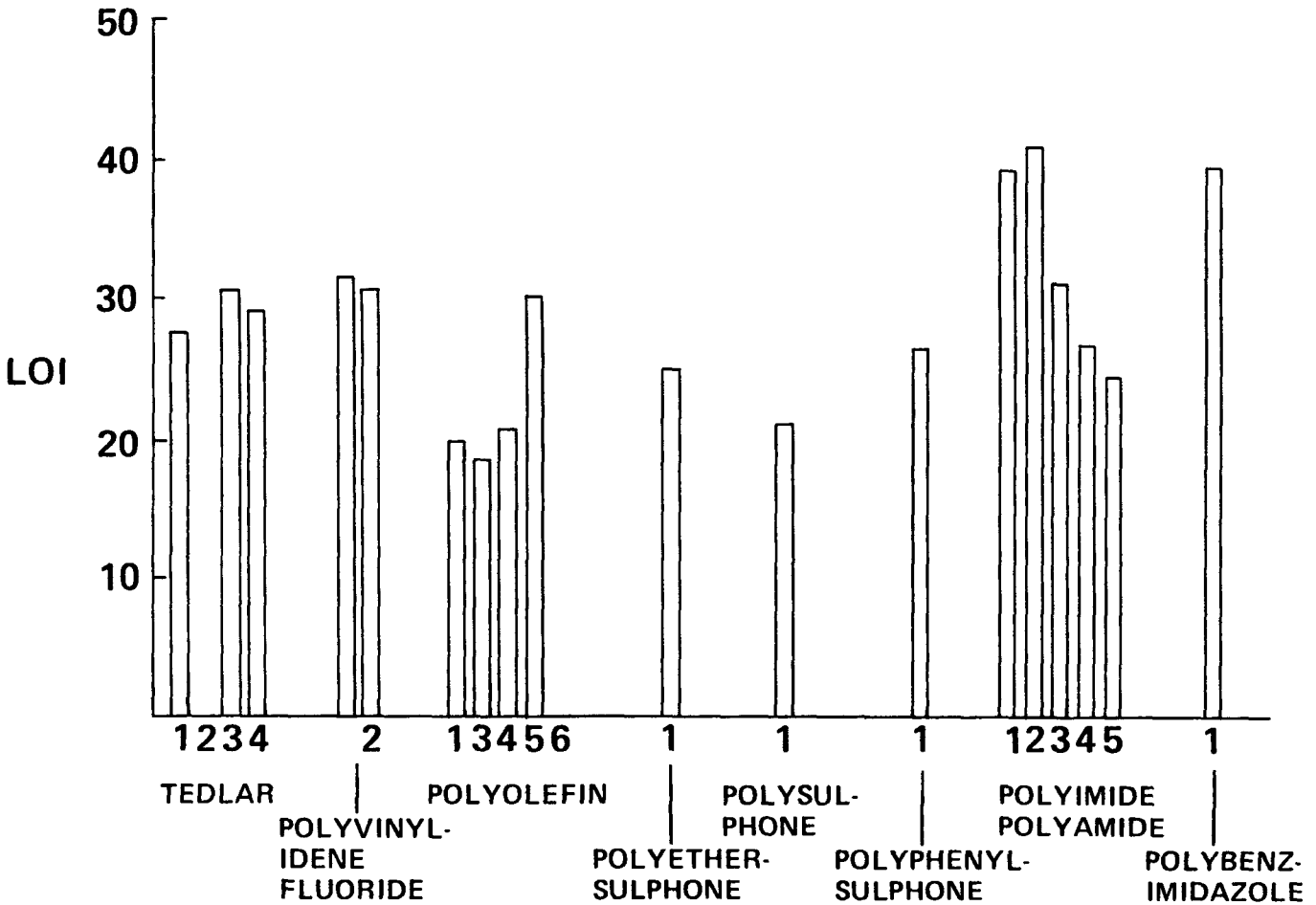
NYLON 6,6

1. .002" CLEAR BLUE WRIGHTON 8400 (INTERNATIONAL PLASTICS PRODUCTS)

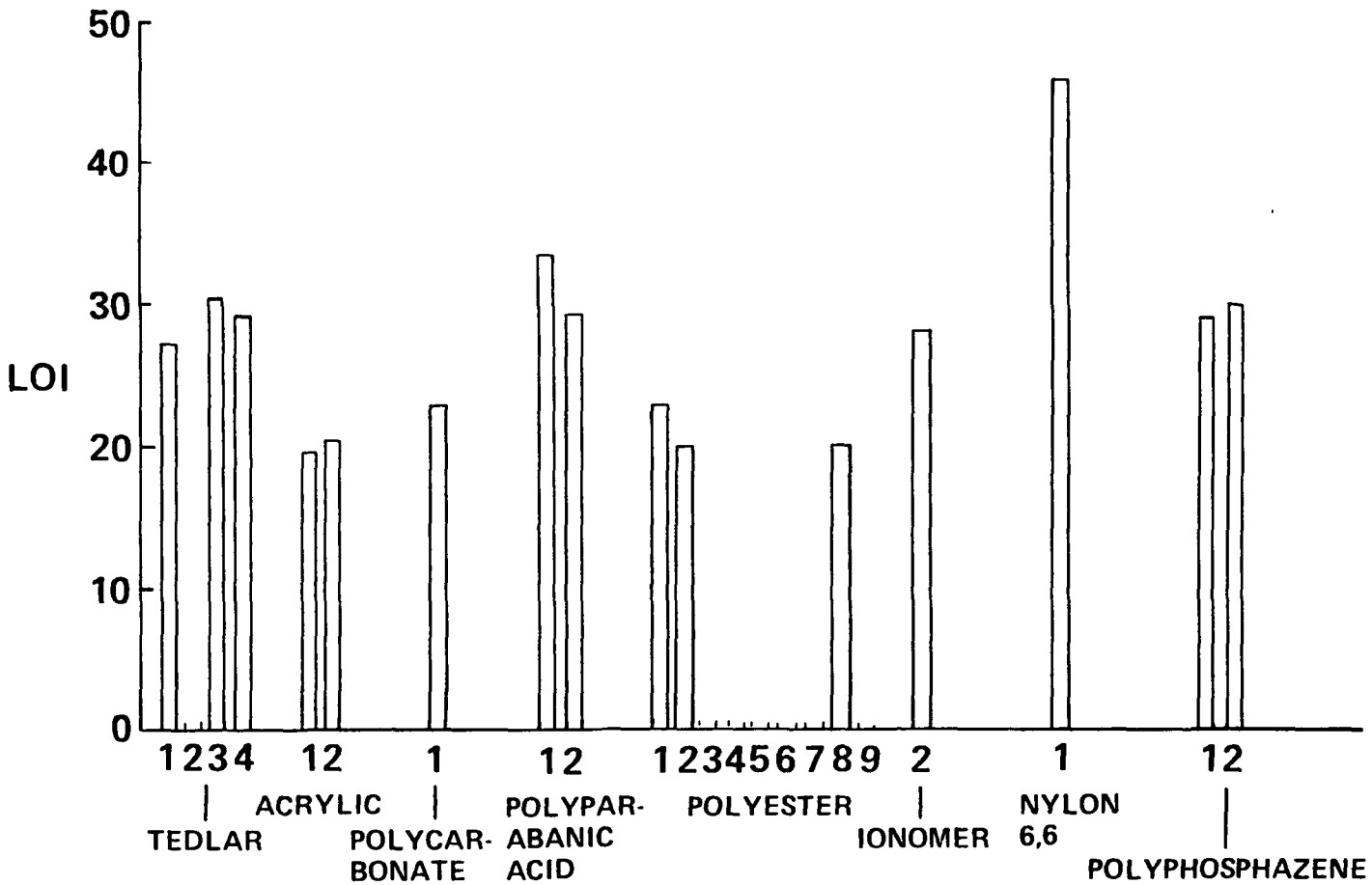
POLYPHOSPHAZENE

1. .007" HORIZONS 1443-24-2 (HORIZONS)
2. .007" HORIZONS 1443-24-1 (HORIZONS)

PROPENSITY TO BURN

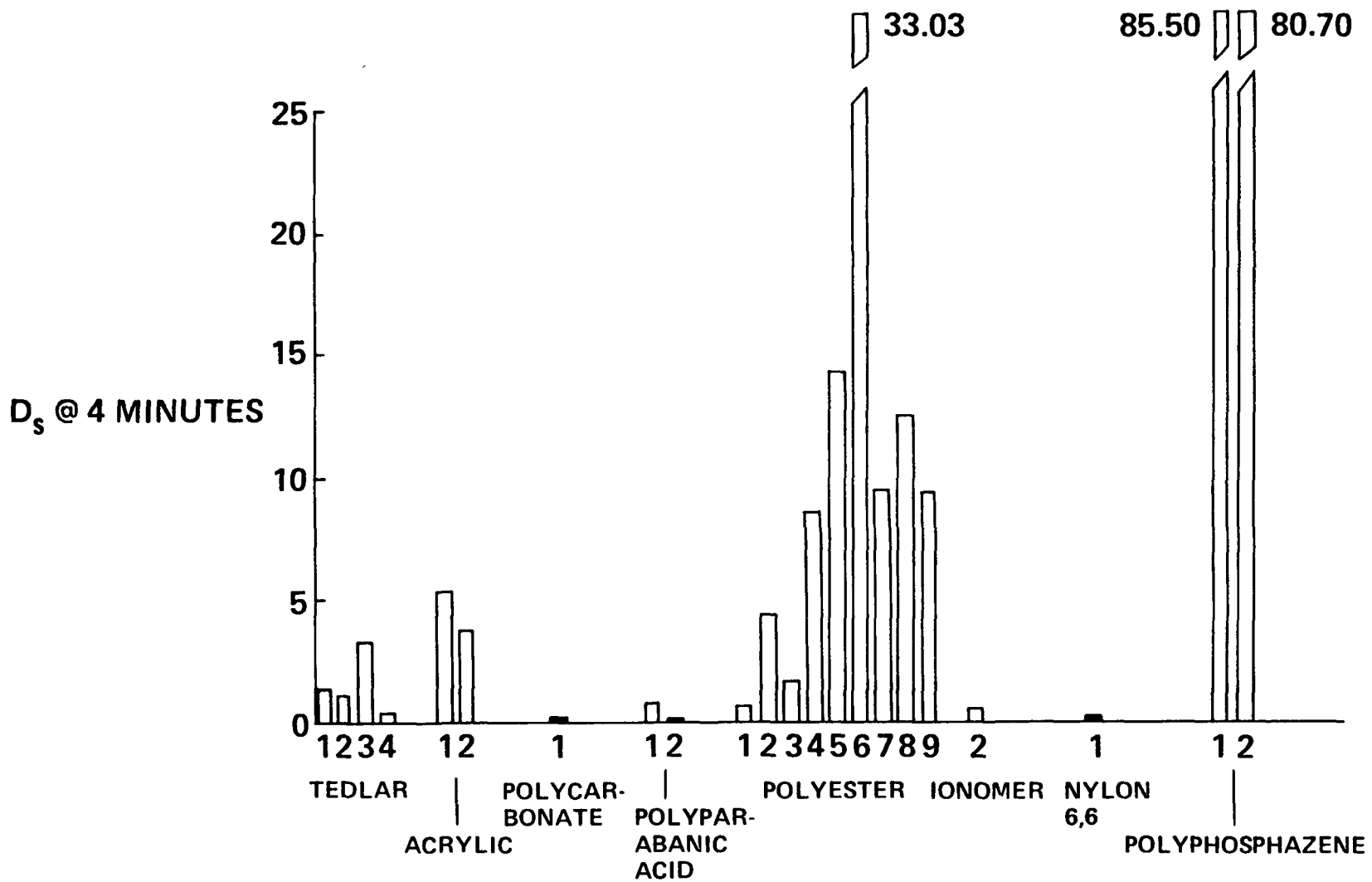


PROPENSITY TO BURN



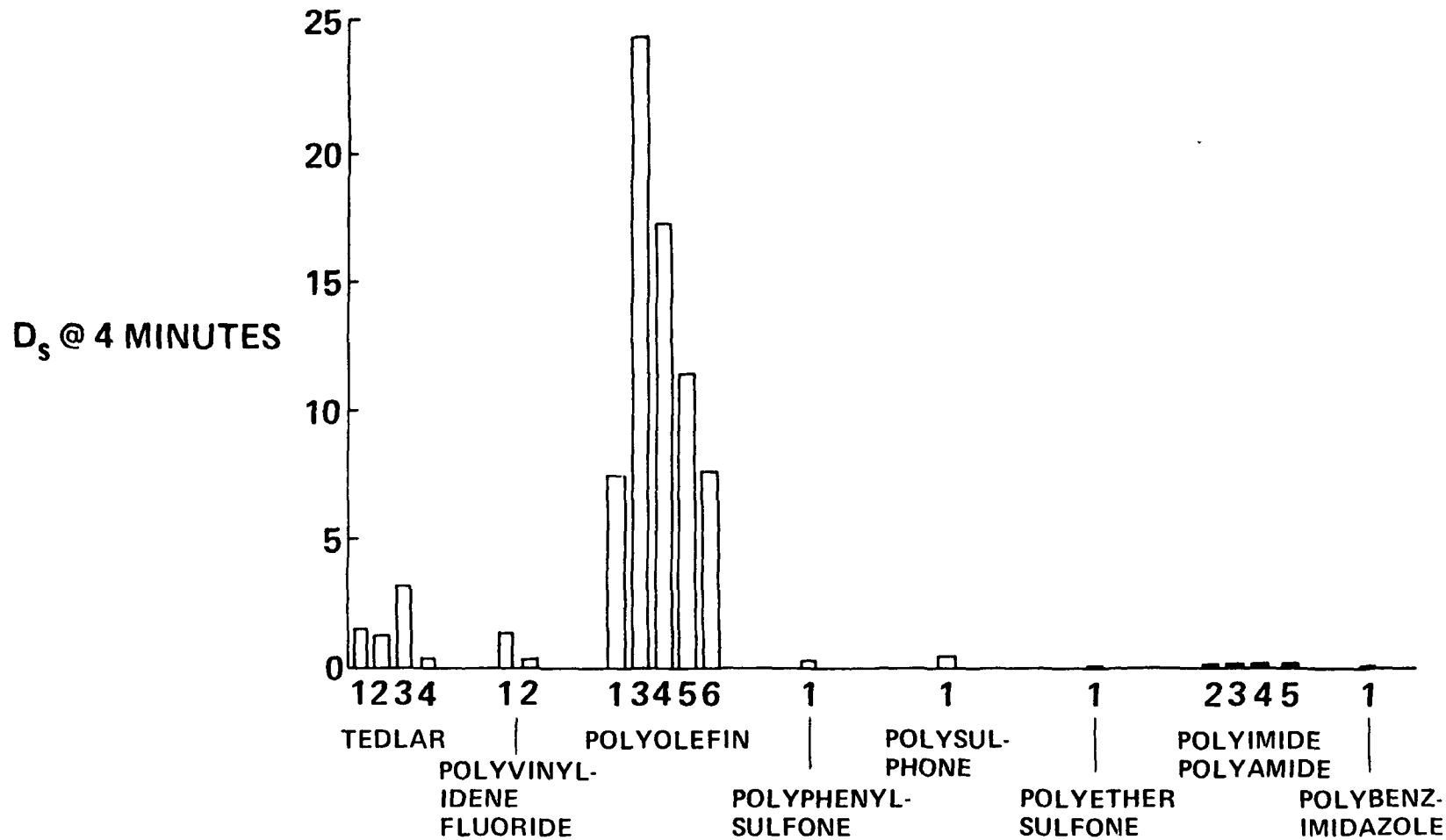
SMOKE EMISSION—NBS CHAMBER

2.5 W/cm^2



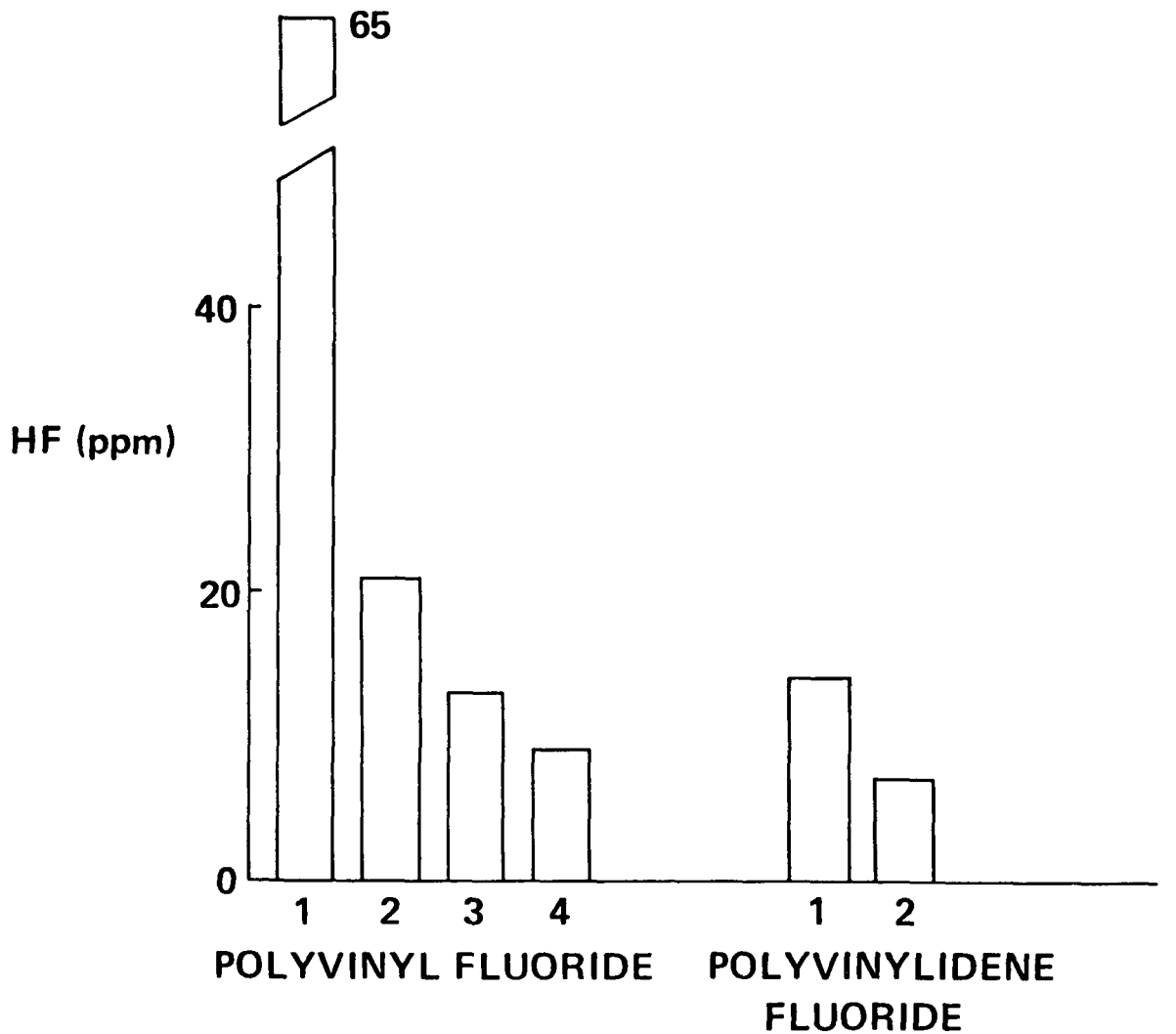
SMOKE EMISSION–NBS CHAMBER

2.5 W/cm^2



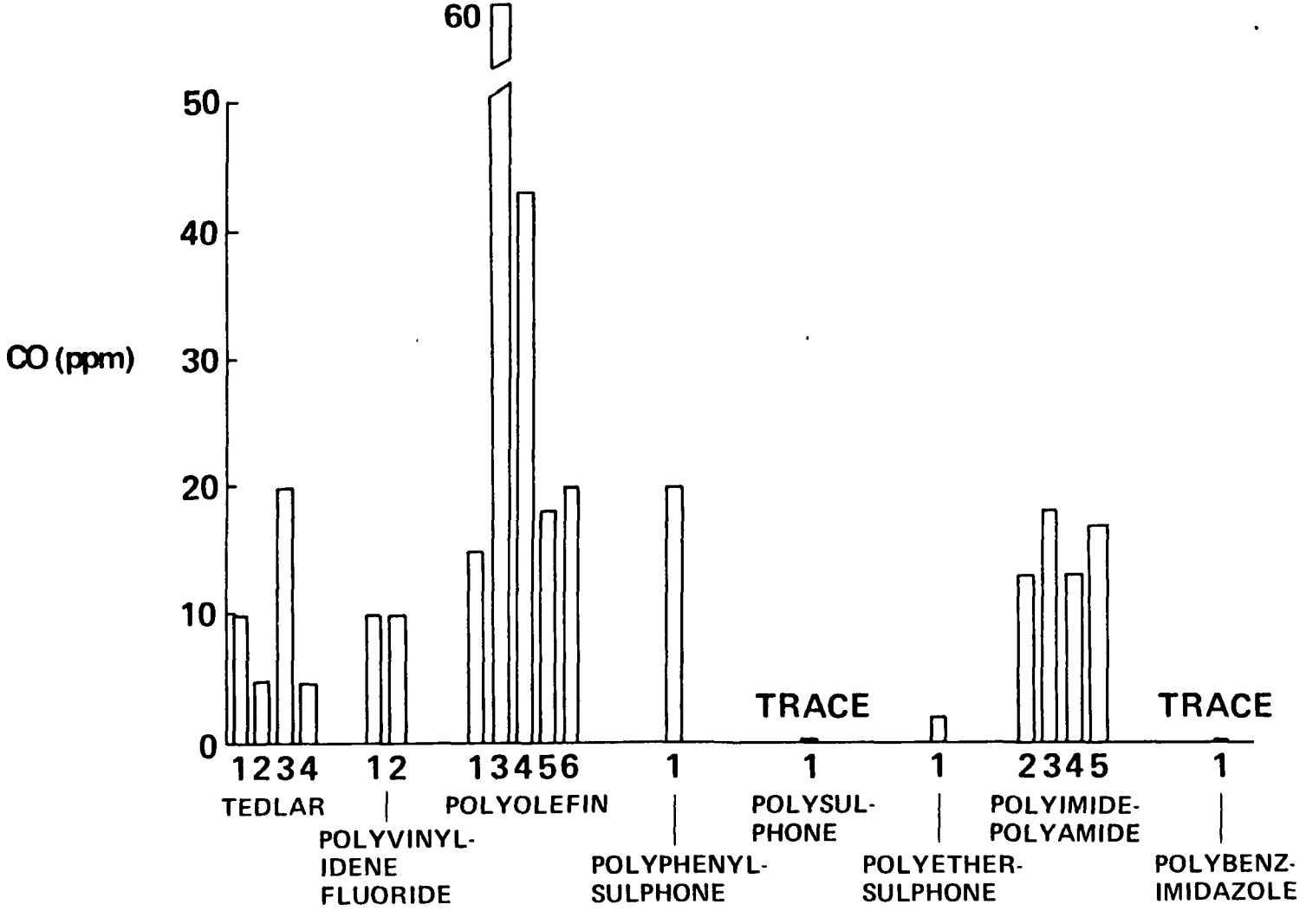
TOXIC GAS EMISSION–NBS CHAMBER

2.5 WATTS/cm^2 –4 MINUTES



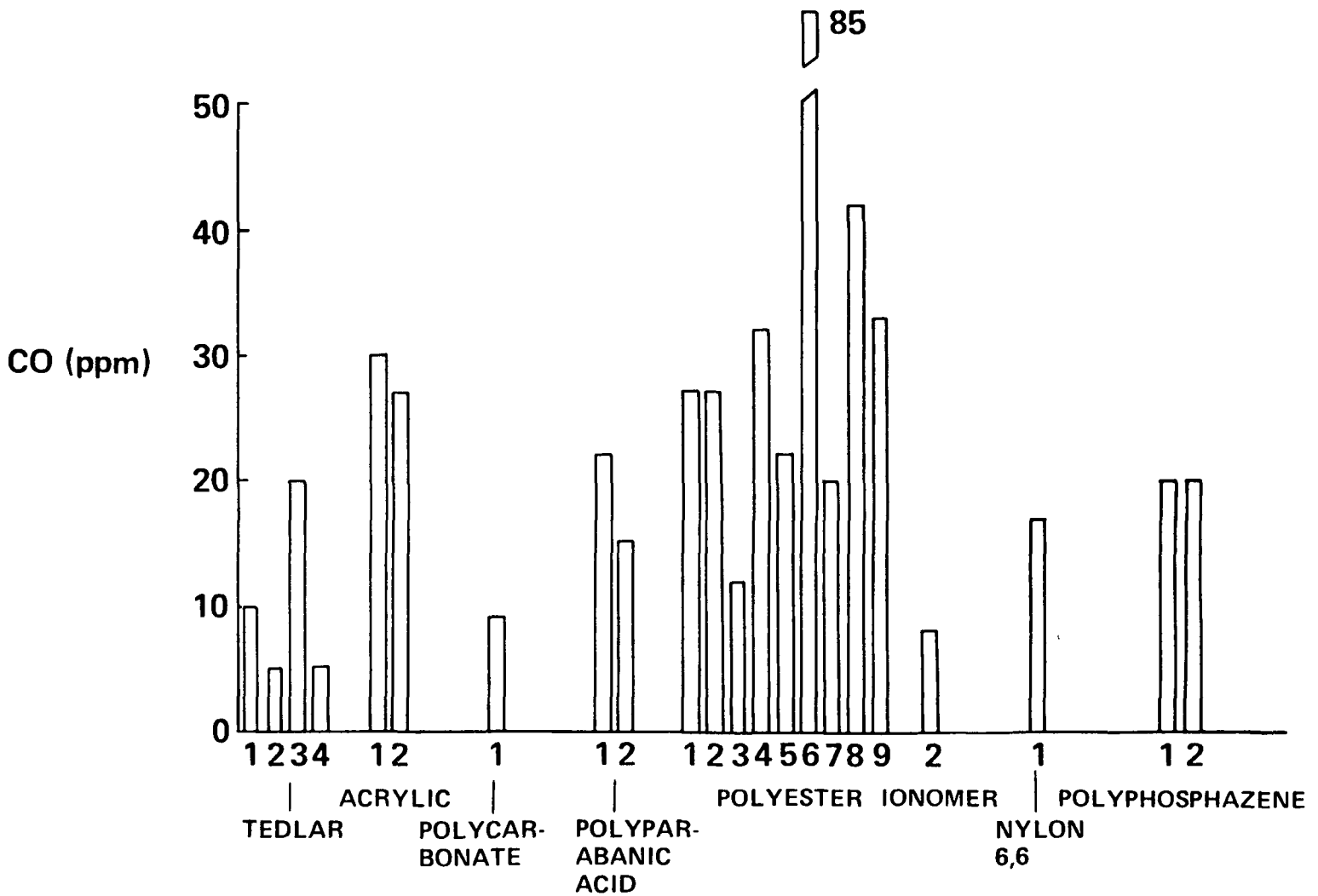
TOXIC GAS DATA–NBS CHAMBER

2.5 WATTS/cm^2 –4 MINUTES

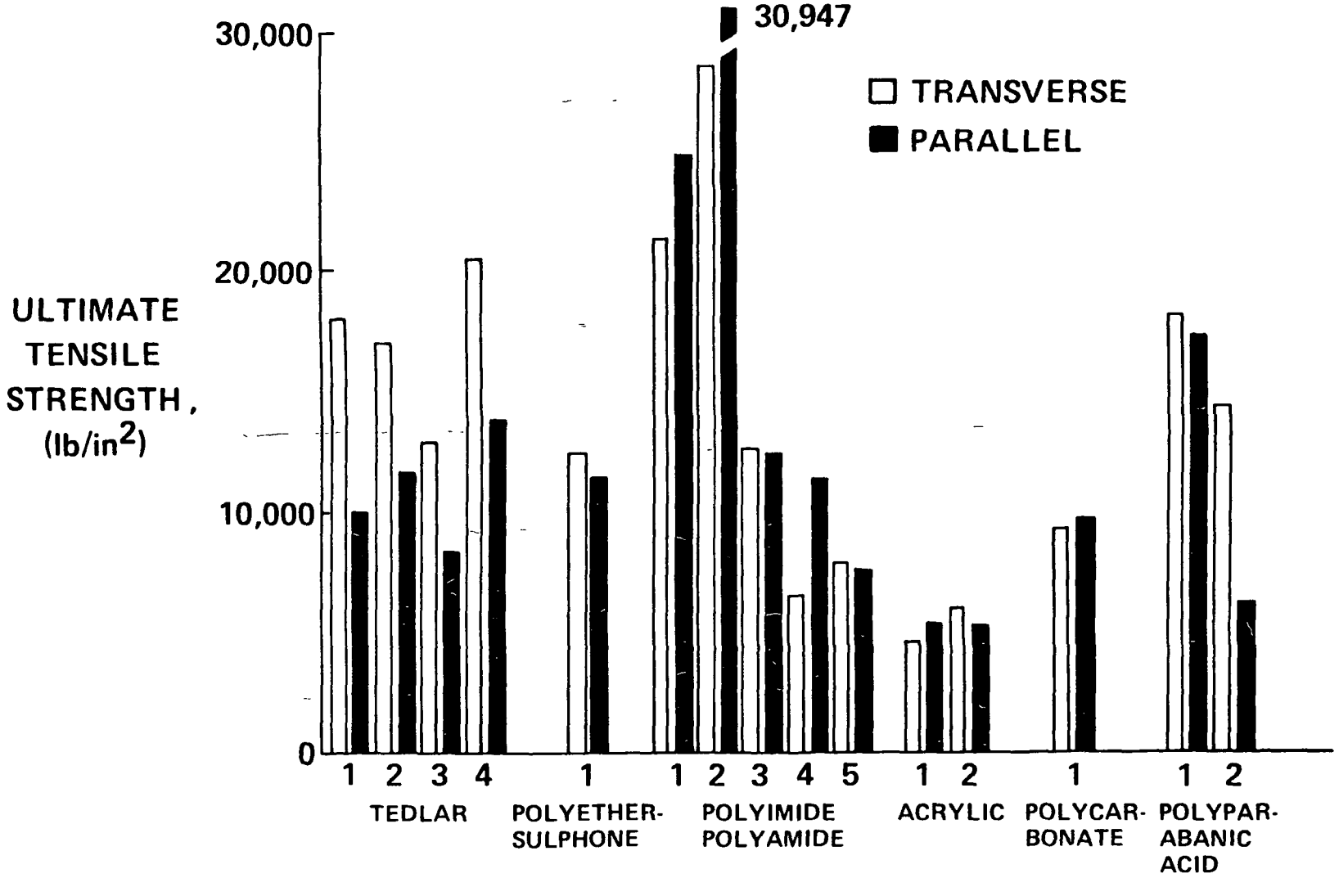


TOXIC GAS DATA–NBS CHAMBER

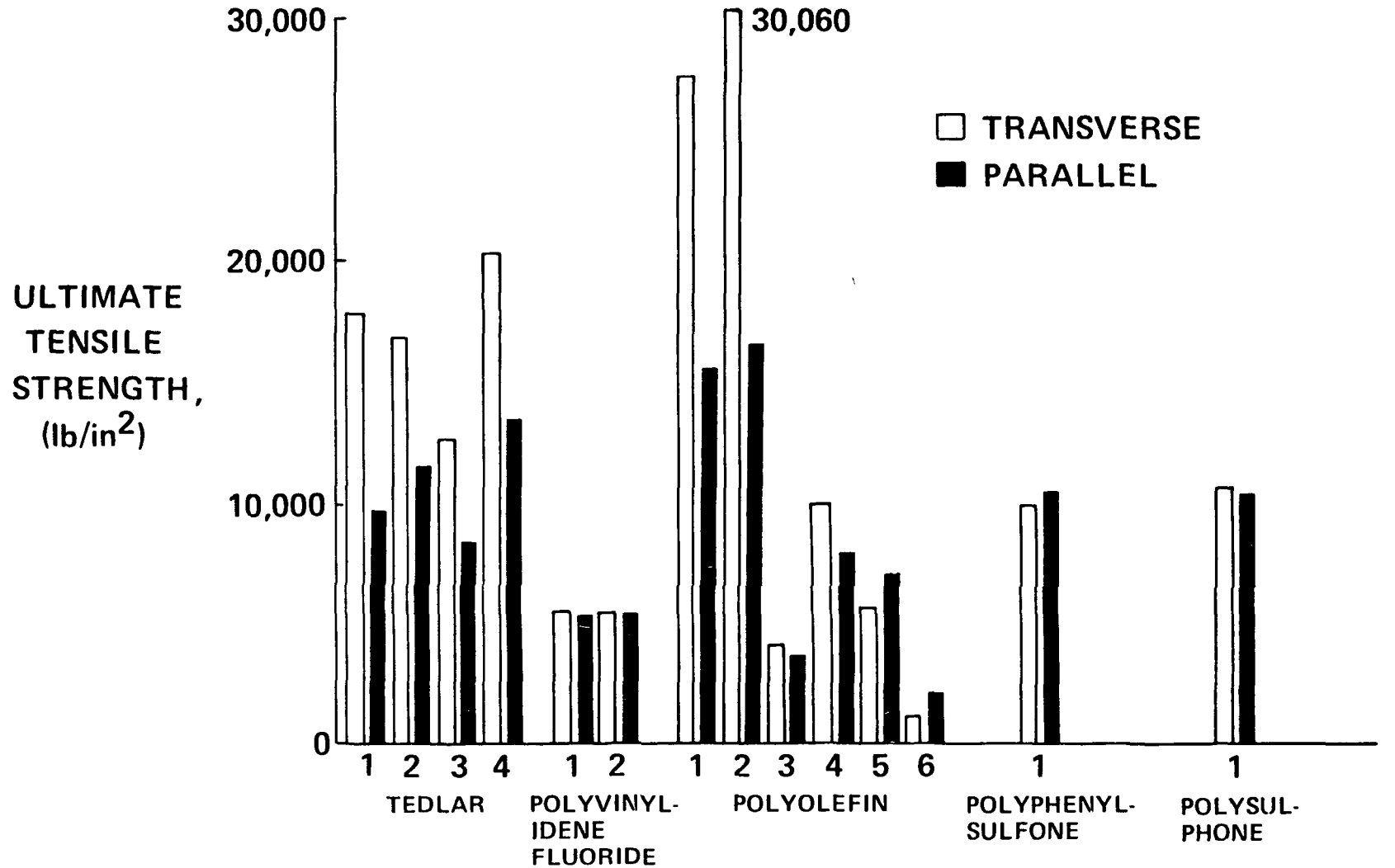
2.5 WATTS/cm^2 –4 MINUTES



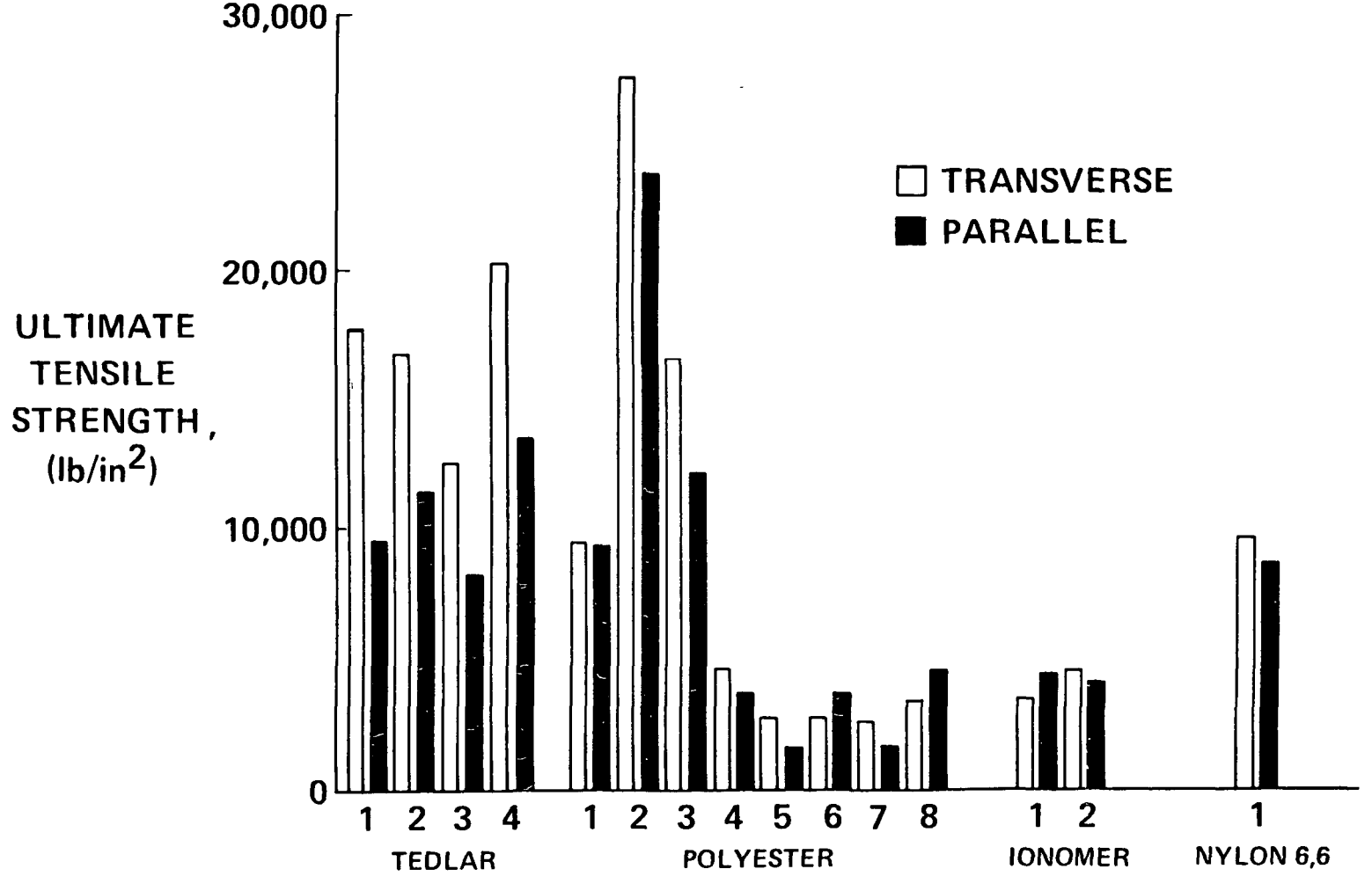
TENSILE PROPERTIES–ROOM TEMPERATURE



TENSILE PROPERTIES–ROOM TEMPERATURE



TENSILE PROPERTIES–ROOM TEMPERATURE



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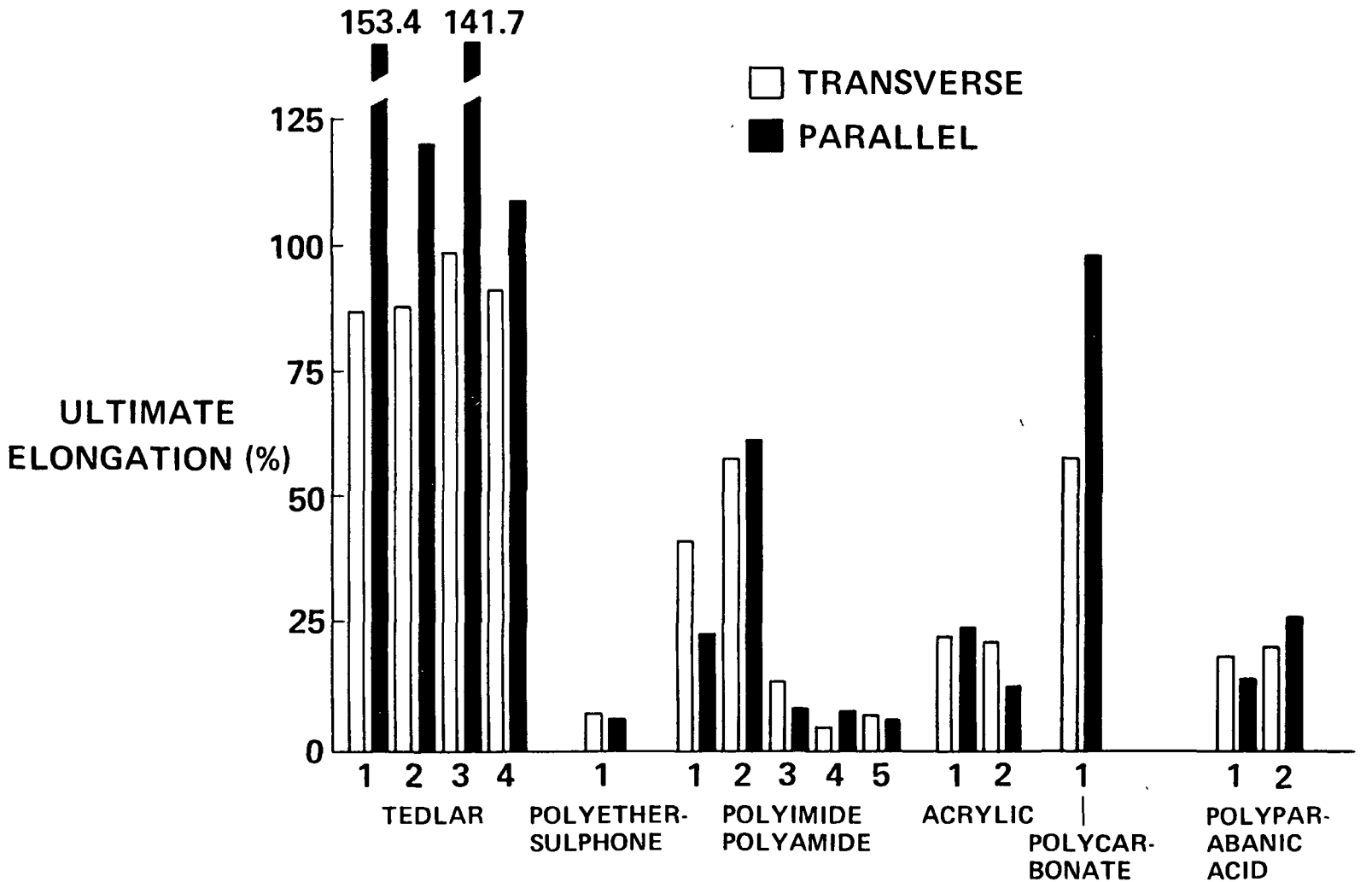
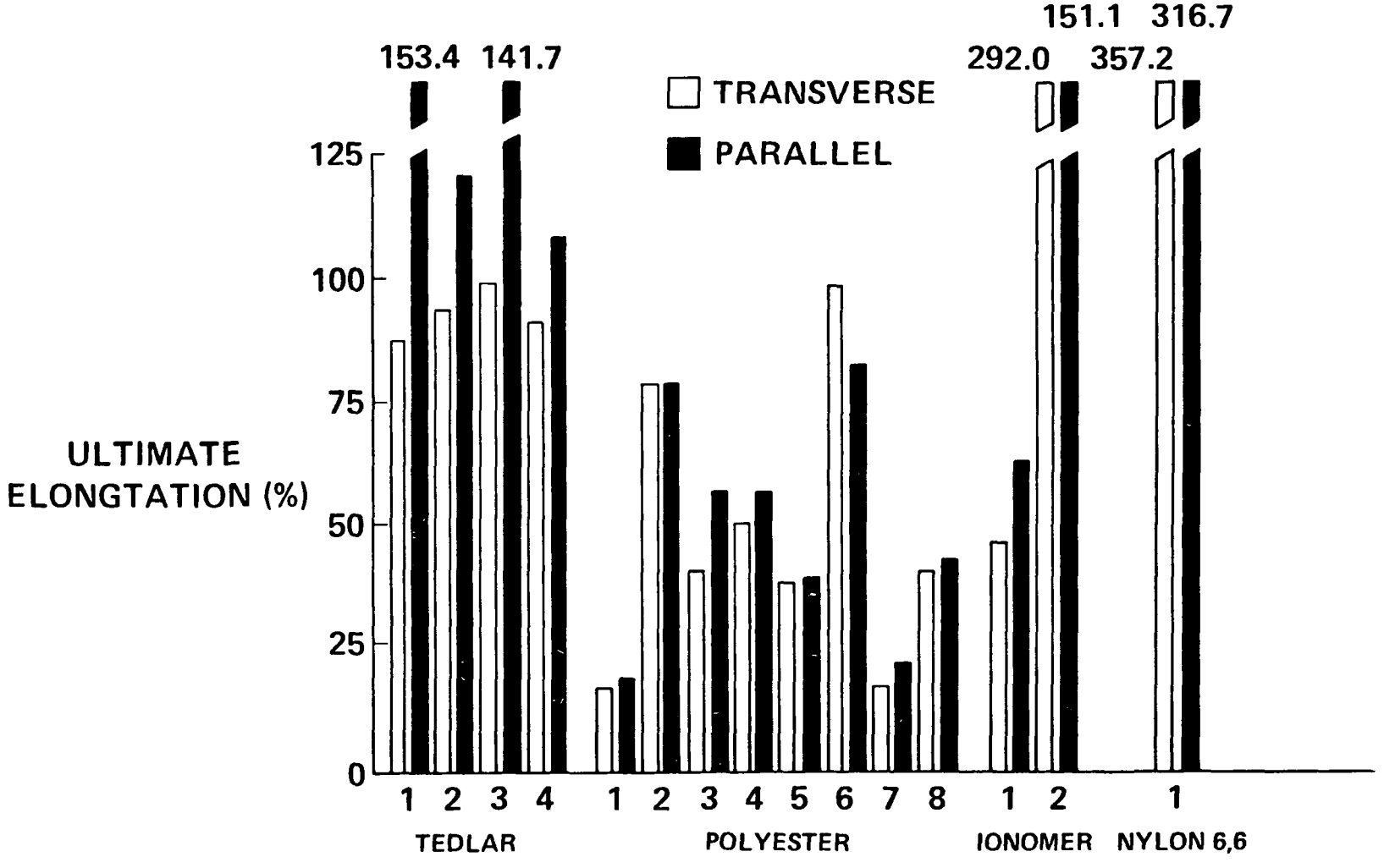
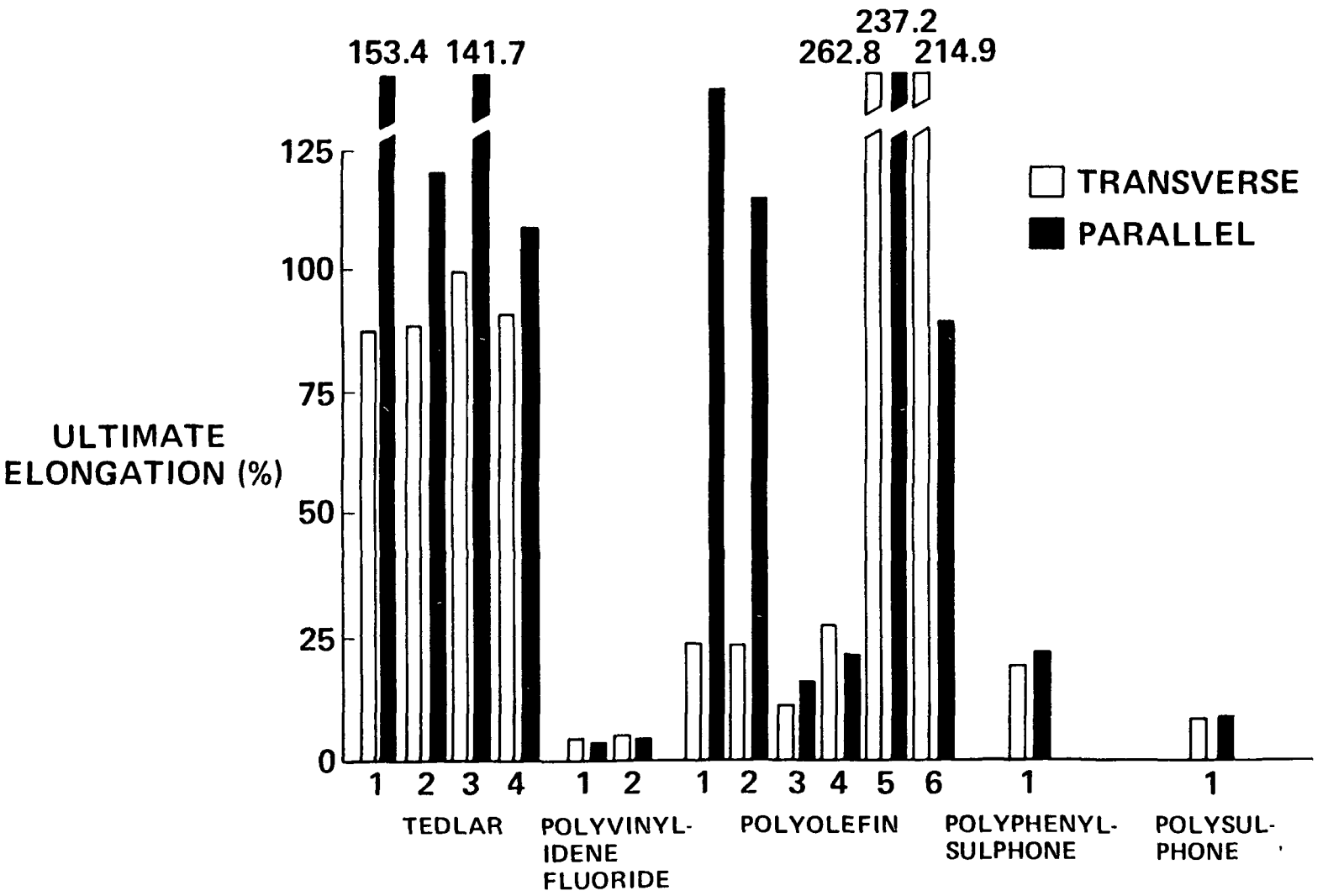


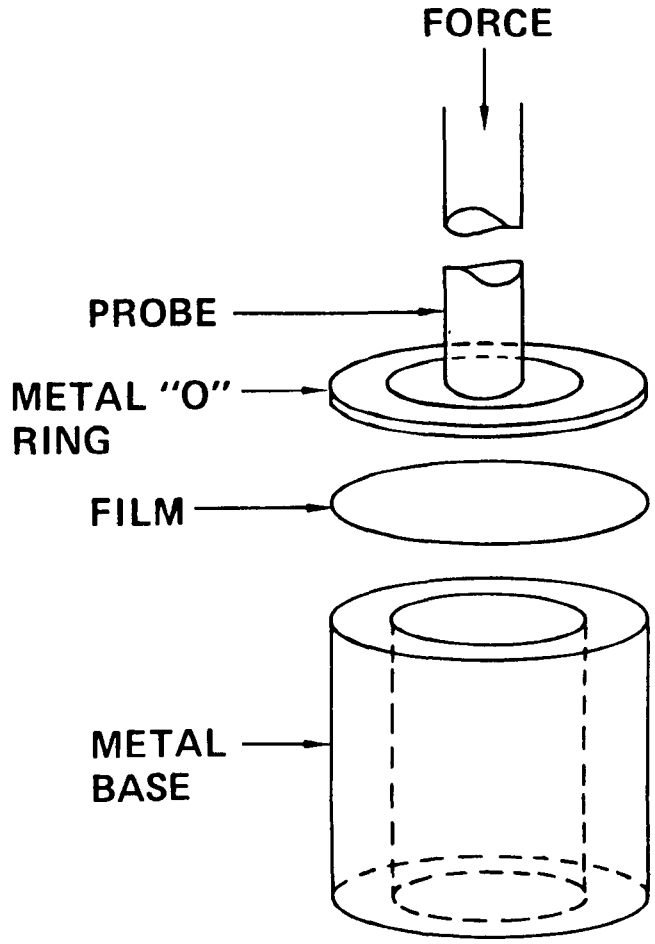
TENSILE PROPERTIES–ROOM TEMPERATURE

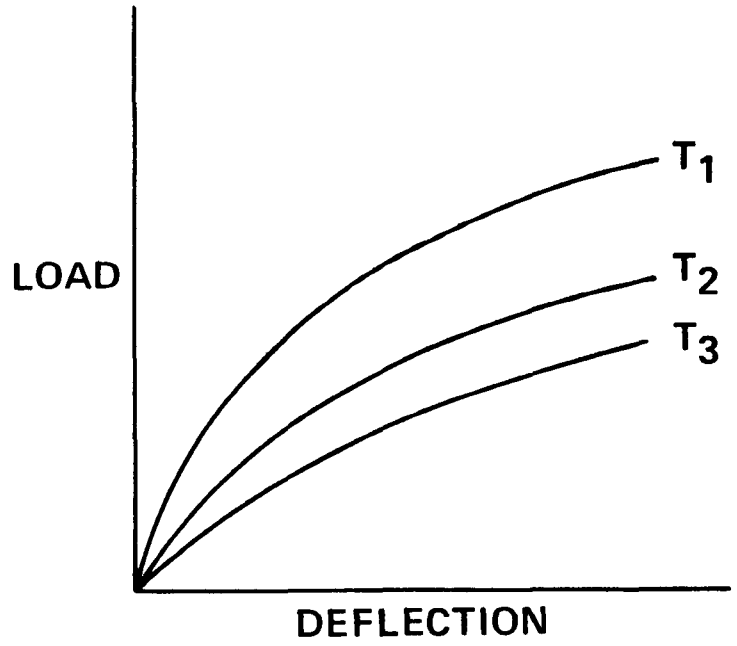


TENSILE PROPERTIES–ROOM TEMPERATURE



MECHANICAL TEST





MATERIALS EVALUATION–TASK 2

- POLYSTYRYLPYRIDINE
  - SOCIETE NATIONALE DES POUDRES ET EXPLOSIFS
- CURE CYCLE
  - 200°C–0 kg/cm^2–1 HOUR
  - 200°C–10 kg/cm^2–3 HOURS
  - 225°C–10 kg/cm^2–2 HOURS
- POSTCURE
  - 4 HOURS–300°C OR
  - 12 HOURS–250°C

PROBLEMS

- CURE CYCLE
- COST
- HANDLING
- AVAILABILITY

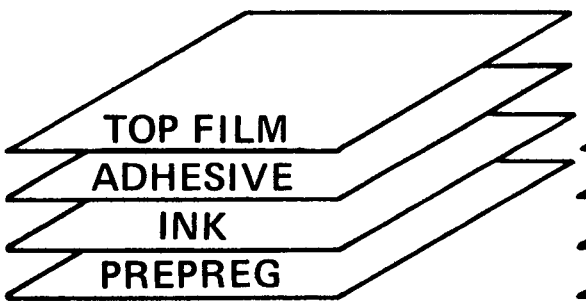
FUTURE WORK

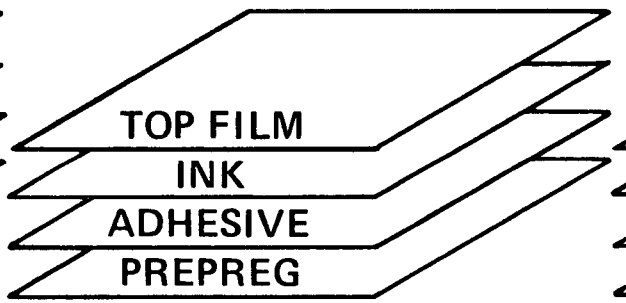
- CANDIDATE FILMS–TASK 1B
  - AROMATIC POLYAMIDE
  - AROMATIC POLYESTER
  - POLYBENZIMIDAZOLE
  - POLYETHERSULFONE
  - POLYIMIDE
  - POLYPARABANIC ACID
  - POLYVINYLIDENE FLUORIDE
  - POLYVINYLFLUORIDE
  - POLYCARBONATE

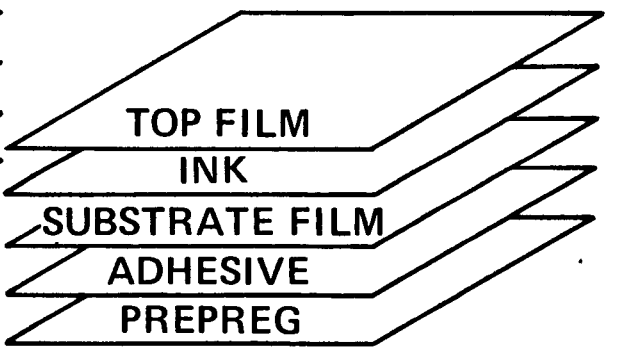
FUTURE WORK

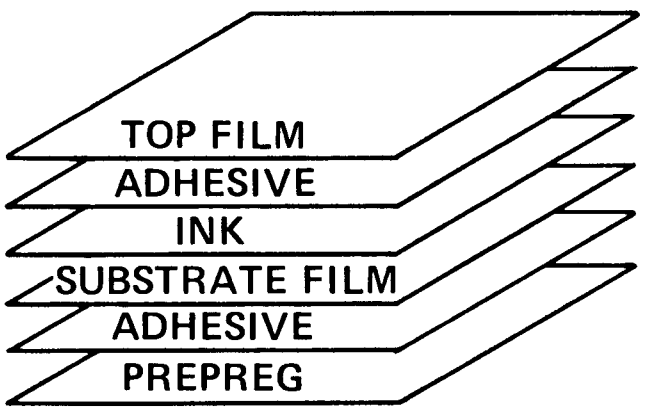
- SUBSTRATE AND TOP FILM EVALUATION
  - PRINTABILITY
  - DECORATIVE CAPABILITY
  - MAINTAINABILITY
- CONTINUED FS & T EVALUATION

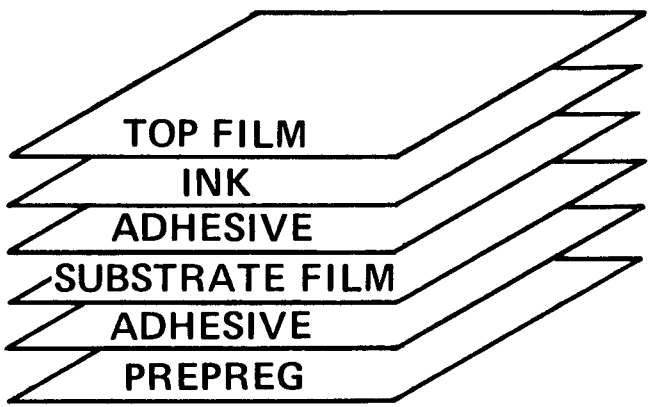
DECORATIVE LAMINATE CONFIGURATIONS



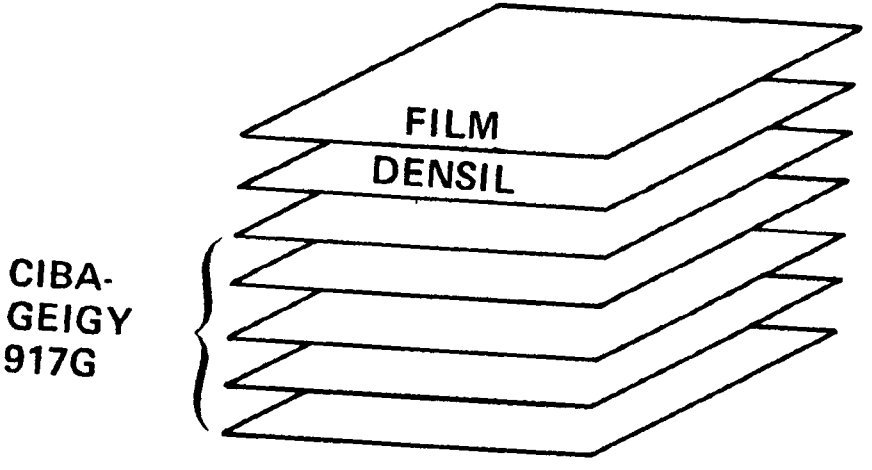








FS & T SPECIMENS



- FLAME SPREAD (ASTM E-162)
- SMOKE EMISSION (NBS)
- TOXIC GAS EMISSION (NBS)
- HEAT RELEASE (OSU)

SCREEN PRINTING INK DEVELOPMENT

PHASE IV

NAS2-9864

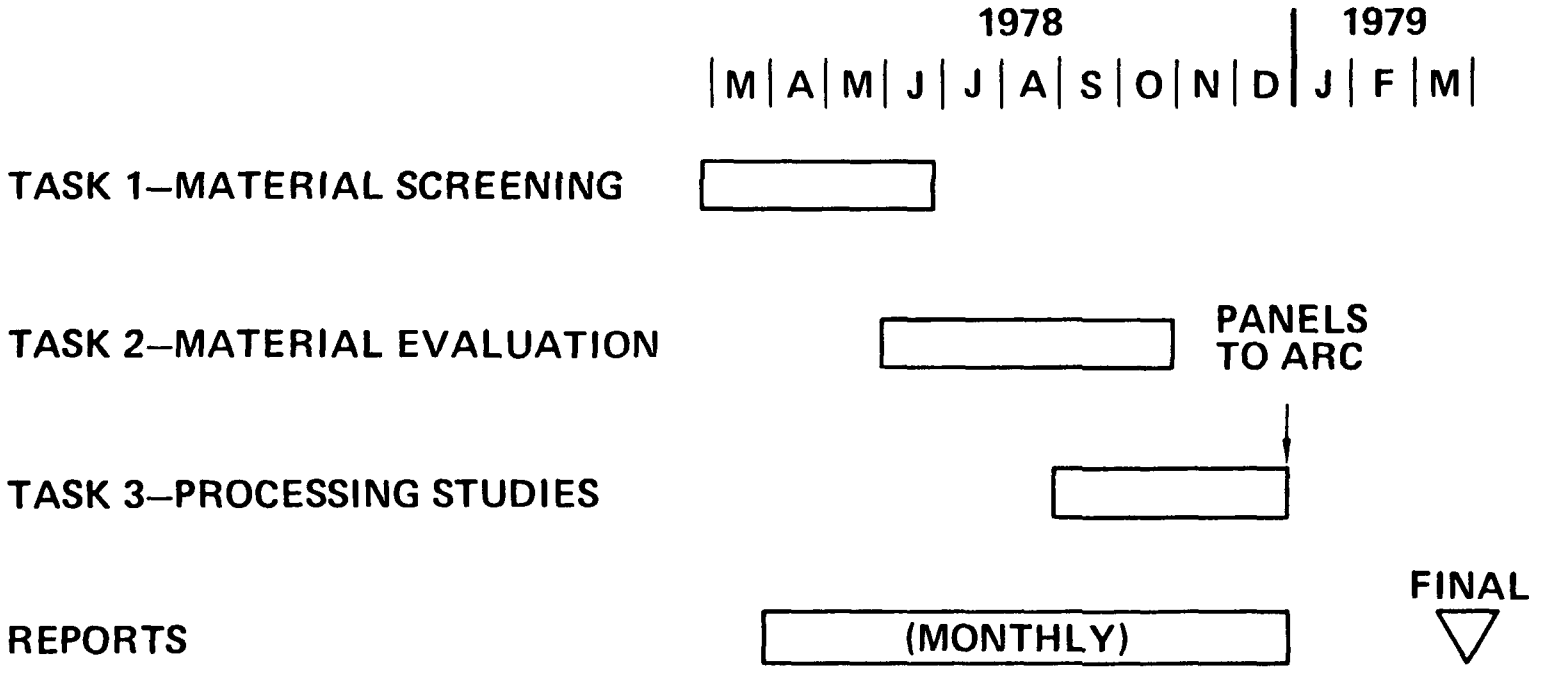
OBJECTIVES

- SIDEWALL, CEILING, AND PARTITION PANEL DEVELOPMENT
- SCREEN PRINTING INK DEVELOPMENT
- LOW SMOKE AND TOXIC GAS EMISSION
- THERMAL STABILITY
- FIRE RESISTANCE
- PROCESS ASSESSMENT
- END ITEM DELIVERY TO NASA-ARC

SCREEN PRINTING INK DEVELOPMENT PROGRAM

- TASK 1—MATERIAL SCREENING
- TASK 2—MATERIAL EVALUATION
- TASK 3—PROCESSING STUDIES

SCREEN PRINTING INK PROGRAM SCHEDULE



TEST PLAN

	TASK		
	1	2	3
• FLAMMABILITY			
PYROLYSIS TUBE–600°C		X	
LIMITING OXYGEN INDEX (LOI)	X	X	
SMOKE & TOXIC GAS EMISSION (NBS)	X	X	X
HEAT RELEASE (OSU)		X	X
TOXICITY (NASA)	X	X	X
• THERMOPHYSICAL			
TGA/DTA	X	X	
• MECHANICAL			
PEEL STRENGTH		X	X
IMPACT STRENGTH			X

TEST PLAN

	TASK		
• OTHER	1	2	3
UV STABILITY		X	X
DENSITY		X	
ODOR AND TOXICITY		X	
CONDITION IN CONTAINER		X	
STORAGE STABILITY		X	
NON-VOLATILE CONTENT		X	
THIXOTROPIC INDEX		X	
WORKING PROPERTIES		X	
FINENESS OF GRIND		X	
COLOR		X	
DRY TIME		X	
HIGH TEMPERATURE AND PRESSURE RESISTANCE		X	

MATERIAL REQUIREMENTS–TASK 1

- LOI $\geqslant$ 35
- DS @ 4 MINUTES $\leqslant$ 20
- TGA IN N_2 (RT $\rightarrow$ 250°C)

RESIN SYSTEMS

- PHOSPHAZENE SUBSTITUTED EPOXY
- PHOSPHORUS SUBSTITUTED EPOXY
- AROMATIC ORGANOSILICONE
- OTHERS TO BE DETERMINED

TASKS 2 and 3

- PANEL TYPES
  - CLASS A–0.002" PVF + INK
  - CLASS B–CLASS A + 0.001" PVF + EPOXY PREPREG
  - CLASS C–NEW FILM + INK
  - CLASS D–CLASS A + 0.001" PVF + PHENOLIC PREPREG
  - CLASS E–CLASS C + NEW FILM + PHENOLIC PREPREG
- TESTING
  - HEAT RELEASE
  - SMOKE RELEASE
  - TOXICITY
  - MECHANICAL PROPERTIES

PHOSPHORYLATED EPOXY ADHESIVES

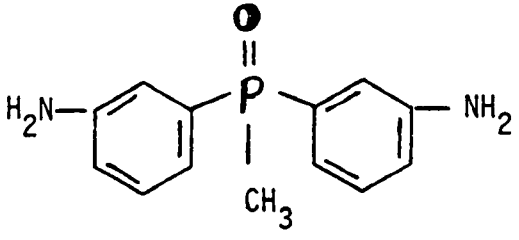
Norman Bilow
Hughes Aircraft Company

HUGHES

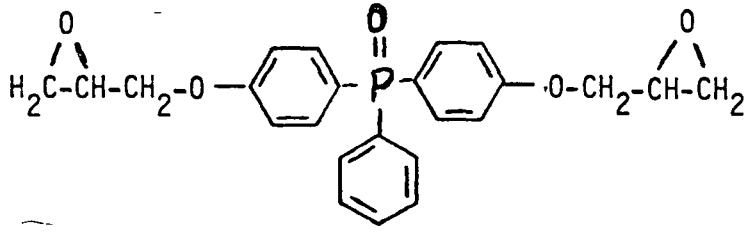
HUGHES AIRCRAFT COMPANY

DEVELOPMENT
OF
FIRE RETARDANT ADHESIVES
FOR
AIRCRAFT INTERIORS

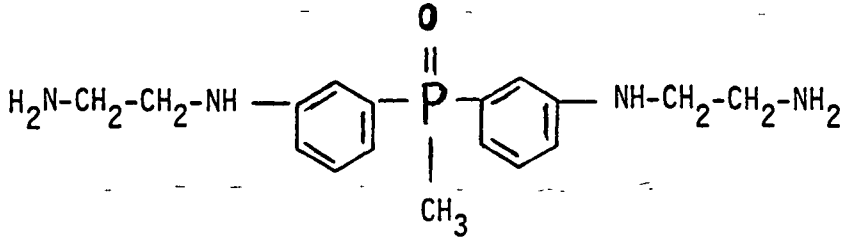
HUGHES
HUGHES AIRCRAFT COMPANY



12.6% P



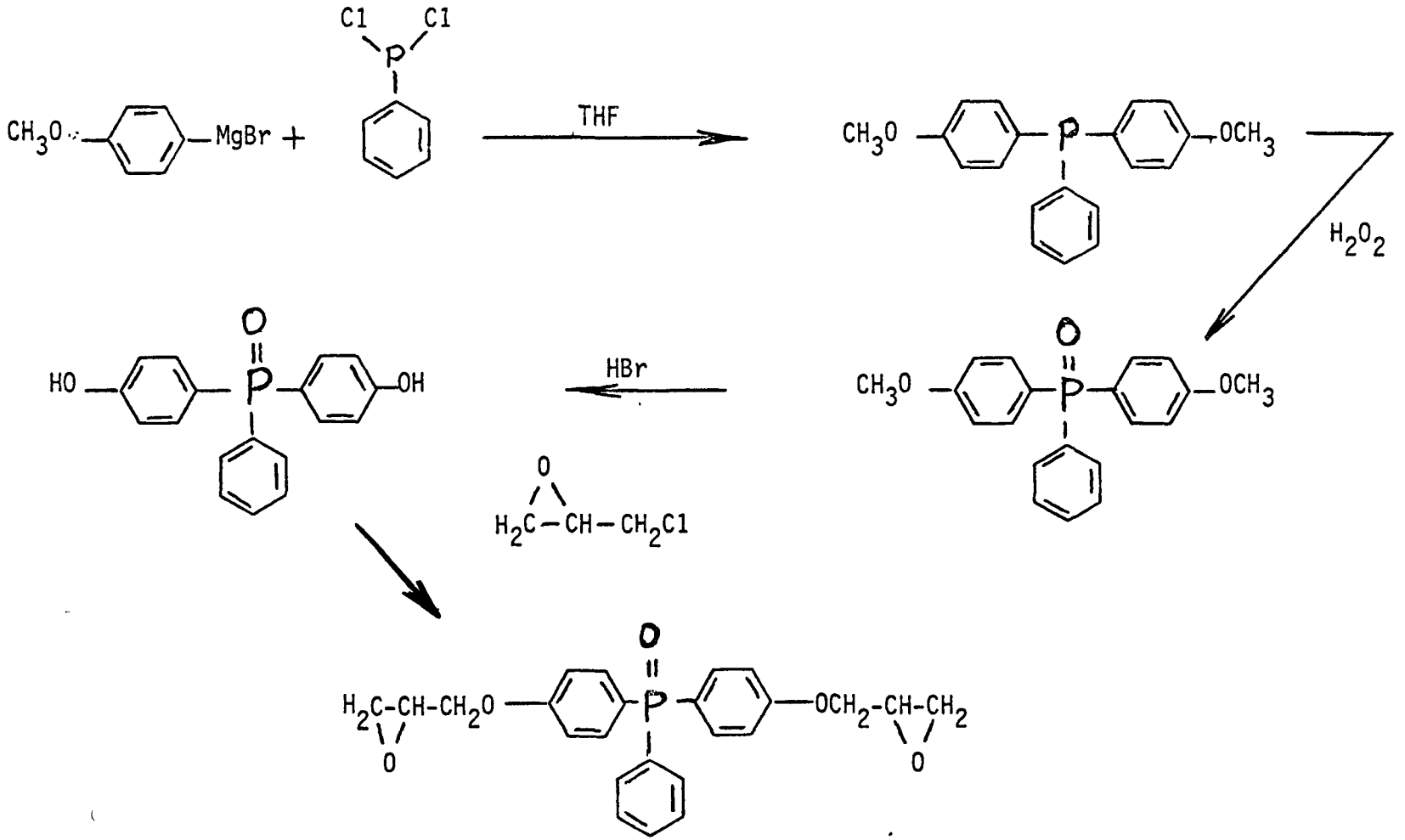
7.35% P



9.3% P

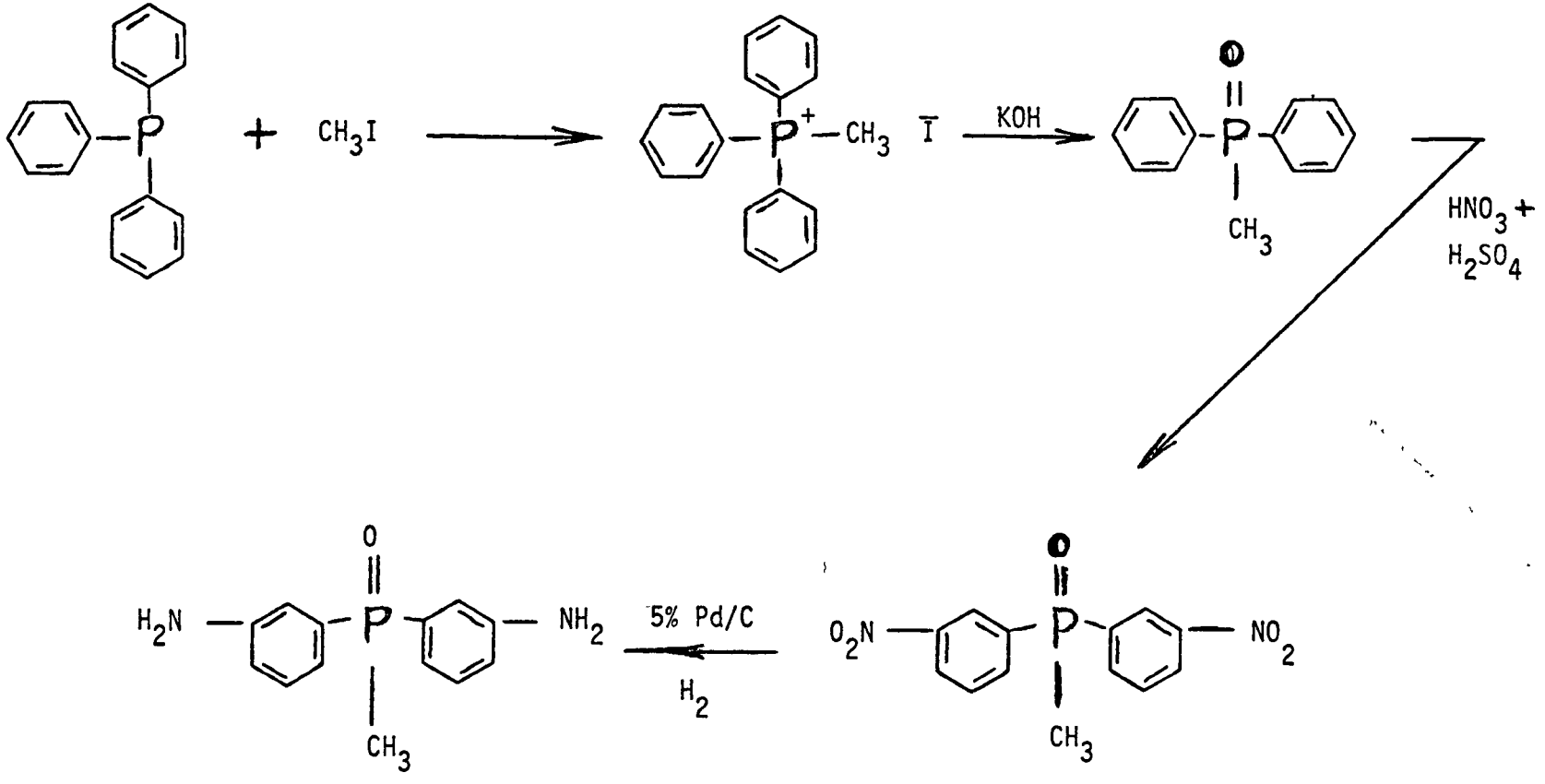
EPOXY SYNTHESIS

HUGHES
HUGHES AIRCRAFT COMPANY



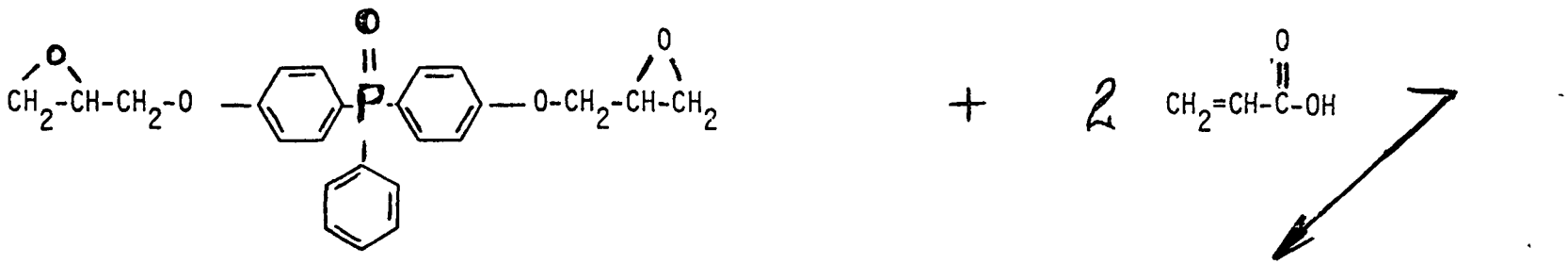
DIAMINE SYNTHESES

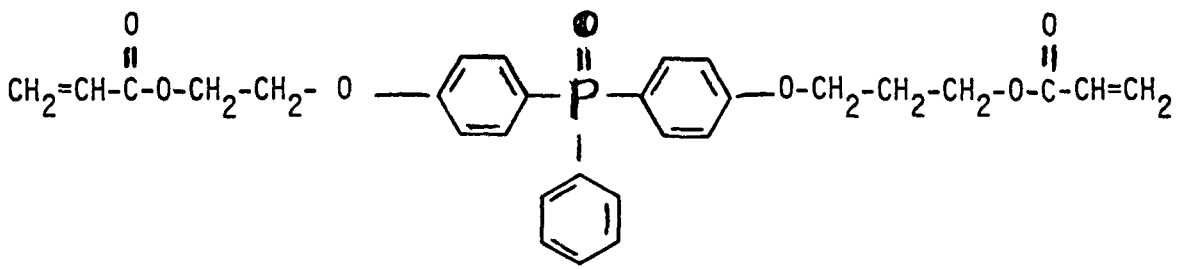
HUGHES
HUGHES AIRCRAFT COMPANY



ACRYLIC MODIFIED EPOXY

HUGHES
HUGHES AIRCRAFT COMPANY





5.8% P

PHOSPHORYLATED AMINE EPOXY BLENDS

HUGHES
HUGHES AIRCRAFT COMPANY

PHOSPHORYLATED AMINE MOLES	PHOSPHORYLATED EPOXY	EPON 825	IMPACT STRENGTH FT. LBS.
1	0	1	0.23
1	0.3	0.7	0.19
1	0.4	0.6	0.07
1	0.5	0.5	0.05

ALL BLENDS WERE FIRE RETARDANT.

EPI REZ 5022 FORMULATIONS

HUGHES
HUGHES AIRCRAFT COMPANY

% EPI REZ	CURE SCHEDULE HR.	CURE SCHEDULE °F.	LAP SHEAR STRENGTHS P.S.I.
26	0.5	450	985
	1.0	450	650
	1.75	450	325
	16	230	1000-1100**
	16	230	1200-1400*
19	1.0	300	1118*
	2.0	300	1589*
	4.0	300	1798*
	0.5	350	1304*
	2.0	350	1102*

** PRIMED SUBSTRATES
* UNPRIMED SUBSTRATES

SUBSTITUTE DIAMINES

HUGHES
HUGHES AIRCRAFT COMPANY

N-AMINOETHYLPIPERAZINE

DIETHYLENETRIAMINE

TRIETHYLENETETRAMINE

DIETHYLAMINOPROPYLAMINE

JEFFAMINE D-400

OTHER EPOXY RESINS*

HUGHES
HUGHES AIRCRAFT COMPANY

*PARTIAL SUBSTITUTIONS

	PROBLEM
EPON 825	BRITTLENESS
EPON 828	INCOMPATIBILITY
EPI REZ 5022	DIFFICULTLY COMPATIBLE BLENDED BY MILLING
EPI REZ 505	INCOMPATIBILITY
DER 732	INCOMPATIBILITY

PHENOLIC/GLASS HONEYCOMB
POLYIMID/GLASS LAMINATE (CLEANED BY HP 9-30)
TEDLAR SODIUM/NAPHTHALENE/THF ETCHED

IN FLATWISE TENSION THE LAMINATE-TO-HONEYCOMB BOND BROKE AT 303 PSI (HONEYCOMB FAILURE)
(ACRYLIC SAMPLE PROVIDED TO HUGHES BY NASA FAILED AT 112 PSI

TEDLAR-TO-LAMINATE

TEDLAR BROKE AT BOND LINE WITHOUT PEELING

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DEVELOPMENT OF FIRE-RESISTANT, LOW SMOKE GENERATING, THERMALLY STABLE END ITEMS FOR AIRCRAFT AND SPACECRAFT

John Gagliani
Solar Turbines International
International Harvester Company
San Diego, California 92138

FIREMEN PROGRAM REVIEW

NASA-AMES RESEARCH CENTER
Moffett Field, California

April 13,14, 1978

PRESENTED BY
John Gagliani
Program Manager -Research

SOLAR TURBINES INTERNATIONAL
An Operating Group of International Harvester
2200 Pacific Highway, P O Box 80966, San Diego, California 92138

FIREMEN PROGRAM REVIEW

DEVELOPMENT OF FIRE RESISTANT, LOW SMOKE GENERATING, THERMALLY STABLE END ITEMS FOR COMMERCIAL AIRCRAFT USING A BASIC POLYIMIDE RESIN

ABSTRACT

The technology for producing cellular materials has been available for many years and a large number of highly flexible and rigid foams have been developed. These foams have also been modified by addition of flame retardants or by reactive additives to produce materials with self-extinguishing characteristics. The many efforts to make conventional foams fire retardant have adversely increased the hazard to personnel, since, once ignited, these foams release large quantities of smoke and toxic products which are often the major cause of death.

Solar offers a new approach to the problem of flammability by the use of new materials obtained by foaming polyimide resins. This recommendation is based upon demonstrated ability of these materials to provide fire protection.

The work conducted under a recently completed program funded by NASA-LBJ Space Center, Mr. D.E. Supkis Technical Monitor, was organized to include the development of processes for producing flexible resilient open cell foam for use in aircraft seating applications. The same polyimide technology was then adapted to fabricate cellular materials for use in thermal acoustical insulation foams, floor panels and wall panels, coated glass fabrics and molded hardware. These products were produced from essentially the same polyimide precursor after modification with fillers or additives to achieve specific properties.

The characterization of the final candidate material for each of the products under study was conducted in accordance with accepted procedures. The flexible resilient foams met physical, mechanical and thermal requirements but were deficient in high cycle fatigue and elongation characteristics. The thermal acoustical polyimide foams were found to give low acoustical attenuation to the 1000 Hz, 2000 Hz and 4000 Hz, but lamination on aluminum foil overcame this deficiency. The only significant deviation in the properties of glass filled polyimide molded resins was the elongation characteristic. The phase dealing with polyimide coated glass fabrics produced materials with outstanding fire-containing properties but did not meet requirements for flexibility and abrasion resistance. Testing of the floor and wall panels is now in progress. Despite some limitations, the properties demonstrated by these materials represent a technological advancement in the art of polyimide resins which warrant additional effort. A continuation program has been undertaken to upgrade the qualities of selected materials from their present level of development, followed by fabrication of these products in larger size and quantity. The materials under study are flexible resilient foams, thermal acoustical insulation materials, wall panels and floor panels.

1. Solar has developed new polyimide materials that offer new approaches to the problem of flammability and smoke. These materials will be discussed in this presentation. The presentation will be divided into two parts. The first part covers the work carried out at Solar under a program funded by NASA-LBJ Space Center and will be followed by a review of a continuation program devised to upgrade the quality of candidate materials and to scale up to full size prototype components.

2. Objectives. The objectives of the program are shown.

3. These products were to be produced from essentially the same polyimide resin precursor. The interrelations between the various tasks are shown in this slide.

4. This slide shows the program schedule. The work plan consisted of 5 phases and described the general objective of the work plan for optimizing selecting and fabricating each of the different types of aircraft structures.

5. Let's discuss each of the products developed, starting with the flexible resilient foams.

6. Four different foaming methods were studied and a variety of copolyimide resins synthesized for selection of final candidates.

7. This slide shows a foam produced by microwave processing.

8. This compares with the same resin foamed by thermal processes. The non-homogeneous structure typical of thermal heating is evident.

9. Large samples of the candidate material were produced and evaluated for all properties in accordance with ASTM method D-1564 covering testing of flexible polyurethane foams. The results are reported in this viewgraph.

10. Floor and Wall Panels

The polyimide resin used in fabrication of floor and wall panels was essentially that used in the preparation of flexible resilient foams. Major effort of this task involved improvement of the mechanical properties through the use of a variety of methods which included use of reinforcements such as:

- Carbon Fibers
- Glass Fibers
- Mats
- Strands
- Honeycomb Configurations

11. This viewgraph shows the sequence for fabrication of rigid panels from a continuous mat.

12. This slide shows the preparation of rigid panels using graphite fibers.

13. This viewgraph shows a configuration using a honeycomb and filling it with a polyimide foam. The technique and data developed in the study of floor panels were applied to the study of wall panels and selections made on the basis of density requirement only. Samples of floor and wall panels were submitted to Boeing for evaluation.

14. These configurations were selected as candidate for final evaluation.

15. Thermal Acoustical Insulation

Thermal acoustical insulation materials were produced from essentially the same polyimide precursors and same processes used for fabrication of the flexible resilient foams.

16. Direct Foaming

Shows a foam produced by conventional microwave processing.

17. Foaming on Glass Batting

Shows a polyimide foam coated and then foamed by thermal process on a glass batting.

18. Summary of Results

The results of testing are reported in this viewgraph. Thermal acoustical foams meet all requirements with the exception of acoustical properties. Note that the density of the polyimide foam is at least half that of the conventional glass batting.

19. Acoustical Attenuation, dB

This viewgraph shows the effect of thickness of the polyimide foam slabs on the acoustical attenuation. The lamination of aluminum foil on one side of the foam enhances the acoustical properties to acceptable levels.

20. Molded Shapes

These high strength components were prepared by simply compressing polyimide rigid panels to the desired density.

21. Summary of Results

The major deficiency of the material at the present stage of development is elongation at break.

22. Flexible Coated Fabrics

This phase of the program covered optimization of coating processes to obtain decorative effects and fire containing properties of fabrics. Polyimide resin compositions were found that produced flexible coatings on satin weave glass fabrics in addition to outstanding fire resistance.

23. Summary of Results

The materials produced in this phase of the program show outstanding fire-containing properties, however, were deficient in flexibility and stiffness.

24. The technology developed under this study has provided the basis for small scale pilot plant processes. These processes require additional effort to optimize the products to large scale production.

A new program has been initiated to investigate optimization of processes for fabrication of:

- Flexible Resilient Foams
- Wall Panels and Floor Panels
- Thermal Acoustical Insulation

25. A program schedule detailing the various tasks is shown. This program which covers a period of 24 months is organized to proceed with investigation of all materials concurrently since there is technology transfer between the various tasks.

26. The interrelation of the various tasks is presented. As it is shown, all products will be produced from essentially the same polyimide resin precursor.

CONCLUSION

Work on this program has been started in January 1978. The major contributions to date are:

- Improved Thermal Acoustical Foam Material
- Resilient Foams Possessing High Flexibility
- Continuous Processes for Producing Polyimide Foam Resins.

S.O. 6-4501-7
NAS9-15050

Development of Fire-Resistant, Low Smoke Generating, Thermally Stable End Items for Aircraft and Spacecraft

for

National Aeronautical & Space Administration
Lyndon B. Johnson Space Center
Houston, Texas 77058

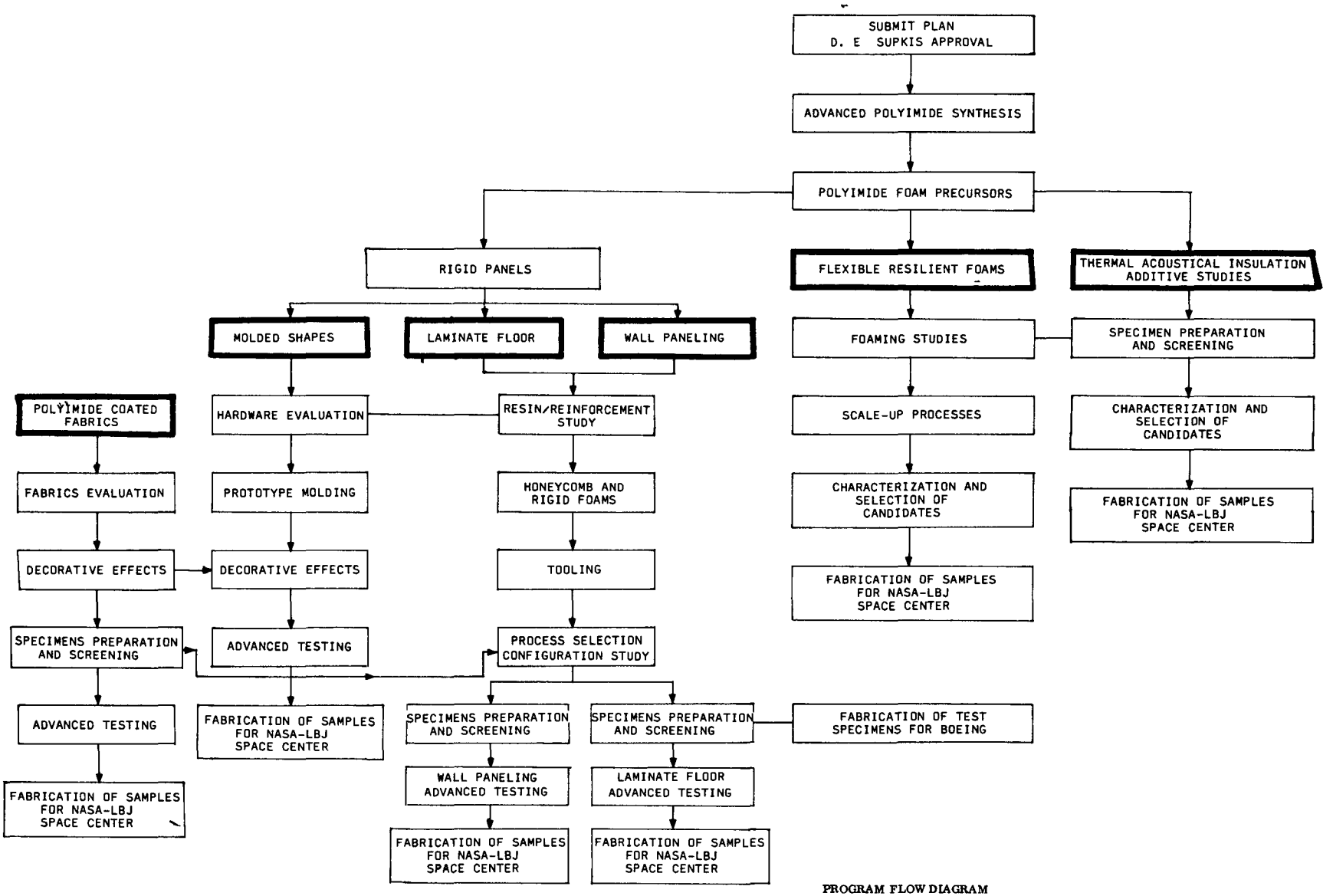
Mr. D. E. Supkis

SOLAR TURBINES INTERNATIONAL
An International Harvester Group 2200 Pacific Highway P.O. Box 80966 San Diego California 92138

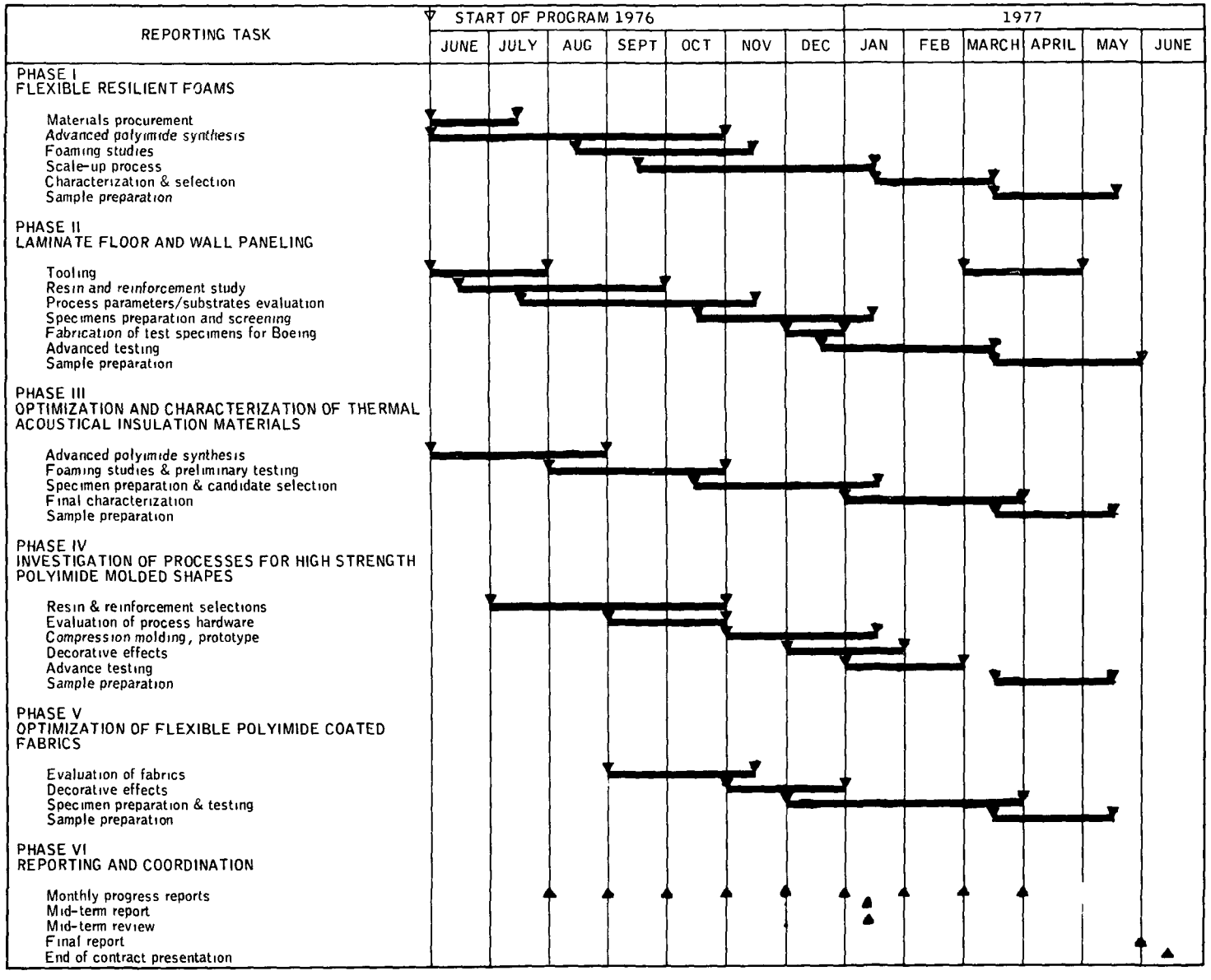
RDR 1826-9
June 1977

OBJECTIVES

- Optimization of the properties of polyimide foams for application in five different types of aircraft cabin structures.
  - Resilient Foams
  - Thermal Acoustical Insulation
  - Floor and Wall Panels
  - Molded Structures
  - Coated Fabrics
- Use of a single resin formulation
- Fabrication of large size prototype samples



PROGRAM FLOW DIAGRAM



Program Schedule

Viewgraph No. 4

FLEXIBLE RESILIENT FOAMS

MAJOR OBJECTIVES:

- Improved hydrolytic resistance
- New heating methods to achieve homogeneous cellular structure.
- Improved fatigue resistance
- Large scale processing

FOAMING STUDIES

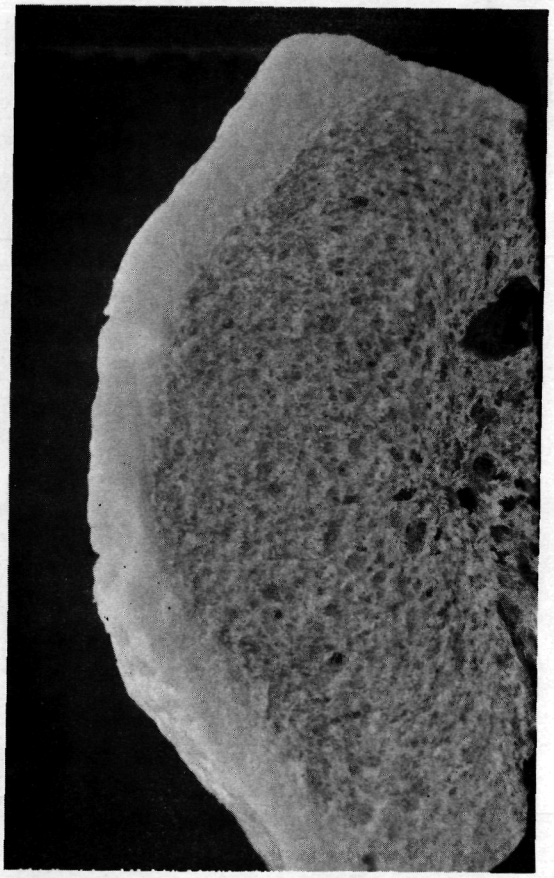
Four different foaming methods were studied:

- Thermal
- Vacuum
- Dielectric
- Microwave

Advanced Synthesis

A total of 90 copolyimide compositions evaluated.

Resilient Polyimide Foam by Microwave Foaming



Foaming by Thermal Processes

Summary of Results. Flexible Resilient Foams

Property	ASTM Method	Units	Goal	Actual
Density	D-1564	Kg/m^3 lbs/ft^3	40.0 2.5	19.2 1.2
Tensile Strength	D-1564	N/m^2 psi	82.7×10^3 12.0	92.4×10^3 13.4
Elongation	D-1564	%	30-50	39
Tear Resistance	D-1564	N/m lbs/inch	175.1 1.0	210.0 1.2
Identation Load Deflection	D-1564			
25%		$N/3.2\ dm^2$ lb-force/50 in^2	111.2-155.6 25-35	164.0 37.0
65%		$N/3.2\ dm^2$ lb-force/50 in^2	667-1112.0 150-250	1260.0 283.0
Compression Set	D-1564			
50%		% Loss	7-10	6.2
Corrosion	FTMS No. 151		None	No Evidence
Resilience Rebound Value	D-1564	%	50 min.	75
Dry Heat	D-1564	% Loss Tensile Strength	20 max.	10.3 (increase)
Humidity 73.9°C (165°F) 100% R.H.	D-1565	% Loss IDL	20 max.	7.5
Fatigue	D-1564	% Loss IDL		
10,000 cycles			20 max.	14.0
20,000 cycles			20 max.	24.0
Odor			None	Not detectable
Oxygen Index	D-2863	% Oxygen	40 min.	45
Smoke Density				
DS uncorrected	NBS	Optical density	30-50 max.	1.0
Thermostability	Thermogravimetric Analysis	Loss 204°C (400°F)	None	No loss
Toxic Product of Combustion				
HCl		10 ppm max.		None present
HF		10 ppm max.		None present
SO_2		10 ppm max.		None present
H_2S		10 ppm max.		None present

FLOOR AND WALL PANELS

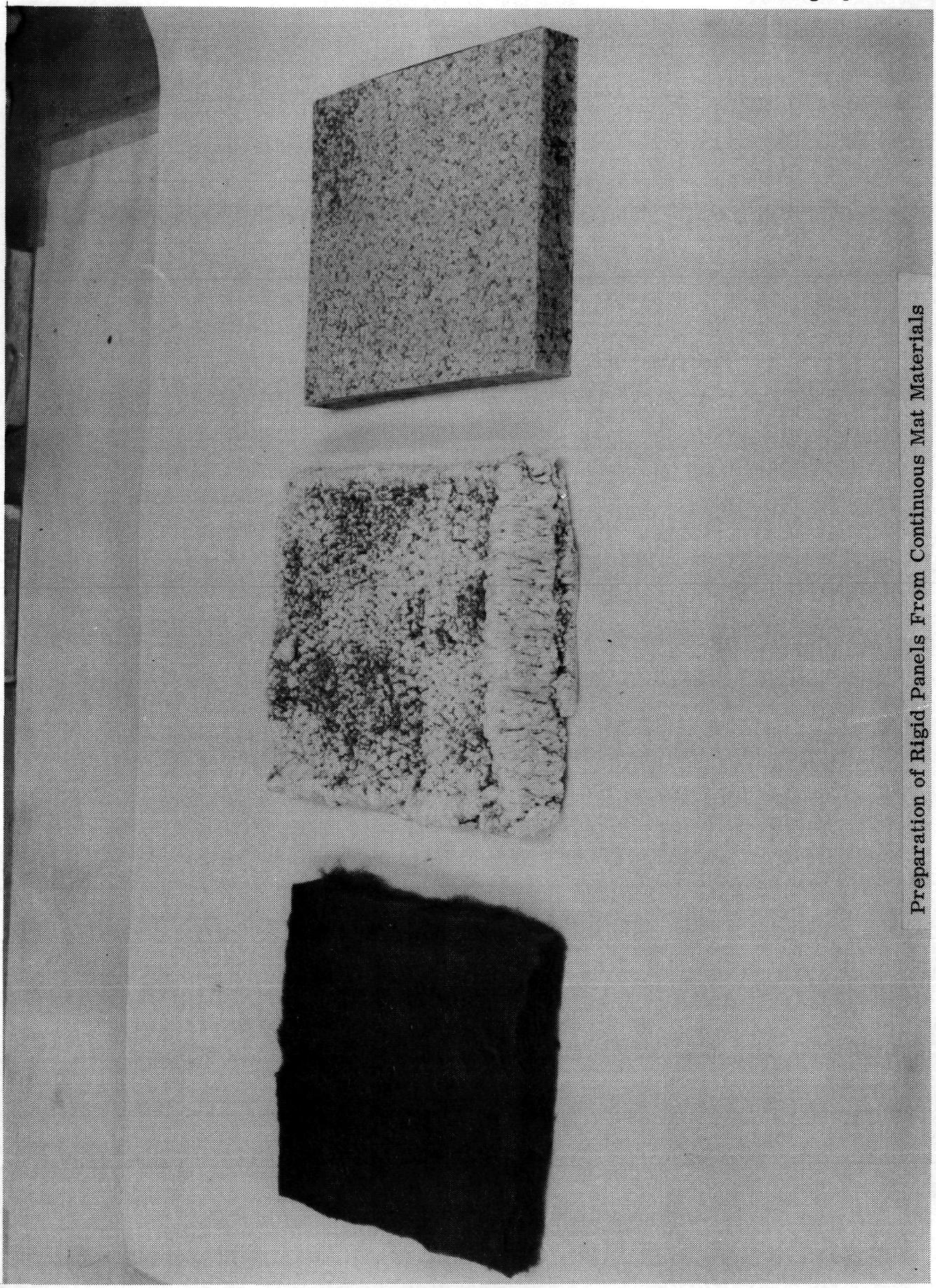
OBJECTIVES:

- Fire-containing properties
- Low weight, high strength

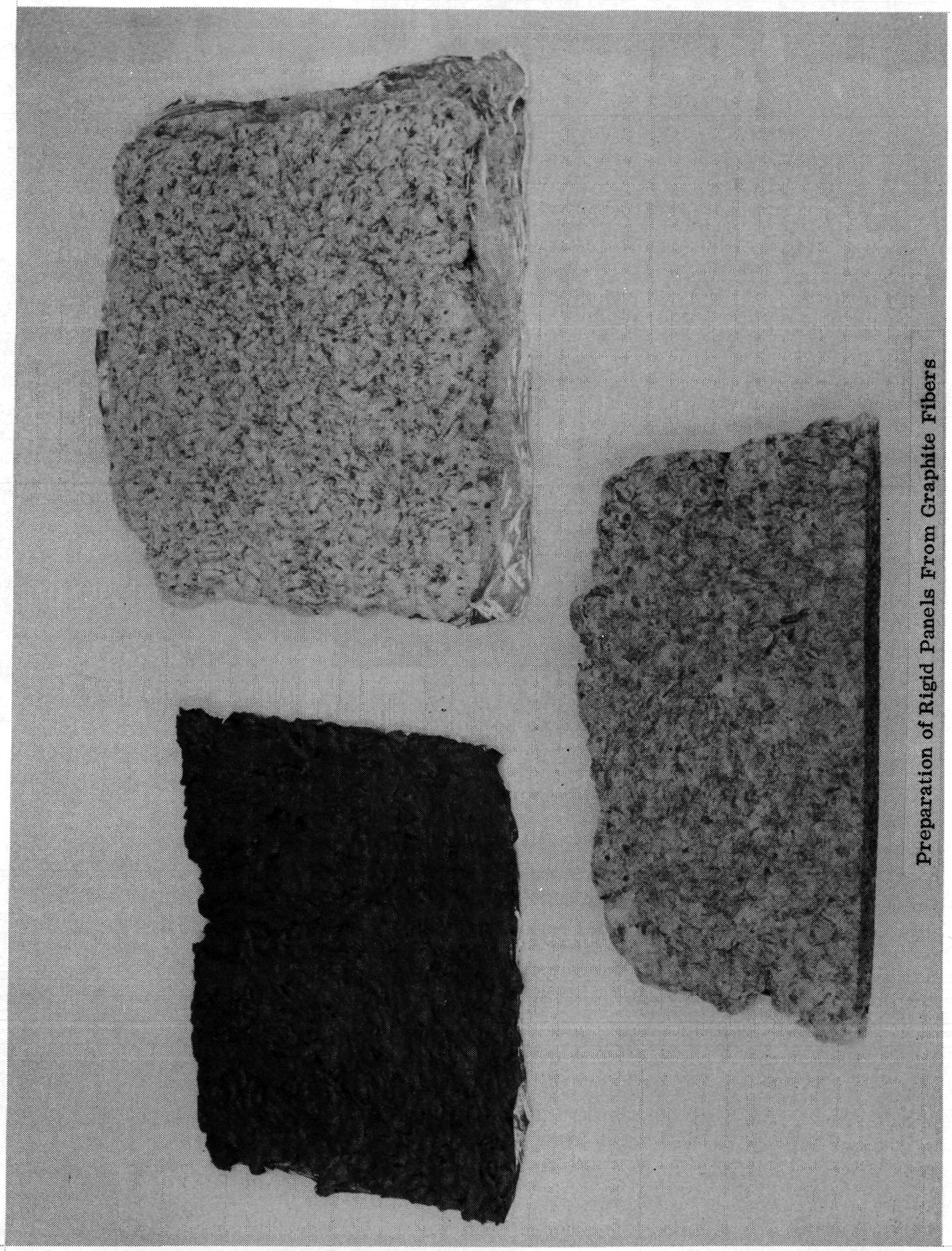
APPROACH:

Polyimide resins modified with reinforcing fillers:

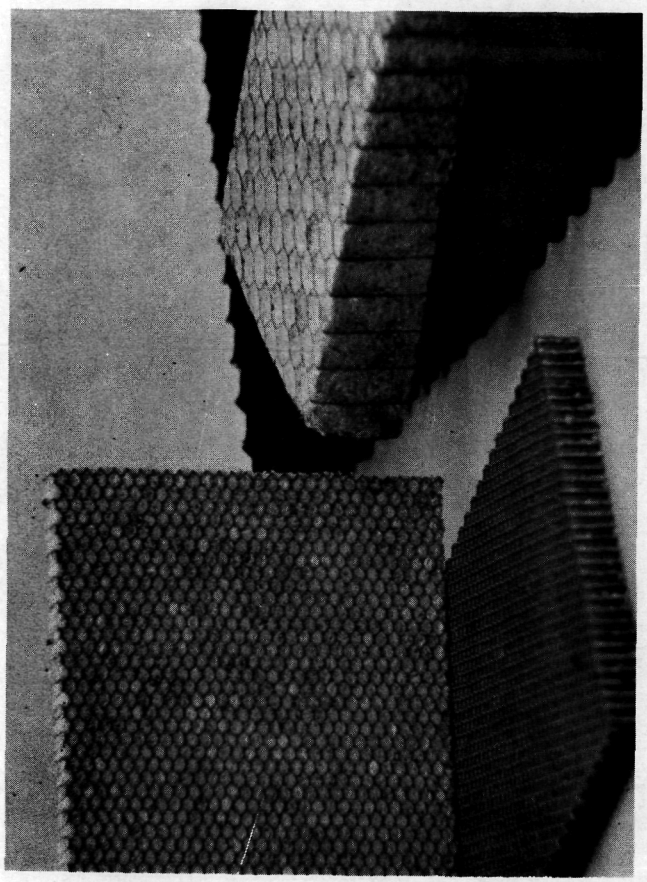
- Carbon Fibers
- Glass Fibers
- Mats
- Strands
- Honeycomb Configurations



Preparation of Rigid Panels From Continuous Mat Materials



Preparation of Rigid Panels From Graphite Fibers



Polyimide Foam Filled Honeycomb

CANDIDATES

Floor Panels

- Chopped carbon mat reinforced polyimide foams
- Glass strands reinforced polyimide foams
- Polyimide foam filled honeycombs

Wall Panels

- Chopped carbon mat reinforced polyimide foams
- Polyimide foam filled honeycombs

THERMAL ACOUSTICAL INSULATION

OBJECTIVES:

- Fire resistant materials
- Acoustical attenuation

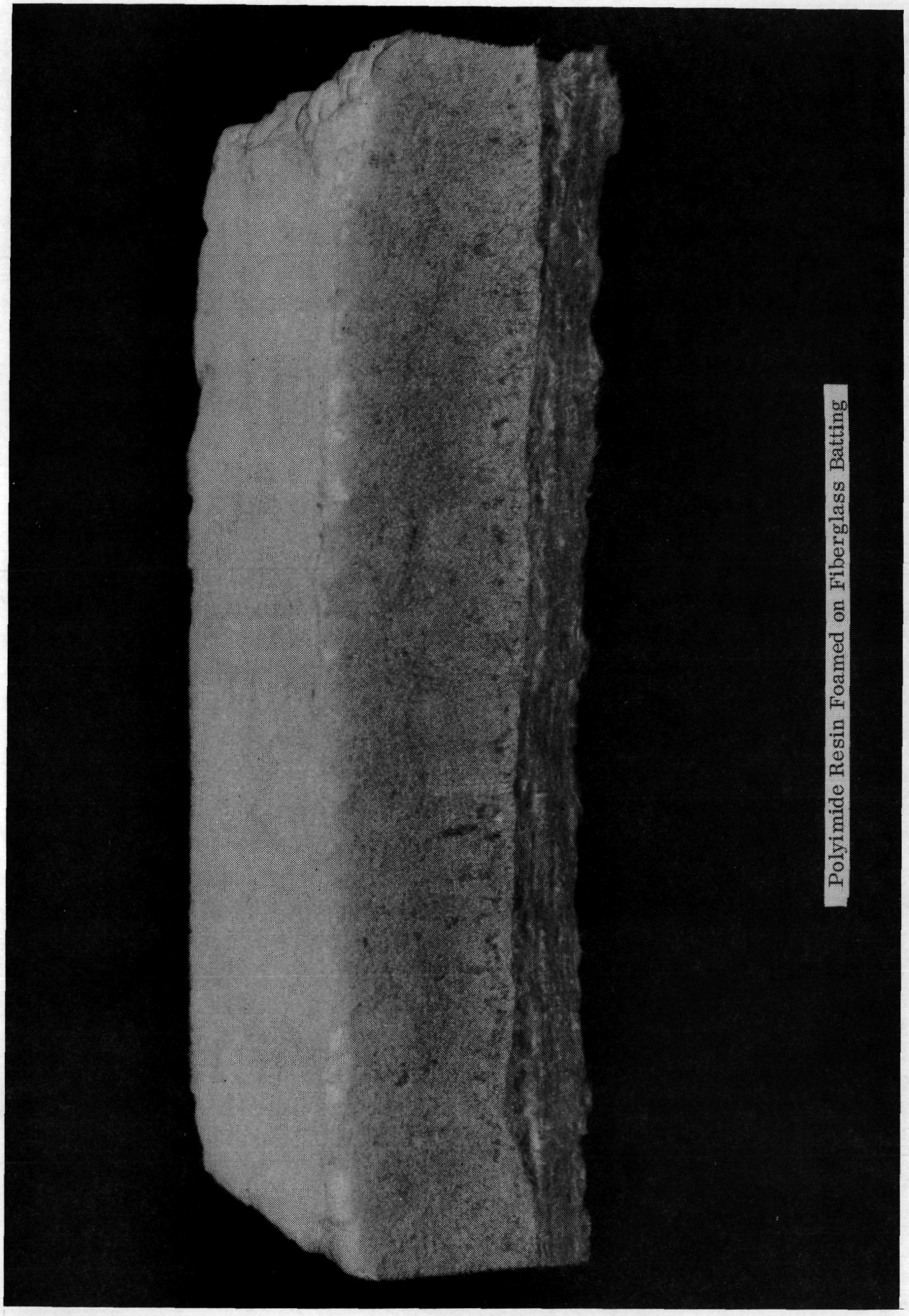
APPROACHES:

- Direct Foaming
- Foaming on Glass Battings
- Coating Glass Battings

CANDIDATE:

- Unfilled Polyimide Foam

Thermal Acoustical Polyimide Foam by Microwave Foaming


Polyimide Resin Foamed on Fiberglass Batting

Summary of Results. Thermal Acoustical Insulation

Property	ASTM Method	Units	Goal	Actual
Density	D-1564	Kg/m^3 lbs/ft^3	9.6 0.6 max.	5.6 0.35
Breaking Strength	CCC-T-191	N/m lbs/in.	175.1 1.0 min.	744.2 4.25
Wicking as received	Water immersion	cm in. precipitate	1.0 max 0.25 max None	None detectable None detectable None detectable
Wicking after oven drying 71.1°C (160°F)	Water immersion	cm in. precipitate	1.0 max. 0.25 max. None	None detectable None detectable None detectable
Flexibility		deterioration after bending on one-foot radius	None	None detectable
Corrosion (Aluminum)		Pitting	None	no pitting)
Elevated Temperature Resistance		Weight loss	15 mg max.	12 mg (water)
Oxygen Index	D-2865	% oxygen	40 min.	45
Smoke Density DS Uncorrected	NBS	Optical Density	30-50 max.	2.0
Verticle Bunsen Burner Test, 60 seconds		Flame Time seconds	10 max.	0
		Burn length cm in.	 15 max. 6 max.	 3.0 1.2
		Dripping		None detectable
1000°C (2014°F) Flame Test (Meker Burner) 10 minutes		Cold Face Temp. °C °F	 260 500	 142 288
Vibration		1 Hr 30 Hz 5 cm amplitude	No damage	None detectable
Acoustical Properties		Absorption Coefficient 1000 Hz 2000 Hz 4000 Hz	 0.736* 0.965* 0.916*	 0.533 0.949 0.737

*Owens Corning PL 105 500W

ACOUSTICAL ATTENUATION, dB

	1000 Hz	2000 Hz	4000 Hz
Owens Corning - PF-105-500W- 3 inches	11	20	29
Polyimide Foam - 3 inches	6	9	13
Polyimide Foam - 6 inches	9	13	19
Polyimide Foam - 3 inches/0.01" Al Foil	11	17	25
Polyimide Foam - 6 inches/0.01" Al Foil	10.5	22	31.5

MOLDED SHAPES

OBJECTIVES:

- Development of high strength polyimide foams to replace conventional plastics.

APPROACHES:

- Compression mold polyimide compositions into high density components.
- Contribution of reinforcements to impact strength.

CANDIDATE:

- Glass filled polyimide resins

Summary of Results - Molded Shapes

Property	ASTM Method	Units	Goal	Actual
Specific gravity	D792	g/cc	1.0-1.5	1.23
Tensile Strength	D-638	psi n/m^2	8000-12,000 55.1×10^6 - 82.7×10^6	6866 47.3×10^6
Elongation	D-638	%	4-8	1.1
Impact Strength	758-48	ft-lb/in. J/m	7-12 374-640	7.3 390
Heat Distortion Temperature (264 psi)	D-648	°C °F	148.9-176.7 300-350	Higher than: 204.4 400
Rockwell Hardness (Alpha)	D-785		R110-R130	R102
Oxygen Index, LOI	D-2863		40 minimum	60
Smoke Density D_s uncorrected	NBS		30-50	1.0
TGA	-		Stable to:	
		°C	204.4	400
		°F	400	752

FLEXIBLE COATED FABRICS

OBJECTIVE - Obtain fire hardening properties and decorative effects of weaved fabrics.

APPROACH - Evaluate and select fabrics compatible with the polyimide resins and with processing parameters.

CANDIDATE - Style 180 and 120 satin weave glass fabrics.

Summary of Results - Coated Fabrics

Property	ASTM Method	Units	Goal	Actual	
				#2 3.0 mil	#3 5.0 mil
Specific Gravity	D-792	g/cc	1.0-1.5	0.95	0.96
Bursting Strength	D-751-68	kPa psi	275 minimum 40 minimum	3000 436	2040 296
Abrasion Resistance	FTMS 1916		250 cycles no loose fibers	200**	250
Blocking	FTMS 191		not higher than 3	1	1
Flex-Crack Resistance	D-2176-69		5000 cycles	890	477
Stiffness	FTMS 1916	cm in.	2.5 minimum 1.0 minimum	22.3 8.8	24.6 9.7
Coating Adhesion*	D-3002-71	% coating removed	0	0	0
Oxygen Index, LOI	D-2863		40 minimum	60	60
Smoke Density D_s (uncorrected)	NBS		30-50	1.0	2.0
TGA	-		Stable to:		
		°C	204.4	400	
		°F	400	725	

*T-Peel test for adhesion was not possible for this type of material. 1.

**Fabric worn out.

Proposal No. 9-BC72-3-7-86P
QR6-6474-1

Development of Fire-Resistant, Low Smoke Generating, Thermally Stable End Items for Commercial Aircraft and Spacecraft Using a Basic Polyimide Resin

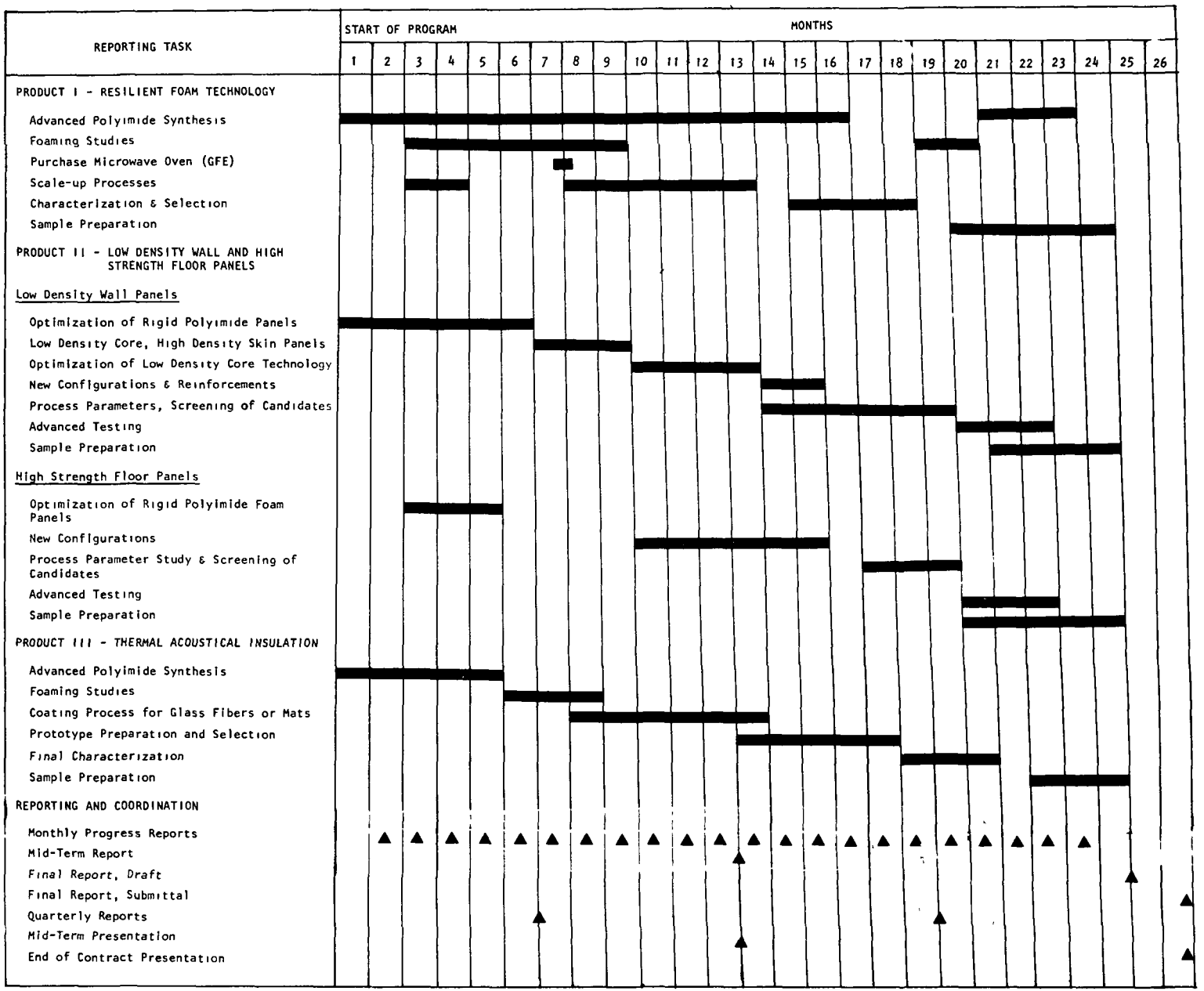
Submitted to:

National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, Texas 77058

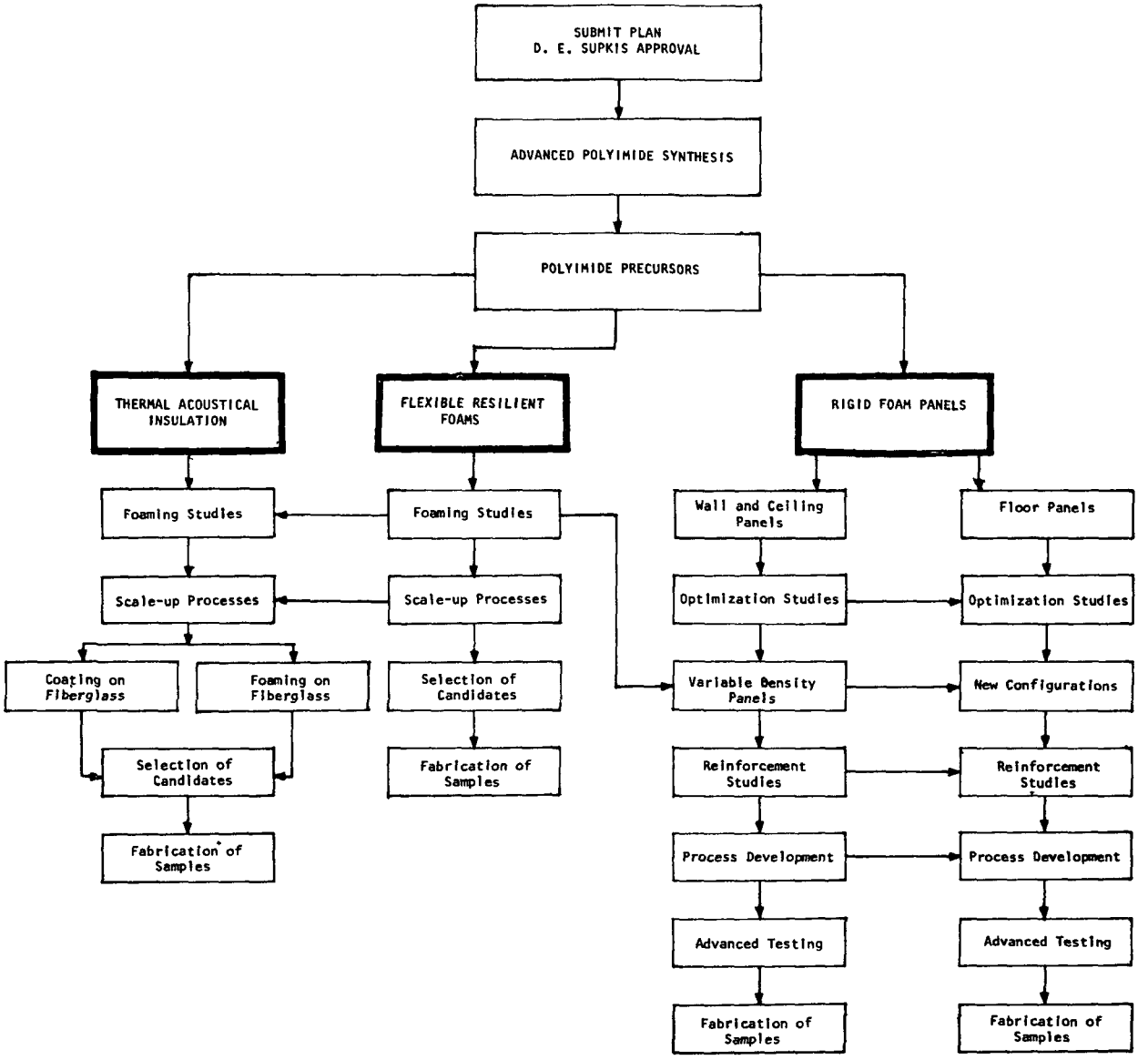
Mr. D. E. Supkis

SOLAR TURBINES INTERNATIONAL
An Operating Group of International Harvester
2200 Pacific Highway, P O Box 80966, San Diego, California 92138

RDP 7737-1
Sept 1977



PROGRAM SCHEDULE



PROGRAM FLOW DIAGRAM

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OVERVIEW OF AIRCRAFT SEAT PROGRAM

Larry L. Fewell
Chemical Research Projects Office
Ames Research Center
Moffett Field, California 94035

THE FIRE RESISTANT AIRCRAFT PASSENGER SEAT MATERIALS PROGRAM -

This program is directed toward the development of improved fire resistant materials for aircraft.

The 'Fire Resistant Aircraft Passenger Seat Materials' program grew out of the need to characterize the thermal behavior of the polymeric materials that comprise the aircraft passenger seat and the increased seating capacity (270 - 525) of wide-bodied jet aircraft.

The non-metallic materials of which aircraft passenger seats are constructed represent a significant quantity of potentially combustible material and therefore, of considerable importance when one considers the fire safety of the interior compartment of an aircraft. This program has generated a technical data base of fire resistant materials and has identified non-metallic candidate seat materials with superior fire resistance and minimal smoke and/or toxic gas.

The program was divided into two phases: phase one was addressed to : (1) preliminary study of advanced materials and their availability, (2) survey of the industry as to their participation in contributing candidate materials (flexible & rigid foams, textiles, leather and leather substitutes, and thermoformable plastics), (3) Conducting FAA Burn and Smoke Screening Tests on all candidate materials, and toxicity and heat release rate tests, and (4) physical tests on those materials meeting screening criteria to ensure compatability with aircraft design and manufacturing requirements for seating.

Phase II of the "Fire Resistant Aircraft Seat Material Program" involves the following goals: (1) evaluation of the thermal resistance of candidate seat materials and fully constructed seat assemblies (2) the development of a maximum realistic and repeatable fire source for the testing of cushions of contemporary design to establish a baseline inorder to compare new candidate materials, these tests will be conducted in the cabin fire simulator. (3) Evaluate cushion materials in various design concepts and their potential for commercial production and service. Candidate materials with superior test results will be presented to seat manufacturers for their consideration in the design of fire resistant seats. (4) Prepare a preliminary materials and design specification for a fire resistant aircraft passenger seat which incorporates the results of this study.

The III Phase of the Fire Resistant Aircraft Passenger Seat Materials Program will involve the following: (1) Coordination of CFS Data with laboratory tests (2) Assessment of fire resistivity level, precessability, and availability of manufacturing feasibility (3) Acceptance criteria for fire safety and performance (4) Report for FAA (5) Manufacturing Specifications (6) Report for Airframe/Seat Manufacturers.

FIRE RESISTANT AIRCRAFT SEAT MATERIALS

Edward L. Trabold
Douglas Aircraft Company
McDonnell-Douglas Corporation
Long Beach, California 90846

FIRE RESISTANT AIRCRAFT SEAT MATERIALS

ABSTRACT

This presentation reviews the earlier Phase I program which was oriented toward establishment of a technical data base for individual seat materials in order to facilitate materials selection.

The main focus is on the current follow-on Phase II program. This program examines the thermal response of multi-layer constructions representative of the basic functional layers of a typical future seat. These functional layers include (1) decorative fabric cover, (2) slip sheet (topper), (3) fire blocking layer, (4) cushion reinforcement, and (5) cushioning layer.

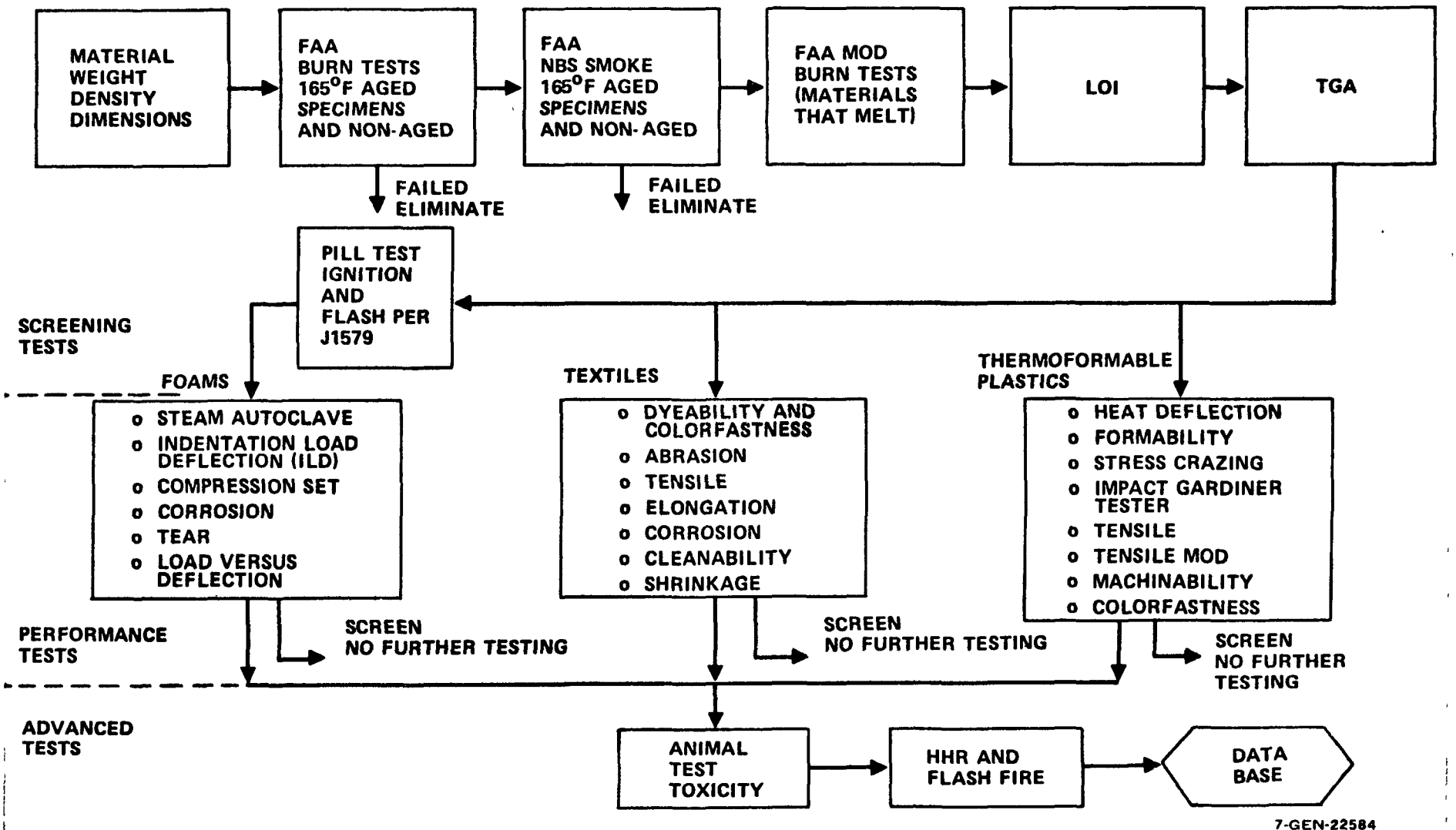
The status of the current test program and test results are reported. The implications for material selection for full-scale seats are discussed.

FIRE RESISTANT AIRCRAFT SEAT MATERIALS

BY: EDWARD L. TRABOLD
DOUGLAS AIRCRAFT CO.

7-GEN-22576

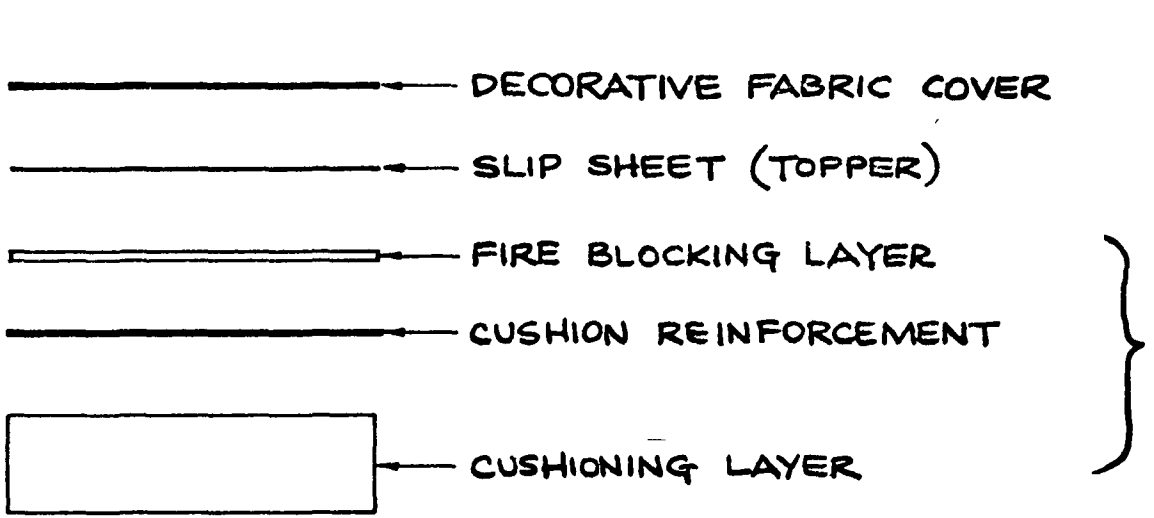
PHASE I MATERIAL TEST PROGRAM



MATERIAL TEST CRITERIA FOR PROGRAM INCORPORATION

1. TEST QUANTITIES MUST BE AVAILABLE FOR PHASE I TESTING BEFORE 1 APRIL 1977
2. QUANTITIES MUST BE AVAILABLE FOR FULL-SCALE SEAT FABRICATION 1 OCTOBER 1977
3. MATERIALS MUST BE COMMERCIALLY AVAILABLE BY 1980
4. MATERIALS MUST WITHSTAND ENVIRONMENT OF -40°F TO 180°F

FUTURE SEAT COMPONENTS



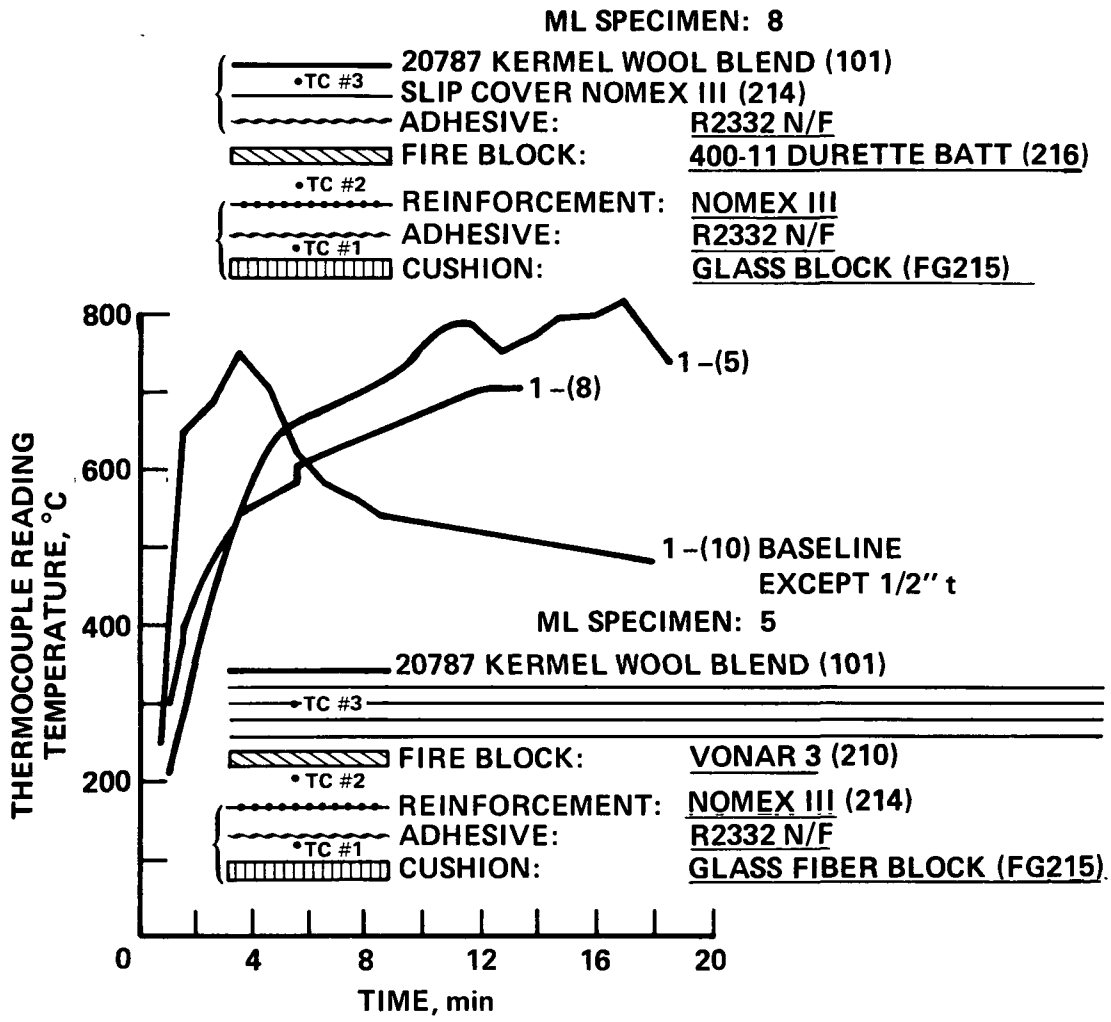
NOTE: SOME COMPONENTS MAY NOT BE INCLUDED IN ALL DESIGNS

HEAT RELEASE RATE TESTING

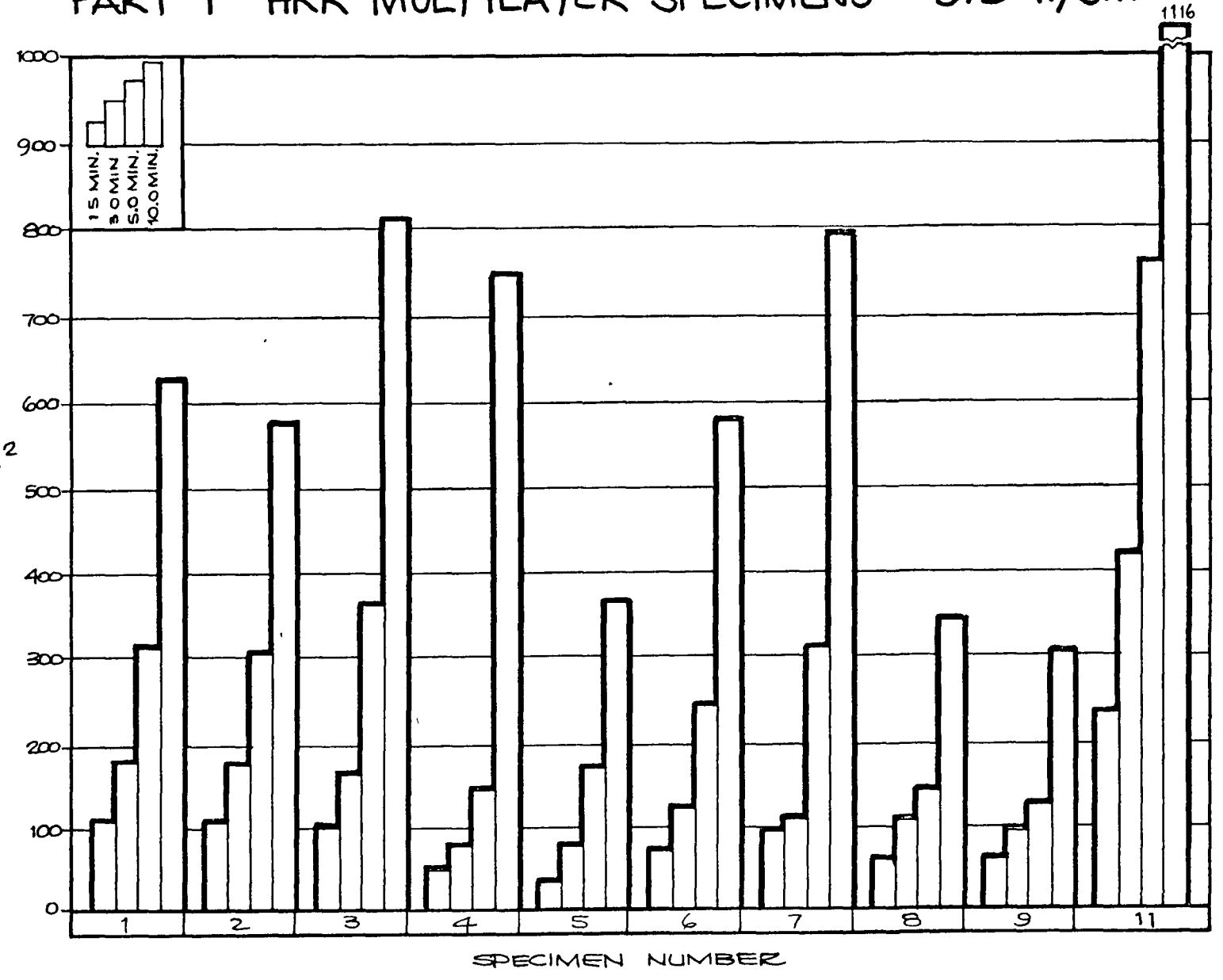
PART 1 STANDARD CUSHION LAYER OF GLASS BLOCKING WITH VARIOUS UPPER LAYERS

PART 2 SELECTED UPPER LAYERS FROM PART 1 WITH VARIOUS CUSHION LAYERS

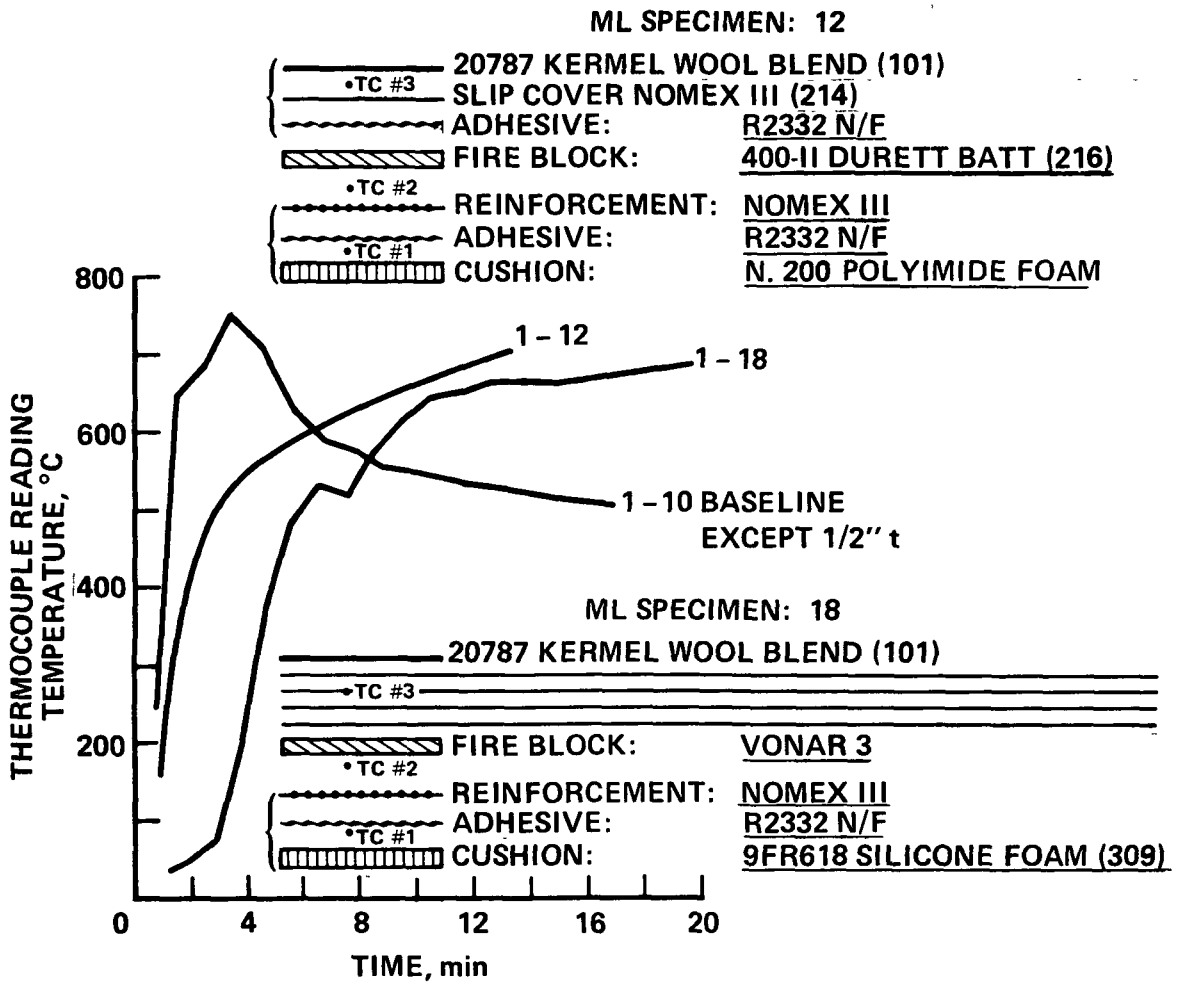
PART 1. HRR AT 3.5 W/cm^2



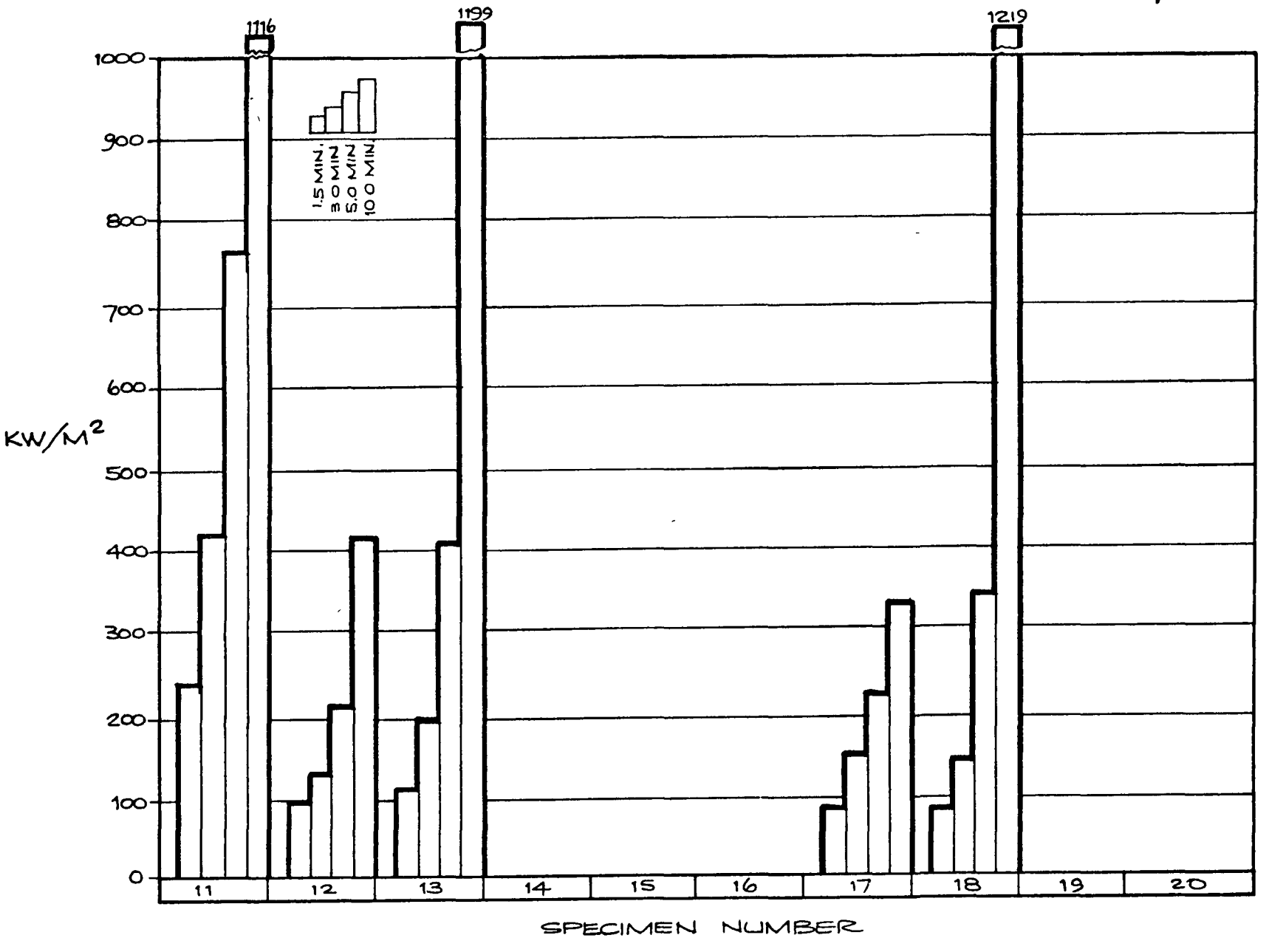
PART 1 HRR-MULTILAYER SPECIMENS - 3.5 W/CM^2



PART 2. HRR AT 3.5 W/cm^2



PART 2 HRR-MULTILAYER SPECIMENS - 3.5 W/CM^2



DISCUSSION

1. MATERIAL PROPERTIES USED IN DETERMING SELECTION CANNOT BE INDEPENDENT OF END USE

2. TWO IMPORTANT ASPECTS OF HEAT RELEASE MUST BE CONSIDERED
   a. EARLY RATE OF RELEASE
   b. TOTAL HEAT RELEASED

3. CONDITIONS OF TEST ASSUMED IN FLIGHT FIRE WITH CONDITIONS OF EXCESS OXYGEN

4. NEW MATERIALS WITH FUTURE SIGNIFICANCE
   POLYPHOSPHAZENE FOAM
   POLYIMIDE FOAM
   HEAT STABILIZED PBI FABRIC

FABRICS FOR FIRE RESISTANT PASSENGER SEATS IN AIRCRAFT

Giuliana C. Tesoro
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Cambridge, Massachusetts 02139

FABRICS FOR FIRE RESISTANT PASSENGER SEATS IN AIRCRAFT

Giuliana C. Tesoro
Massachusetts Institute of Technology

The essential elements of the problem and of approaches to improved fire resistance in aircraft seats are briefly reviewed. In the context of performance requirements and availability of materials, delay in the ignition of upholstery fabric by a small source may be considered a realistic objective. Results of experimental studies on the thermal response of fabrics and fabric/foam combinations suggest significant conclusions regarding (a) the ignition behavior of a commercial 90/10 wool/nylon upholstery fabric relative to fabrics made from thermally stable polymers; (b) the role of the foam backing; (c) the behavior of seams. These results, coupled with data from other sources, also confirm the importance of materials' interactions in multicomponent assemblies, and the need for system testing prior to materials' selection. The use of an interliner or thermal barrier between upholstery fabric and foam is a promising and viable approach to improved fire resistance of the seat assembly, but experimental evaluation of specific combinations of materials or systems is an essential part of the selection process.

FABRICS FOR FIRE RESISTANT PASSENGER SEATS IN AIRCRAFT

LIST OF SLIDES

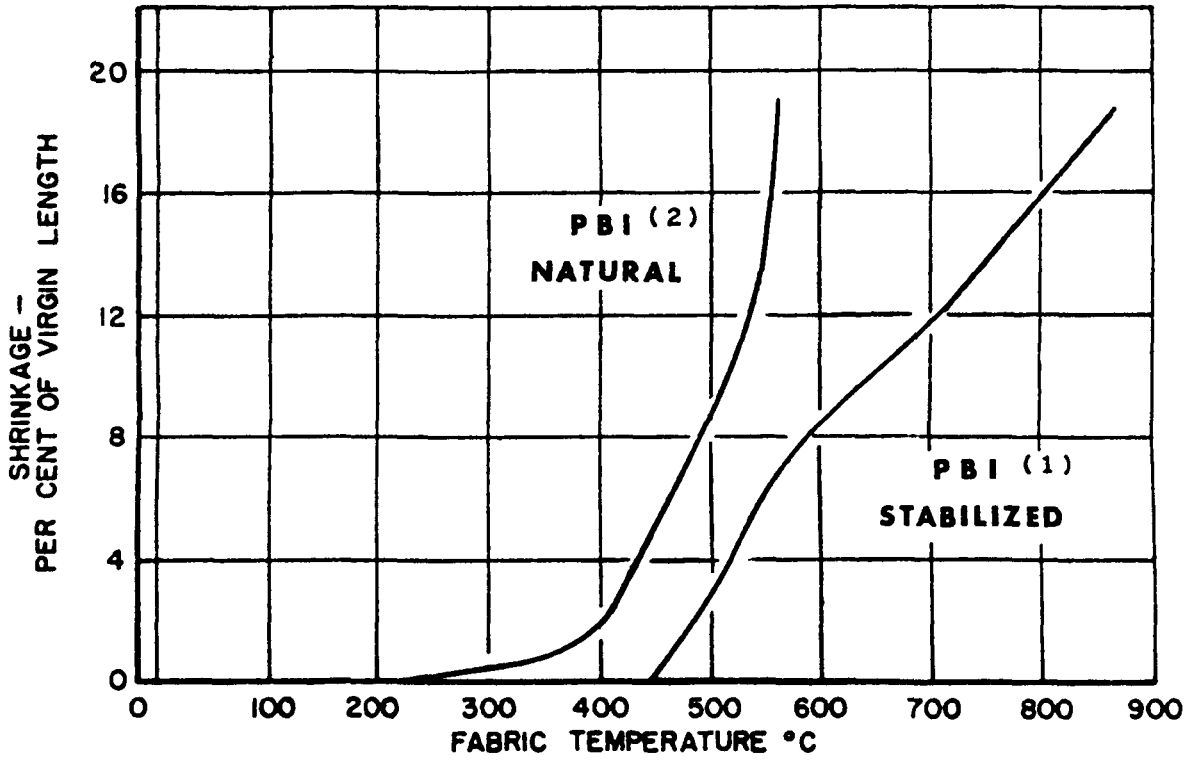
1. Seat upholstery fabrics
2. Fibers from thermally stable polymers
3. Performance requirements of seat upholstery fabrics
4. Possible approaches to improved assembly

Ref. NASA TM X-73, 144

5. Stabilization (thermal) of PBI (shrinkage vs. temperature)
6. Examples of commercial upholstery fabrics (summary of sources and properties)
7. Oxygen Index of wool/nylon blends (O.I. vs % wool)
8. Oxygen Index of wool blends (O.I. vs % wool)
9. Maximum measured heat flux levels from various sources
10. Schematic diagram of experimental apparatus for study of thermal response
11. Imposed heat flux as function of radius from spot center
12. Materials used in experimental investigation of thermal response
13. Time to smoke (fabrics alone)
14. Time to char, hole or melt (fabrics alone)
15. Time to ignition (fabrics alone)
16. Time to smoke, melt, ignition for wool/nylon with foam backing
17. Time to smoke, char, ignition for PBI with foam backing
18. Time to smoke, char, ignition for Kynol with foam backing
19. Time to ignition (fabrics with foam backing)
20. Schematic diagram of single felled seam
21. Conclusions

CELANESE
FIBERS MARKETING COMPANY

THERMAL DIMENSIONAL STABILITY



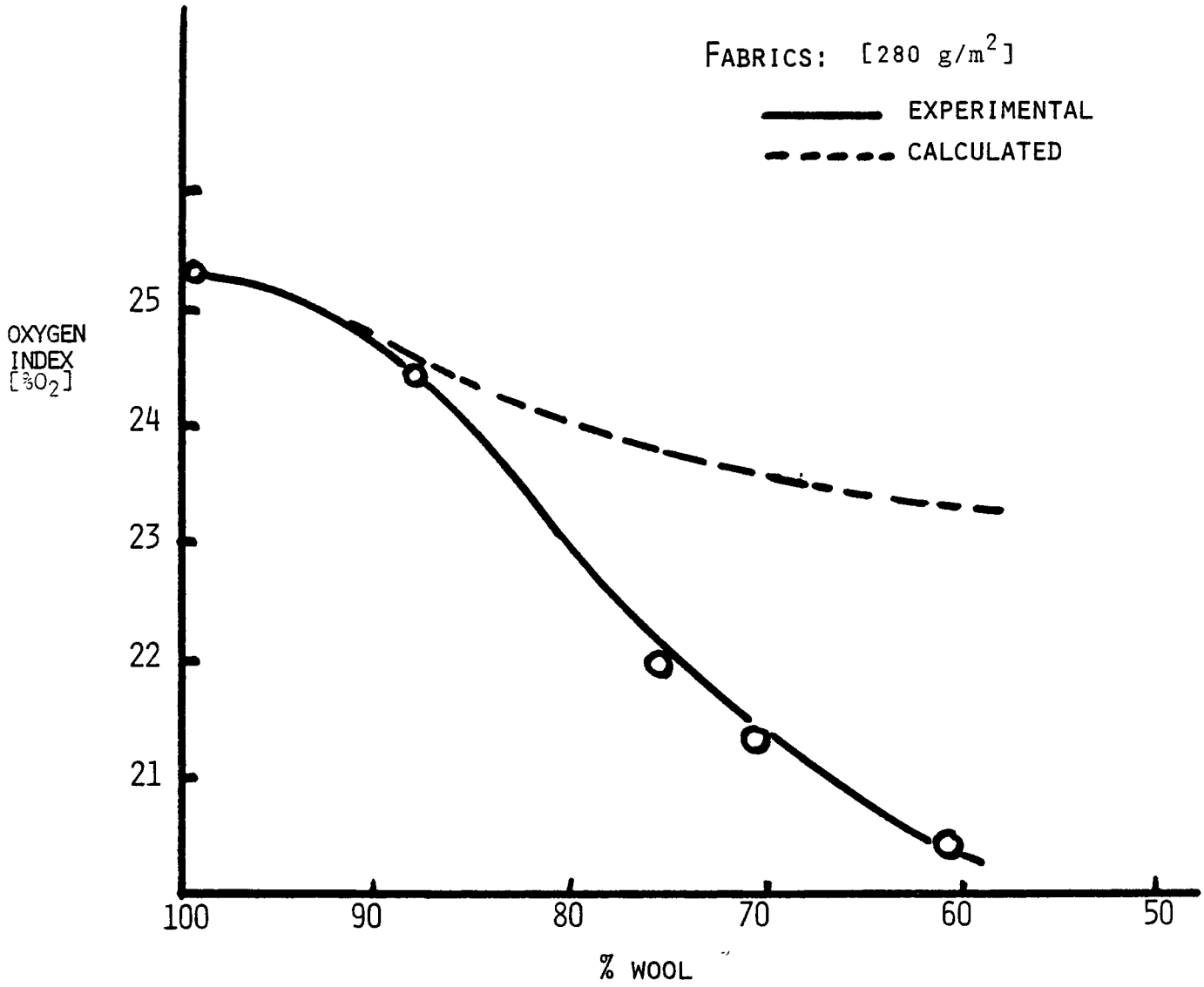
1. 4.5 OZ/YD^2 FABRIC, AFML-TR-73-28
2. DRAWN, TEXTILE YARN

UPHOLSTERY FABRICS - (EXAMPLES)

ADEQUATE FLAME RESISTANCE [FAR 25.853(B)]

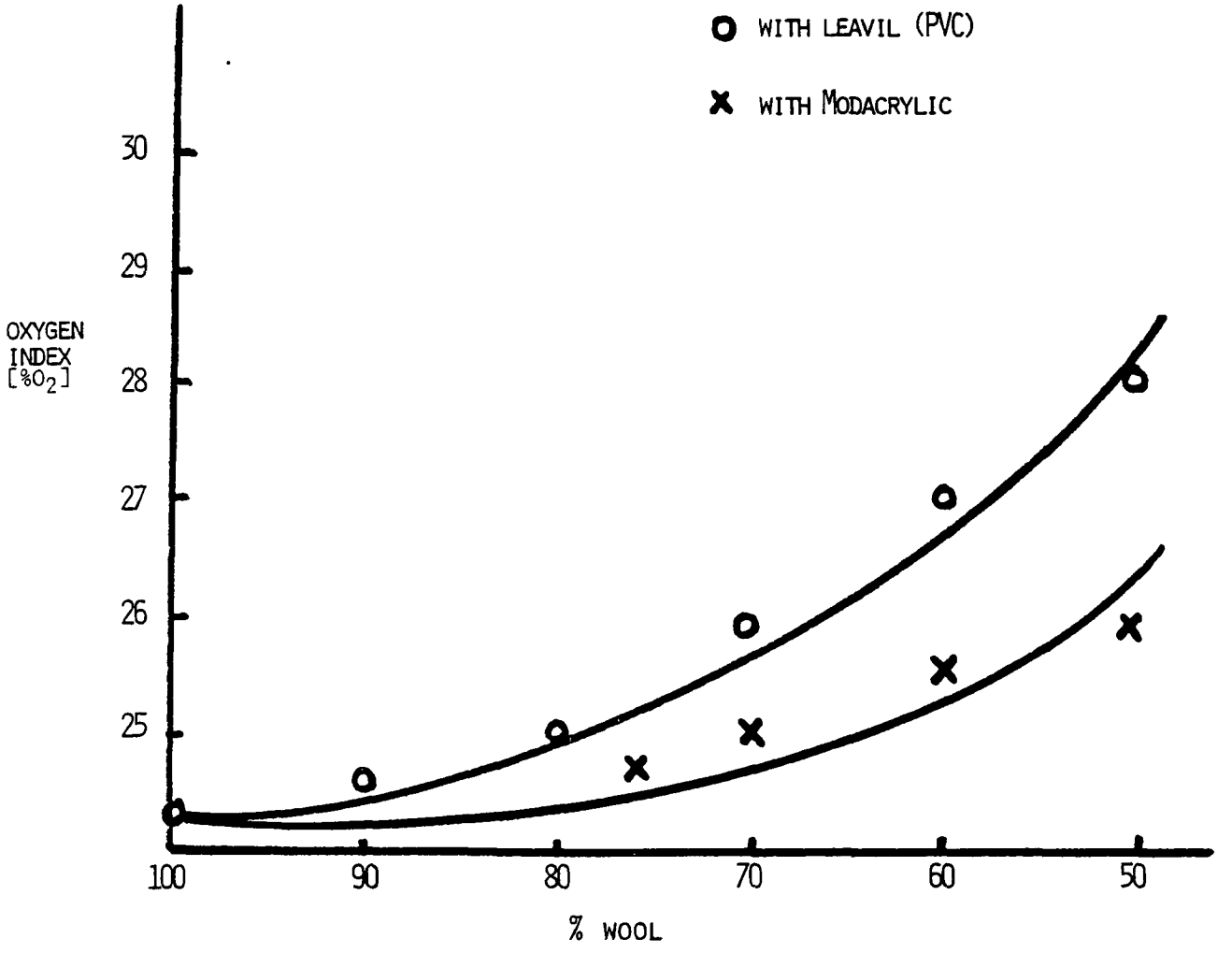
MANUFACTURER	FIBER COMPOSITION	COLORS	LIGHT FASTNESS	WEIGHT OZ/YD^2	TENSILE STRENGTH LB/IN WARP	FLAME RETARDANT TREATMENT	SMOKE GENERATION	TOXICITY OF COMBUSTION PRODUCTS	OXYGEN INDEX RANGE REPORTED [$\%O_2$]
AMERICAN KYNOL	50/50 KYNOL/ ARAMID	FEW	-	10.0	-	-	-	MODERATE	29-32
COLLINS & AIKMAN	100% NOMEX	SEVERAL	POOR	12.2	170	-	LOW	MODERATE	26-29
	90/10 WOOL/ NYLON	MANY	GOOD	14.5	159	+	MODERATE	HIGH	-
	100% NYLON	MANY	GOOD	22.0	400	+	LOW	HIGH	-
ORINOKA-AVIATION FABRICS SALES INC	90/10 WOOL/ NYLON	MANY	GOOD	14.5	130	+	MODERATE	HIGH	-
JP STEVENS & CO INC	100% MOD-ACRYLIC	MANY	GOOD	6.5	-	-	-	HIGH	28-30
CELANESE FIBERS MARKETING CO.	100% PBI STABI-LIZED	GOLD (NATURAL); GREEN (PIGMENTED)	POOR	4.5	-	-	LOW	LOW	38-43

O.I. OF WOOL/NYLON BLENDS*



*L. BENISEK - J. TEX. INST. 1976, P. 262

O.I. OF WOOL BLENDS*



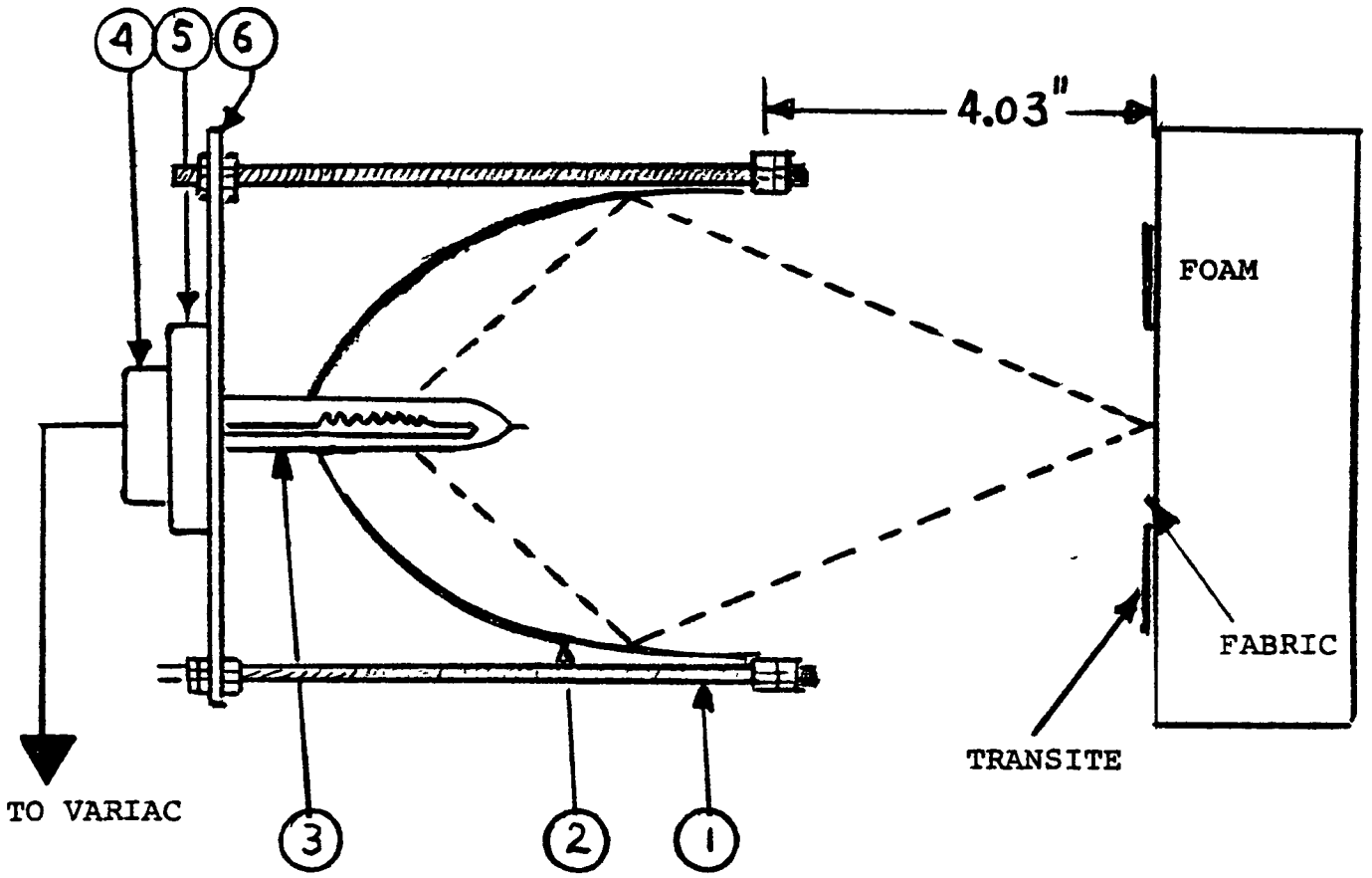
*L. BENISEK - TEX. CHEM. COLORIST, FEB. 1974, P. 25

MAXIMUM MEASURED HEAT FLUX LEVELS FROM VARIOUS SOURCES*

Source	Maximum Flux w/cm^2
Hot Plate (0.8 kw)	3
Hot Plate (2.6 kw)	5
Kitchen Gas Range	
Kenmore 119.15031	6
Kenmore 71731	6
Match	5.4
Lighter	5.8
Candle	7.8
Methane Flame Microburner	15-16

*P. Durbetaki et al. Third Annual Report to the National Science Foundation by Georgia Institute of Technology, NTIS-PB-242-740/AS.

Schematic Diagram of the Experimental Apparatus



(1) Three 3/32" threaded rods and nuts.

(2) Ellipsoidal Reflector #4085-A, Research Inc., Minneapolis, Minnesota.

(3) Quartz light bulb, 500 Watts, General Electric #Q500CL/DC.

(4) Bulb socket.

(5) Transite spacer.

(6) 1/8" aluminum plate.

Slide 7

Imposed heat flux as function of radius from spot center

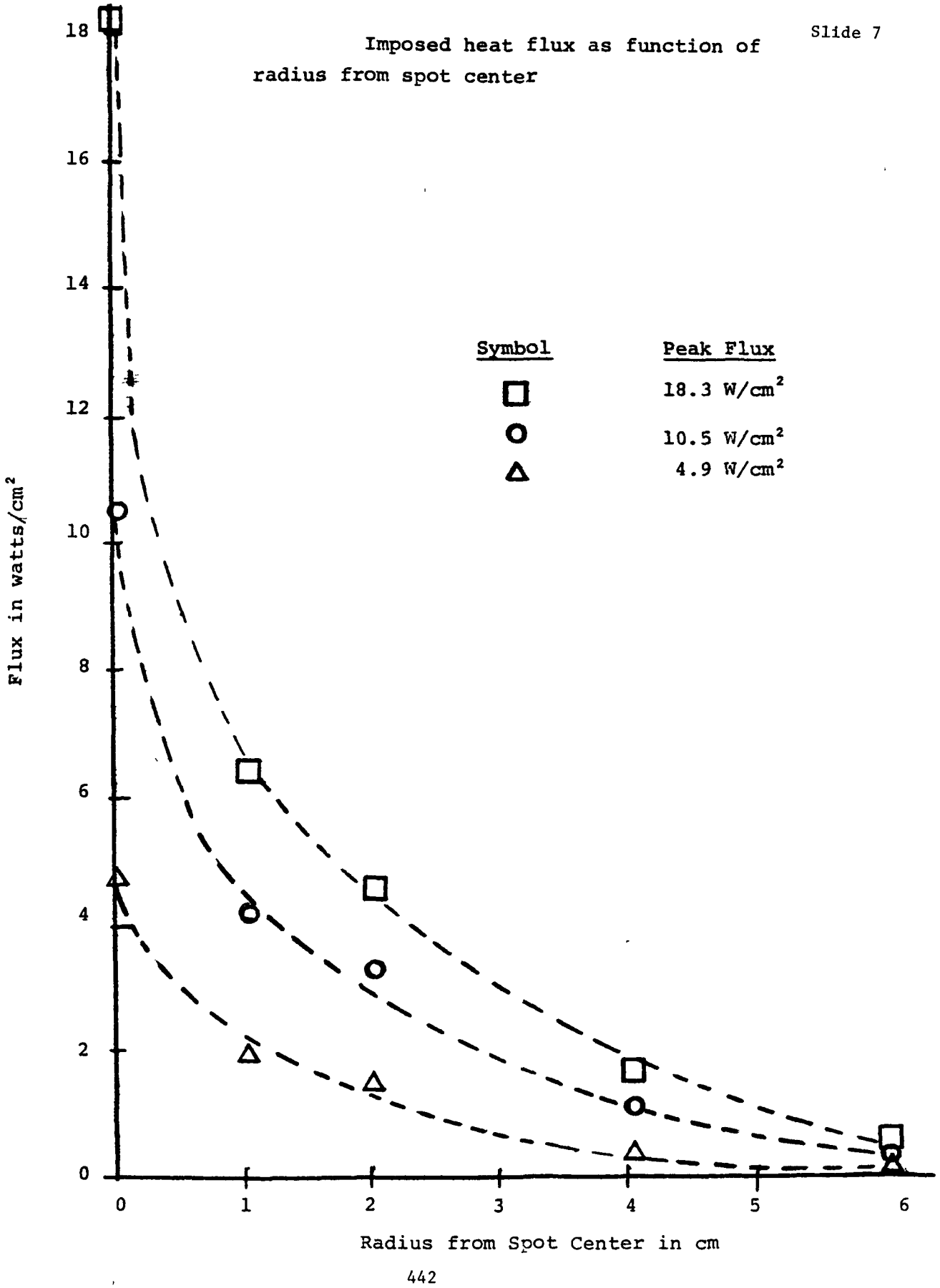


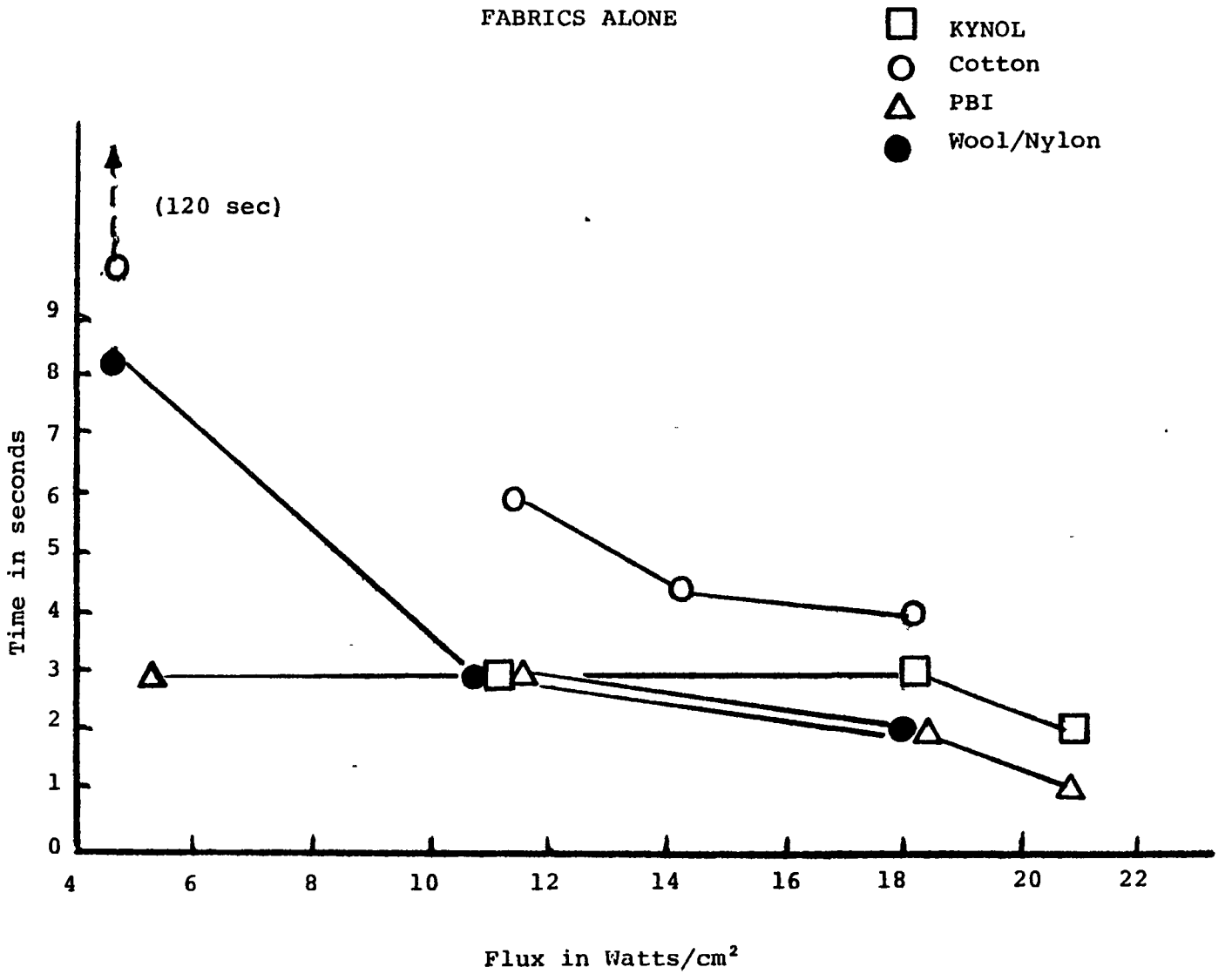
Table 1

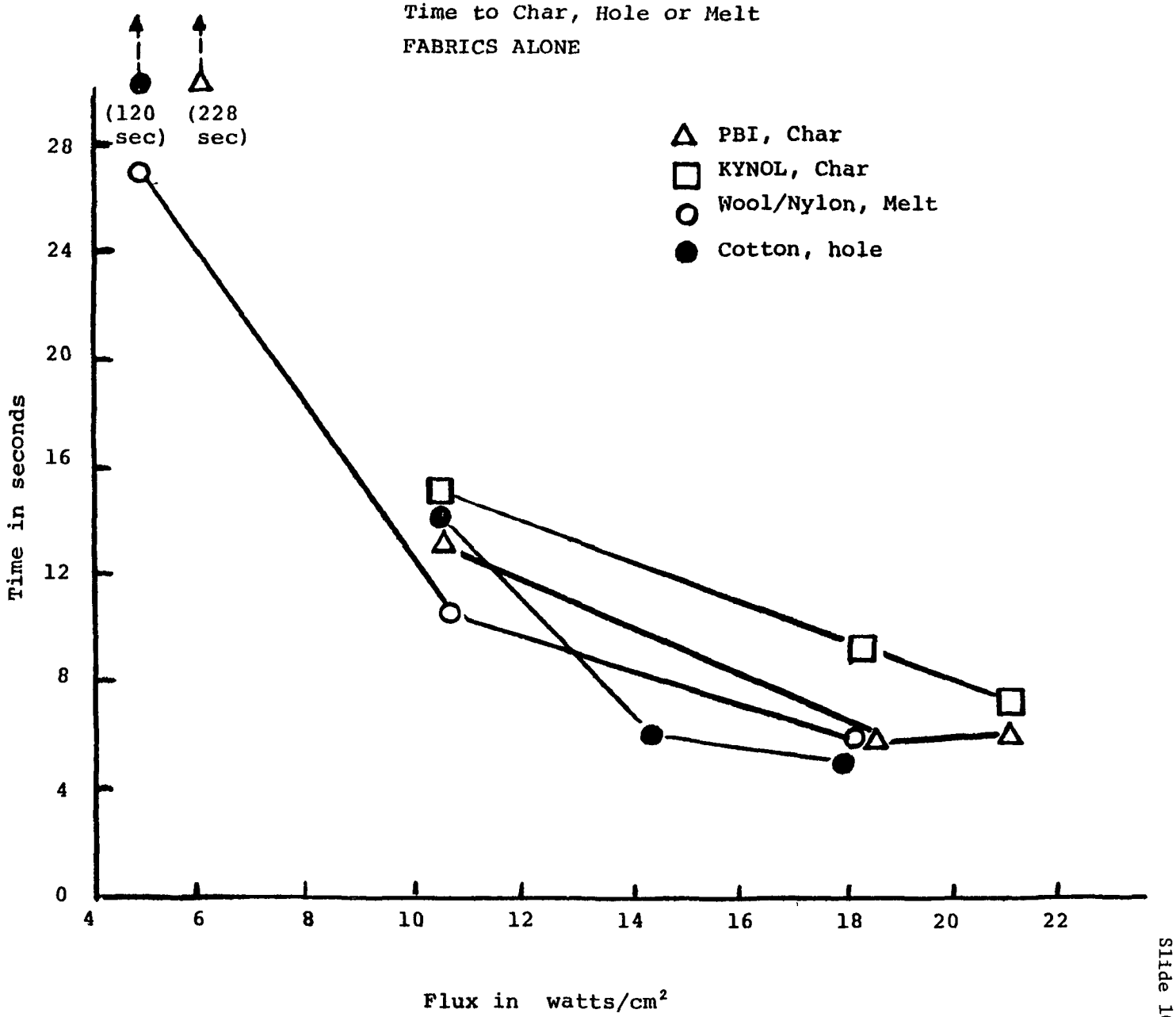
Fabric*	Description	Supplier
Wool-nylon (state-of-the-art)	R76423 Sun-Eclipse Blue/Red; ST7427-115, Color 73/3252; 90% wool/10% nylon	UOP Corporation, Aerospace Div., Bantam, Conn.
PBI (experimental)	#40-90/0-1; 5 oz/yd^2	Celanese Research Corporation Summit, New Jersey
KYNOL (experimental)	#7979; 10.7 oz/yd^2	Collins and Aikman Corporation, New York, N.Y.
Cotton (reference)	White, 2.6 oz/yd^2	N/A
Foam		
Urethane (state-of-the-art)	4" thick UU-44(FR) urethane foam, 1.9 lb/ft^3	UOP Corporation, Aerospace Div., Bantam, Conn.
Neoprene	RP medium, 2" thick, 7.4 lb/ft^3	Toyad Corporation, Latrobe, Penna.

*NOTE: Among the fabrics tested, only the wool/nylon was an upholstery fabric with regard to construction (yarn, weave, weight, etc.) and color. This fact must be considered in interpreting the results of the comparative evaluation.

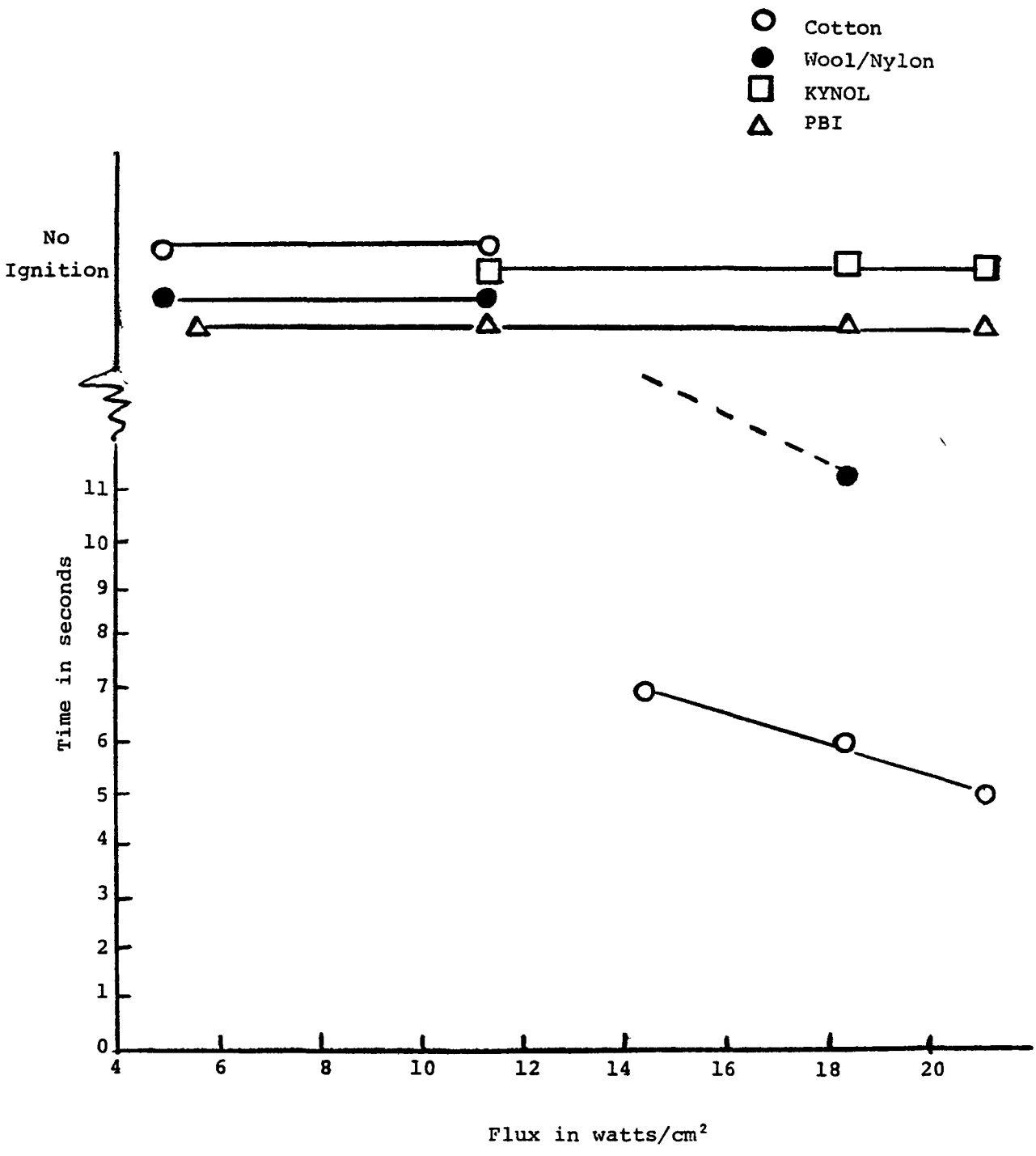
Time to Smoke

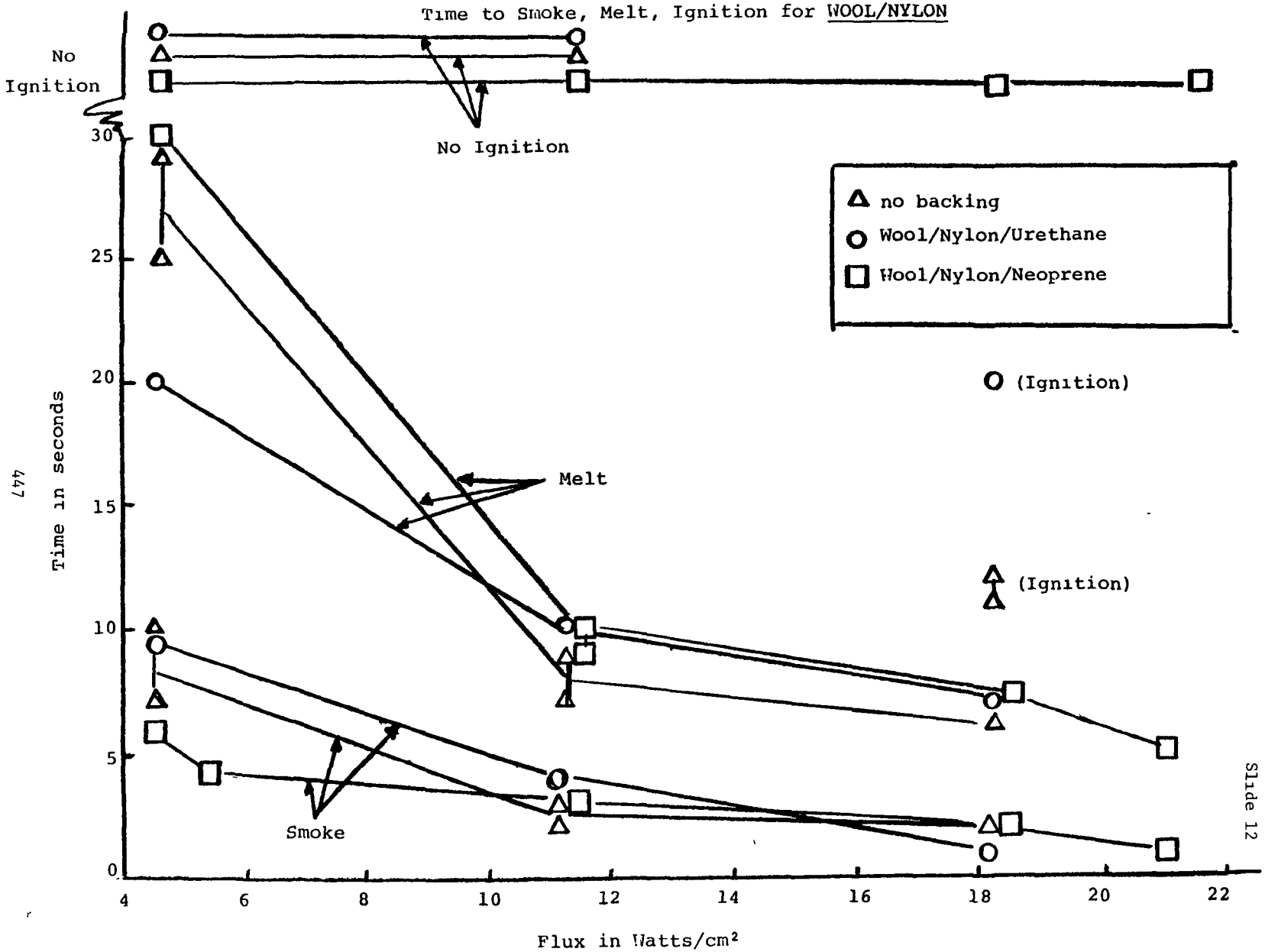
FABRICS ALONE

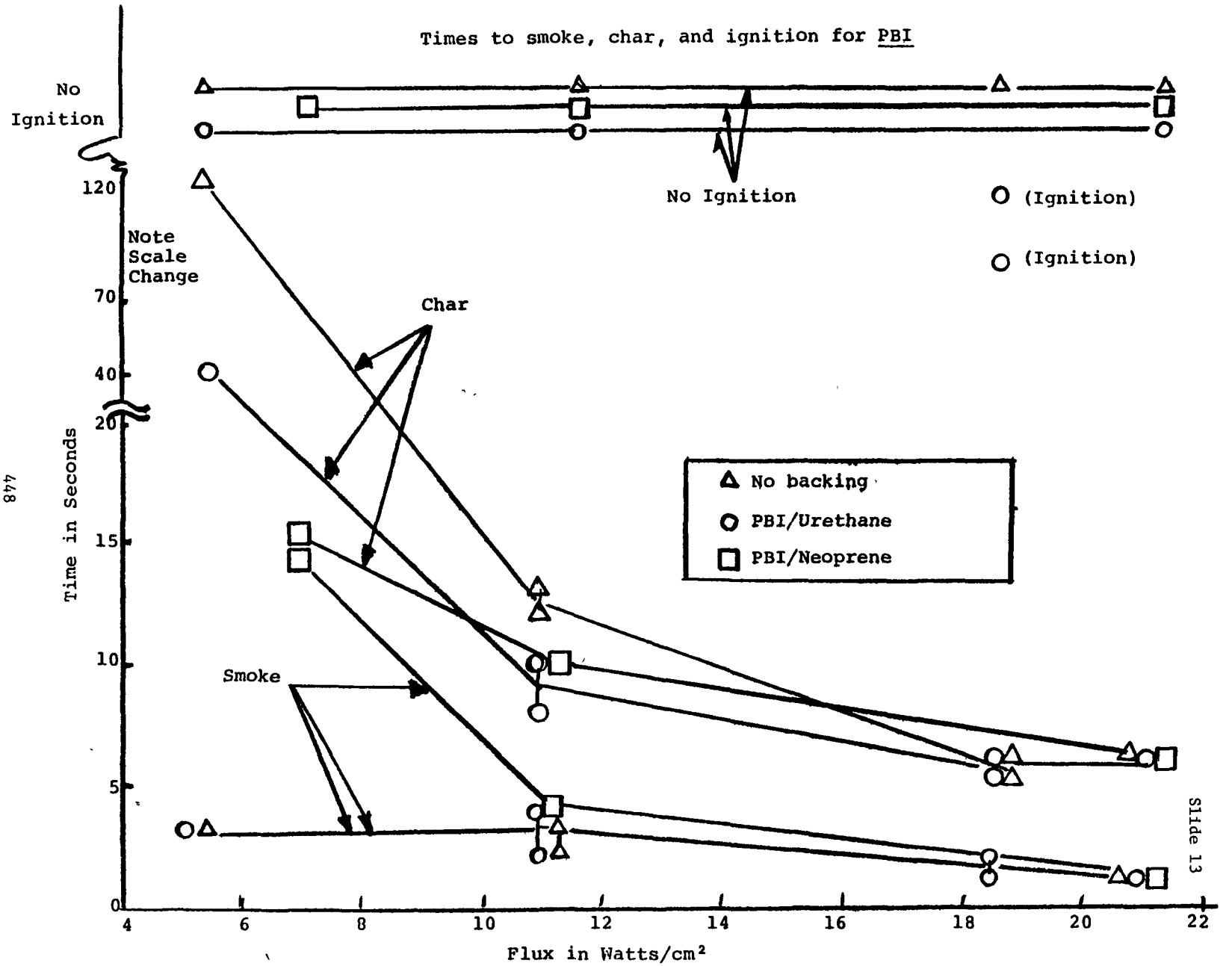


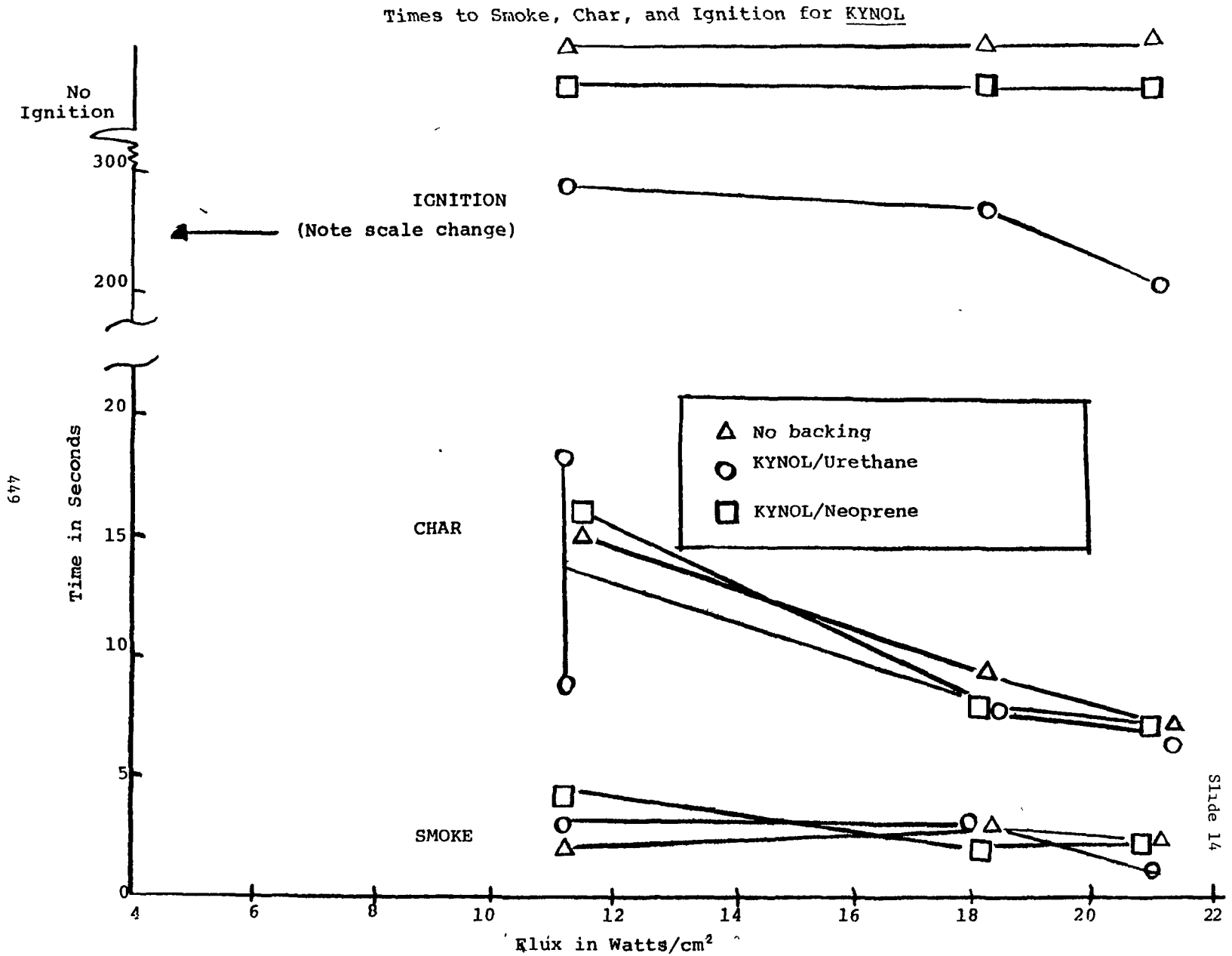

Time to Char, Hole or Melt
FABRICS ALONE
(120 sec)
(228 sec)
PBI, Char
KYNOL, Char
Wool/Nylon, Melt
Cotton, hole
Time in seconds
0
4
8
12
16
20
24
28
4
6
8
10
12
14
16
18
20
22
Flux in watts/cm²

Time to Ignition, FABRICS ALONE

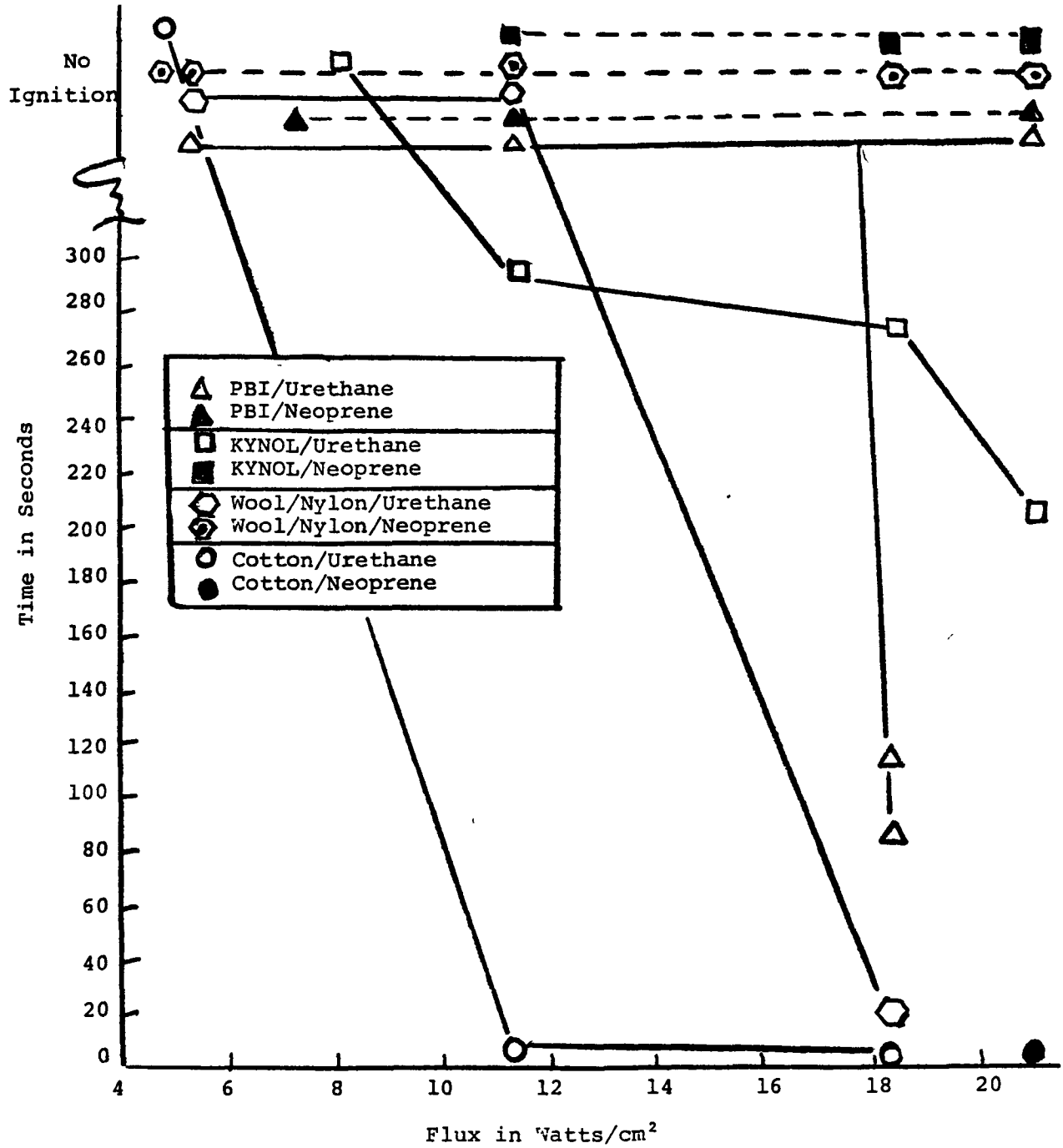



Time to Smoke, Melt, Ignition for WOOL/NYLON
No Ignition
No Ignition
no backing
Wool/Nylon/Urethane
Wool/Nylon/Neoprene
(Ignition)
(Ignition)
Melt
Smoke
Time in seconds
Flux in Watts/cm²
0
5
10
15
20
25
30
4
6
8
10
12
14
16
18
20
22


Times to smoke, char, and ignition for PBI
No Ignition
No Ignition
(Ignition)
(Ignition)
Note Scale Change
120
70
40
20
Char
Smoke
No backing
PBI/Urethane
PBI/Neoprene
Time in Seconds
15
10
5
0
4
6
8
10
12
14
16
18
20
22
Flux in Watts/cm²

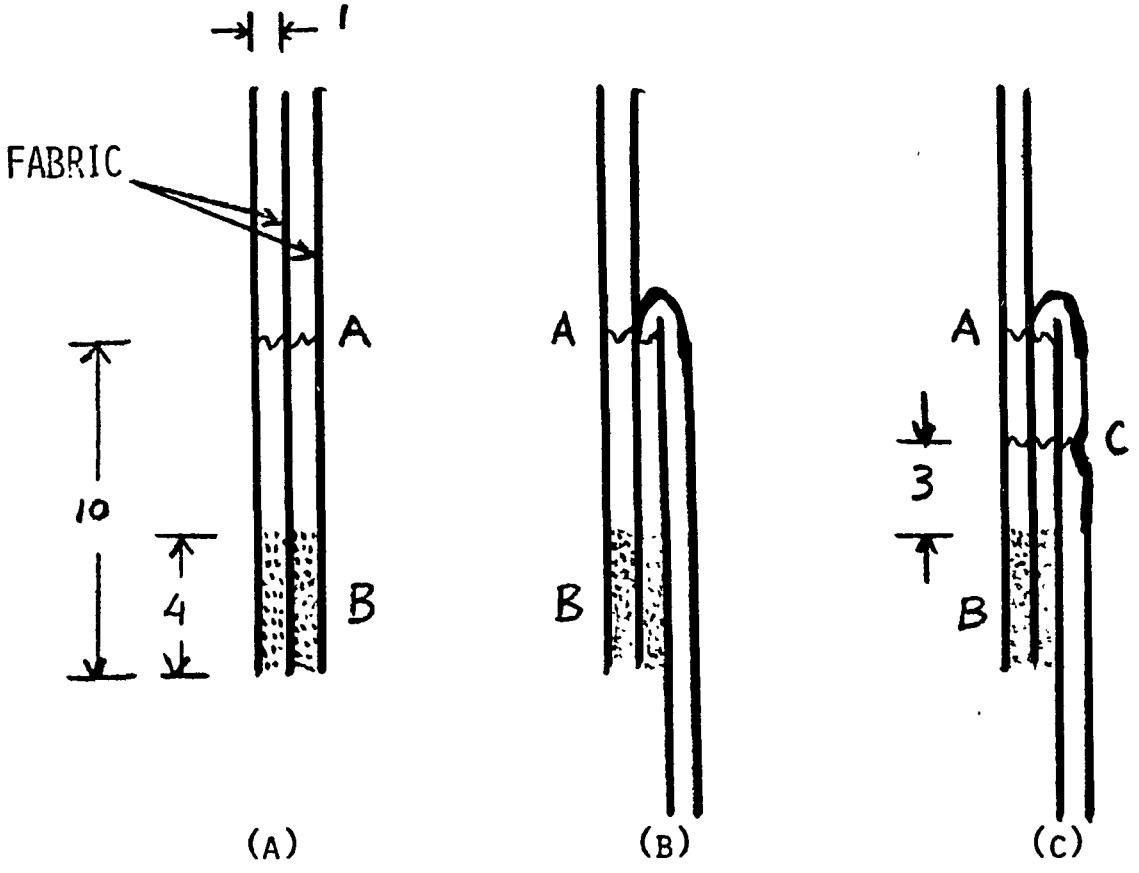

Times to Smoke, Char, and Ignition for KYNOL
No Ignition
300
200
IGNITION
(Note scale change)
20
15
10
5
0
Time in Seconds
CHAR
SMOKE
No backing
KYNOL/Urethane
KYNOL/Neoprene
4
6
8
10
12
14
16
18
20
22
Flux in Watts/cm²

Time to Ignition, FABRICS/FOAM



SINGLE FELLED SEAM WITH THREE STITCHES

(TWO LOCK, ONE OVERCAST)

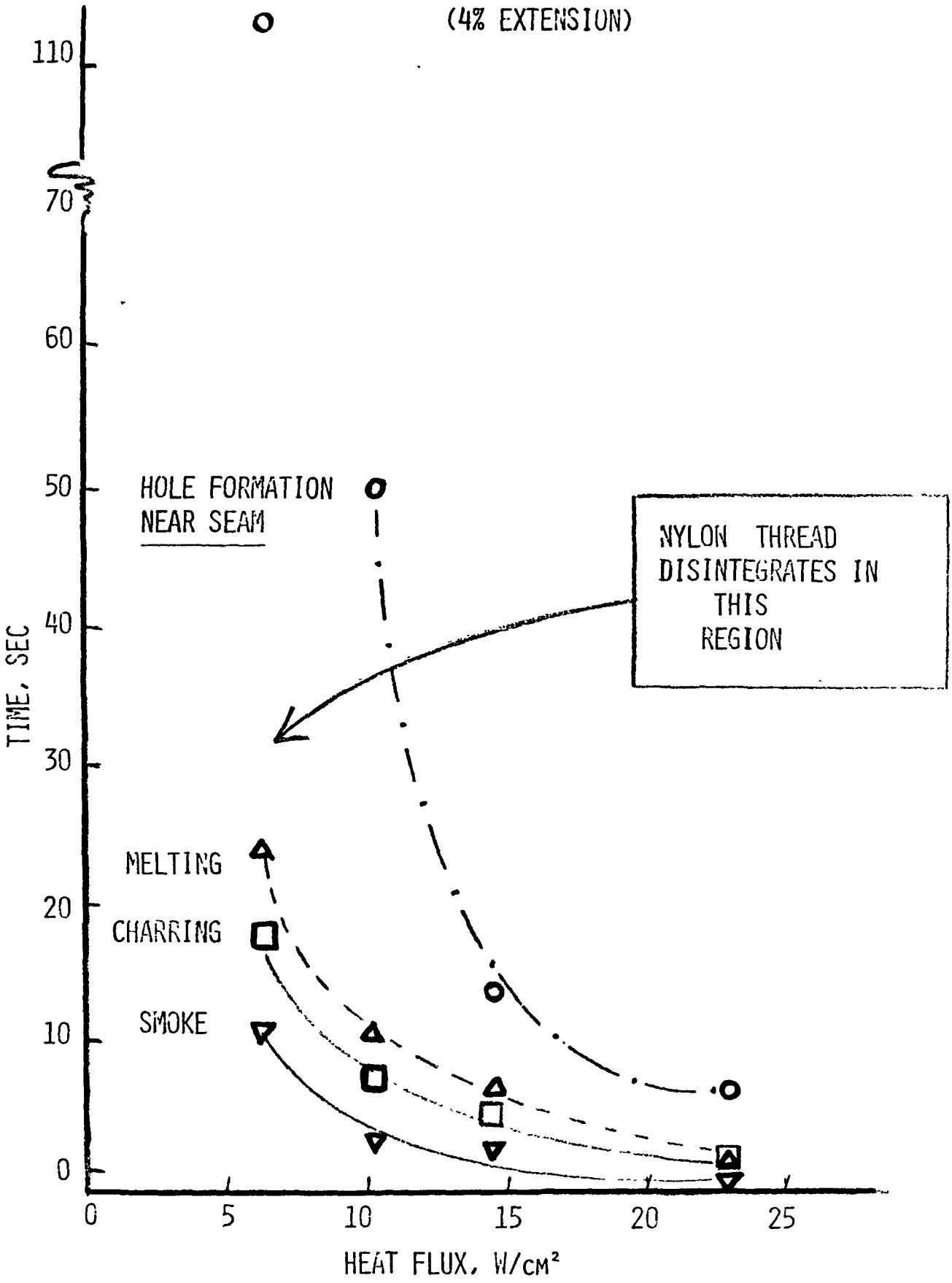


ALL DIMENSIONS IN MM

LOCK STITCH

OVERCAST STITCH

RESPONSE OF SEAMED FABRIC TO RADIATIVE HEATING (4% EXTENSION)



SMOLDERING OF UPHOLSTERY COVERED FLEXIBLE PU FOAMS AT ATMOSPHERIC CONDITIONS**

Weight of Cotton Upholstery Fabric	PU Foam* A	B	C
0.07 g/cm^2	SUSTAINED SMOLDERING	SUSTAINED SMOLDERING	SUSTAINED SMOLDERING
0.03 g/cm^2	"	SUSTAINED SMOLDERING	TRANSITION TO EXTINGUISHMENT
Bare Block	"	TRANSITION TO EXTIN-GUISHMENT	TRANSITION TO EXTINGUISHMENT

*Foam block: 5 x 12 x 45cm (cigarette initiation)

**T. Y. Toong et al. Final Report to the Product Research Committee by Massachusetts Institute of Technology - January 1978 - RP-76-U-3.

SMOKE EMISSION OF AIRCRAFT SEAT MATERIALS*

MATERIAL	Ds 4 MINUTES** -	+
WOOL FABRIC	200	111
NOMEX FABRIC	-	-
PU FOAM SLAB	172	50
PU FOAM SLAB + MUSLIN	158	165
PU FOAM COLD CURING	55	31
PU FOAM COLD CURING + MUSLIN	102	88

- WITHOUT FLAME
+ WITH FLAME

*G. BORSINI & C. CARDINALI, J. FIRE FLAMMABILITY 7, 530-539 (1976)

**PROPOSED LIMITING VALUE: 100

VONAR INTERLINERS*

(NEOPRENE LATEX FOAM-CONTAINING HYDRATED ALUMINUM OXIDE AND ANTIMONY OXIDE)

MATERIALS	HEAT INPUT AT IGNITION BTU	TIME TO CORE INVOLVEMENT
POLYPROPYLENE FABRIC + PU FOAM	12	2 MIN
POLYPROPYLENE FABRIC BACKCOATED WITH VONAR + PU FOAM	3375	>30 MIN
POLYPROPYLENE FABRIC + VONAR INTERLINER + PU FOAM	85	9.5 MIN
COTTON/RAYON FABRIC + PU FOAM	38	2 MIN
COTTON/RAYON FABRIC BACKCOATED WITH VONAR + PU FOAM	525	12 MIN
COTTON/RAYON FABRIC + VONAR INTERLINE + PU FOAM	5160	34 MIN

*DUPONT INDUSTRY NEWS, MAY 19, 1976, AND "A GUIDE TO VONAR INTERLINERS."

CONCLUSIONS

1. CURRENT (1978) AVAILABILITY OF UPHOLSTERY FABRICS MADE FROM ADVANCED MATERIALS AND MEETING PERFORMANCE REQUIREMENTS, IS NOT ADEQUATE.

2. IGNITION OF STATE-OF-THE-ART UPHOLSTERY FABRICS CAN BE DELAYED BY A CAREFULLY SELECTED LAYER OR INTERLINER BETWEEN FABRIC AND FOAM.

3. THERMAL RESPONSE OF MULTICOMPONENT ASSEMBLIES IS DEPENDENT ON HEAT FLUX AND ON THE SPECIFIC MATERIALS EMPLOYED. THUS, EXPERIMENTAL EVALUATION OF CANDIDATE SYSTEMS IS AN ESSENTIAL PART OF MATERIALS' SELECTION.

ENCLOSURE FIRE MODELING

Clifford D. Coulbert
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California 91103

Description of Figures (viewgraphs)
used in Firemen Program Review
presentation by C. D. Coulbert, JPL

"Enclosure Fire Modeling"

Figure

1. Introductory orientation summarizing the quantities describing an enclosure fire and its constraints.

2. The liquid fuel burning rate becomes effectively constant - approximately 4.5 mm/min -- for pools greater than one meter in diameter, independent of type of fuel. The rates are variable for pool diameters less than one meter.

3. The various relative energy release criteria (RERC) are listed and defined by simple analytic formulae having empirical constants in the stated metric units where applicable. For nomenclature see attachment from Reference 2.

4. Global quantities are analytically defined which provide potential scaling parameters for enclosure fire characterization. They are measures of the enclosure temperature rise, smoke density, and toxic gas concentration. For nomenclature see 3. above.

5. The application of the RERC for enclosure fire development is illustrated graphically. Each criterion is independent of the others.

6. A specific example of RERC application to tests is introduced by the description of Stanford Research Institute (SRI) enclosure fire experiments and the listing of corresponding JPL determined RERC values.

7-10. The corresponding specific titles are sufficient descriptions for the comparisons of SRI experimental data with RERC. See Reference 1, pages 19 & 20 for discussions.

11&12. The total heat fluxes, as determined from the average value at a calibrated test panel, are correlated with the burning rates of four fuels over the burning time of each SRI experiment for specified ventilation rates and patterns.

13. The RERC indicates for NASA-JSC/BOEING full-scale test No. 18 with trash fuel that the fuel load is the main constraint on fire development. The enclosure volume is great enough that the ventilation rate would not constrain the fire growth with the limited fuel available.

14. The RERC indicates for NASA-JSC/BOEING full-scale tests Nos. 16 & 17 with Jet-A fuel that the fuel surface is the initial and main constraint followed by the fuel load and then the enclosure volume in the later stages and that the ventilation rate is not controlling the fire development nor the maximum heat release.

References

1. Roschke, E. J. and Coulbert, C. D., "Application of the Relative Energy Release Criteria to Enclosure Fire Testing," Jet Propulsion Laboratory, to be published.

2. Coulbert, C. D., "Enclosure Fire Hazard Analysis Using Relative Energy Release Criteria," Jet Propulsion Laboratory, to be published.

3. Coulbert, C. D., "Energy Release Criteria for Enclosure Fire Hazard Analysis--Parts I & II," Fire Technology, Vol. 13, Nos. 3 & 4 August & November 1977.

NOMENCLATURE

A_f = Fuel surface area, meters^2

A = Ventilation opening area, m^2

b = Flame front length, m

c = Specific heat at constant pressure, KW-min/Kg-°C

D_s = Smoke specific density

F_m = Fuel mass, Kg

g = Gravitational constant, 9.8 m/sec^2

H = Vertical dimension of ventilation opening, m

ΔH = Heat of combustion, Kw-min/Kg

K_1, K_2, K_3 = Proportionality factors in consistent units

I_o/I = Radiant intensity ratio

$\dot{Q}$ = Heat release rate, Kw

$\dot{Q}_s$ = Heat release rate during flame spreading, Kw

$\dot{Q}_f$ = Fuel surface controlled heat release rate, Kw

$\dot{Q}_v$ = Ventilation controlled heat release rate, Kw

$(\dot{Q}/A)$ = Heat release rate per unit area; a material property Kw/m^2

Q = Total heat released, Kw-min

Q_e = Total heat released by complete combustion of air in enclosure Kw-min

(Q/A) = Total heat released by complete combustion of unit area of fuel carpet: A material property Kw-min/m^2

U_{air} = Mass flow of air, Kg/sec

v = Flame spread velocity, m/min

R = Fuel burning rate, Kg/min

T = Temperature, °C

NOMENCLATURE (Continued)

ΔT_m = Mixed mean adiabatic temperature rise, °C

t = Burning time, min

t_e = Fire duration, min

V_e = Enclosure volume, m^3

ρ = Air density, Kg/m^3

Γ = Fraction of fuel evolved as smoke

t_s = Time for fire to spread to total fuel surface, min

m = Fuel mass loss, Kg

L = Optical path length, m

ENCLOSURE FIRE MODELING*

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California Institute of Technology
Pasadena, CA 91103

ABSTRACT

JPL has developed a fire characterization methodology which for the first time provides a unified analysis framework for the integration of all fire test data on a common basis. This fire characterization approach provides a basis for relating fire temperatures, smoke densities, toxic gas concentrations and heat fluxes to material properties, enclosure geometry, and ventilation factors. This fire characterization concept also provides a basis for utilizing small-scale and laboratory material test data in full-scale fire models (such as the cabin fire model developed by Dayton Research for FAA) to predict the response of aircraft components or whole cabin interiors to various fire scenarios.

The JPL fire characterization methodology in its present stage of development has already been used to develop an enclosure fire hazard analysis procedure capable of predicting the probable course of fire development in an enclosure and indicating which fire parameters would control fire development during its critical phases. Fire test data on burning rates from a wide variety of sources, fuels, and test methods have been compiled and correlated on a common basis and have revealed heretofore unrecognized interrlationships and a potential basis for improved predictions of material response to fire.

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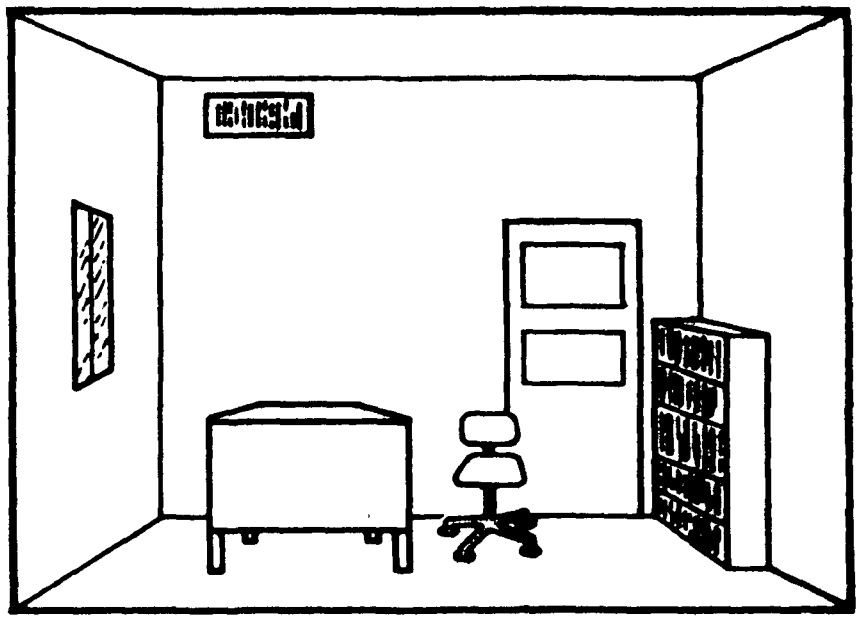
*This abstract represents one phase of research performed by the Jet Propulsion Laboratory, California Institute of Technology sponsored by the National Aeronautics and Space Administration, Contract NAS7-100.



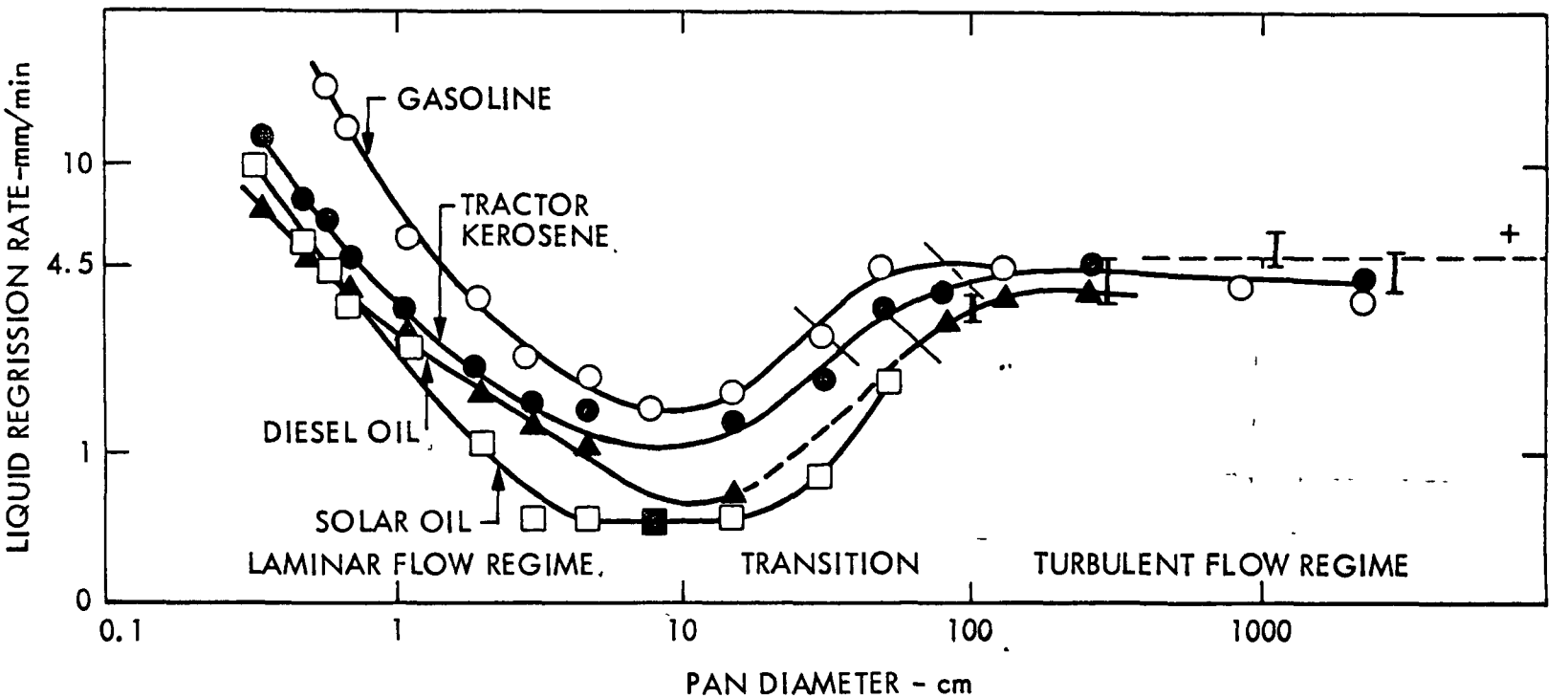
ENCLOSURE FIRE PARAMETERS

- ROOM VOLUME
- FUEL LOAD (MASS)
- FUEL SURFACE
- VENTS & OPENINGS
- FORCED VENTILATION
- FUEL FLAMMABILITY

FIRE CONSTRAINTS

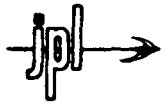
- INITIAL AIR SUPPLY
- FLAME SPREAD RATE
- AIR SUPPLIED FROM OUTSIDE
- MAXIMUM HEAT RELEASE RATE
- TOTAL HEAT RELEASED

Fig. 1



BURNING RATES OF LIQUID FUEL FIRES

Fig. 2



ENCLOSURE FIRE ANALYSIS
RELATIVE ENERGY RELEASE CRITERIA

FLAME SPREAD RATE

$\dot{Q}_s = (\dot{Q}/A)bvt$ (LINEAR)

$\dot{Q}_s = (\dot{Q}/A)\pi v^2 t^2$ (RADIAL)

FUEL SURFACE LIMIT

$\dot{Q}_f = 2500\ A_f$ (GASOLINE)

$\dot{Q}_f = 100\ A_f$ (WOOD)

BURNING CARPET

$\dot{Q}_s = (Q/A)bv$ (LINEAR)

$\dot{Q}_s = 2\pi(Q/A)v^2 t$ (RADIAL)

VENTILATION LIMIT

$\dot{Q}_v = 1580\ AH^{\frac{1}{2}}$

ENCLOSURE VOLUME

$$t_e = \frac{58V_e}{\dot{Q}}$$

FUEL LOAD

$$t_e = \frac{Fm\Delta H}{\dot{Q}}$$

NOTE: UNITS ARE:

KILOWATTS

METERS

KILOGRAMS

MINUTES

Fig. 3

ENCLOSURE FIRE CHARACTERIZATION

MIXED MEAN ADIABATIC AIR TEMPERATURE (T_M)

$$\Delta T_M = \frac{\int_o^t \dot{Q}\,dt}{C\rho V_e} \quad \text{OR} \quad \frac{\beta_1 \int_o^t \dot{m}_f\,dt}{V_e}$$

AVERAGE MASS OPTICAL DENSITY (MOD)

$$MOD = \frac{D_s A_f}{m} = \frac{V_e}{mL} \log_{10}\left(\frac{I_o}{I}\right)$$

$$\log_{10}\left(\frac{I_o}{I}\right) = (MOD \downarrow V_e \int_o^t \dot{m}\,dt$$

AVERAGE TOXIC GAS CONCENTRATION ($\dot{G}_T$)

$$G_T \propto \frac{\Delta M_{CO}}{V_e} \text{ (OR) } \frac{\beta_2 \int_o^{t_o} \dot{m}\,dt}{V_e}$$

Fig. 4

RELATIVE ENERGY RELEASE CRITERIA
FOR ENCLOSURE FIRE DEVELOPMENT

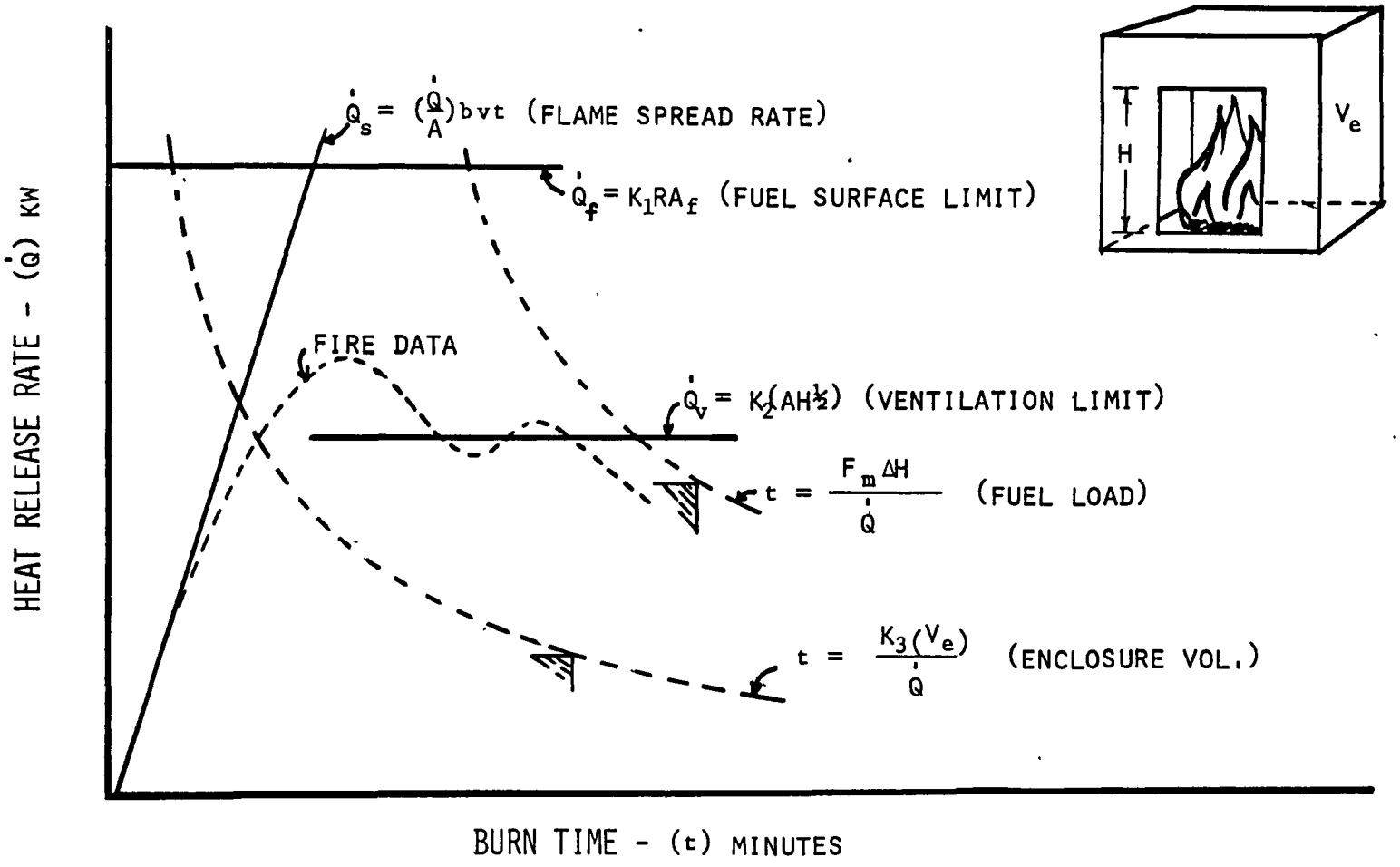


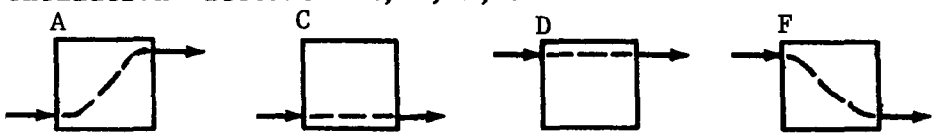
Fig. 5

Table 1. The Description of SRI Enclosure Fire Experiments and the Determination of RERC

Constant Room Volume: V_e = 1050 ft^3

Four Ventilation Rates: 71, 154, 237, 348 ft^3/min

Four Ventilation Patterns: A, C, D, F



Four Types of Fuel: Load ~15 kg = 33 lb

(Liquid) MeOH and JP4-36" Diam Pools

(Solid) { Wood Cribs - 3/4" Square Sticks
Rubber Tire Segments - Pyramid Piles

Basic Data from SRI: Fuel Weight Loss with Time
Heat Flux Data (Radiometers)
(No gas temperature or composition)

RERC (Calculated by JPL from SRI data)

Flame Spread Rates: (Not calculated)

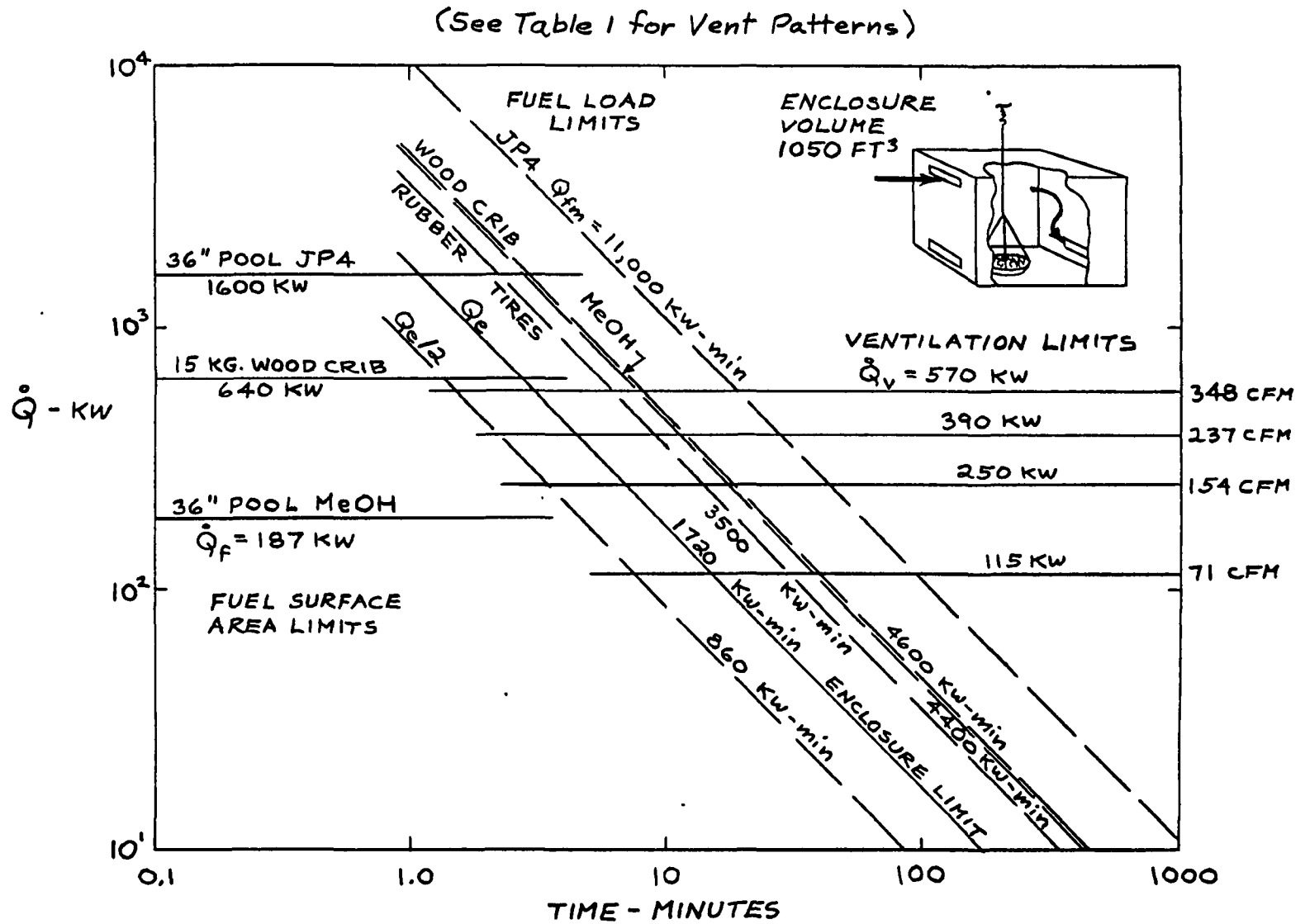
Ventilation Limit: $\dot{Q}_v$

$\dot{Q}_v$ = 115 kW for 71 cfm
= 250 kW " 154 cfm
= 390 kW " 237 cfm
= 570 kW " 348 cfm

Enclosure Volume: Q_e = 1720 kW-min
$Q_e/2$ = 860 kW-min

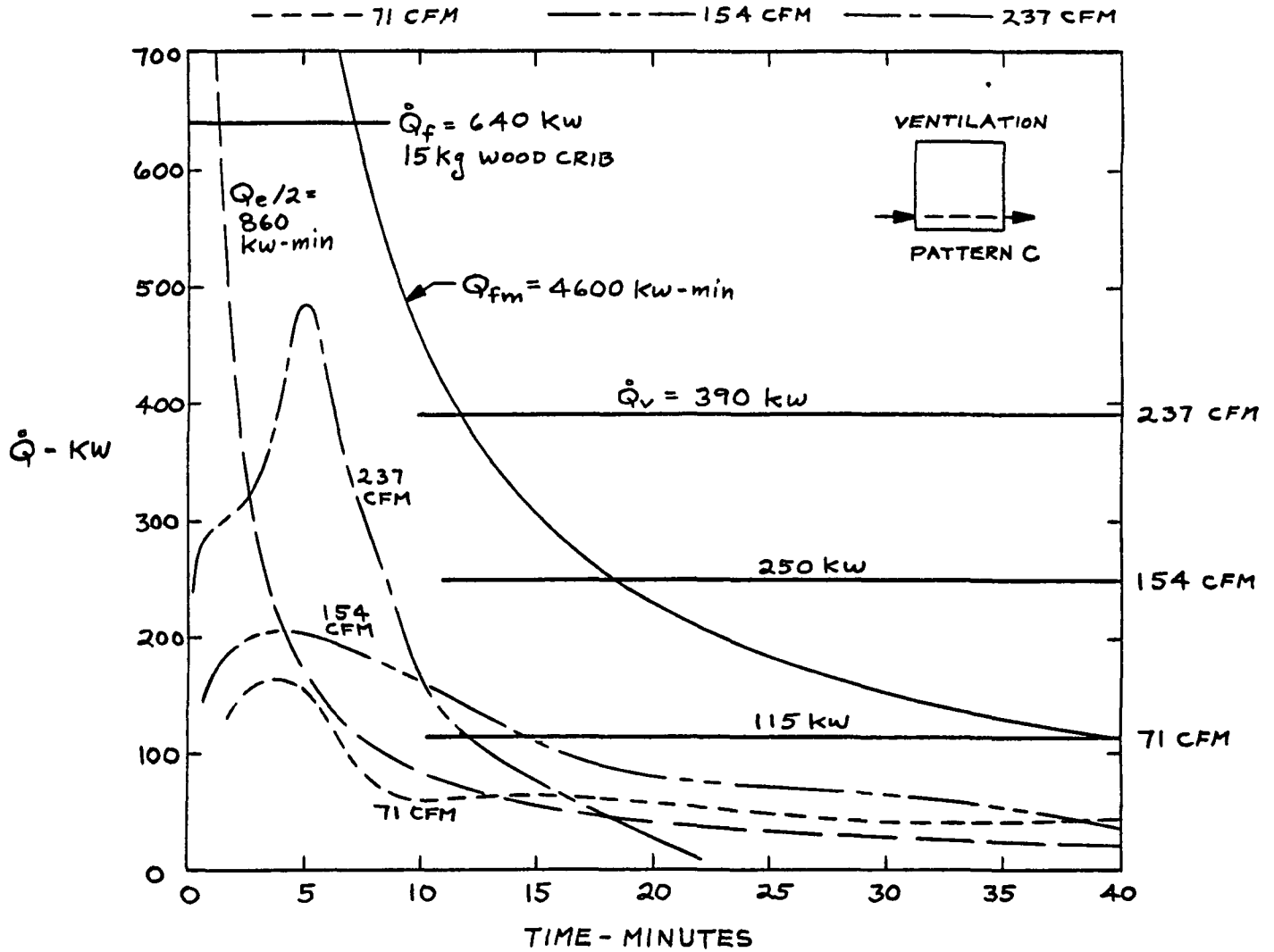
Fuel Limits:

	Fuel Surface Limit $\dot{Q}_f$ kW	Heat of Combustion ΔH (kW-min)/kg	Fuel Load Q_{fm} kW-min
Wood Cribs	640	308	4600
MeOH Pools	187	297	4400
JP4 Pools	1600	736	11,000
Rubber Tires	-	234	3500



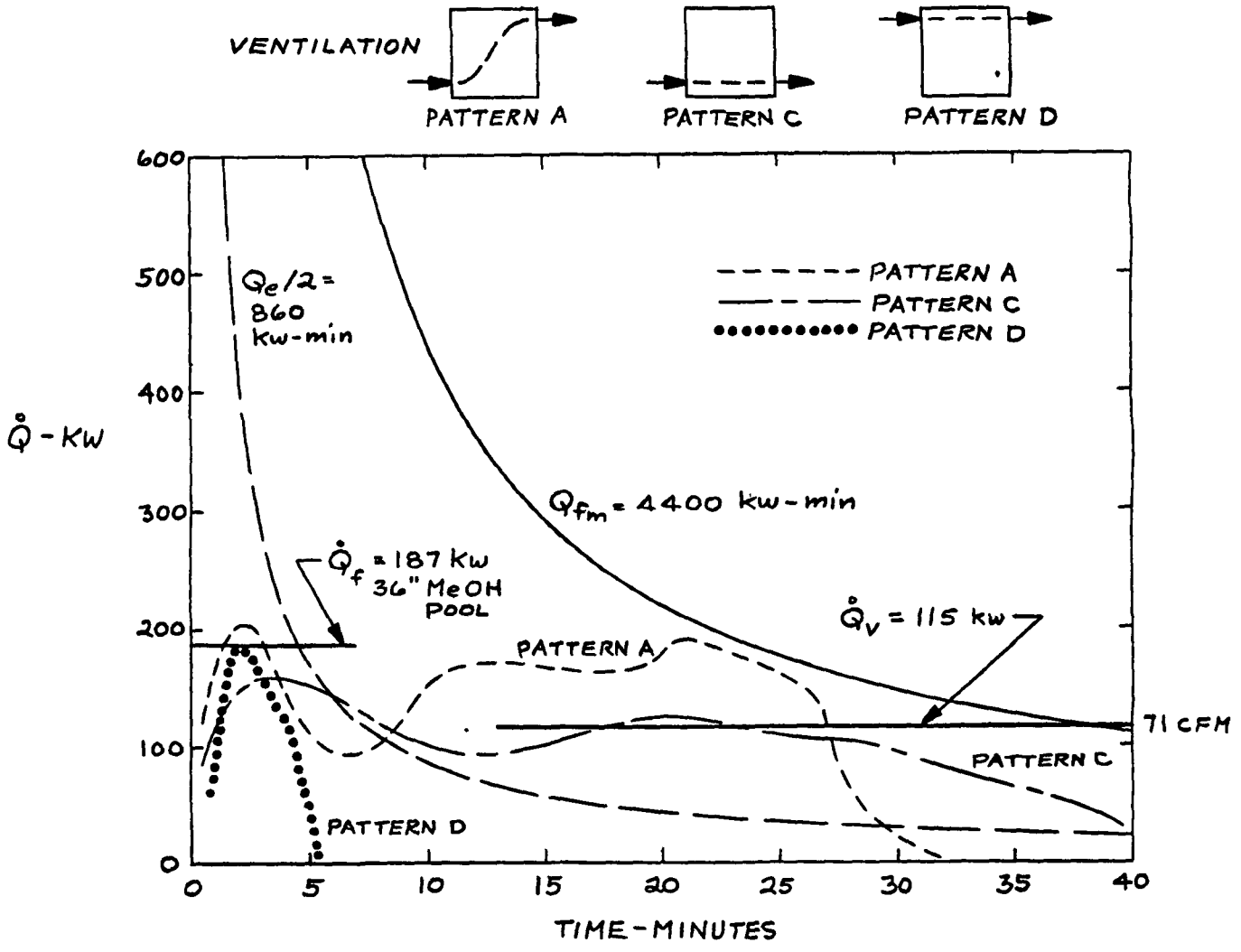
Relative Energy Release Criteria (RERC) for SRI Experiments

Fig. 6



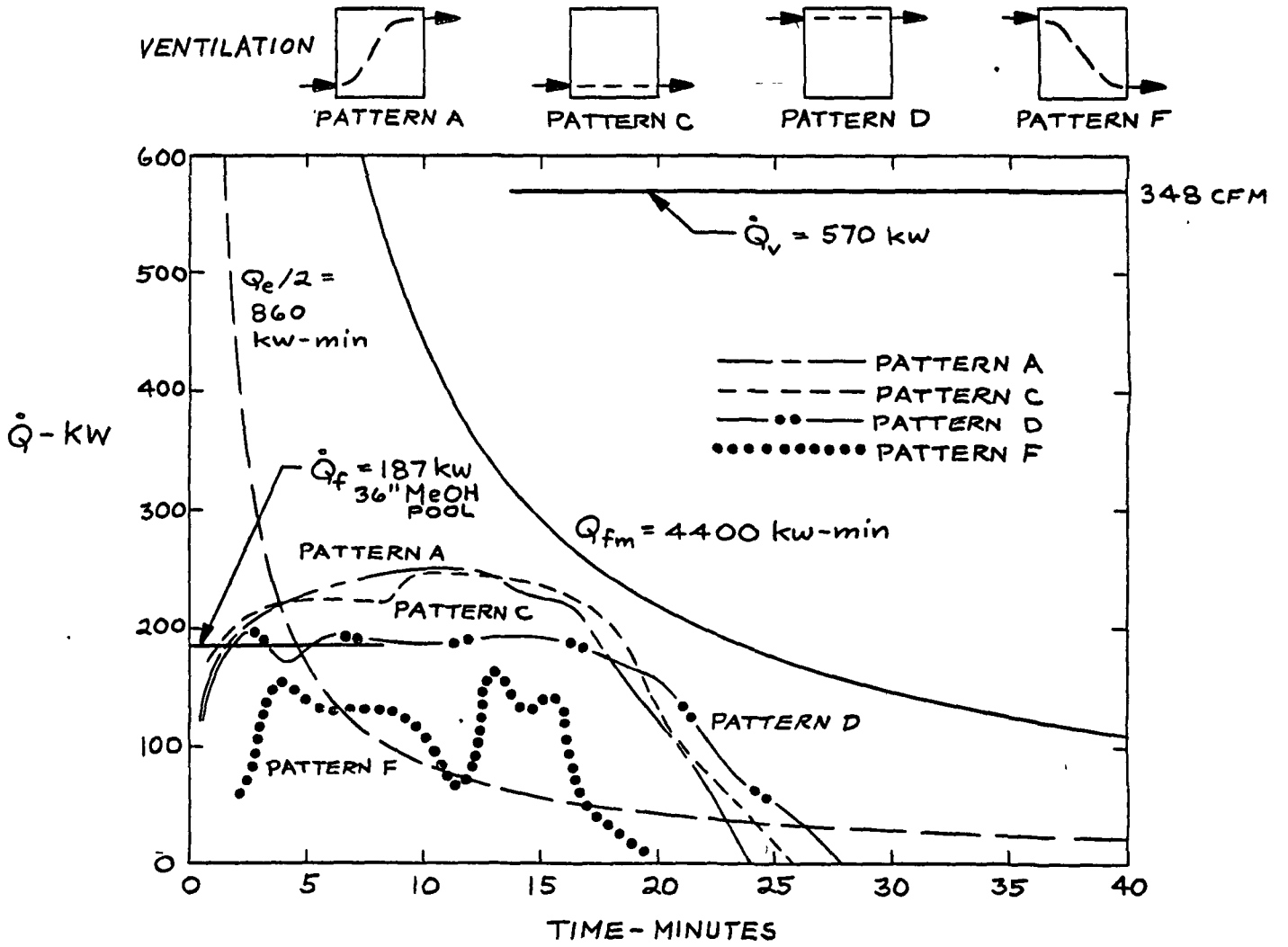
SRI Experimental Data Compared With RERC. Wood Cribs with Vent Pattern C at Three Ventilation Rates. Enclosure Volume of 1050 ft^3.

Fig. 7



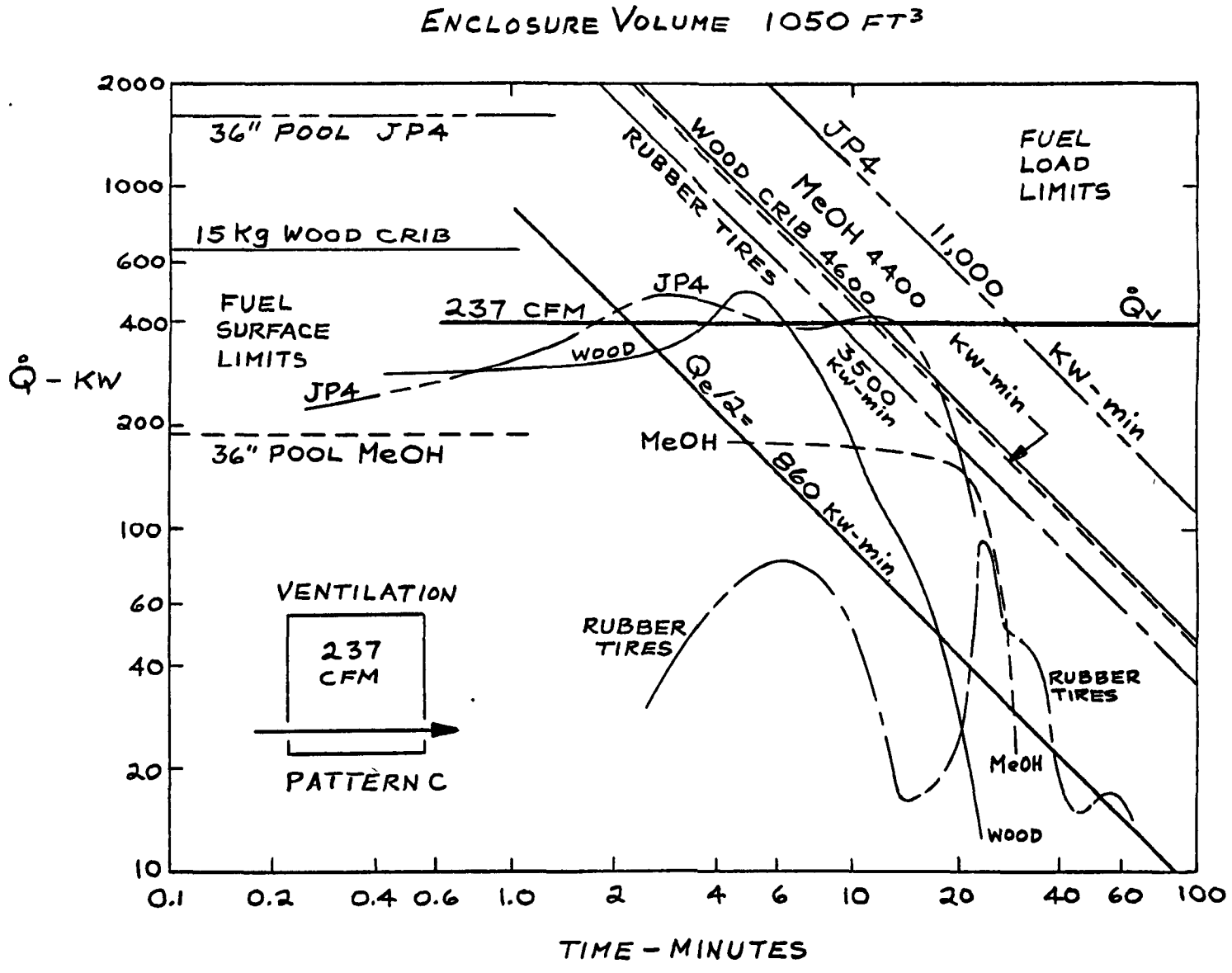
SRI Experimental Data Compared With RERC. Methanol Pools at a Ventilation Rate of 71 cfm with Three Ventilation Patterns. Enclosure Volume of 1050 ft^3.

Fig. 8



SRI Experimental Data Compared With RERC. Methanol Pools at a Ventilation Rate of 348 cfm with Four Ventilation Patterns. Enclosure Volume of 1050 ft³.

Fig. 9



SRI Experimental Data Compared with RERC. Four Fuels with Vent Pattern C at a Ventilation Rate of 237 cfm.

Fig. 10

PANEL HEAT FLUX TO FUEL HEAT RELEASE CORRELATION

VENTILATION RATE ~71 cfm

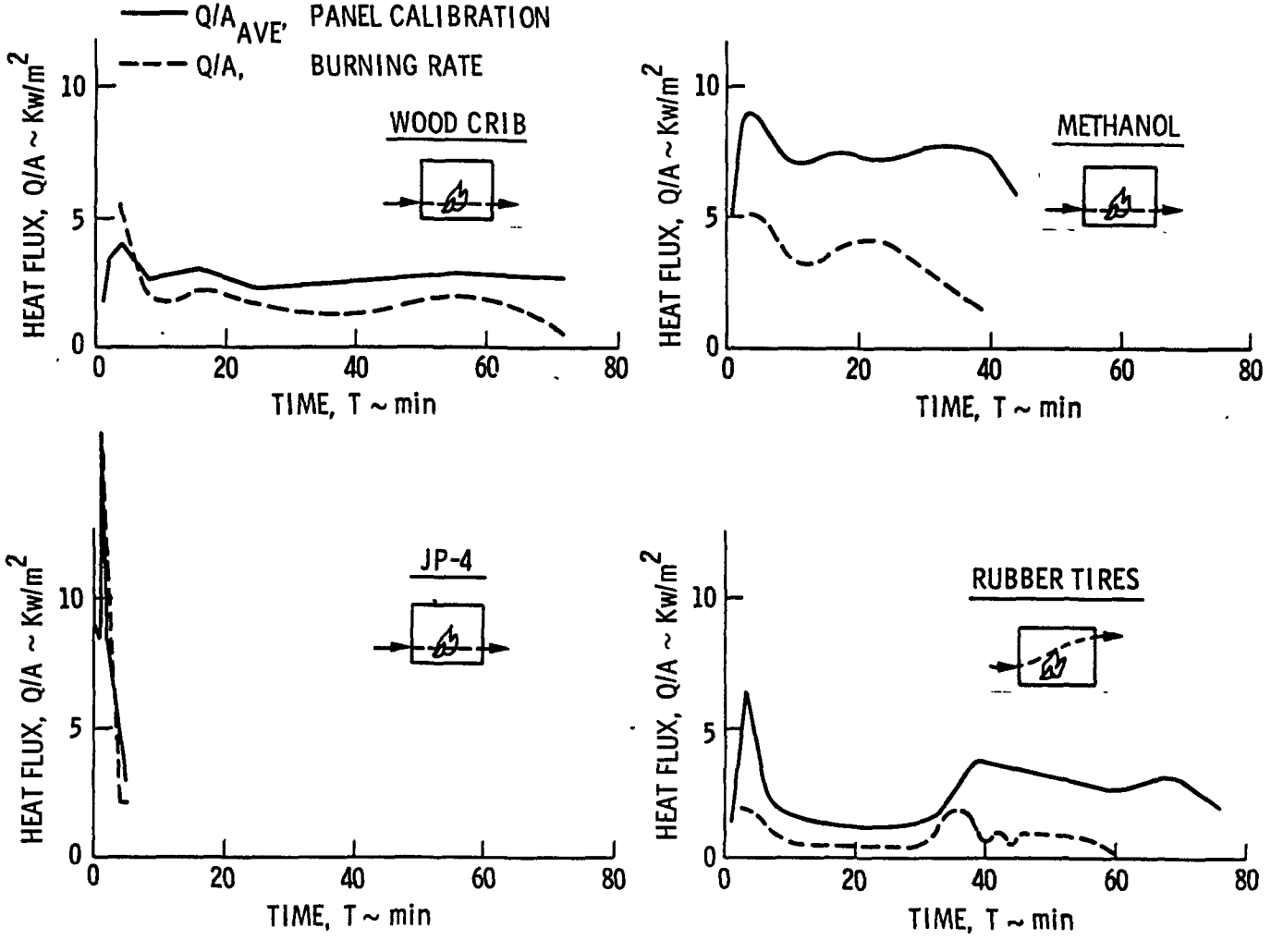


Fig. 11

PANEL HEAT FLUX TO FUEL HEAT RELEASE CORRELATION

VENTILATION RATE, $\dot{V}$

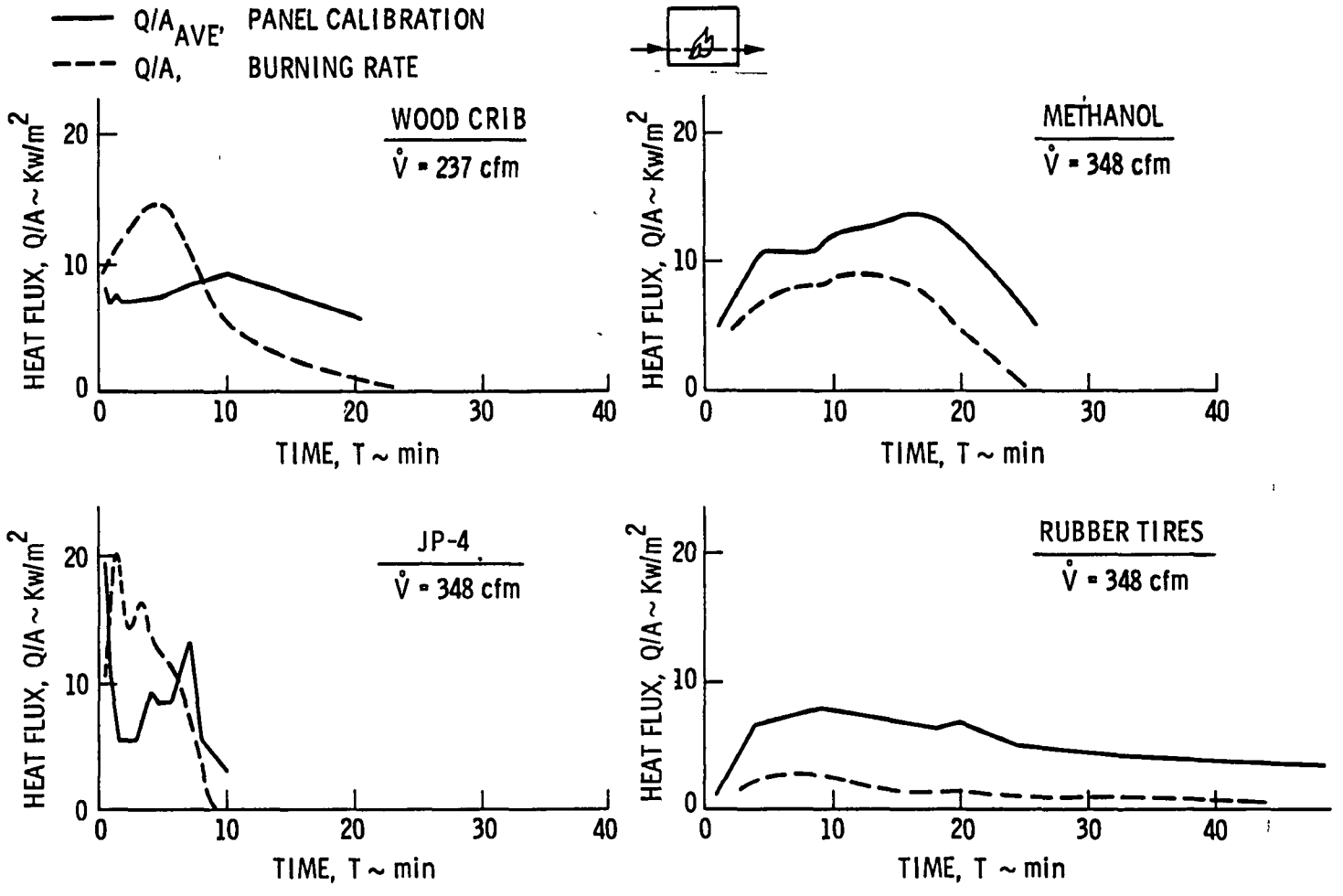
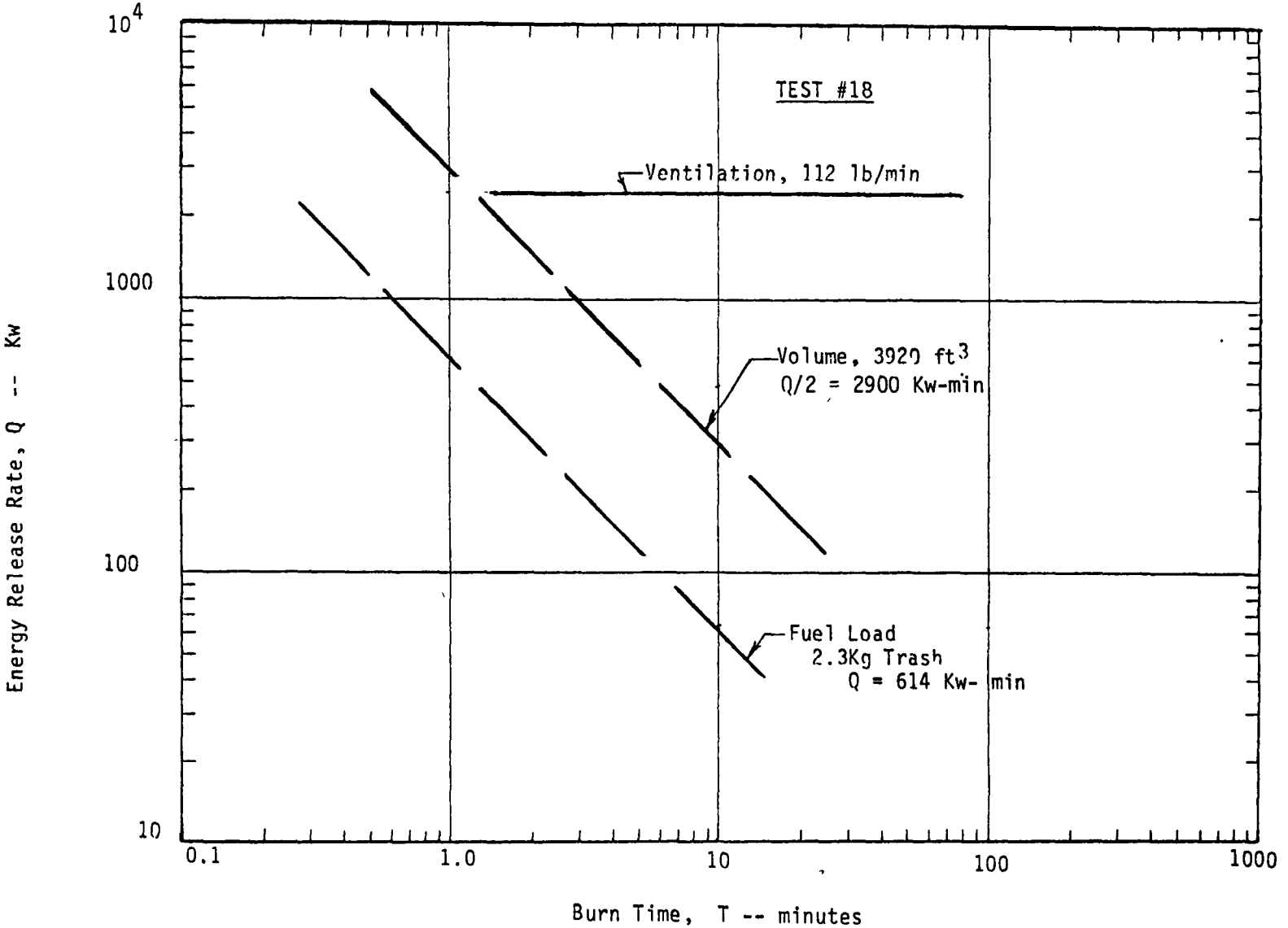
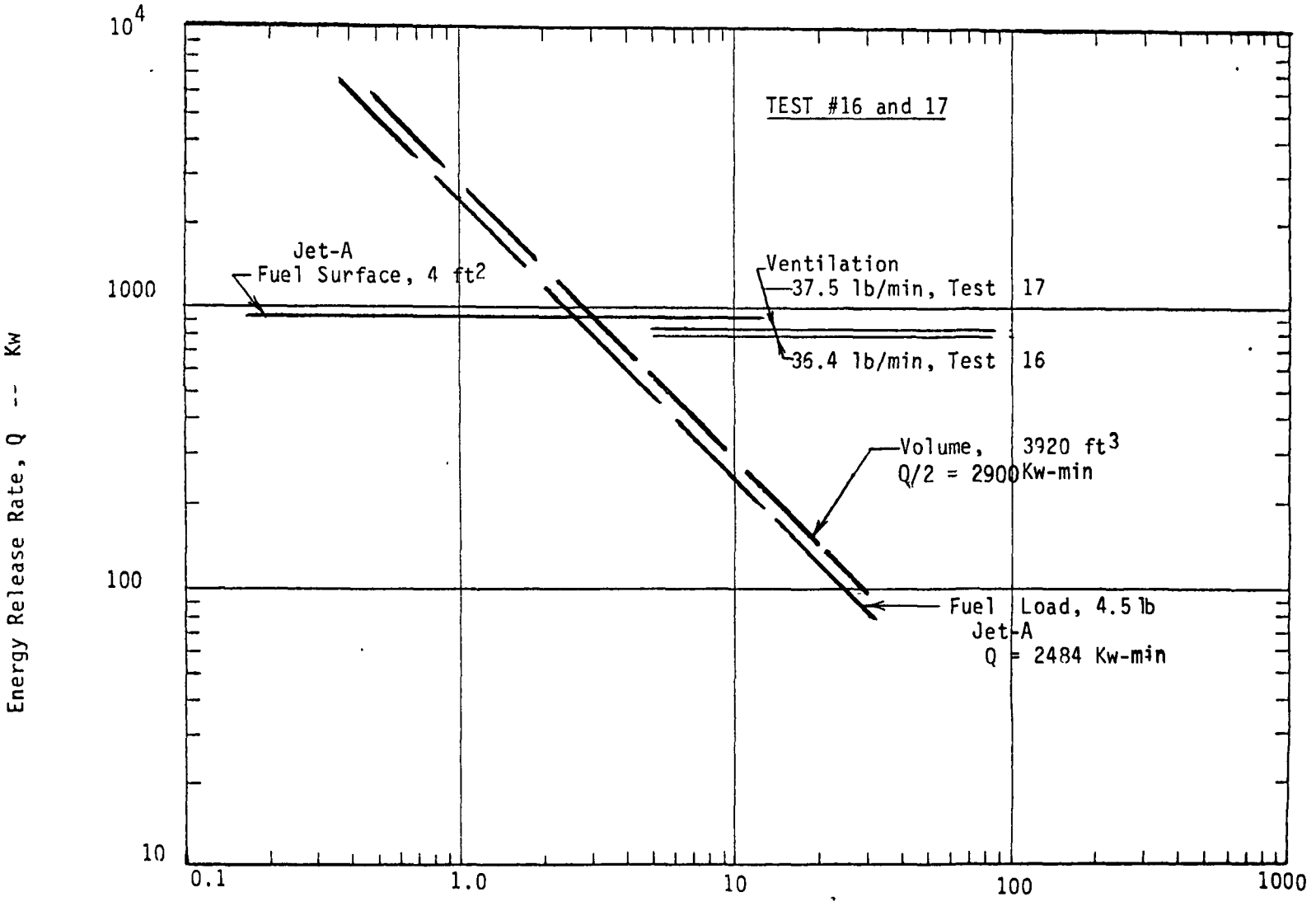


Fig. 12



RERC for Enclosure Fire Development
for NASA-JSC/Boeing Full-Scale Tests

Fig. 13



RERC for Enclosure Fire Development
for NASA-JSC/Boeing Full-Scale Tests

Fig. 14

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MODEL FIRE TESTS ON POLYPHOSPHAZENE RUBBER AND POLYVINYL CHLORIDE (PVC)/NITRILE RUBBER FOAMS *

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ABSTRACT

A video tape record of model room fire tests was shown, comparing polyphosphazene (P-N) rubber and polyvinyl chloride (PVC)/nitrile rubber closed-cell foams as interior finish thermal insulation under conditions directly translatable to an actual fire situation.

Flashover did not occur with the P-N foam and only moderate amounts of low density smoke were formed, whereas with the PVC/nitrile foam, flashover occurred quickly and large volumes of high density smoke were emitted.

The P-N foam was produced in a pilot plant under carefully controlled conditions. The PVC/nitrile foam was a commercial product, which met the requirements of military specification MIL-P-15280H.

A major phase of the overall program involves fire tests on P-N open-cell foam cushioning.

INTRODUCTION

Laboratory fire tests for measuring ease of ignition, flame spread, smoke density, and rate of heat release, provide a means of screening many materials. However, tests of this type, even when employed collectively, are inadequate for assessing the potential fire risk of closed-cell foams as interior finish thermal insulation, or of open-cell foam cushioning for furnishings. The David W. Taylor Naval Ship Research and Development Center, and the National Bureau of Standards, Center for Fire Research, are engaged in a cooperative program for evaluating the fire risks of interior finish and furnishing materials.

APPROACH

Full scale room fire testing, under controlled conditions, is regarded as a reliable method for evaluating the fire risks of interior finish and furnishing materials. Full scale testing is not always feasible from the standpoints of time and cost. Nevertheless, numerous full scale room fire tests have been conducted at the NBS Center for Fire Research (CFR). More importantly, however, model room fire testing has been developed at CFR to the point where good correlation has been achieved between full scale and model room fire testing of interior finish materials, and to some extent, of furnishing materials.

DESCRIPTION OF MODEL ROOM AND MATERIALS

The tests described in this paper were conducted in a 1/4-scale model of a room 10 ft (3.05m)X 10ft (3.05m) X 8 ft (2.44m) high, having an open doorway 80 in (203.2cm) high X 30 in (76.2 cm) wide. The volume of the model chamber is 1/64th that of the room. For the test on the experimental polyphosphazene material, the walls and ceiling of the model chamber were lined with 1/2-in. (1.27 cm) thick closed-cell polyphosphazene foam insulation, produced in a pilot plant under carefully controlled conditions. The physical properties of this material, identified as APC, Sample No. 2, are given in Table 1. In a comparative test, the walls and ceiling of the chamber were lined with 1/2 in (1.27 cm) thick closed-cell PVC/nitrile rubber foam, meeting the requirements of military specification MIL-P-15280H, Plastic Material, Uni-cellular (Sheets and Tubes).

INSTRUMENTATION AND TEST CONDITIONS

Thermocouple trees were located inside the chamber and at the doorway. A photoelectric cell was used to measure smoke density continuously as it was emitted through the doorway. The ignition source was a methane diffusion burner, located at the right rear corner of the chamber. The heat output of the burner was 320 Btu/min (337.5 KJ/min), representing a small fraction of that needed to cause flashover

Table 1

Phosphazene Closed-Cell Foam, Pilot Plant Production
Physical Property Data Sheet

	APC #2	
Density, lbs/ft^3 (kg/m^3)	5.79	(92.7)
Tensile Strength, psi (MPa)	33.4	(0.23)
Elongation, %	40.0	
Compression Resistance, psi (MPa)	2.58	(0.018)
Water Absorption lbs/ft^2 (kg/m^2) of skinless area	0.0225	(0.11)
Dimensional Change @ 180°F (82°C), %	-3.5	
Water Vapor Permeability, perm-in. (kg/Pa·s·m)	<0.3	(<0.44x10^{-12})
Thermal Conductivity, k75 Btu · in./h · ft^2 · °F (W/m · K)	0.352	(0.051)
Compression Set, Method B, %	28.0	
NBS Optical Smoke Density		
D_m Flaming	55.0	
D_m Smoldering	63.0	

(full fire involvement) of the space. Carbon monoxide was measured continuously by infra-red equipment. Colorimetric indicator tubes were used to monitor HCN and HCl. Visual records of the tests were obtained by means of video tape and 16 mm motion picture film.

TEST RESULTS

In the test with the PVC/nitrile rubber foam, flashover occurred at 51 seconds, and dense black smoke poured from the doorway (Figure 1). At 58 seconds, the PVC/nitrile rubber foam was fully involved (Figure 2). No flashover occurred with the polyphosphazene foam, although the test was continued for 15 minutes. Figure 3 demonstrates the absence of flashover, with clock still running at 14 minutes, 50 seconds. A very limited amount of white smoke was produced by the polyphosphazene foam. A summary of the test results is given in Table 2.

Table 2

Quarter-Scale Model Room Fire Tests on Closed-Cell Foam Interior Finish Thermal Insulation

Material Under Test	Burner Output Btu/min (KJ/min)	Time to Flashover (sec,)	Max. Doorway Temp. T_1 (^oC)[1]	Time to T_1 (sec.)	Max. Interior Temp. T_2 (^oC)[2]	Time to T_2 (sec.)	Combustion Products, Peak Concentration[3] CO (%)	HCl (ppm)	HCN (ppm)
PVC/nitrile rubber foam (MIL-P-15280H)	320 (337.5)	51	532	51	603	51	3.8	Approx. 1000	>600
Polyphosphazene (P-N) rubber foam, APC #2	320 (337.5)	>900	231	141	304	114	<0.1	<200[4]	$\leq$ 20

Notes: (1) One inch (2.54 cm) down from top of doorway opening
(2) One inch (2.54 cm) down from center of ceiling.
(3) Occurs at or immediately after flashover for PVC/nitrile. Applies throughout the test period for P-N foam.
(4) The P-N foam as produced is chlorine-free. Colorimetric detector tubes are subject to cross-sensitivity and the presence of combustion products other than those being evaluated may lead to erroneous indications.

DISCUSSION

It is noteworthy that the maximum temperature reached in the interior of the test chamber was approximately twice as high for PVC/nitrile rubber foam as for polyphosphazene foam. A similar relationship exists for doorway temperatures. The most significant, and striking, features of the polyphosphazene foam test were the absence of flashover and the low smoke output. The white smoke formed in a layer near the top of the chamber, but dissipated after 2 minutes, with none appearing thereafter. In the case of the PVC/nitrile rubber foam, severe (deep) charring occurred in the vicinity of the ignition source. In the remaining areas considerable surface charring was observed. Charred material produced on the polyphosphazene foam was not more than 1/8 in (0.32 cm) thick in the vicinity of the burner, and 1/32 in (0.08 cm) to 1/16 in (0.16 cm) thick in adjacent areas. The wall to the left of the doorway (and farthest from the burner) exhibited no charred material. The PVC/nitrile rubber foam produced approximately 200 ppm of HCl just prior to flashover and 4 to 5 times this amount after flashover. Similarly, HCN concentration was 300 ppm just prior to flashover and >600 ppm after flashover. A maximum of 3.8% carbon monoxide was observed at flashover. The corresponding figures for polyphosphazene foam (no flashover) were <200 ppm of HCl, ≤ 20 ppm of HCN, and

< 0.1% carbon monoxide. It should be pointed out that the polyphosphazene foam as produced, is chlorine-free. Colorimetric detector tubes are subject to cross-sensitivity and the presence of combustion products other than those being evaluated may lead to erroneous indications.

CONCLUSIONS

These tests emphasize the great potential that polyphosphazene foams have for military and commercial applications, by reason of their flame resistance, low smoke-producing and low toxicity characteristics. Recently, the price of phosphazene polymers used in foam manufacture was substantially reduced. The price reduction also applies to phosphazene polymers for insulated wire and cable. The development of thermal insulation, foam cushioning, wire covering, paint systems and other polyphosphazene end products is continuing. It is anticipated that they will eventually take their place in competitive markets.

ACKNOWLEDGMENT

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funding for all polyphosphazene research and development is provided by Naval Sea Systems Command (NAVSEA) Materials and Mechanics Division. Fire research on polyphosphazene foams is supported by funds from both NBS and NAVSEA.

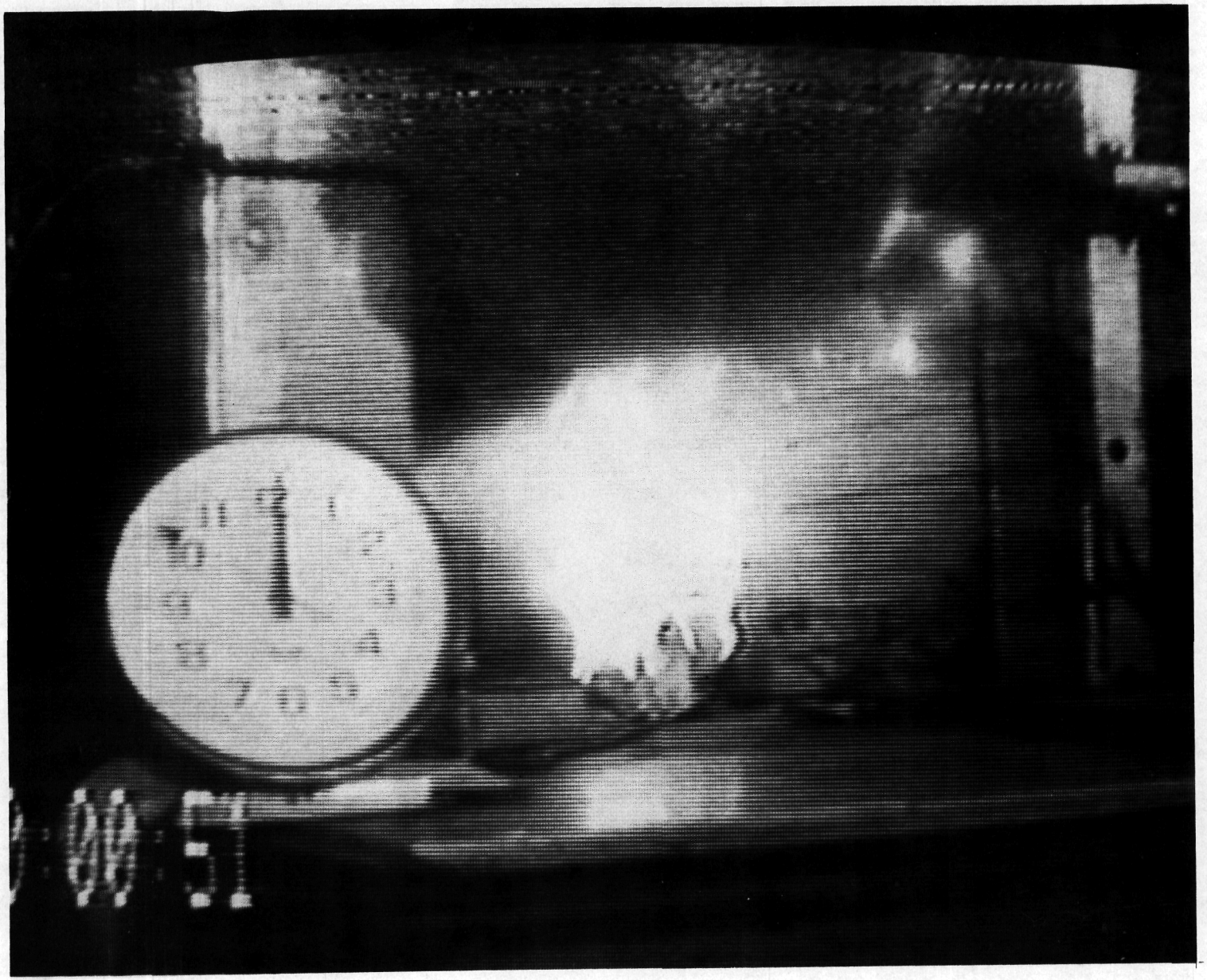

Fig. 1

Fig. 2

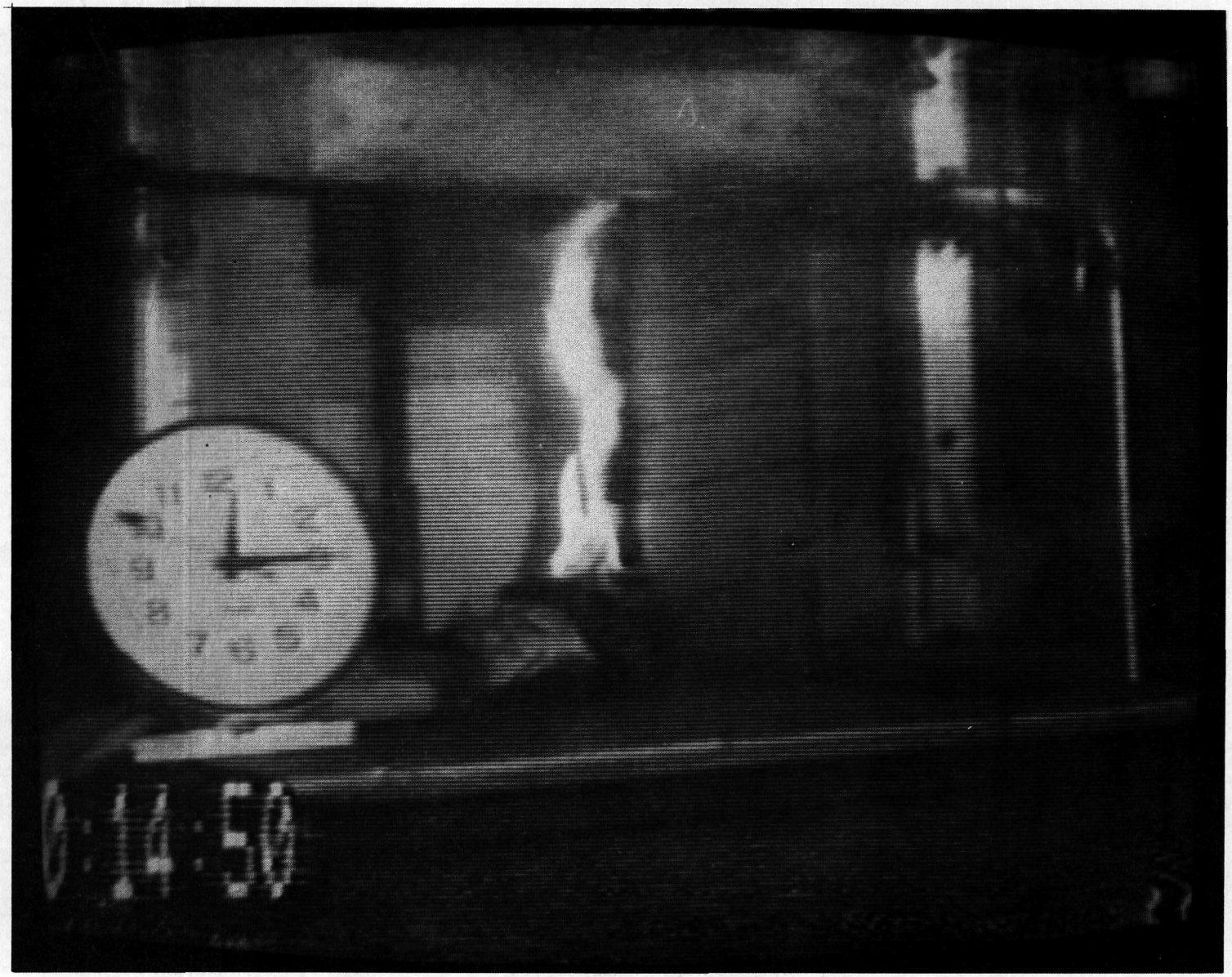

Fig. 3

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16 Abstract

A conference was held at Ames Research Center to ascertain the state-of-the-art of aircraft interior materials in commercial aircraft applications. The purpose of the conference was to review the status and the progress of the development of advanced aircraft interior materials and to review the specific programs conducted at the various NASA Centers. In addition, a bibliography is provided which is relevant to the FIREMEN Program.

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