NAFEC TECHNICAL LETTER REPORT

NA-78-41-LR

PRELIMINARY ASSESSMENT OF THE INTEGRITY OF AIRCRAFT EVACUATION SLIDE MATERIAL WHEN EXPOSED TO THERMAL RADIATION

by

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June 1978

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ABSTRACT

As a consequence of the Continental DC-10 aircraft accident at Los Angeles International Airport (LAX) on March 1, 1978, which involved an extensive fuel spill fire and the subsequent loss of the evacuation slides, a cursory look at the potential fire failure modes of slide fabrics was initiated at NAFEC.

An evaluation of the thermal resistivity of aircraft evacuation slide materials was conducted employing laboratory and outdoor fire test procedures. Laboratory findings in the NBS Smoke Chamber were based upon both visual failure times and smoke density measurements of flat rectangular samples of slide material. Additional laboratory determinations were based on the depressurization times of short inflated samples of slide materials when exposed to known radiant heat flux levels. Outdoor tests were conducted by exposing a representative slide material to a free burning aviation fuel fire in both the pressurized and unpressurized modes. The experimental results include radiation and temperature data and visual observation of the behavior of the slide samples.

CONCLUSIONS

Based on the results of this cursory investigation, it is concluded that:

1. The low resistance of evacuation slide materials to radiant heat produced by a free-burning fuel fire can cause early deflation of the escape slides.

2. Failure of the yellow uncoated inflated slide sample occurred within 29 to 45 seconds when exposed at a distance of 9 feet upwind and to the sides of a free burning fuel fire where the heat flux varied from 0.95 to 2.07 Btu/ft^2 - sec.

3. Failure of the yellow uncoated inflated slide sample 18 feet downwind of the free burning fuel fire occurred in 17 seconds as a consequence of conductive and radiative heat flux caused by significant flame bending.

4. Good correlation was established between the failure time of the slide materials in the laboratory and outdoor fire exposure tests.

5. A significant improvement in the thermal resistance of a slide fabric was observed when the exposed surface was covered by a reflective coating of aluminum.

RECOMMENDATIONS

Based on this cursory investigation, it is recommended that:

1. A more detailed laboratory and full-scale testing program be conducted to collect adequate technical data for a possible rule change on the flammability and radiant heat resistance qualities of evacuation slides.

2. Consideration be given to coating the outsides of evacuation slides with a reflective coating to increase their thermal resistivity.

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INTRODUCTION

PURPOSE. The purpose of this quick response investigation was to develop laboratory and outdoor fire test data suitable for estimating the thermal resistance of aircraft evacuation slide materials to failure when exposed in the proximity of a free-burning aviation fuel fire.

BACKGROUND. Evacuation slides and slide/rafts are the principle means employed by deplaning passengers during an aircraft emergency. Therefore successful deployment and inflation of the slides is essential for their safe self evacuation. The 14 CFR 25.803, 25.809, 121.310, and 37.175 specify criteria for the design, manufacture, installation, and inspection of emergency evacuation slides.

On March 1, 1978, a Continental DC-10, Flight 603, was cleared for takeoff on Runway 6 Right at Los Angeles International Airport (LAX). The gross takeoff weight was 429, 700 pounds which included 18,000 gallons of Jet A fuel. There were 184 passengers and 14 crew members onboard.

Preliminary information indicated that during rollout two front tires failed on the left main landing gear which caused the takeoff to be aborted. The aircraft came to rest off the end of the runway slightly to the right of the centerline. The landing gear ruptured tanks one and two in the left wing and the fuel (9,000 gallons) poured onto the ground on the left side of the aircraft and ignited.

Before all of the passengers were able to evacuate, several of the slides failed. Of the 184 passengers onboard, 73 were injured and two died as a result of the fire.

The above accident prompted NAFEC to conduct this preliminary investigation of the resistance of slide materials to radiant heat.

DISCUSSION

LABORATORY EXPERIMENTS. The NAFEC modified NBS Smoke Chamber (Figure 1) was used to assess the resistivity of slide fabrics to thermal radiation. In the initial stages of this evaluation the smoke densitometer provided an indication of material decomposition and the onset of failure.

Initial testing of slide fabrics was performed in the less severe non-pressurized mode to roughly establish the radiation levels that would produce failure. Subsequently, pressurized tests were performed on small cylindrical samples to more precisely and realistically establish the radiation levels required to cause failure for each material. Finally, a full-size tube section was inflated and exposed to radiant heat to establish the validity of the small-scale pressurized fabric cylinder test results.

Six types of slide samples were tested (Table 1). Four of these were obtained from the American Safety Equipment Corporation of Miami, Florida. The fifth and sixth samples tested were obtained from a surplus Boeing 707 slide manufactured by the Garrett Corporation, Air Cruisers Division. This slide had a reflective aluminum coating on the outside of the tubular sections and the more typical (uncoated) yellow surface on the inside of the tubes, thus providing both a reflective and nonreflecting surface sample for experimentation.

All material samples were tested in the NBS Smoke Chamber in accordance with the standard procedure (Reference 1). The test schedule is summarized in Table 2 and indicates the sample exposure time at four radiation levels for each of 24 experiments.

The subjective failure time for each sample is plotted as a function of the radiant heat flux in figure 2. The criteria for failure comprised any warping, hole development or discoloration of the sample or when there was an arbitrary 6-percent reduction in light transmission due to smoke generation. Based upon these observations, five samples failed in less than 90 seconds when exposed to 1.5 Btu/ft^2-sec. However, the aluminum coated fabric showed no appearance of failure under these conditions. A visual indication of the failure mode of each individual sample is presented in figure 3.

In a second series of experiments, the slide fabrics were exposed to thermal radiation in the pressurized mode to determine the significance of stress on failure time and to provide a more definitive means of measuring failure through a loss of pressure. For these tests the fabric was rolled into 3-inch-diameter tubes approximately 7 inches in length and sealed. This tube size was optimum for total thermal exposure in the NBS Smoke Chamber. End caps for the tube were fabricated from 0.5-inch-thick aluminum stock and provided with an air line and pressure transducer. The prefabricated tubes were then slid over the end caps and clamped.

To impose equal tensile stress on the fabric in the small tube section (3 inch diameter) as that produced in the fully extended slide (18 inch diameter) pressurized between 2 to 3 pounds per square inch guage (psig), it was necessary to overpressure the small tubes to 10 psig (reference 2). The yellow tube fabric materials were exposed to 1.0, 1.3, and 1.5 Btu/ft^2-sec and the aluminum neoprene coated fabric to 1.5, 2.0, 2.25, and 2.5 Btu/ft^2-sec.

The time from thermal exposure to fabric failure, indicated by a loss in pressure, was well defined by the pressure transducer data in these experiments. The profiles presented in figure 4 show fabric failure time as a function of heat flux. The yellow fabrics consistently failed earlier in the pressurized mode when exposed to 1.5 Btu/ft^2-sec than did the flat samples. Conversely, at 1.0 Btu/ft^2-sec, longer failure times were obtained under pressure, for the two fabrics obtained from American Safety Equipment Corporation, than in the flat sample tests. Although these two materials charred slightly and emitted smoke (criteria for flat sample test failure), they continued to maintain the required tube pressure. While all three yellow fabrics exhibited failure times of less than 45 seconds when exposed to 1.5 Btu/ft^2-sec, the aluminum neoprene coated fabric still had not failed after 20 minutes of exposure to the same heat flux. Here again the pressurized fabric tube experiments indicated a higher thermal resistivity over that originally indicated by the flat sample tests.

A final series of experiments was conducted on tubular sections taken from the surplus Boeing 707 slide. Experiments were conducted on both the uncoated (yellow) and the aluminum neoprene coated fabric.

The objective of these tests was to obtain information suitable for determining the validity of the fabric failure time data developed using the overpressurized 3-inch-diameter tubular sections. The 18-inch-diameter by 20-inch-long tubular sections were capped, sealed, and pressurized to 2 psig. The time to fabric failure was determined at the same heat flux levels as those employed with the 3-inch-diameter sections. In general fabric failure times were somewhat longer in the full-size tests than those obtained in the small-scale tests when exposed to the same heat flux.

The fabric failure times obtained for both the 3-inch and 18-inch-diameter tubular specimens are presented as a function of radiant heat flux in figure 4. A comparison of these data indicate that the failure times for the yellow fabric materials varied from 20 seconds at 1.5 Btu/ft^2-sec to 180 seconds at 1.0 Btu/ft^2-sec. The aluminum neoprene coated fabric in the 18-inch-diameter tube tests failed in 15 seconds at 2.5 Btu/ft^2-sec and in 210 seconds when exposed at 2.25 Btu/ft^2-sec, which demonstrates a significant improvement in thermal resistivity over the uncoated fabric.

<u>OUTDOOR POOL FIRE TESTS.</u> The most important factors relating fires and evacuating aircraft passengers were considered to be: area of fire spread, time to achieve maximum burning rate, wind velocity, orientation of the evacuation slide in terms of wind direction (upwind, downwind, etc.) and distance from the edge of the fire pool perimeter.

The paucity of data in the literature concerning the thermal resistivity of aircraft evacuation slide materials when exposed under free burning pool fire conditions required a preliminary assessment to be made in order to establish the optimum test bed configuration. Based upon previous experimental work conducted at NAFEC (reference 3) concerning radiation levels from outdoor fuel fires, a series of profiles was constructed to provide a data base for establishing the fire size and the optimum distribution of the fabric samples around the fire pit. Figure 5 presents a series of profiles for fires of Jet A fuel floating on water of 6, 12, and 18 feet in diameter showing heat flux as a function of distance from the pool under several ambient wind conditions.

From these data two experimental test bed configurations were developed for this series, both of which employed water base Jet A fuel fires as the heat source. The first test was designed to expose flat samples of evacuation slide material around a 20-foot-square fire, while in the second test the same fabric was exposed in the pressurized mode around a similar fire pool.

The fire test bed configuration employed in the first experiment is shown schematically in figure 6. The principle objective of this experiment was to validate the adequacy of the distance of the test samples from the pool perimeter, in all directions and to observe the general failure mode of the fabric. The test samples were cut from two different sections of the Boeing 707 evacuation slide (Garrett Corporation) and mounted on 9- by 14-inch-rectangular steel frames and positioned around the 20-foot-square pit as indicated in figure 7. Although all of the fabric samples appeared identical in texture and thickness, the ones removed from the support tube were positioned 9 feet from the rim of the fire and those taken from the side rails, at 15 feet from the pit. One additional sample was positioned 20 feet from the side of the fire and approximately perpendicular to the wind direction.

The thermal resistivity of these flat samples was estimated by continuous observation through high-powered binoculars. A summary of the data developed by this means is presented in table 3. From these data, it is apparent that the most severe thermal conditions occurred downwind of the fire and the least destructive on the upwind side of the pit. Fabric samples exposed on the sides of the fire pit at right angles to the wind direction failed somewhere between these extremes.

All of the test samples exposed 9 feet from the perimeter of the pit failed by developing holes and splits within 85 seconds after fuel ignition. While those samples exposed 15 feet from the sides and upwind of the fire showed visual evidence of smoke and/or vapor within 90 seconds. However the samples positioned 9-feet and 15 feet downwind of the fire were completely consumed within 20 seconds after fuel ignition. Therefore, these data tend to confirm the 9- and 15-foot positions of the test samples from the fire perimeter as being adequate to assess their thermal resistivity.

Based upon the data derived from the first experiment, a second test article was developed for exposing the slide fabric under an internal pressure of 2.5 psig to an equivalent heat flux. This pressurized mode for evaluating the thermal resistivity of slide materials more closely approximates the environmental exposure conditions encountered in aircraft accidents involving fire. The prototype unit comprised a 12- by 15-inch steel pail with an 8.75 by 17.0-inch (148.75 square inches) opening cut in the side. The fabric sample was placed over the opening from the inside and hermetically sealed with mastic and bolted in place with metal straps on both sides.

To monitor the failure time of the slide material during thermal exposure a manometer was constructed in the end of each unit and filled with mercury (Figure 8) in which was floated an aluminum rod painted red. When the unit was pressurized to 2.5 psig the red tip of the rod was exposed approximately 2.5 inches. However, when fabric failure occurred the rod disappeared from view within the manometer tube. During the fire test this action was viewed and the fabric failure time determined by personnel strategically positioned around the fire pit employing high powered binoculars.

The aircraft passenger evacuation slide from which the test samples were cut was the same as that employed in the 3- and 18-inch-diameter tubular sections used in the laboratory experiments. Since this fabric had an aluminum neoprene reflective coating on the outside and an uncoated surface on the inside it was expedient to assess the thermal resistivity of both material surfaces simultaneously. Accordingly, the test configuration shown in Figure 9 was developed.

Directly beneath each of these pressurized units, flat samples of the same materials were exposed on 9 by 14-inch steel frames.

The instrumentation employed to monitor the progress of fire exposure upon the test articles was limited, but included four radiometers and thermocouples distributed around the fire pit as indicated in figure 10 to detect any changes in the environmental air temperature caused by sudden or drastic changes in the wind direction. Thermocouples were also installed inside the test fixture displaying the yellow fabric at stations T3 and T7, adjacent to the fire pit and perpendicular to the wind direction.

The test was performed by placing 450 gallons of Jet A fuel in the fire pit and permitting it to burn freely for a period of 230 seconds after which it was extinguished by foam. The fabric failure times resulting from this exposure are presented in figure 10 and were derived from the instrumentation data and by visual observation. These data indicate that at a distance of 9 feet from the pool perimeter the heat flux varied from 0.95 to 2.07 Btu/ft^2-sec at the sides and upwind of the fire causing the yellow fabric to fail within 29 to 45 seconds. The thermocouples inside the test articles at stations T3 and T7 showed an average internal temperature rise of approximately 36°F above the external ambient temperature (68°F) at the instant of failure. This moderate rise in temperature is not considered to have materially contributed to the failure time of the samples.

In contrast, the test article exposing the aluminum neoprene-coated fabric at the sides of the fire pit adjacent to the yellow fabric samples (figure 11) failed at 155 seconds and 220 seconds with corresponding heat flux levels of 1.8 and 2.07 Btu/ft^2-sec, respectively. Therefore, these data clearly demonstrate the superior thermal resistivity provided by the aluminum neoprene coating on the fabric surface.

Failure of the yellow fabric sample exposed 18 feet from the downwind side of the fire occurred within 17 seconds (1.3 Btu/ft^2-sec) after fuel ignition which was 13 seconds before the fire reached equilibrium burning conditions. This short failure time resulted from both conductive and radiative heating of the fabric sample as a consequence of significant flame bending caused by the prevailing wind conditions. From an analysis of all of the thermocouple data, it is apparent that the wind direction was perpendicular to the upwind edge of the fire pit throughout the burning cycle.

The work described herein was undertaken under in-house project 975-420-002, Flammable Characteristics of Inservice Materials, with verbal concurrence from AFS-100 and ARD-500. The authors of this letter report are George B. Geyer, Louis J. Brown, Lawrence M. Neri, and John H. O'Neill. Mr. George B. Geyer is the NAFEC Project Manager and may be contacted at (609) 641-8200, extension 2645, for further information.

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1. D. Gross, J. J. Loftus, and A. F. Robertson Method for Measuring Smoke From Burning Materials ASTM Special Technical Publication No. 422 (1967)

2. S. Timashenko, Gleason H. MacCullough Elements of Strength of Materials D. Van Nostrand Co., Inc., New York

3. G. Geyer, Evaluation of Aircraft Ground Firefighting Agents, and Techniques, AGFSRS 71-1 (1972)

TABLE 1. IDENTIFICATION OF EVACUATION SLIDE MATERIAL

Material Identification Number	Material/Composition	Nominal Weight (oz/yd^2)	Application
A. American Safety Equipment Corporation			
505-2	Hypalon-Coated Nylon Fabric	12.5	Slide Floor Fabric, Older LSR Series, 727, 707
502-12	2-Ply, Neoprene-Coated Nylon Fabric	8.4	Slide Tube Fabric, Older LSR Series, 727, 707
502-36	1-Ply, Neoprene-Coated Dacron Fabric	7.5	Slide Floor Fabric, Newer D-4000 Series, 727, 737
502-39	2-Ply, Neoprene-Coated Nylon Fabric	8.4	Slide Tube Fabric, Newer D-4000 Series, 727, 737
B. The Garrett Corporation			
M-11297	Urethane-Coated Nylon Fabirc	7.4	Slide Tube Fabric, Yellow (Inside) Type 88, 707, 720
M-11297/M-11105	Urethane-Coated Nylon Fabric with Aluminum Neoprene Paint	8.7	Slide Tube Fabric (Outside) Type 88, 707, 720

TABLE 2. NBS SMOKE CHAMBER EVACUATION SLIDE FLAT SAMPLE TEST SCHEDULE

Radiant Heat Flux Btu/ft^2-sec	Sample Identification Number Exposure Time (minutes)					
2.0	A4 2.5	B4 2.5	C4 2.0	D4 2.0	E4 1.5	F4 1.5
1.5	A3 3.0	B3 3.0	C3 3.0	D3 3.0	E3 3.0	F3 3.0
1.0	A2 5.0	B2 5.0	C2 5.0	D2 5.0	E2 5.0	F2 10.0
0.5	A1 10.0	B1 10.0	C1 10.0	D1 10.0	E1 10.0	F1 10.0
	B707 aluminized tube	B707 yellow tube	Older B727, B707 tube	Newer B727, B737 tube	Newer B727, B737 floor	Older B 727, B707 floor
	Surplus B707 Slide		American Safety Equipment Corp.			

TABLE 3. SUMMARY OF THE OUTDOOR FIRE FLAT RECTANGULAR SAMPLE

Material Sample	Location	Distance from Fire ft.	Time To Equilibrium Burning Conditions sec	Failure Mode: Burn Through Time sec	Failure Mode: Vapor/ Smoke Time sec	Remarks
T1	Side-Left	9	20	35	--	Some Carbonizing, Numerous Holes
T2	Down Wind			20	--	Complete Destruction
T3	Side-Right			55	--	Holes and Splits
T4	Up Wind			85	--	Large Holes and Splits
T5	Side-Right	20		--	--	No Visible Damage
R1	Side-Left	15		--	50	No Visible Damage
R2	Down Wind			20	--	Complete Destruction
R3	Side-Right			--	60	No Visible Damage
R4	Up Wind			--	90	No Visible Damage

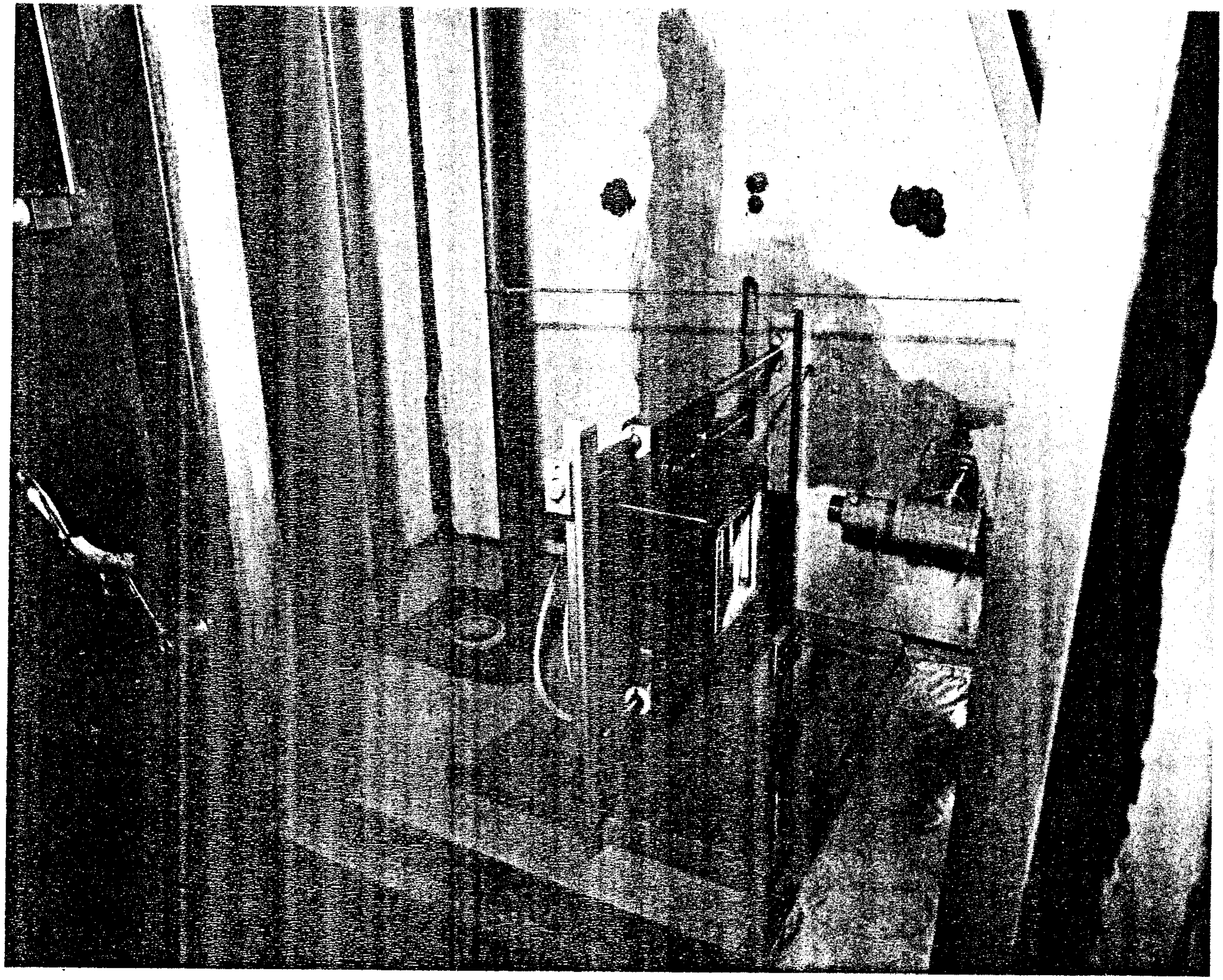

FIGURE 1 INTERIOR VIEW OF THE NAFEC MODIFIED NBS SMOKE CHAMBER

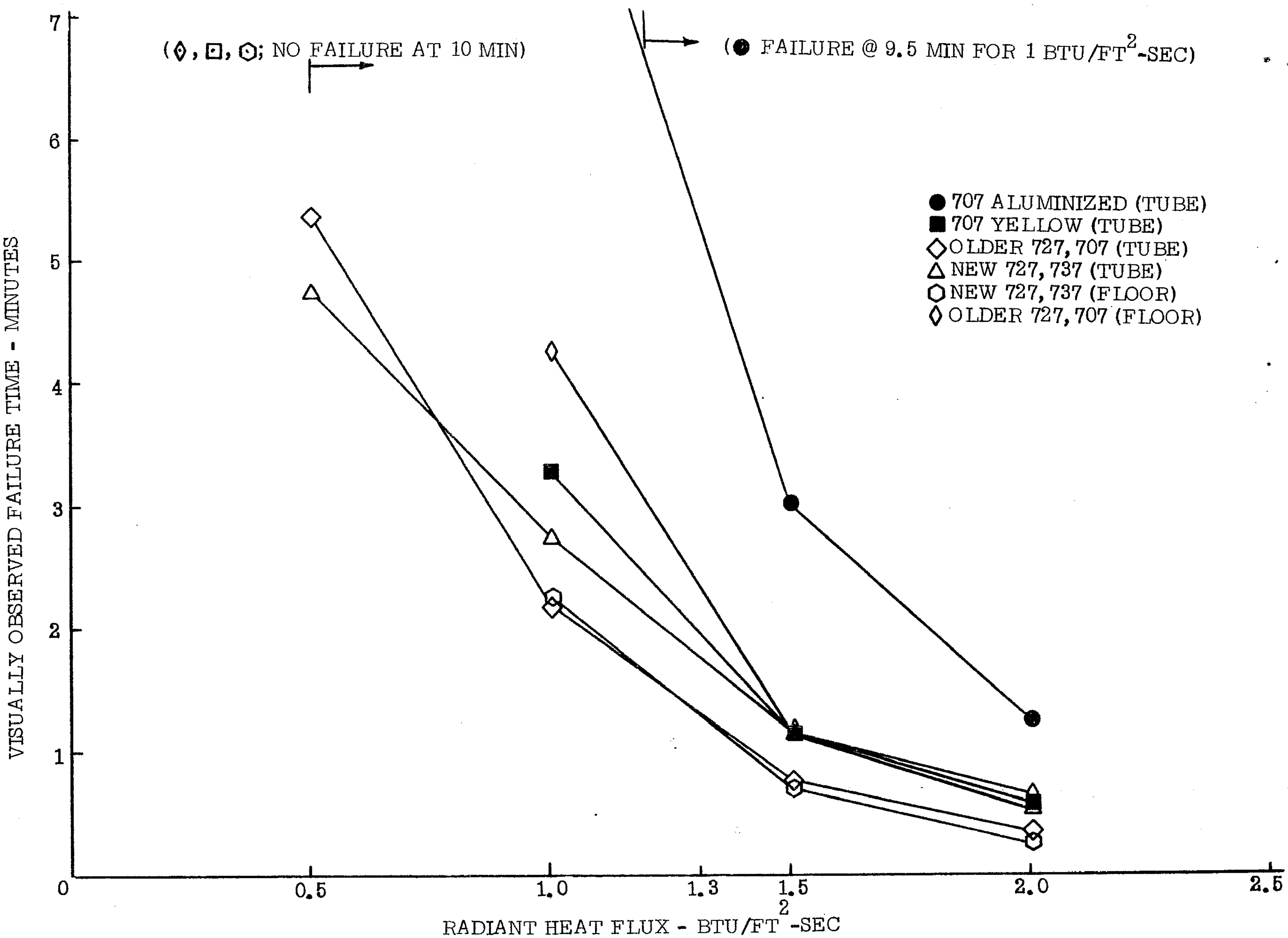

FIGURE 2 NBS SMOKE CHAMBER FLAT SAMPLE TEST DATA

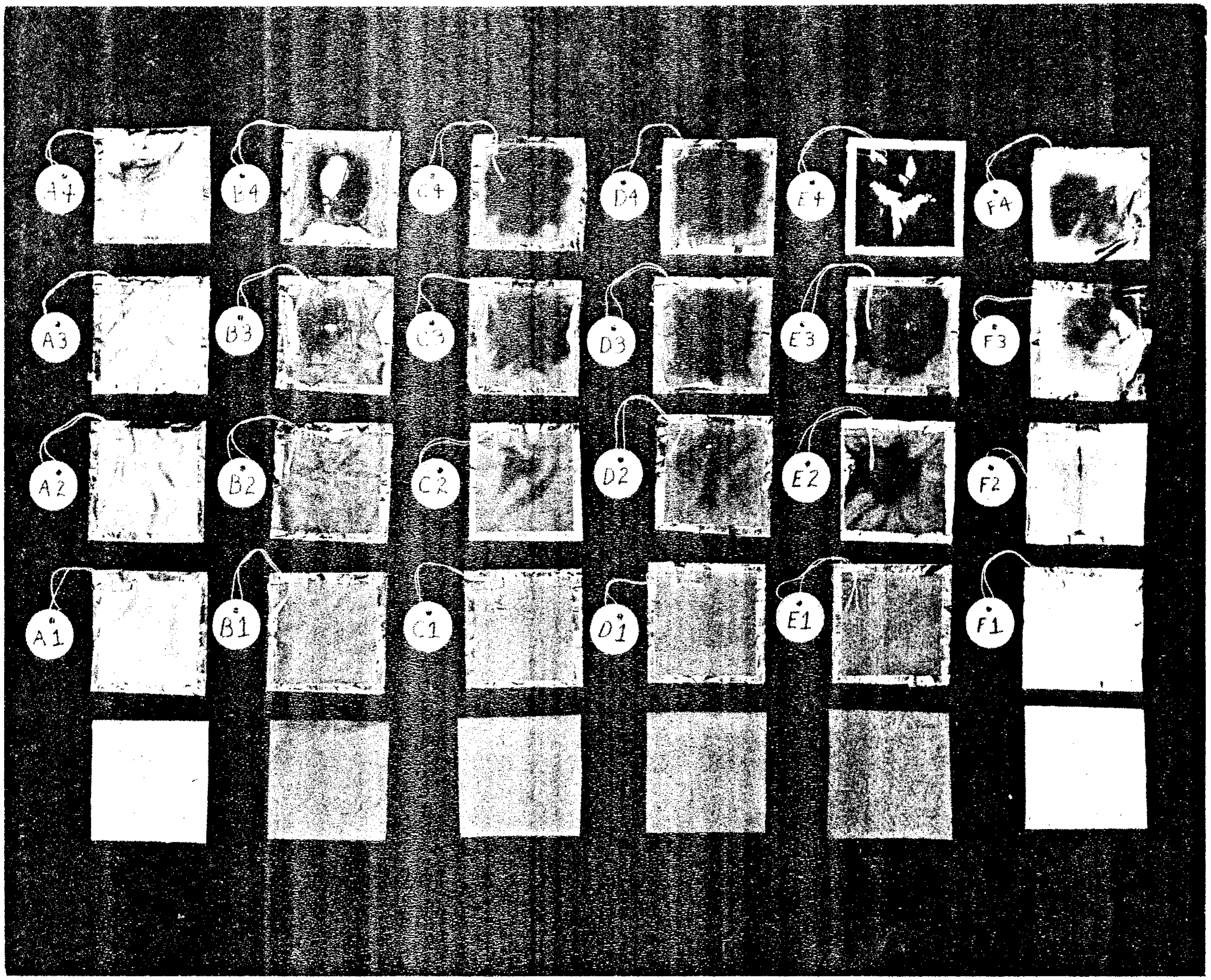

FIGURE 3 FAILURE MODES OF THE FLAT SLIDE SAMPLES IN THE NBS SMOKE CHAMBER

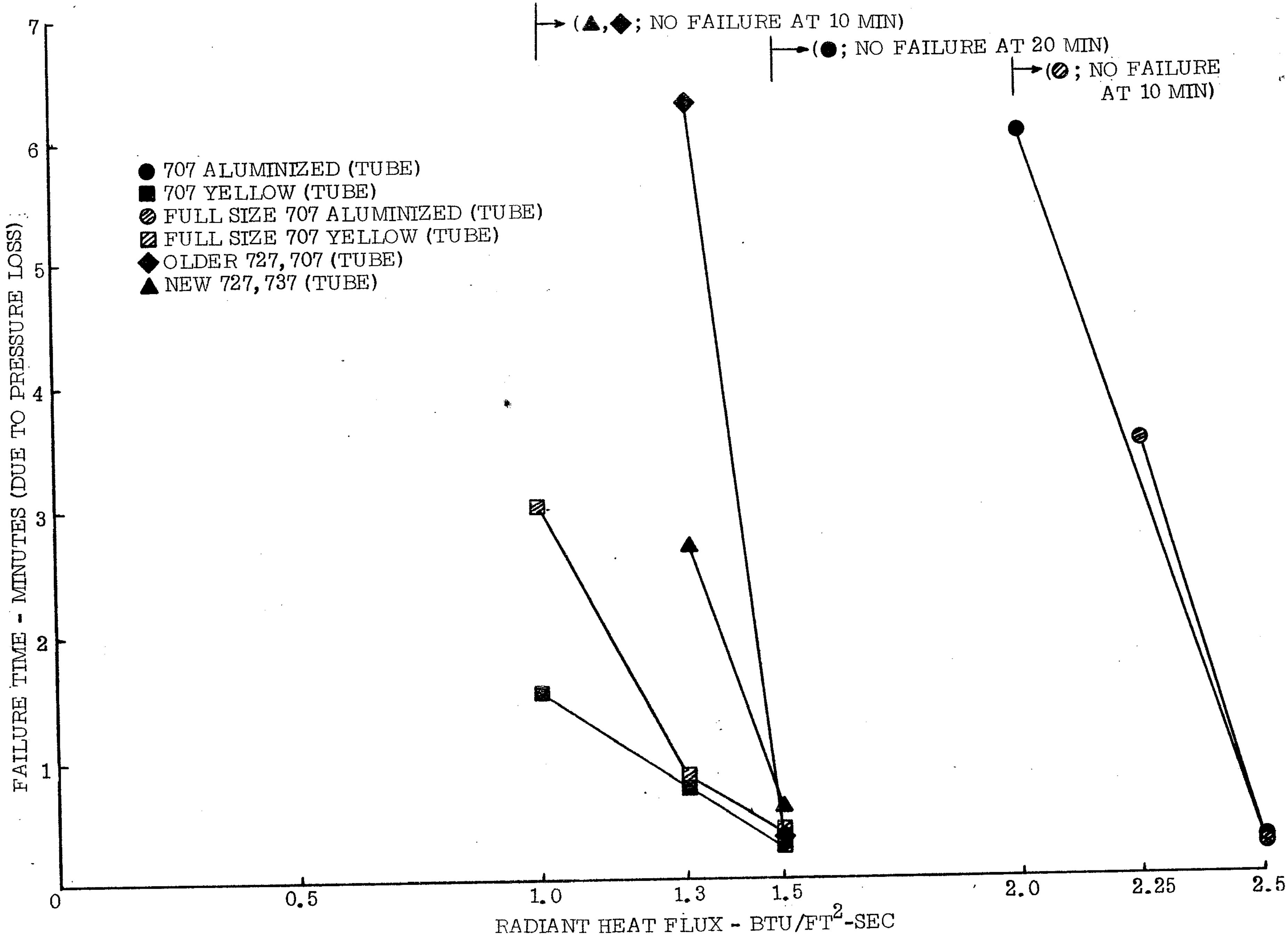

FIGURE 4 PRESSURIZED TUBULAR FABRIC FAILURE TIMES AS A FUNCTION OF THE RADIANT HEAT FLUX

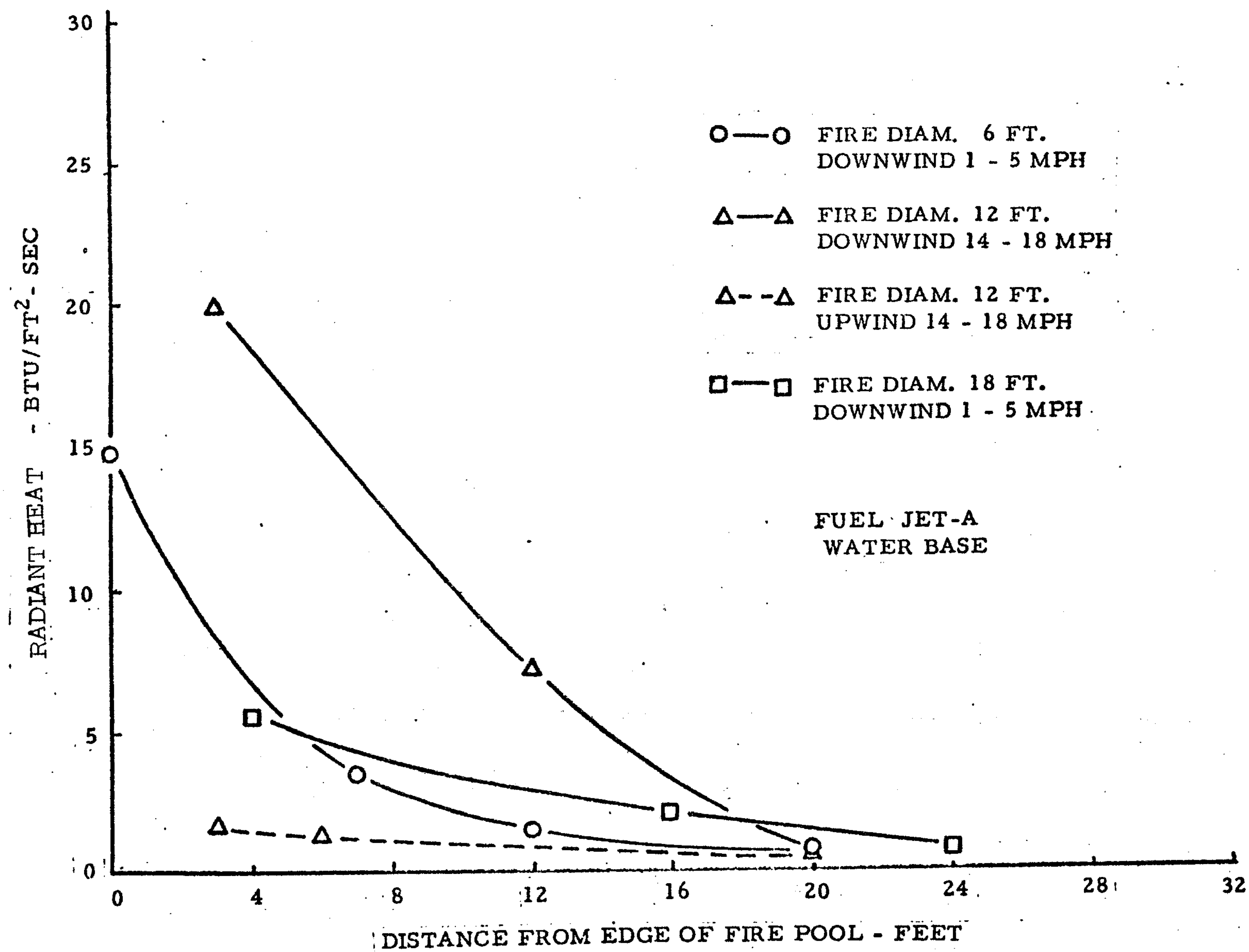

FIGURE 5 HEAT FLUX AS A FUNCTION OF WIND VELOCITY AND DISTANCE FROM FIRE PERIMETER

FIGURE 7 FIRE TEST PIT PRIOR TO FUEL IGNITION

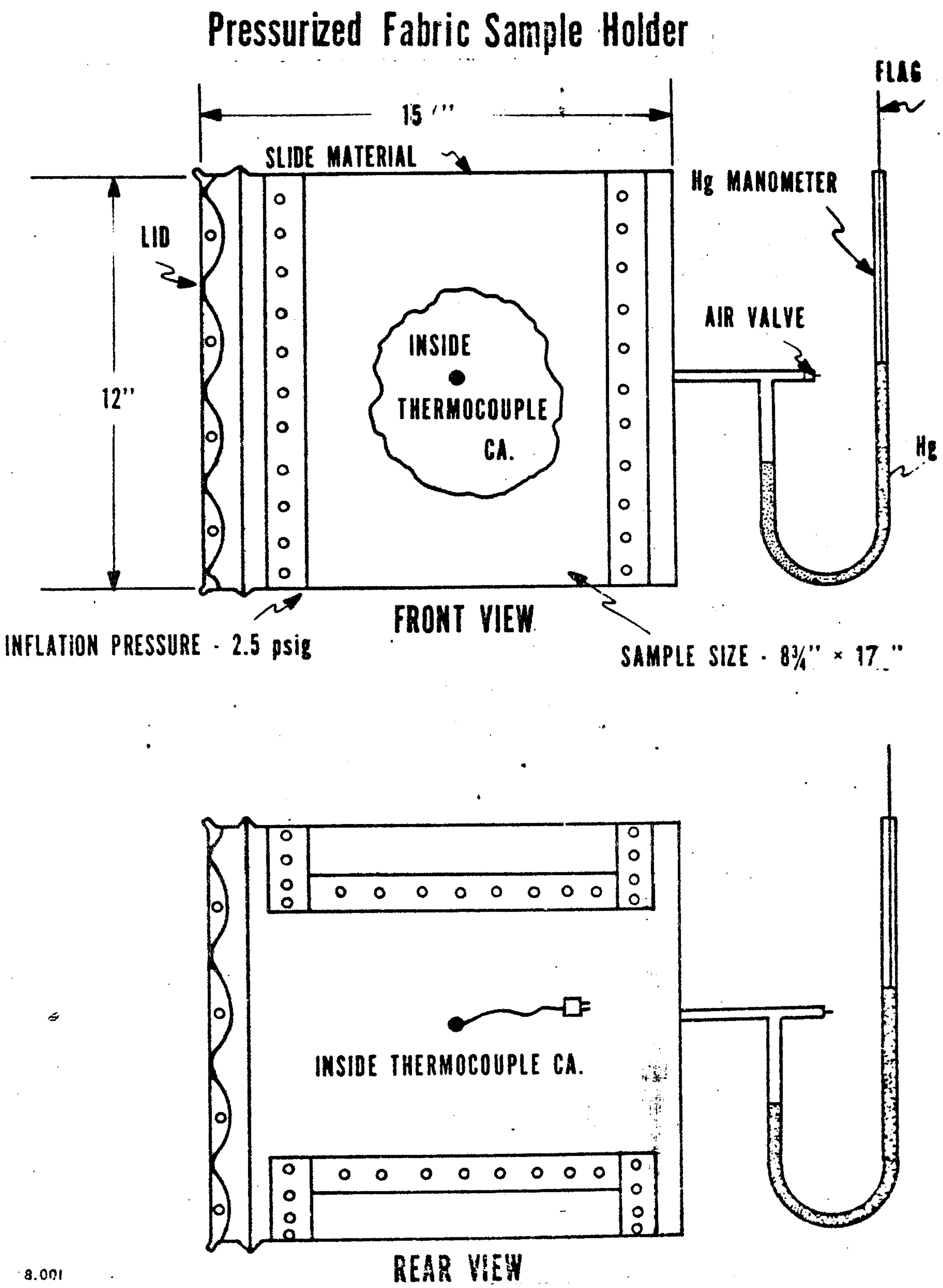

FIGURE 8 CONFIGURATION FOR DETERMINING THE THERMAL RESISTIVITY OF SLIDE FABRICS UNDER PRESSURE

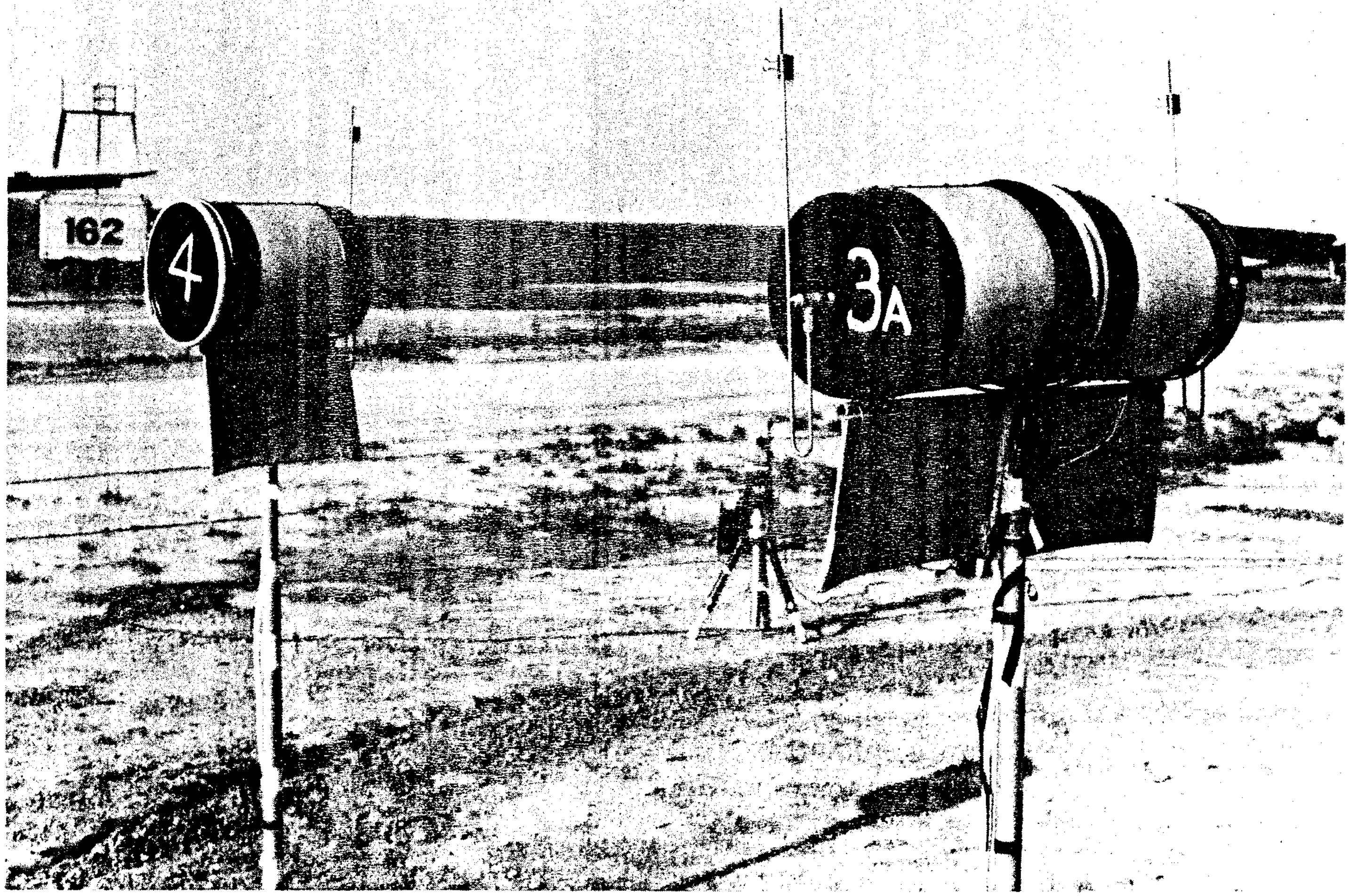

FIGURE 9 CONFIGURATION EMPLOYED TO EXPOSE SLIDE FABRICS IN THE PRESSURIZED AND UNPRESSURIZED MODES TO RADIATION

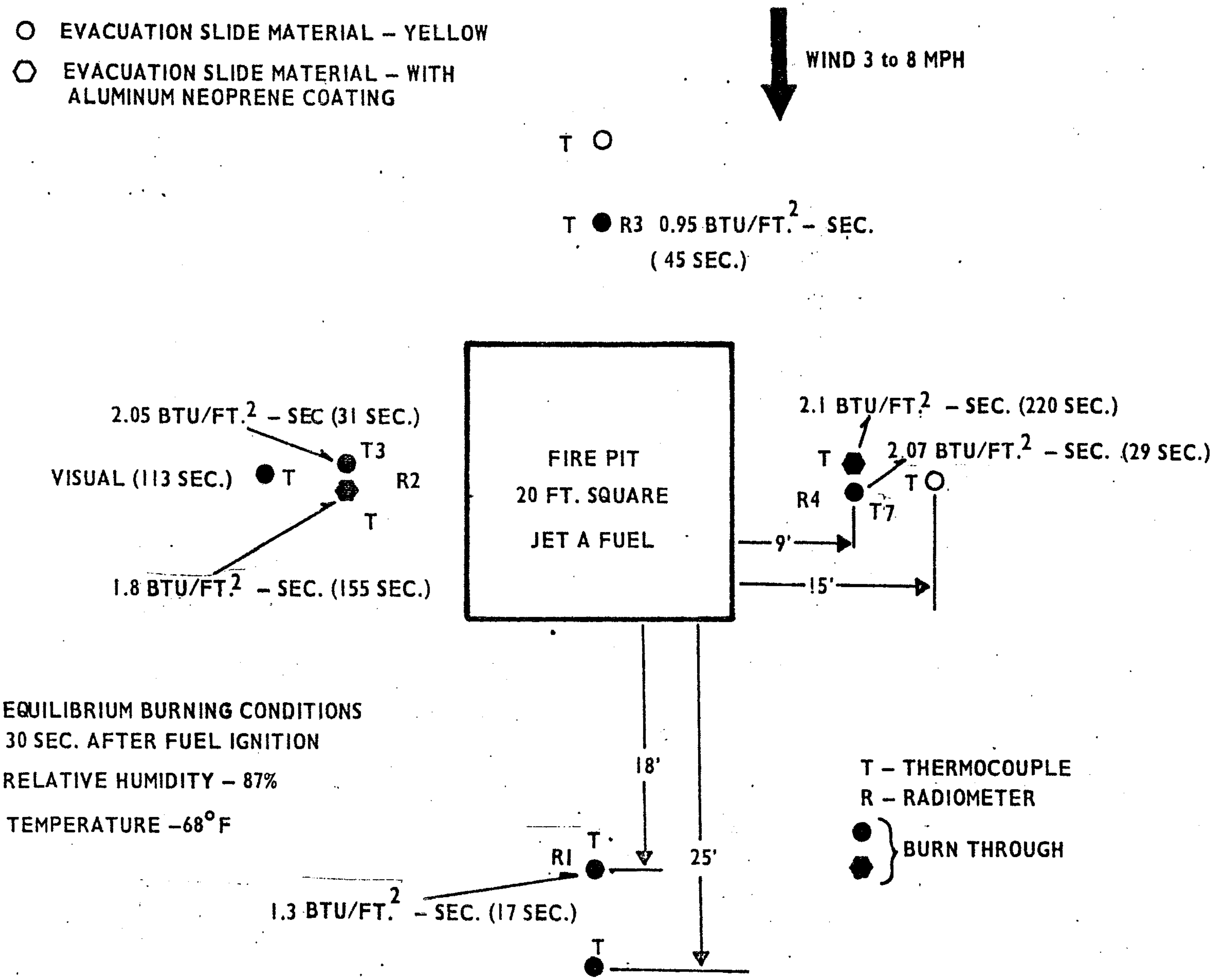

FIGURE 10 TEST BED CONFIGURATION FOR EXPOSING FLAT RECTANGULAR AND PRESSURIZED SAMPLES OF SLIDE FABRICS TO THERMAL RADIATION

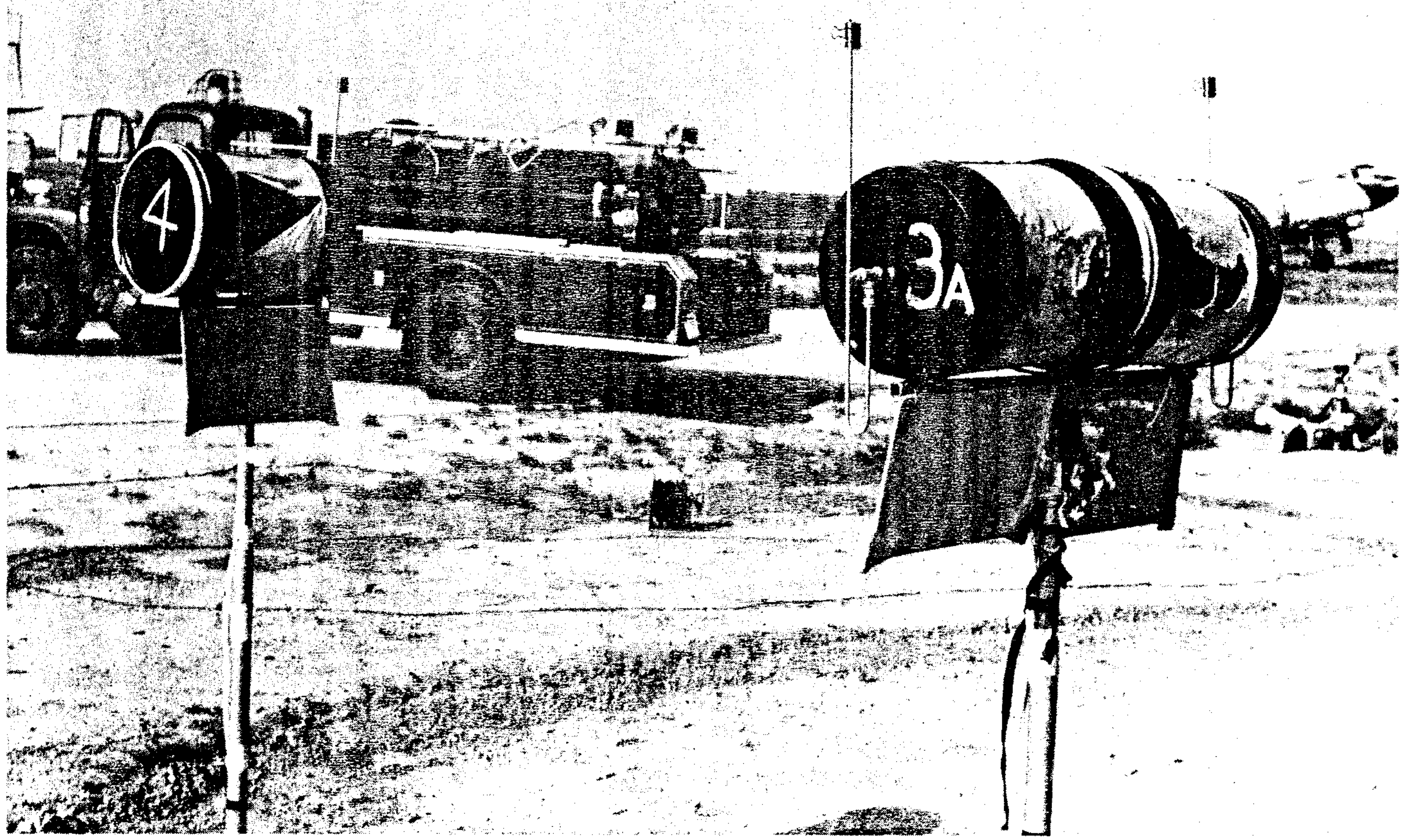

FIGURE 11 THERMAL DAMAGE CAUSED TO SLIDE FABRIC SAMPLES AFTER FIRE EXPOSURE

APPENDIX A

NA-78-41-LR

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