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AIR TRANSPORT CABIN MOCKUP FIRE EXPERIMENTS

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16. Abstract
A study was made of the burning characteristics of airplane interior materials ignited inside a 640-cubic-foot cabin mockup enclosure. Test conditions were varied to investigate the effects of a number of factors on the ignition and propagation of flames within enclosures; namely, (1) flammability ratings of the materials as obtained from standard laboratory tests, (2) intensity, duration and type of the ignition source whether flaming or incandescent, (3) ventilation rate as provided by different size openings into the cabin enclosure, (4) partitioning of the cabin space by use of a fire barrier curtain, and (5) discharge of bromotrifluoromethane (CF_3Br) into the cabin atmosphere, both at different rates and total quantities of application before and during a fire occurrence. Comparative tests conducted on flame-retardant (FR) urethane and neoprene foams showed that the flash-fire hazard prevalent with the use of regular foam could be greatly reduced by replacement with these two self-extinguishing foams. A high-rate discharge system employing CF_3Br(1301) was shown to be effective in rapidly extinguishing the flames of a foam fire. A curtain divider placed across the ceiling was shown to be useful as a fire barrier to arrest flame propagation. Roof venting of the mockup at a location away from the fire was relatively ineffective in preventing rapid buildup of smoke and flame spread from a flash fire involving urethane foam.

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INTRODUCTION

Purpose

The purpose of this project was to study and test a wide variety and combinations of aircraft interior plastics and synthetic materials for flammability, smoke, and toxic gas characteristics leading to the implementation of tests, procedures, and criteria for improved airworthiness standards.

Background

The cabin fire studies covered by this report are part of a continuing project effort since 1963, to investigate the possible fire, smoke, and toxic gas hazards that may jeopardize passenger safety in aviation because of the use of various combustible interior cabin furnishings and construction materials. From its inception, the overall program has emphasized the conduct of laboratory scale tests on numerous and representative cabin materials with the objective of establishing a technical basis for new design criteria and improved performance standards. In contrast, the work described herein is concerned with large-scale tests on selected materials considered to be most critical to fire safety, in partiular seat upholstery and foam padding. An attempt was made to evaluate the effects on fire growth and extinguishment of different modes of ignition under various cabin physical and environmental conditions and, to the extent possible, relate the results to those obtained from laboratory scale testing. Accordingly, the goals of the investigation were to establish criteria for assessing the degree of fire hazards under more diverse and realistic conditions than those represented by the standard laboratory fire tests. Materials selected for study constituted those considered more critical in view of their relative abundance in cabin interiors and greater combustibility.

As an aftermath of the Salt Lake City Boeing 727 crash-fire accident in November of 1965, followed shortly by the Apollo disaster, attention became focused on possible deficiencies in materials and a need for better means of fire control and evacuation. Test programs to study the various aspects of air transport fires in order to either minimize or better combat the dangers were greatly accelerated and given very high priority. The Federal Aviation Administration (FAA) and the larger airframe manufacturers undertook extensive studies aimed at encouraging the development of new materials and techniques needed to substantiate improved standards to insure greater safety in the event of another crash fire (Reference 1). Crashworthiness task groups were formed in 1966, within FAA and among airframe manufacturers represented by the Aerospace Industries Association (AIA), to coordinate R & D activities. Results of industry's effort with recommendations for improvements in crashworthiness concepts were presented to FAA in July of 1968 in a series of reports. The results of this very broad and comprehensive test program most directly concerned with, and of particular interest to, the work conducted here are contained in Report AIA CDP-2, titled, "Fire Suppression, Smoke and Fume Protection," (Reference 2). The AIA tests were conducted on 8-foot, 15-foot, and 40-foot mockups of typical furnished fuselage sections. These tests were much more extensive in scope than the effort covered in the present study which was limited to fires originating entirely within the cabin materials. Included in the AIA study were tests with the fire originating outside the cabin with the fuel fire spreading to the inside of the cabin to involve the interior materials through a simulated break or opening in the fuselage. Under this program, cabin fire extinguishment tests were also conducted as part of the overall study of the problem. In addition to the use of bromotrifluoromethane (CF_3Br) as an extinguishing agent, tests were also conducted to evaluate the effectiveness of water spray and high-expansion foam as alternate systems for cabin fire protection.

A more fundamental study of the phenomena of fire initiation and propagation in cabins is being conducted by the National Bureau of Standards (NBS) for the FAA (Reference 3). Two small model enclosures, one measuring 20 inches square by 24 inches in length and the other 24 inches square by 192 inches in length have been employed in this test program. This work is presently being continued with more advanced type of model aircraft cabins. The use of relatively small enclosures as models to predict the behavior of full-scale fires has been the object of considerable research in recent years (References 4, 5, and 6). Because of the relatively large effort and costs necessitated by full-scale fire testing of aircraft fuselages, this type of activity becomes either completely prohibitive or restricted to a "one-shot affair" as in the past when suitable surplus aircraft were made available (Reference 7). Model or small-size enclosure fire tests, although limited by the present state of technology, have the advantage of providing practical means for conducting a series of tests where any one parameter can be selected for study and varied independently to evaluate its effect on the fire. This approach was used in this investigation.

Fire Testing

The fire problem is seen to differ in kind from the typical engineering problem, in that by nature it is primarily experimental and as such not amenable to theorectical or even empirical solutions with the present state of technology.

Thus, the lack of suitable analytical means to attack the problem from known parameters makes it difficult to generalize on the phenomena with any degree of confidence. This has led to considerable controversy over the importance and relation between the many factors that govern the initiation, growth, and extinguishment of an actual fire. This situation is aggravated by the difficulty of controlling the test conditions so as to be able to obtain sufficient reliable data by which to analyze the fire problem and make valid projections for engineering specifications.

DISCUSSION

Instrumentation

Fire tests were conducted in a trailer compartment approximately 6-foot square by 17 feet in length with a volume of approximately 640 cubic feet as shown in Figure 1. The interior of the housing was insulated by 2-inch-thick blankets constructed of high-temperature refractory fibers with a melting point above 2000°F. The interior lining consisted of a standard aircraft headliner glass fabric, but without the vinyl exterior coating. Thus, neither the lining nor the insulation contained any combustible coatings or binders.

The fuel load, interior surfaces, and cabin air temperatures were continuously recorded by 24 Chromel-Alumel Thermocouples Gage No. 26 AWG. One radiometer was employed to measure total heat flux on the end wall opposite the fire. Smoke density measurements at two separate locations over an optical path of 1 foot using a photocell arrangement were continuously recorded. The terminology of smoke density, as generally understood and used in this report, refers to the obscuration of a light source viewed by a transducer with response similar to the human eye. Oxygen deficiency, combustibles, carbon monoxide and carbon dioxide present in the cabin at the two smoke sampling points were also continuously recorded. A paramagnetic type of detector was used to obtain oxygen readings. Combustibles were measured from the heating value of the gases in terms of carbon monoxide percent. An infrared type of detector was used to obtain the carbon monoxide and carbon dioxide readings. Indications of other toxic gases were obtained by periodic sampling with commercial colorimetric detector tubes at one ceiling location. Locations of the instrumentation sensors and sampling points within the cabin enclosure are shown in Figure 1.

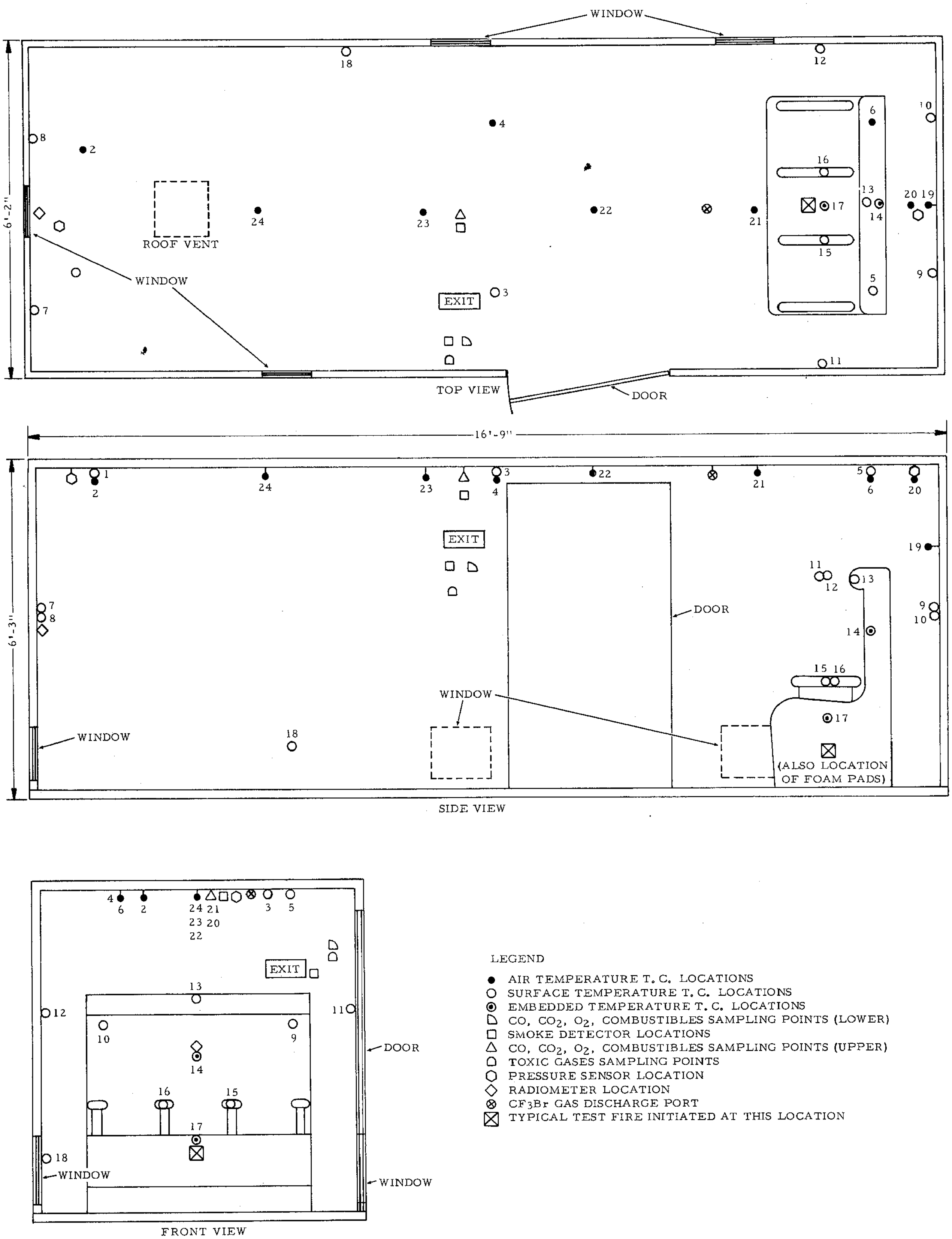

FIG. 1 CABIN MOCKUP SCHEMATIC AND INSTRUMENTATION

Test Procedures

A listing of the fire tests with a brief description of the test conditions, pertinent data values, and summary of test results are given in Table 1. Ceiling air temperatures recorded in the table and plotted in the curves as most typical of 10 other ceiling locations were taken at the center of the cabin mockup 3 inches below the ceiling. Also, reported in Table 1 are maximum cabin temperatures obtained by 19 thermocouples on or near the ceiling and sidewalls. A total of 28 tests was conducted. These are divided into seven general categories consisting of the following: (1) seat fire tests, (2) foam pad fire tests within an enclosure, (3) foam pad fire tests outdoors, (4) interior materials fire tests, (5) cabin partitioning fire tests, (6) cabin venting fire tests, and (7) fire extinguishing tests. Except for Test No. 8 on drapery, all the fire tests utilized either complete seat assemblies or various types of seat foam as a fuel load placed at the front end of the cabin mockup as shown in Figure 1. Fires were initiated by employing several different modes of ignition sources of varying intensities consisting of both open flaming and incandescent heating. For the open flaming type of ignition, a propane-fed Bunsen burner was used with flame height adjustable from 3 to 10 inches. The flames were applied on the bottom side of the fuel load, and the burner extinguished after 30 to 60 seconds or after a self-sustaining fire was obtained. For the chemical fire, a 40-ounce mixture of hexamethylenamine, potassium chlorate, and gunpowder primer was ignited by a heated wire to produce very intense bright flames several feet in height. The chemicals were burned on the upper surface of the foam pads. An incandescent calrod heater connected either to a 110-volt or 220-volt supply was used as an alternate ignition source to open flaming. The heated calrod was placed on top of the foam pads, except for Test No. 22, when it was placed instead between two foam pads.

In tests investigating the destructive effect of flash fires caused by the burning of urethane foam pads, interior materials were suspended both horizontally and vertically down from the ceiling. The thermal degradation of the more typical materials in the cabin was checked against that obtained in an electrical furnace for comparison. Destruction of the materials was judged from the degree of melting and charring observed.

In tests conducted to determine the effect of partitioning the cabin space on the propagation of flash fire, an asbestos curtain was suspended from the ceiling and across the entire

TABLE 1. — DATA SUMMARY OF CABIN MOCKUP FIRE TESTS

Test No.	Type of Fire Test	Environment	Fuel Load	Ignition Source Type	Ignition Source Time (min)	Ceiling Temp. (°F)	Temp. (Max.) (°F)	Smoke Density (Max.) (%)	Oxygen (Min.) (%)	Carbon Monoxide (Max.) (%)	Combus-tibles (Max.) (%)(1)	Radiant Heat (Max.) Btu/ft-2s	Other Toxic Gases (ppm)	Remarks
1	Passenger Seat	Closed Cabin	Triple Seat with Conventional Materials (wool)	Propane/Air Burner	0.5	1070	1600	100	1.0	+1.5 0.5%/26.0 min 1.0%/26.5 min	N.D.(2)	N.D.(2)	HCL-150 HCN-10 NH_3-20 NO_2-0 Cl^2-8 $COCl_2$-1	Flash-fire at 25.5 min. No appreciable rise in temp. for 22 min.
2	Passenger Seat	Closed Cabin	Triple Seat with Conventional Materials (nylon)	Propane/Air Burner	1.0	1050	1970	100 50%/5.3 min 85%/10.0 min	1.8	+1.5 0.5%/12.8 min 1.0%/13.1 min	3.3	2.1		Flash-fire at 12.5 min. Exit sign partially legible in 50% smoke and obliterated in 85% smoke. Weight loss of seat 3.1 lb.
3	Passenger Seat	Vented Cabin— 1 Ft^2 Roof Vent	Triple Seat with Conventional Materials (nylon)	Propane/Air Burner	1.0	1270	+2000	100 50%/14.3 min 85%/16.1 min	3.0	+1.5 0.5%/16.5 min 1.0%/16.8 min	2.1	1.7		Flash-fires first at 16 min second at 22.5 min. +2000°F backwall near vent. Extensive destruction of seat and wall lining.
4	Urethane Seat Foam	Closed Cabin	Regular Urethane Foam Approx. - 10 lb	Propane/Air Burner	0.5	1420	+2000	100 50%/1.9 min 85%/2.2 min	2.5	+1.5 0.5%/3.1 min 1.0%/3.3 min	2.4	2.9		Flash-fire at 2.6 min. Reignition of foam after door opened in 12.0 min. Lazy type low intensity flames seen near floor after door closed for 13 min. All foam consumed.
5	Extinguishment-Slow Discharge of Agent 1301 During Early Stage of Fire	Inerted Cabin— 10.7 lb CF_3Br (4.1% by V)	Regular Urethane Foam Approx. - 10 lb	Propane/Air Burner	1.0 Sporadic(3) (5 min)	100	150	58 58%/6.0 min	20.6	0.1	0.2	<0.10	HF>15 Br_2-0.5	Flash-fire prevented by gas discharge after 3.1 min. Destruction of foam less than 10%.
6	Extinguishment - Slow Rate Agent 1301 Discharge Just Prior to Anticipated Flash-Fire	Inerted Cabin— 9.8 lb CF_3Br (3.6% by V)	Regular Urethane Foam Approx. - 10 lb	Propane/Air Burner	1.0 Sporadic (5 min)	330	1580	100 50%/3.1 min 85%/3.4 min	16.7	1.1	0.6	0.35	HCL-75 HF-8 Br_2-5 $COCl_2$-0.8	Flash-fire prevented by gas discharge after 3.5 min. Propane burner operation erratic. Will not continue to maintain flames when spark ignited.
7	Extinguishment - Slow Rate Agent 1301 Discharge Before and After Ignition	Inerted Cabin— 9.2 lb CF_3Br Bottle No. 1 9.1 lb Agent Bottle No. 2 Total 18.3 lb (7.1% by V)	Regular Urethane Foam Approx. - 10 lb	Propane/Air Burner	Sporadic (7.5 min)			99 50%/12.2 min 85%/15.0 min	20.0		0.1	< 0.05	HCL-100 Br_2> 50 $COCl_2$-1.5	No flash-fire or flaming of the foam observed. Burner will not ignite in 7.1% by V gas atm. Foam charred by heated calrod but did not flame. Foam burst into flame and burned completely after door was opened. Very pungent bromide odor.
				Chemicals	1									
				Incandescent Calrod (500w)	6	250	260		19.2	0.45	0.7	< 0.05		
8	Extinguishment - Slow Rate Agent 1301 Discharge Before Ignition	Inerted Cabin— 10.1 lb CF_3Br (3.9% by V)	Wool Drapery	Propane/Air Burner	Sporadic (5.5 min)	150	200	38	20.0	0.09	0.1	<0.05		Drapery fire prevented. No open flaming of the fabric. Chemicals burned intensely with high flames for 1 to 1.5 min until consumed. Fabric charred by heat - 12% by W.
				Chemicals	1									
				Incandescent Calrod (500w)	5									

TABLE 1.– DATA SUMMARY OF CABIN MOCKUP FIRE TESTS (CONTINUED)

Test No.	Type of Fire Test	Environment	Fuel Load	Ignition Source Type	Ignition Source Time (min)	Ceiling Temp. (F)	Temp. (Max.) (F)	Smoke Density (Max.) (%)	Oxygen (Min.) (%)	Carbon Monoxide (Max.) (%)	Combus-tibles (Max.) (%)	Radiant Heat (Max.) $Btu/ft^{-2}s$	Other Toxic Gases (ppm)	Remarks
9	Extinguishment - High Rate Agent 1301 Discharge (10 sec) When Ceiling Temperature Reached 200°F	Inerted Cabin– 14.1 lb CF_3Br (5.8% by V)	Regular Urethane Foam - Approx. - 10 lb	Propane/Air Burner	1.0 Sporadic (4 min)	180	220	60 50%/4.0 min	19.4	0.06	0.13	<0.05		No flash-fire. Flaming of foam pad rapidly extinguished. Chemicals and calrod did not cause open flaming.
				Chemicals	1									Destruction of foam only 12% by W.
				Incandescent Calrod (2000 W)	10			78	19.0	0.18	0.25	< 0.05		Bromide odor much less noticeable than above.
10	Flame-Retardant (FR) Urethane Seat Foam	Closed Cabin	FR Urethane Foam - Approx. - 11 lb	Propane/Air Burner	12	120	130	65 50%/5.9 min	20.0	< 0.1	< 0.1	< 0.05	HCL-2 Br_2-0.5 $COCl_2$-0.5	No flash-fire or appreciable rise in cabin temp. Destruction of foam less than 10% by W. Burning of foam only in direct contact with propane flames. Heavy white smoke in 4.0 min.
11	Flame-Retardant (FR) Urethane Seat Foam	Closed Cabin	FR Urethane Foam - Approx. - 11 lb	Chemicals	1	250	280	96 50%/1.1 min	20.5	0.6	0.5	<0.05		Chemical fire ignited foam causing open flaming for 1.7 min after chemicals consumed.
				Incandescent Calrod (2000 W)	3.8	560	1650	100 50%/1.7 min	20.0	0.7	0.6	0.25		Incandescent calrod caused flash-fire in 4 min. Destruction of foam about 50% by W.
12	Flame-Retardant (FR) Urethane Seat Foam	Closed Cabin	FR Urethane Foam - Approx. - 11 lb	Kerosene Pan Fire - 8 oz	3	300	410	100 50%/0.7 min 85%/0.9 min	18.7	0.37	0.5	0.07		No flash-fire or evidence of self-flaming of foam. Complete obliteration of Exit sign in 0.9 min. Destruction of foam less than 10% by W.
13	Flame-Retardant (FR) Urethane Seat Foam	Vented Cabin – 1 ft^2 Roof Vent	FR Urethane Foam - Approx. - 11 lb	Kerosene Pan Fire - 8 oz	3	280	350	100 50%/0.9 min 85%/1.3 min	19.3	0.23	0.3	0.07		No flash-fire. Fire growth and smoke build-up similar to closed cabin test (No. 12). Exit sign completely obliterated in 1.1 min.
14	Urethane Seat Foam Fire Outdoors	Free Burning	Regular Urethane Foam - Approx. - 10 lb	Kerosene Pan Fire - 1 oz	2	No Measurements								Regular urethane foam completely consumed in 6.0 min.
			FR Urethane Foam - Approx. - 11 lb	Kerosene Pan Fire-10 oz	6									FR urethane foam flames out in 2.7 min although fire burned about 10 min. Foam only consumed directly above kerosene fire.
15	Interior Materials - Initiated By Foam Flash-Fire	Closed Cabin	Regular Urethane Foam - Approx. - 5 lb	Propane/Air Burner	1.0	480	525	100 50%/2.9 min 85%/4.1 min	15.0	0.29	0.4	0.25		Interior materials slightly damaged but still serviceable. No flash-fire of foam as expected. High humidity conditions.
16	Interior Materials - Initiated By Foam Flash-Fire	Closed Cabin	Regular Urethane Foam - Approx. - 10 lb	Propane/Air Burner	0.5	1440	1440	100 50%/7.4 min 85%/8.2 min	4.4	+1.5	1.9	1.0		Interior materials extensively damaged by flash-fire. Temp. range of 1000°F to 1500°F sustained for approx. 1 min. Even the heaviest materials tested were totally charred.
17	Curtain Divider Effect On Fire Spread	Closed Cabin – Asbestos Curtain 37 in Length Suspended From Mid-Ceiling	Regular Urethane Foam - Approx. - 10 lb, Strips of Interior Materials Also Suspended From Ceiling	Propane/Air Burner	0.5	1570	1570	100 50%/5.9 min 85%/6.5 min	3.2	+1.5	2.1	0.6		Ceiling temp. directly behind curtain 600°F lower than in front towards fire. Initial smoke buildup behind curtain delayed 1.5 min. Suspended materials protected behind curtain showed less fire damage than in front.
18	Neoprene Foam Fire Outdoors (4 Types)	Free Burning	Neoprene Foam - Approx. - 12.5 lb	Kerosene Pan Fire - 10 oz	4	No Measurements								No flash-fire. Improved FR neoprene foam burned with no appreciable self-flaming but with heavy smoke. Foam continued to smolder until totally reduced to char after several hrs.
19	Neoprene Foam Fire Outdoors (Improved Type)	Free Burning	Neoprene Foam - Approx. - 12 lb	Kerosene Pan Fire - 10 oz	3	No Measurements								Fire out in 2.3 min. Foam did not appear to self-flame. Foam charred only to a depth of 1 in. No fire penetration of foam pad.

TABLE 1. – DATA SUMMARY OF CABIN MOCKUP FIRE TESTS (CONTINUED)

Test No.	Type of Fire Test	Environment	Fuel Load	Ignition Source Type	Ignition Source Time (min)	Ceiling Temp. (°F)	Temp. (Max.) (°F)	Smoke Density (Max.) (%)	Oxygen (Min.) (%)	Carbon Monoxide (Max.) (%)	Combustibles (1) (Max.)	Radiant Heat (Max.) Btu/ft-2s	Other Toxic Gases	Remarks
20	Curtain Divider Effect Onfire Spread	Closed Cabin	Regular Urethane Foam - Approx. - 10 lb	Propane/Air Burner	0.5	950	1400	97 50%/10.7 min	5.0	1.3	1.5	0.5		Materials suspended over fire exposed to temp. of 1200°F to 1400°F for 1 min completely destroyed. Materials suspended at opposite end of fire exposed to 600°F to 700°F for 1 min. only minor damage.
21	Curtain Divider Effect Onfire Spread	Closed Cabin – Asbestos Curtain 12 in Length Suspended From Mid-Ceiling	Regular Urethane Foam - Approx. - 10 lb	Propane/Air Burner	1.0	980	1480	98 50%/9.8 min 85%/11.1 min	4.0	1.1	1.0	0.9		Materials suspended behind curtain exposed to temp. of 800°F to 1000°F partially charred. Materials located at far end from fire exposed to 600°F to 800°F only partially melted and blistered.
22A	Neoprene Seat Foam (Improved Type)	Closed Cabin	Neoprene Foam - Approx. - 14 lb	Alcohol Pan Fire-20 oz	8	230	240	94 50%/3.4 min	18.3	0.21	0.3	<0.05		No flash-fire by either alcohol flames or incandescent calrod. Slow buildup of smoke and CO. Odor not offensive as with urethane. Slow and total destruction of foam by char formation after several hours outdoors.
22B	Neoprene Seat Foam (Improved Type)	Closed Cabin	Neoprene Foam - Approx. - 14 lb	Incandescent Calrod (2000 W)	10	100	100	72 50%/12.4 min	20.5	0.01	< 0.5	<0.05		
23	Window Opening Effect On Urethane Foam Fire	Vented Cabin – 4 ft² Opening	Regular Urethane Foam - Approx. - 10 lb	Propane/Air Burner	1.0	1360	1610	99 50%/8.3 min 85%/11.3 min	6.4	+1.5	1.8	1.6		Flash-fire and smoke buildup not appreciably affected by opening. Foam completely consumed in 28 min.
24	Window Opening Effect On Urethane Foam Fire	Vented Cabin – 9 ft² Opening	Regular Urethane Foam - Approx. - 10 lb	Propane/Air Burner	1.0	1650	2140	100 50%/8.0 min 85%/8.9 min	0.5	+1.5	3.8	1.5		Very severe flash-fire with destruction of cabin lining. Oxygen depletion surprisingly high with rapid recovery to 16% in 1 min. Foam completely consumed in 20 min. Large flames extending out of opening.
25	Window Opening Effect On Urethane Foam Fire	Vented Cabin – 9 ft² Opening	FR Urethane Foam - Approx. - 11 lb	Kerosene Pan Fire-8 oz	3	1580	1810	100 50%/1.3 min 85%/1.5 min	3.0	1.4	N.A.	0.9		Flash-fire unexpected with FR foam. Large flames extending out of opening. Note * No flash-fire in similar tests with closed cabin as in Tests 10, 12, and 13.
26	Door Opening Effect On Urethane Foam Fire	Vented Cabin – 18 ft² Opening	FR Urethane Foam - Approx. - 11 lb	Kerosene Pan Fire-8 oz	3	1800	+2200	100 50%/1.9 min 85%/2.2 min	2.0	+1.5	N.A.	1.3		Very severe flash-fire unexpected. Foam melted and burned on the floor. Very high temperatures obtained.
27	Kerosene	Closed Cabin	No Other Fuel Load	Kerosene Pan Fire-8 oz	3	330	360	80 50%/1.6 min	17.5	0.03	N.A.	<0.05		No flash-fire. Only gradual increase in temp. Exit sign still visible but not legible.
28A	Passenger Seat	Closed Cabin	Triple Seat With Improved Materials (S.E. (4) Type)	Propane/Air Burner - 10 in Flames	15	90	100	41	21.0	0.02	N.A.	<0.05		No flash-fire. Seat fabrics and foam burned only in area of 10-in. propane flames. No appreciable change in ambient conditions.
28B	Passenger Seat	Closed Cabin	Triple Seat With Improved Materials (S.E. Type)	Kerosene Pan Fire-8 oz	3	450	610	100 50%/1.3 min 85%/1.7 min	16.0	0.45	N.A.	0.20		No flash-fire as in previous seat tests. Fire damage only to center seat directly above kerosene fire. Extensive damage to center bottom bad. Very heavy smoke in 1 min. almost obscured Exit sign. Re-ignition of foam pad and open flaming after door opened in 10 min. Heavy gray choking smoke.

NOTES:
(1) Data in terms of CO percent heating value.
(2) N.A. meaning no data taken.
(3) Discharge of CF_3Br gas extinguished propane/air burner flames. However, gas burner could be reignited sporadically in CF_3Br by continuous electrical sparking.
(4) S.E. meaning self-extinguishing.

width of the cabin at its midpoint. Smoke and temperature measurements were recorded on both sides of the divided ceiling area.

Direct comparison of the ignition characteristics and burn rates for different types of foams burning freely outdoors was provided by side-by-side tests.

In the fire extinguishment tests, cylinders of halogenated gas (1301) were discharged into the cabin from the ceiling by means of a special type of aspirator nozzle located above and about 2 feet forward of the fuel load. In the high-rate discharge test, a spherical bottle pressurized with nitrogen to 600 psi and fired by an explosive cartridge was used to obtain rapid extinguishment as in aircraft powerplant fires. Commercial type colorimetric tubes placed inside the cabin and sampled from the outside were used to measure the suspected pyrolized decomposition products of the extinguishing agent and the interior materials.

A 12-inch-square hole was cut into the roof of the cabin, 2-1/2 feet from the rear bulkhead opposite the fire to provide venting to the outside atmosphere. In other tests to investigate the effect of openings on the fire, the large door opening was blocked by a metal partition to obtain different size openings to the cabin.

Seat Fire Tests

Five tests were conducted to study the burning characteristics of typical aircraft passenger seats of two different manufacturers to determine their relative susceptibility to ignition and rapidity of flame propagation within an airplane cabin mockup.

Tests Nos. 1 and 2, each involving one triple seat, differed in the type of upholstery fabric but used the same type of rapid-burning urethane padding in the seats. Employing a small flame of about 3-inch length from a propane-fed Bunsen burner as an ignition source, as shown in Figure 2, the nylon seat covers burned much more rapidly than the wool covers. This was apparently due to the melting of the nylon which then exposed the underlying and more flammable seat foam to direct flame impingement by the burner. Although the ignition time was doubled to 1 minute in the second test to insure a more rapid self-flaming of the seat, it was believed that this would not account for the much greater flammability observed with the nylon seat covers. Horizontal burn tests by Federal Standard CCC-T-191, Test Method 5906, had shown that while the 12-inch wool test specimen was self-extinguishing and

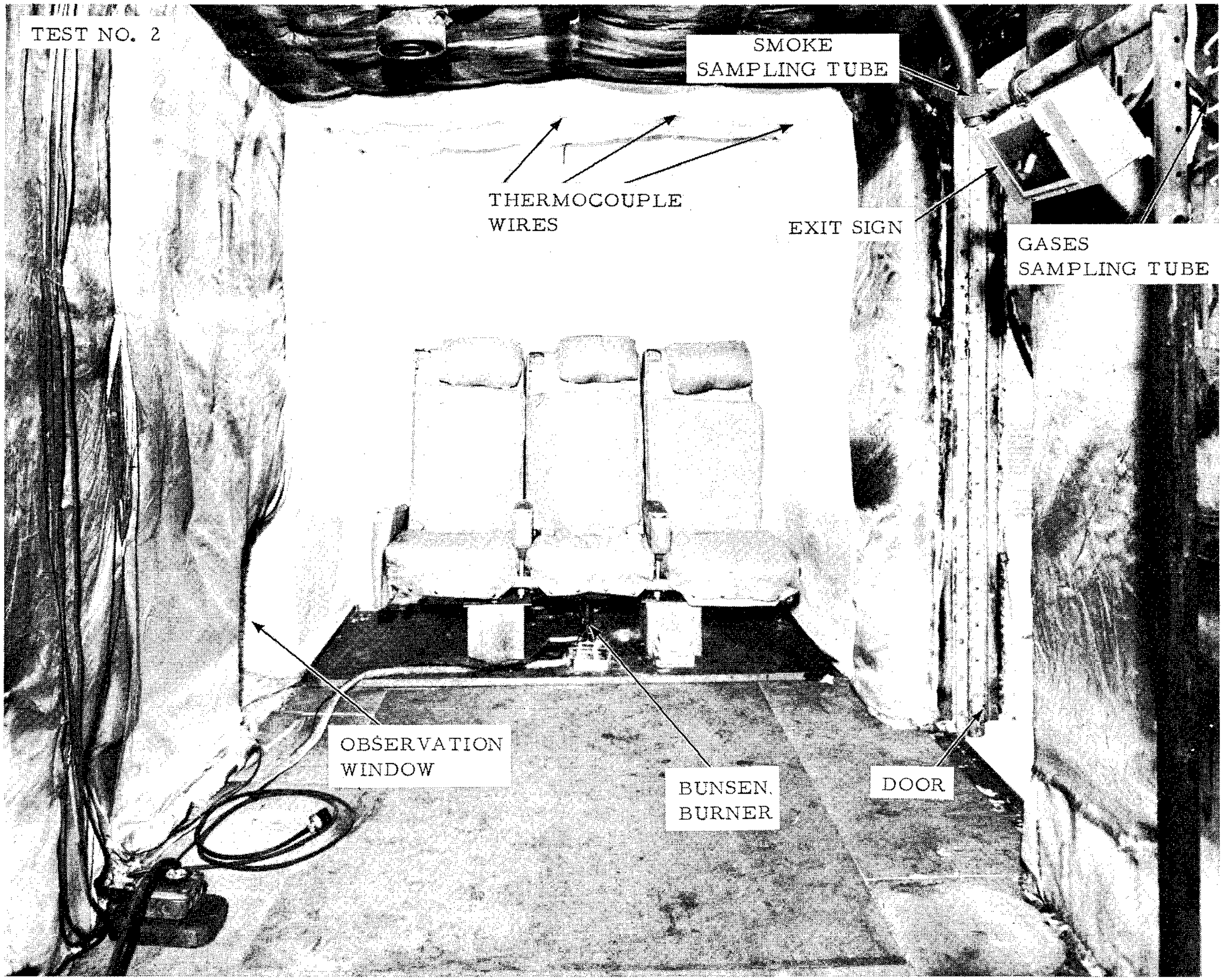

FIG. 2 SEAT FIRE TEST WITH CONVENTIONAL MATERIALS IN CLOSED CABIN (BEFORE FIRE)

only burned a few inches, the nylon specimen burned completely at a rate of from 1 to 2 inches per minute. Also, unlike wool which formed a protective char, the nylon melted away from the burner flame. In both tests, after a relatively slow buildup of the fire with no significant change other than some smoke, very rapid rise in cabin temperature, oxygen depletion, combustibles, carbon monoxide, carbon dioxide, and pressure occurred within a time period of 2 minutes or less. Extensive fire damage was sustained by the center seat foam cushion and by the seat covers as shown in Figure 3. However, oxygen depletion to a level of a few percent following the fire allowed only partial destruction of the seat materials. Of particular interest was the abrupt rise in cabin temperatures accompanied by almost complete depletion of oxygen in the air, followed by extinction of open flaming. This experience is typical of the flash fire or flashover phenomena. Apparently, there occurred a sudden ignition of hot unburned combustible gases accumulating at the ceiling. This would be comparable to a mild form of explosion which is made apparent from a sudden and short outburst of flames throughout the cabin and a sudden transient pressure rise. Displacement in time of a series of temperature rise curves at increasing distances from the ignition source along the cabin ceiling and at the floor from the seats is shown in Figure 4. Typical of the cabin fire tests were the low temperatures recorded at the lower levels above the floor which apparently were not engulfed in flames. The relation of six of the eight measured parameters to each other and to a common time reference is shown by a series of curves in Figure 5. The most interesting aspect of the curves is the very low oxygen level which results from a flash fire unlike that of the more typical fire. Without the intervention of a flash fire resulting in the very low oxygen atmospheres recorded, open flaming of the fuel load would gradually cease as the oxygen content of the air reached about 15 percent. It should be noted that further reduction from this figure would support smoldering combustion of the fuel load but not the rapid type of flaming combustion. In the absence of the occurrence of flash fire, flaming would have been confined to the immediate area above the fuel load as experienced in subsequent seat fire tests with self-extinguishing seat materials.

Increase in oxygen content following the flash fire, exhibited by the curves, was due to the inhalation of fresh air by the cabin to equalize inside and outside pressures.

The curves for smoke (i.e., percent light absorbtion) and carbon monoxide are typical for a flash fire in that both climb very rapidly, one to reach complete obscuration at the 100-percent level and the other to go off-scale at the 1.5-percent concentration in air level. In these tests, carbon dioxide recordings, which are not reported, frequently went off-scale indicating a maximum concentration level above 10 percent.

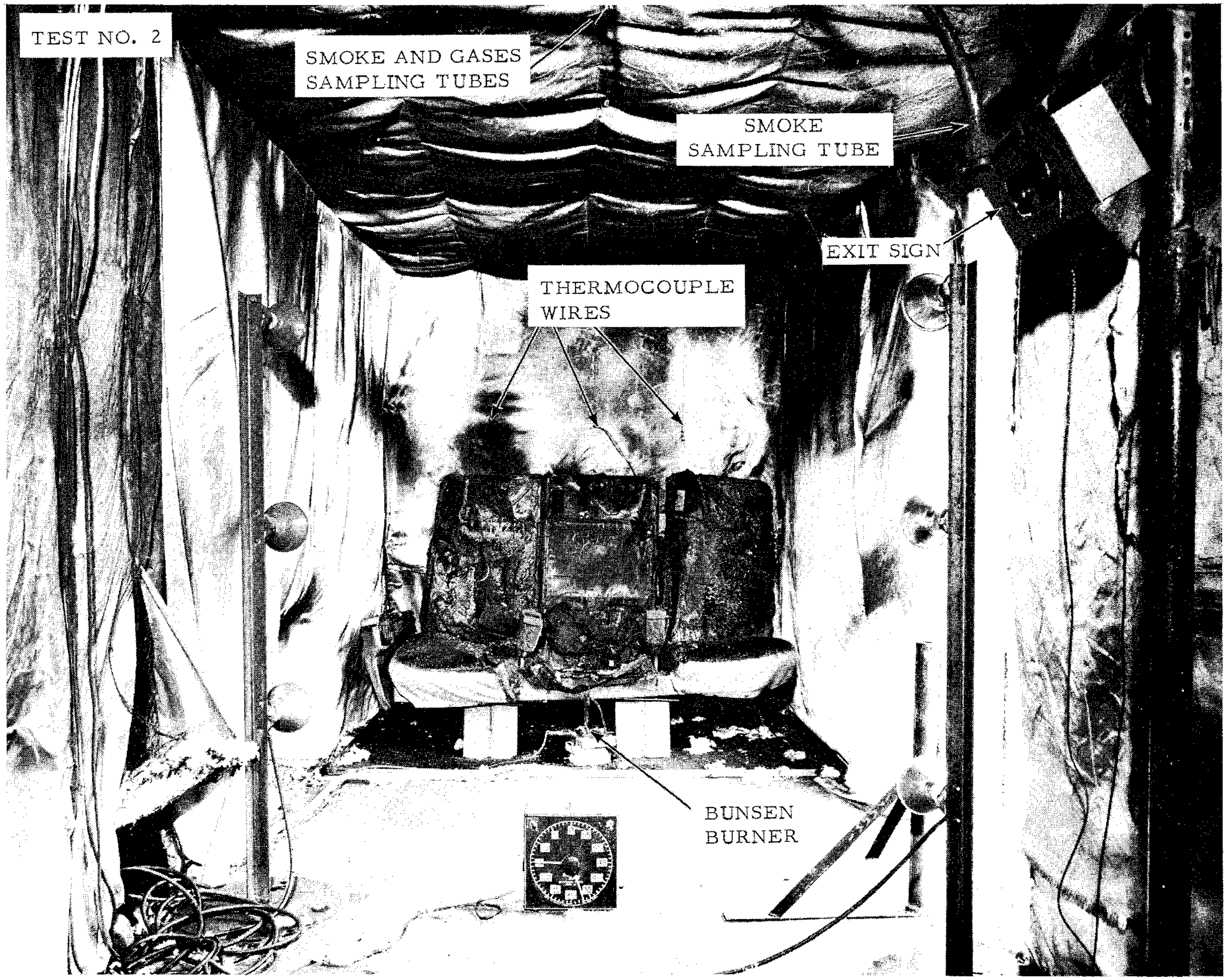

FIG. 3 SEAT FIRE TEST WITH CONVENTIONAL MATERIALS IN CLOSED CABIN (AFTER FIRE)

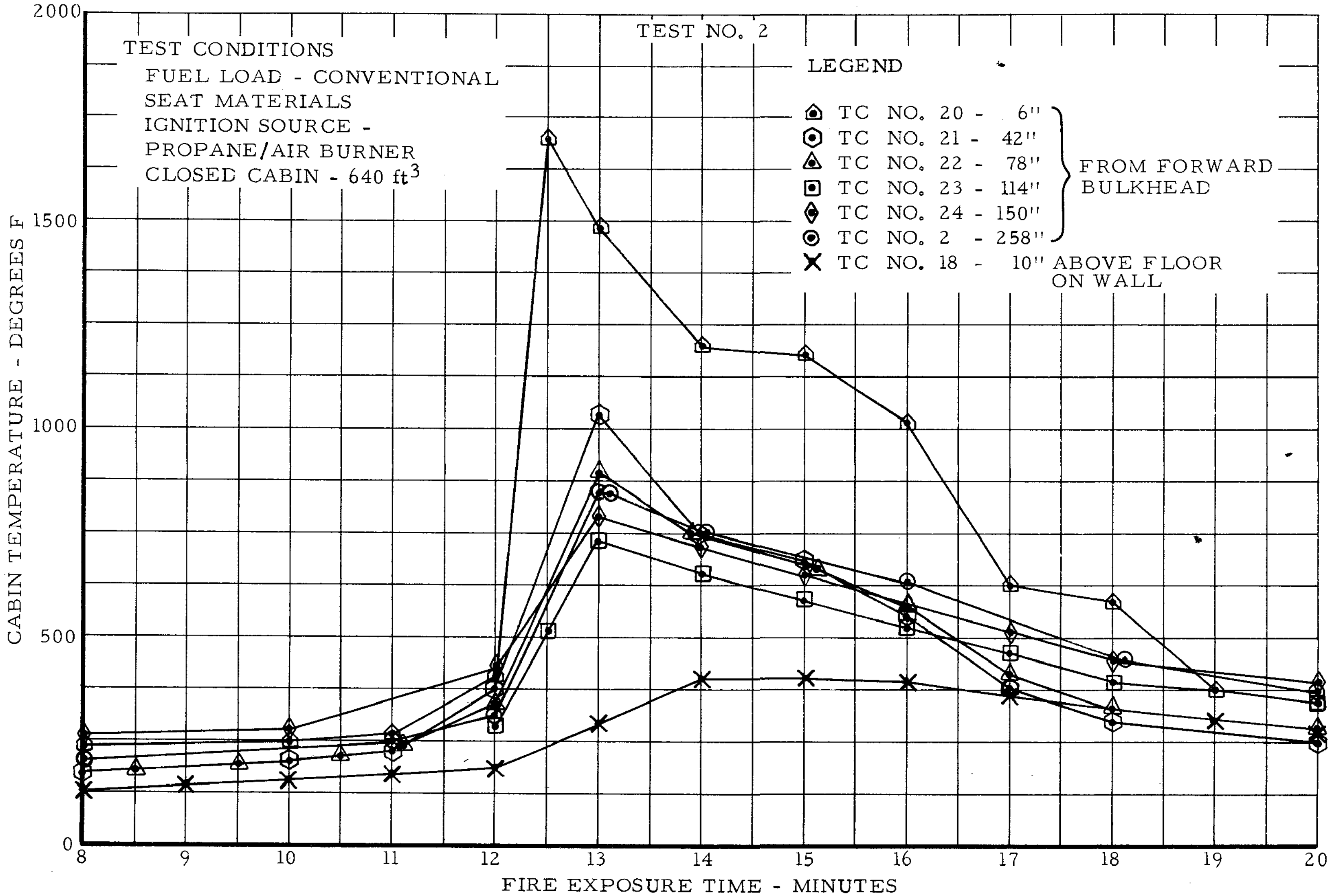

FIG. 4 CEILING FLASHOVER TEMPERATURES FROM SEAT FIRE IN CLOSED CABIN

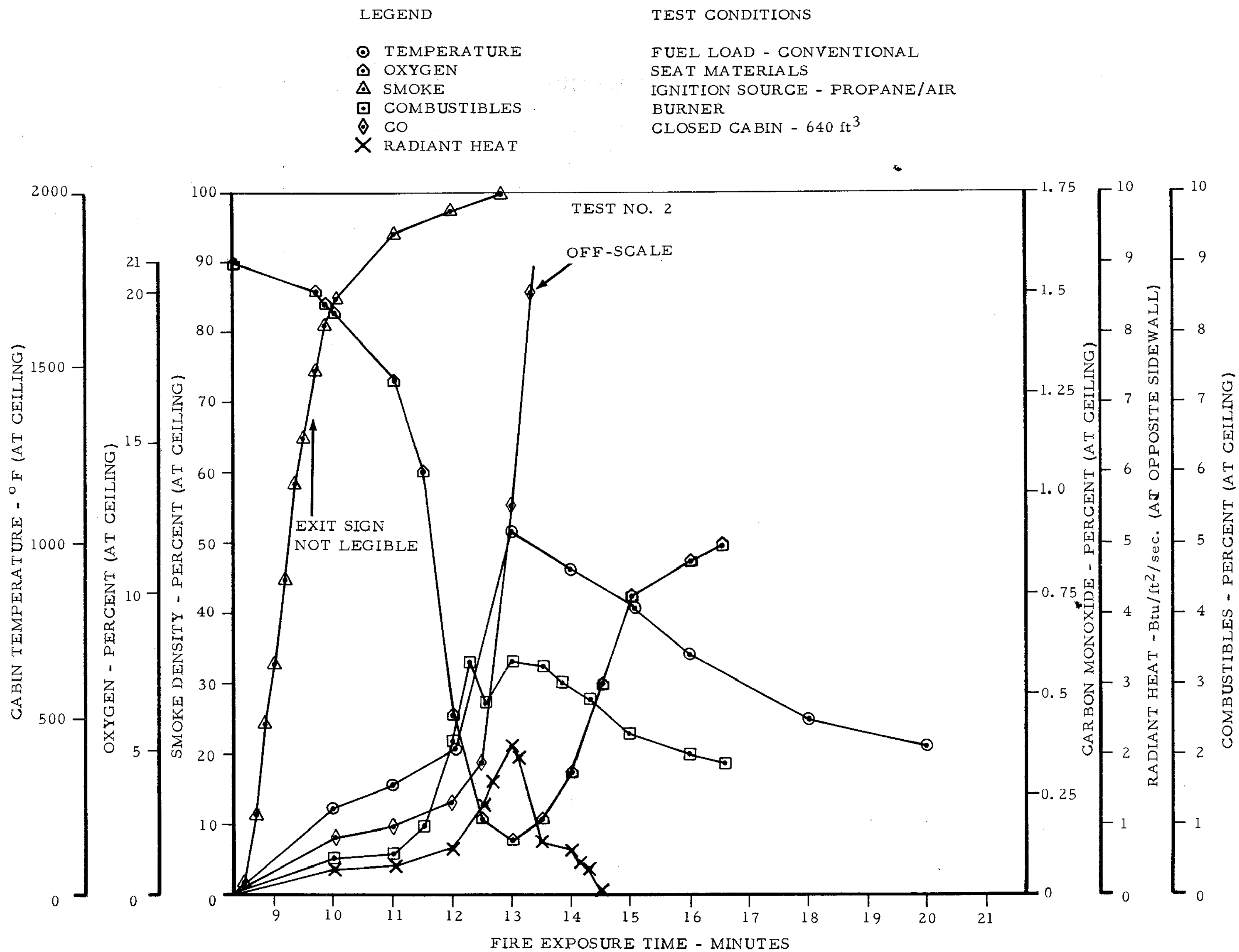

FIG. 5 SEAT FIRE PARAMETERS WITH CONVENTIONAL MATERIALS IN CLOSED CABIN

The conditions for Test No. 3 were identical to Test No. 2 except that a roof vent was provided at the far end from the fire location for the exhaust of smoke and hot gases. Very little difference in the behavior of the fire, except for a more gradual initial rise in smoke density, is seen in the curves presented in Figure 6. However, temperature recordings above the fire and in particular near the vent were very much higher, in some cases exceeding 2000°F. Much more extensive damage than in Tests Nos. 1 and 2 to the cabin lining and destruction of the seats, including the metal frame, can be seen in Figure 7. Unlike the seat tests with the closed cabin configuration, fresh air admitted from the roof vent combined with the development of a flue draft caused the fire to flare up intermittently and burn very intensely for about 30 minutes, after which the fire was extinguished by the discharge of carbon dioxide from a fixed CO_2 system.

For Tests Nos. 28A and 28B, the more typical seat covers and urethane foam used in Test No. 3 were replaced with self-extinguishing materials, namely Nomex fabric, a high temperature nylon, glass ticking and flame-retardant (FR) urethane foam. Vertical burn test by Federal Standard CCC-T-191, Test Method 5903, had shown that the Nomex fabric was self-extinguishing within a burn length of less than 1 inch. This constituted a much more severe test than the horizontal burn test which it has largely displaced in recent years for the approval of aircraft interior materials. The laboratory tests also showed the very great improvement in flame resistance achieved with the flame-retardant type of foams. While the 12-inch regular foam test specimen burned completely in less than 30 seconds, the FR foam showed that it was self-extinguishing by Test Method 5903, within a burn length of 6 inches. In Test No. 28A the bottom of the seat cushion, as in earlier tests, was subjected to a bunsen burner flame. However, since the seat materials did not show any tendency to flame of their own accord, even after the Bunsen burner flames were increased to 10 inches in height, exposure to the burner was continued during the entire duration of the 15-minute test. No significant increase in temperature or change in the other fire parameters recorded as shown in Table 1 was experienced except for smoke density which reached a density level of 41 percent. Very little damage except at the forward end of the seat cushion in direct contact with the burner flames was experienced by the seats as depicted in Figure 8.

Test No. 28B was identical to Test No. 28A, except that the fire was initiated by burning 8 ounces of kerosene in a pan directly under the center seat. The behavior of the fire is shown by curves of six parameters plotted against time in

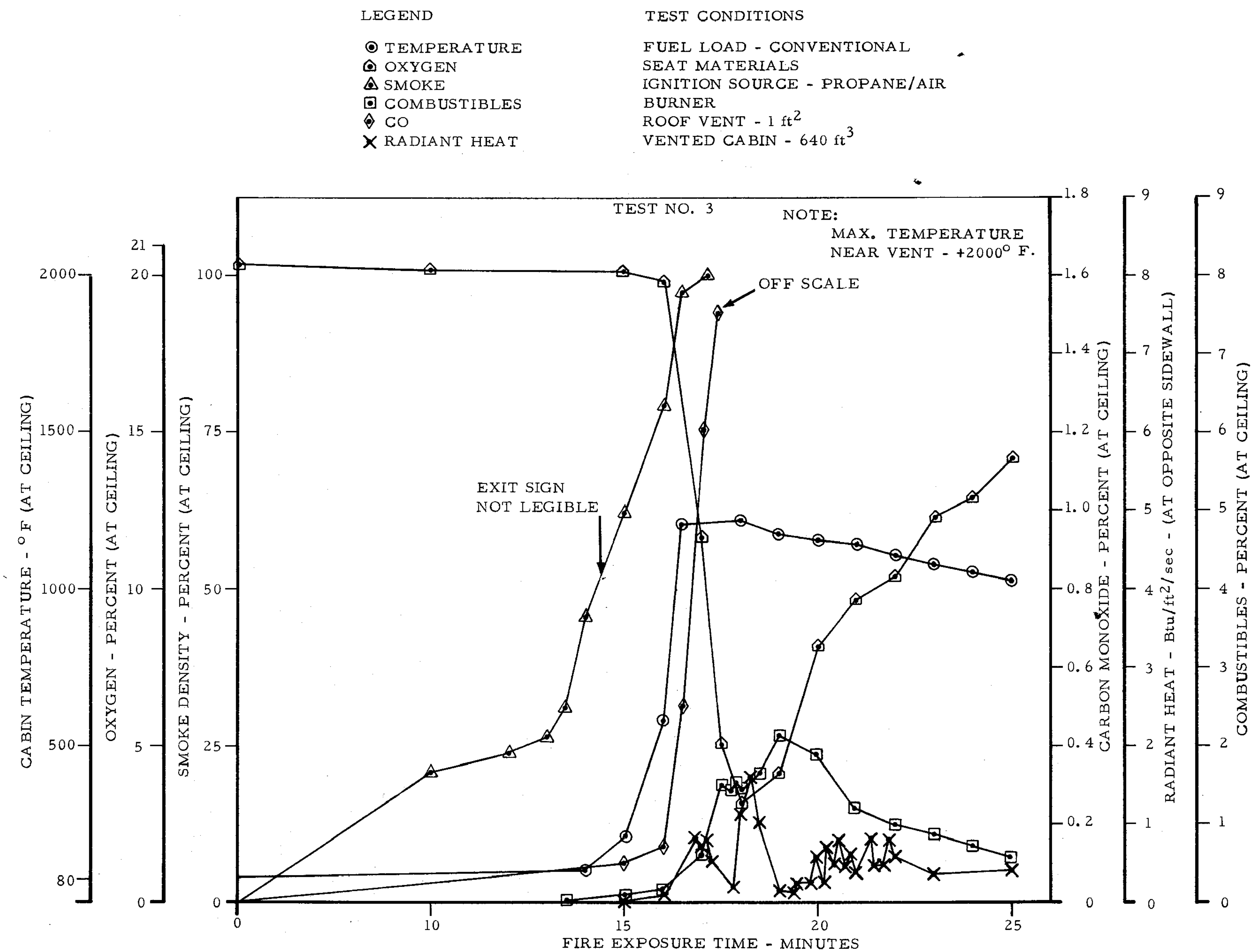

FIG. 6 SEAT FIRE PARAMETERS IN ROOF-VENTED CABIN

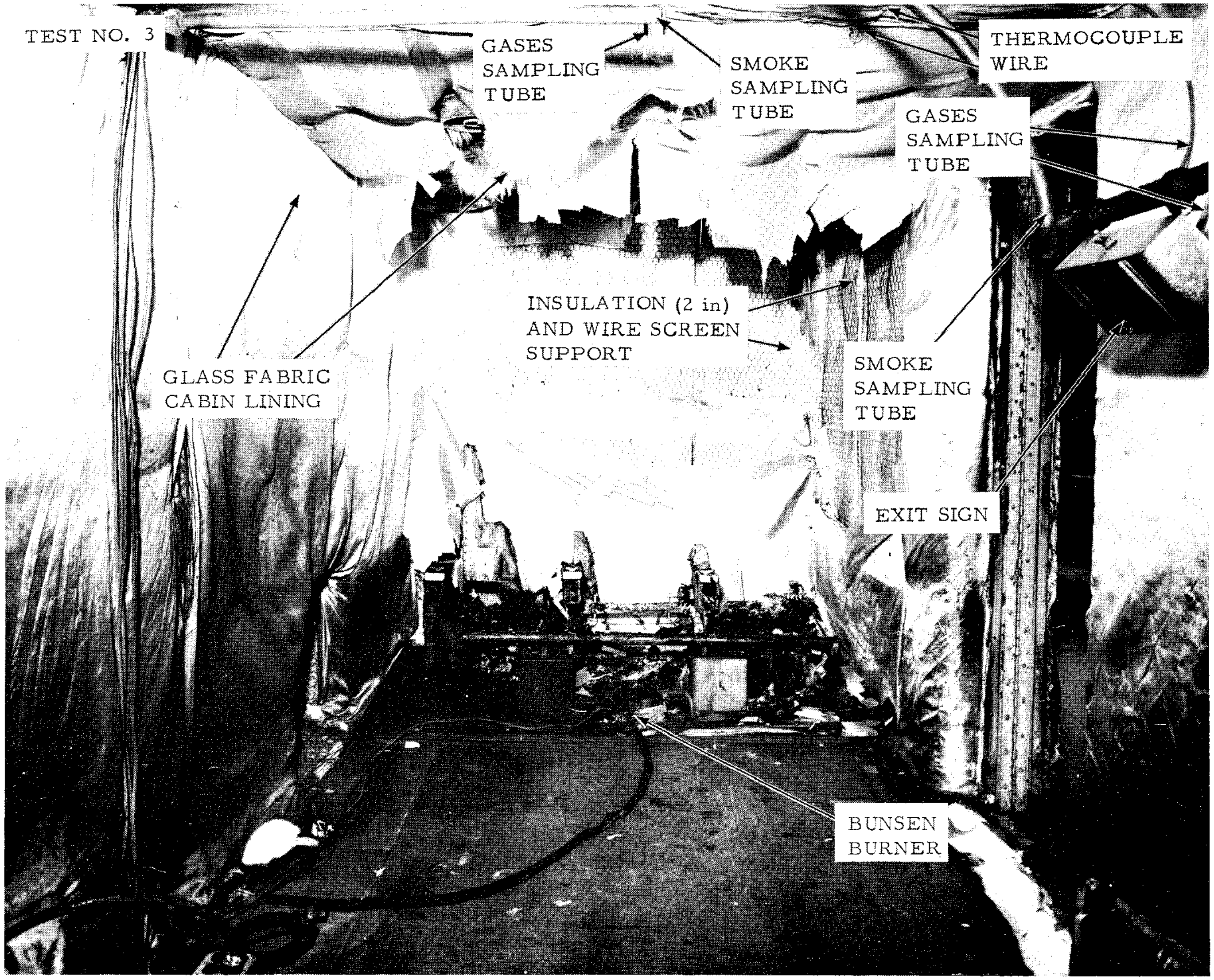

FIG. 7 SEAT FIRE TEST WITH CONVENTIONAL MATERIALS IN ROOF-VENTED CABIN (AFTER FIRE)

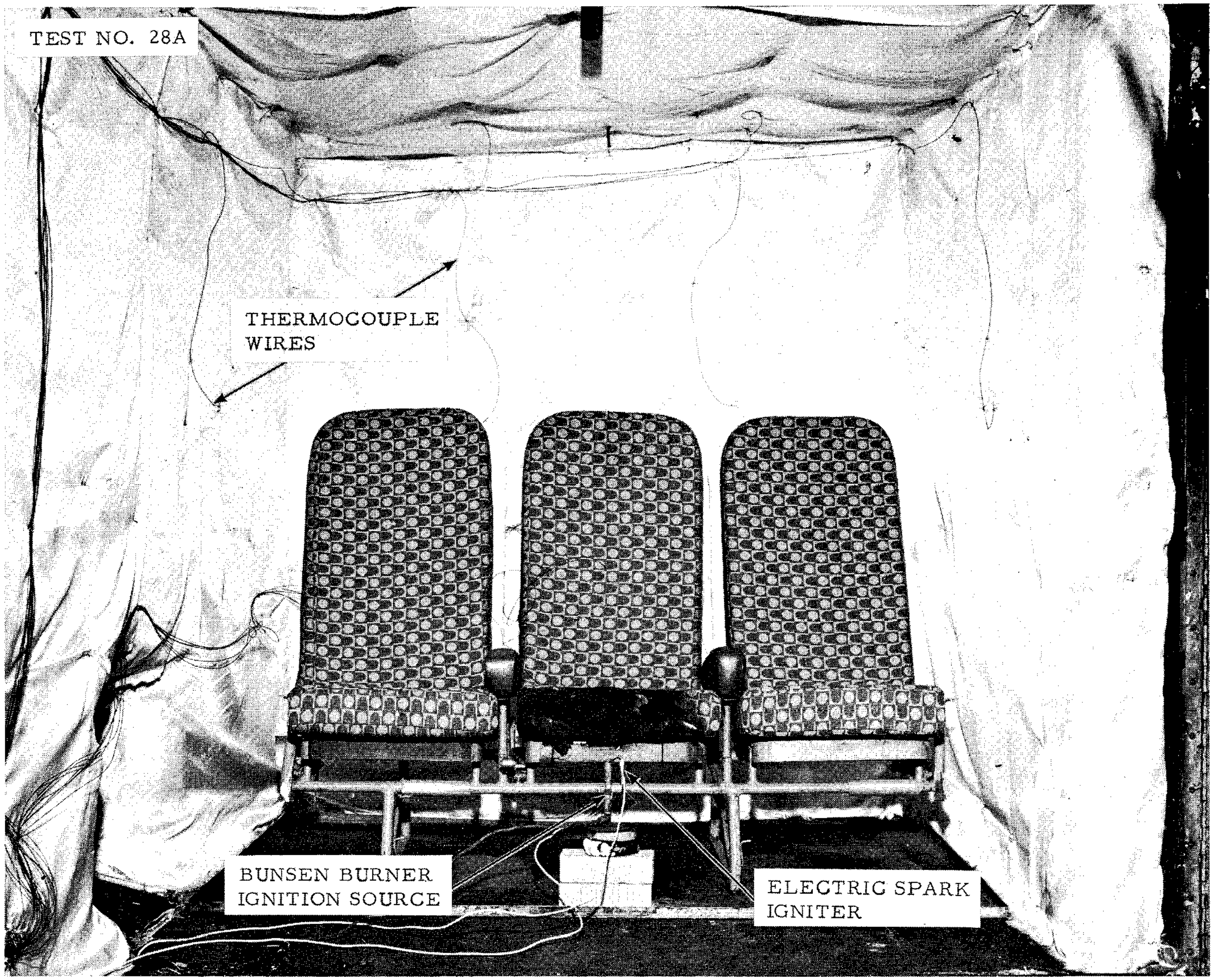

FIG. 8 SEAT FIRE TEST WITH IMPROVED MATERIALS (PROPANE GAS INITIATED)

Figure 9. No flash fire occurred in this test as shown by the gradual decrease in oxygen content of the air and also by the relatively low ceiling temperatures recorded. However, it is important to note that the foam was heated sufficiently high during this test to ignite and flame for about 1 minute when the door was opened admitting fresh air at the end of the test. The fire damage resulting from the test was confined to the center seat pad and seat covers as shown in Figure 10.

Foam Pad Fire Tests

Tests were conducted with three different types of seat foam; namely, (1) regular urethane presently used in air transports, (2) FR urethane of the type that would be required to meet the latest proposed standards under NPRM 34 FR-13036, dated August 1969, and (3) neoprene foam offered as a more fire-resistant substitute than urethane. The three foams were subjected to various types and severity of ignition sources both indoors and outdoors. The purpose of these tests was to determine the relative ignitibility and tendency of the more flame and/or fire-resistant foams to flash fire, compared to regular urethane foam now in use which is notorious in this respect. This hazardous condition is represented by the series of curves of the fire parameters plotted in Figure 11. It should be noted that the shape of these curves is similar to that for the complete seats.

No tendency to flash fire was evident with either the FR urethane or FR neoprene foams when a bunsen burner or kerosene fire was allowed to impinge on the underside of the foam pads as shown in Figures 12, 13, and 14. With the normal Bunsen burner flame ignition, the only fire damage sustained by the FR urethane foam was the burning of a circular hole about 3 to 4 inches in diameter through the top of the two pads. Similarly, with the kerosene fire the hole burned through the foam was limited to the area of kerosene flame impingement. In both instances, the foams were considered to be self-extinguishing under these different kinds of fire exposures since flaming of the pads was not self-propagating. Very little change in the ambient conditions inside the cabin occurred during the attempt to burn the foam with the 10-inch flame of the Bunsen burner during a 12-minute period in Test No. 10 as shown in Figure 12. Similarly, in Test No. 12 with the much larger in area and more intense kerosene fire ignition source, the fire parameters, except for smoke, remained relatively low as shown in the curves presented in Figure 13. Even better performance was demonstrated by the neoprene foam subjected to the flames of a 20-ounce alcohol fire as shown in the curves presented in Figure 14. Alcohol which burns with very little smoke, was used in this test so as not to mask the effect of the smoke obscuration produced by the

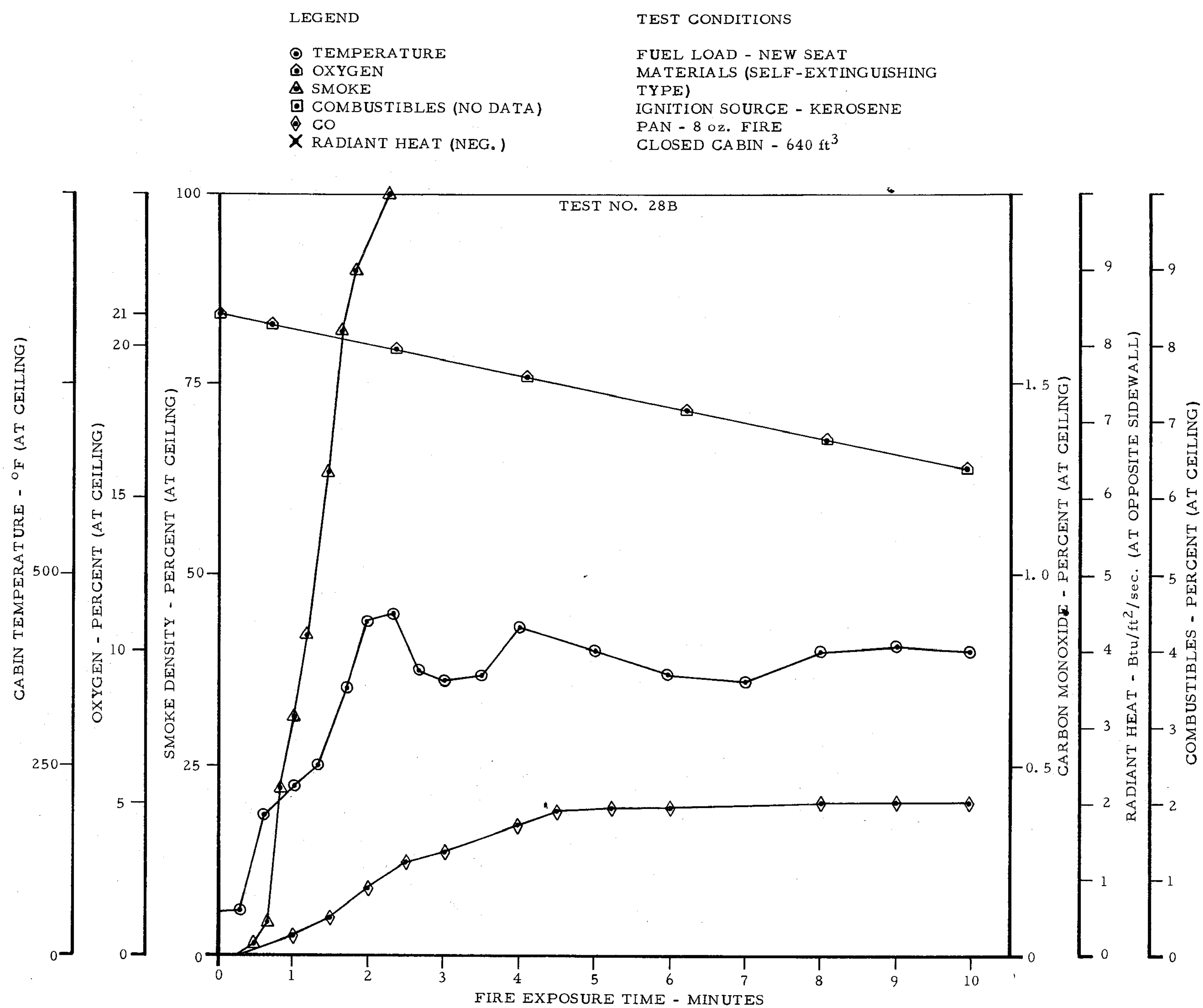

FIG. 9 SEAT FIRE TEST PARAMETERS WITH IMPROVED MATERIALS IN CLOSED CABIN

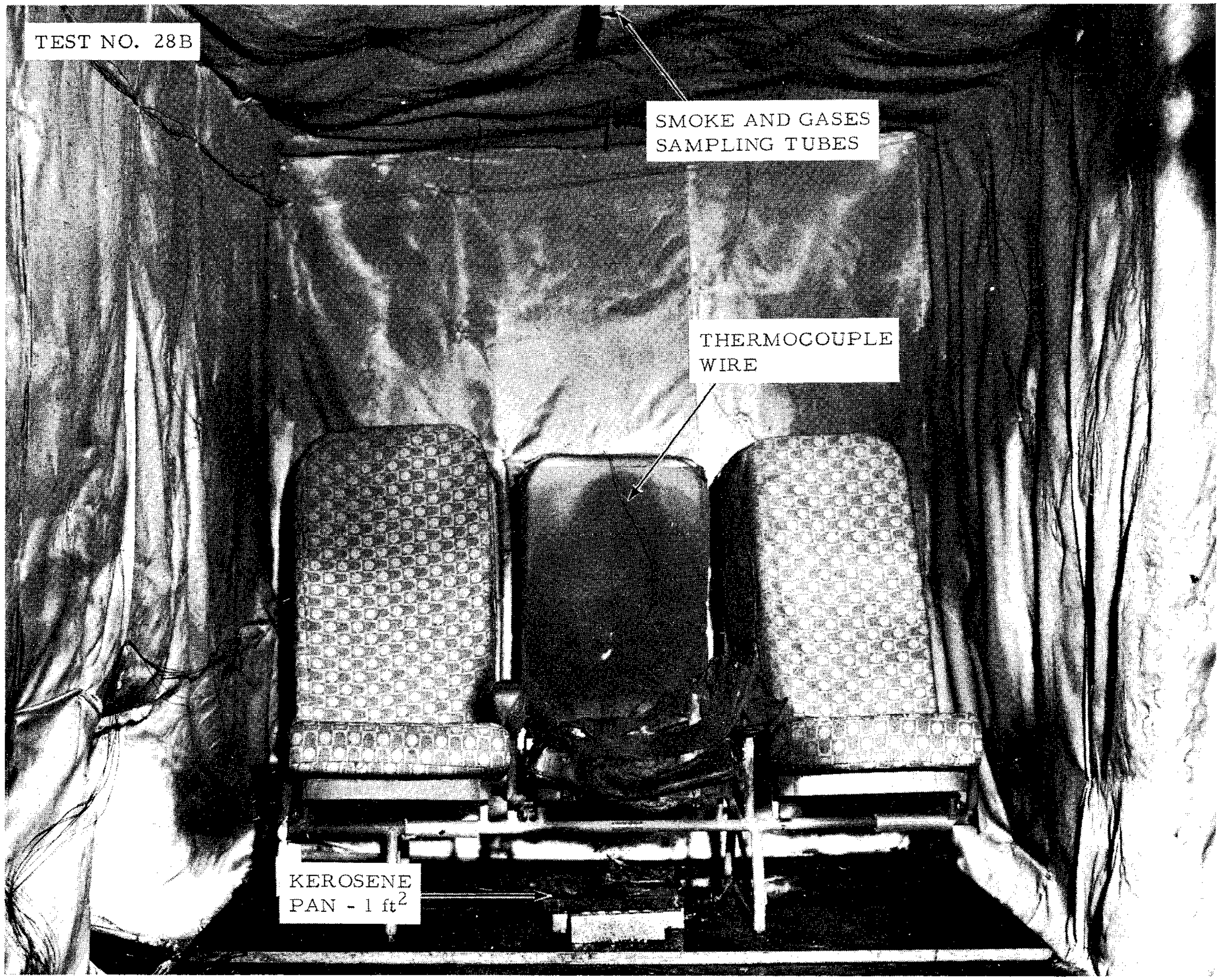

FIG. 10 SEAT FIRE TEST WITH IMPROVED MATERIALS (KEROSENE FUEL INITIATED)

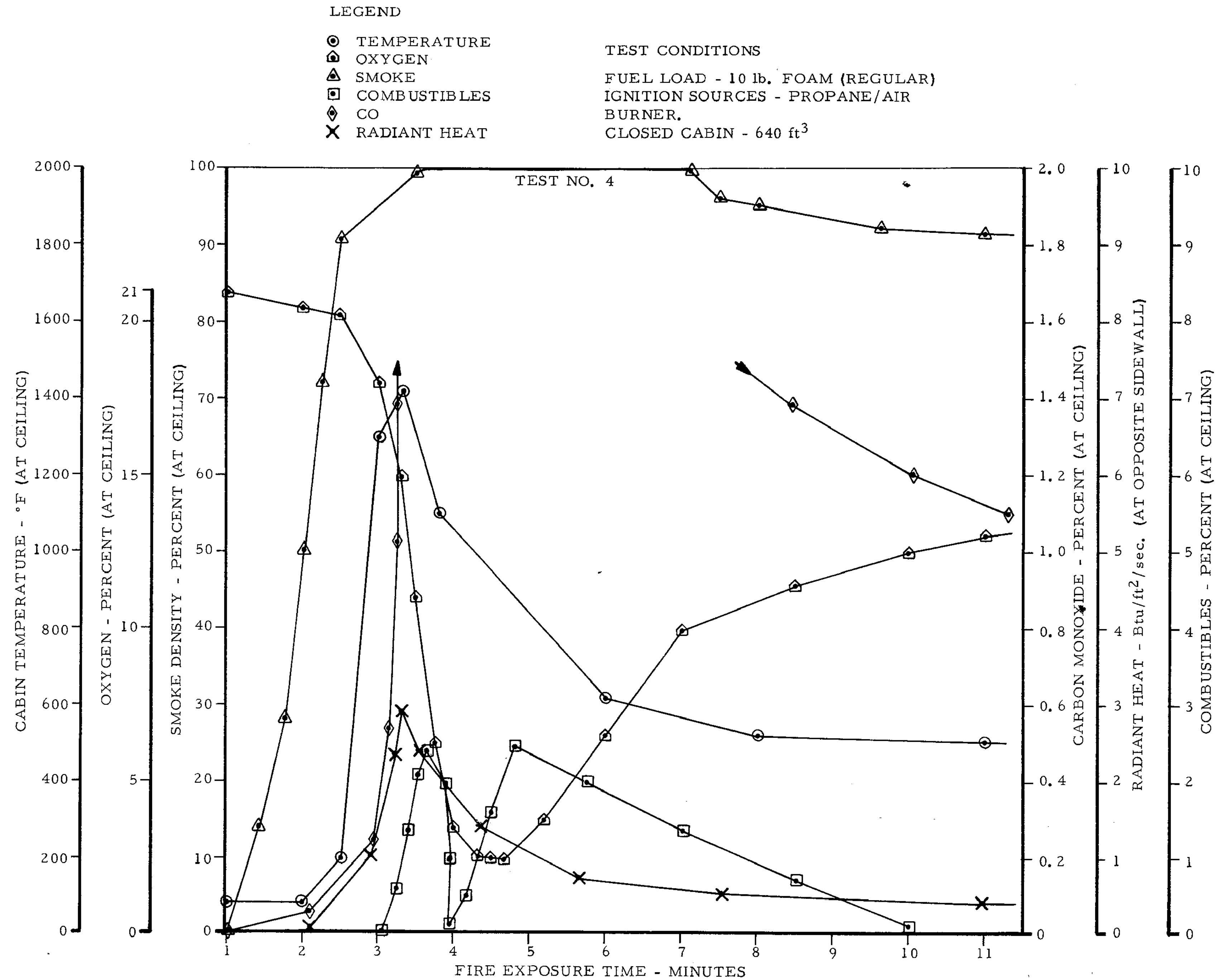

FIG. 11 REGULAR URETHANE FOAM FIRE PARAMETERS IN CLOSED CABIN

LEGEND

- ⊙ TEMPERATURE
- OXYGEN
- SMOKE
- ⊡ COMBUSTIBLES (NEG.)
- CO
- X RADIANT HEAT (NEG.)

TEST CONDITIONS

FUEL LOAD - 11 lb. FOAM (FR)
IGNITION SOURCE - PROPANE/AIR
BURNER - 10 in FLAMES - 12 min.
CLOSED CABIN - 640 ft^3

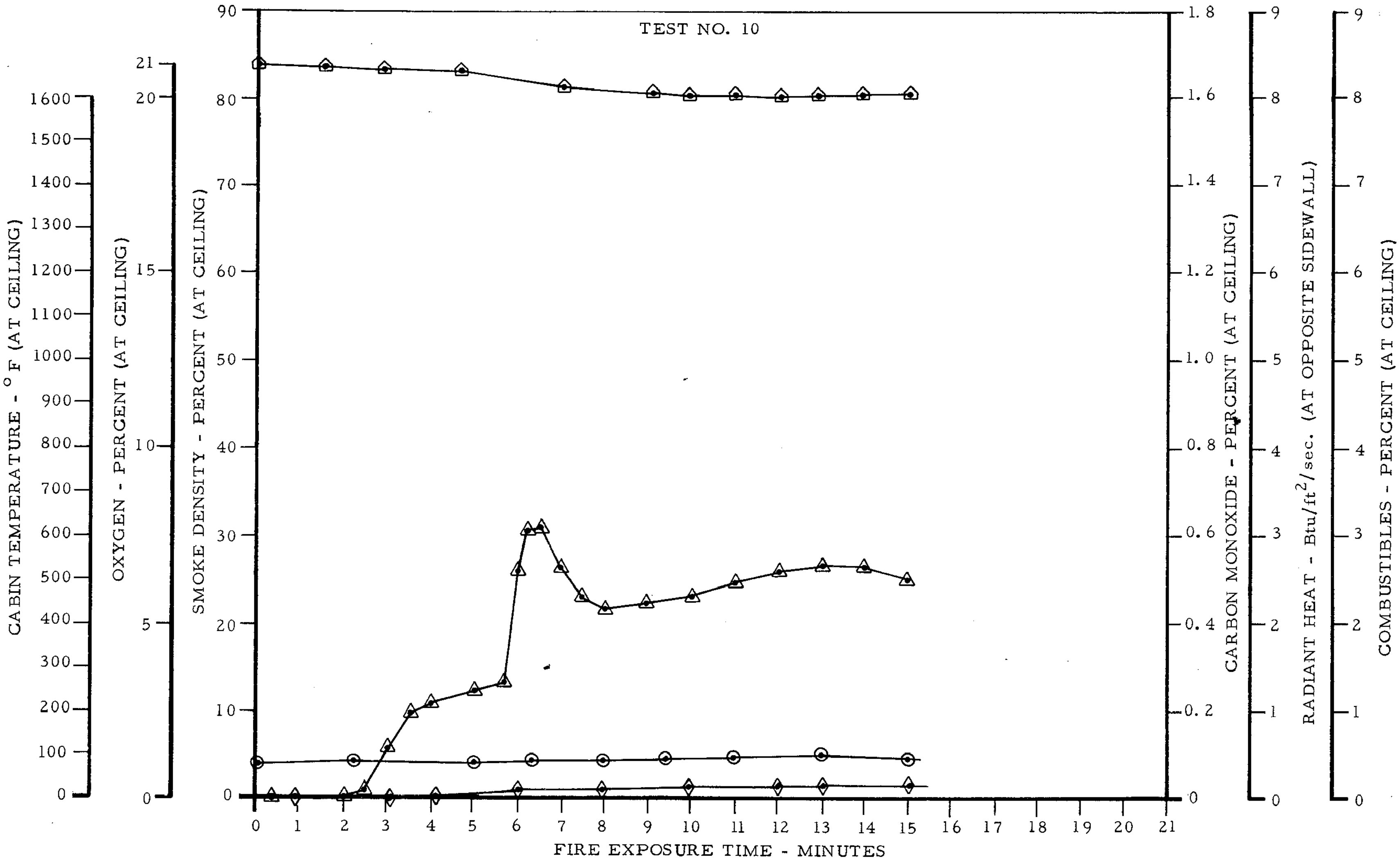

FIG. 12 FLAME-RETARDANT (FR) URETHANE FOAM FIRE PARAMETERS IN CLOSED CABIN (PROPANE GAS INITIATED)

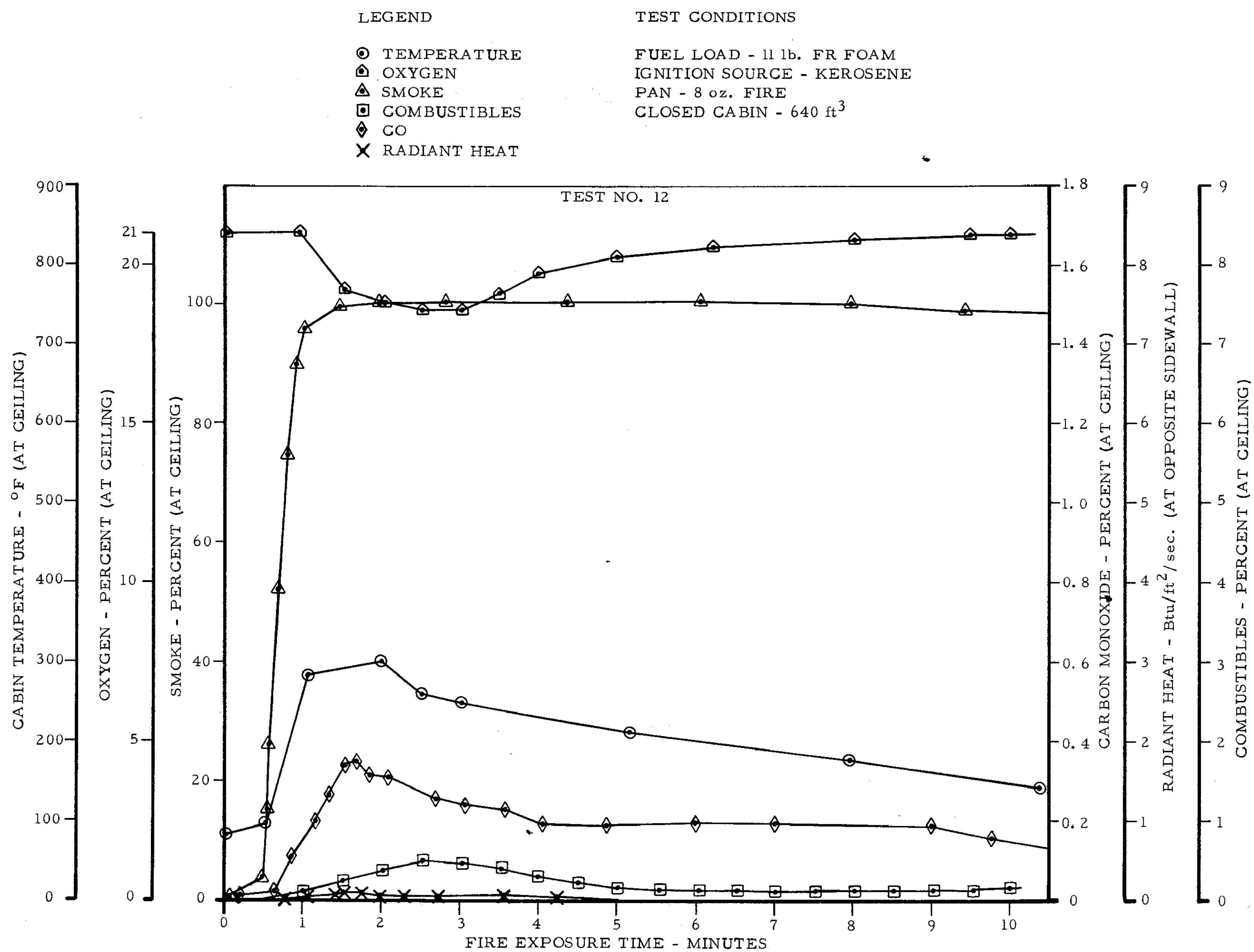

FIG. 13 FLAME-RETARDANT (FR) URETHANE FOAM FIRE PARAMETERS IN CLOSED CABIN (KEROSENE FUEL INITIATED)

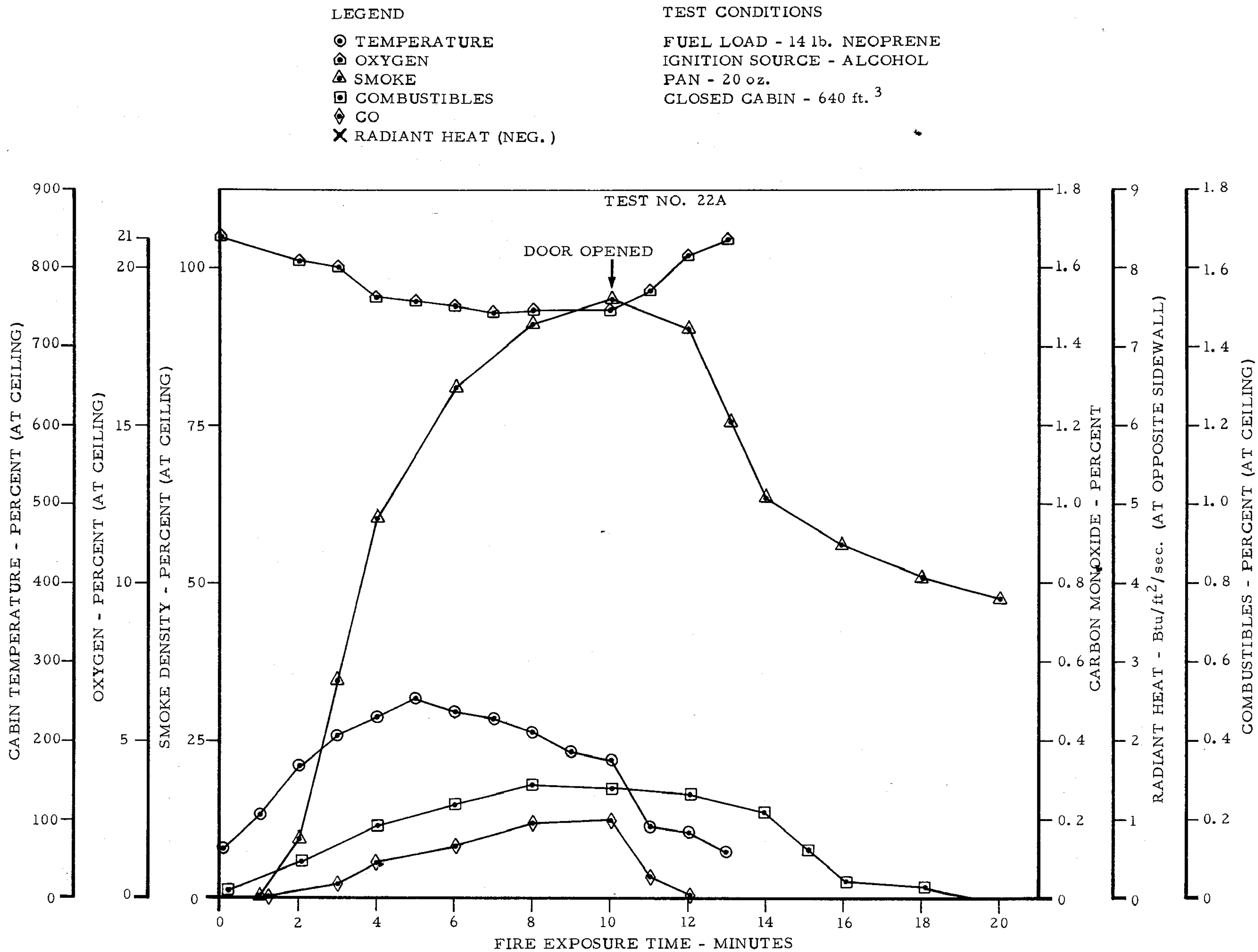

FIG. 14 NEOPRENE FOAM FIRE PARAMETERS IN CLOSED CABIN (ALCOHOL FUEL INITIATED)

neoprene foam by itself. In addition, Test No. 27 was conducted to determine the smoke contributed from an 8-ounce kerosene fire burning alone in the absence of any other combustibles. The results showed that the smoke produced was much less than for the seat foam, which completely obscured the exit sign.

Interior Materials Fire Tests

A large number of different interior materials consisting of fabrics, thermoplastics, and composites were subjected to the effects of a typical flash fire obtained by burning regular urethane foam as described in previous tests. Test specimens were suspended from the ceiling both horizontally and vertically at different locations in reference to the foam. The results showed that even the heaviest materials exposed containing organics were either completely melted or charred by temperatures of 1000° to 1500°F, even for periods as short as 1 to 2 minutes. At temperatures of 500° to 600°F, even for exposures of 5 minutes, many of the same materials were still serviceable. Damage to interior materials resulting from Test No. 16 is shown in Figure 15. Details of the tests are presented in Table 1.

Cabin Partitioning Fire Tests

Three tests were conducted to investigate the effect on the fire behavior of partially partitioning the cabin space by suspending a 12- and 37-inch-deep curtain from the ceiling midway across the length of the cabin. The conditions and results of Tests Nos. 17, 20, and 21 utilizing the curtain dividers are presented in Table 1. The arrangement of the curtain divider and test specimens of interior materials suspended from the ceiling were as illustrated in the photograph in Figure 16. The 37-inch curtain employed in Test No. 17 was especially effective in shielding the upper part of the cabin near the ceiling from the flash fire propagation. This was determined from temperature measurements and observed fire damage sustained by test specimens 18 inches in length suspended vertically from the ceiling on both sides of the curtain partition.

Cabin Venting Fire Tests

Five tests were conducted to determine the effect of an opening in the cabin, such as a roof vent or window, on the behavior of the fire. Of the five tests, two each were conducted on regular and FR foams. In general, maximum

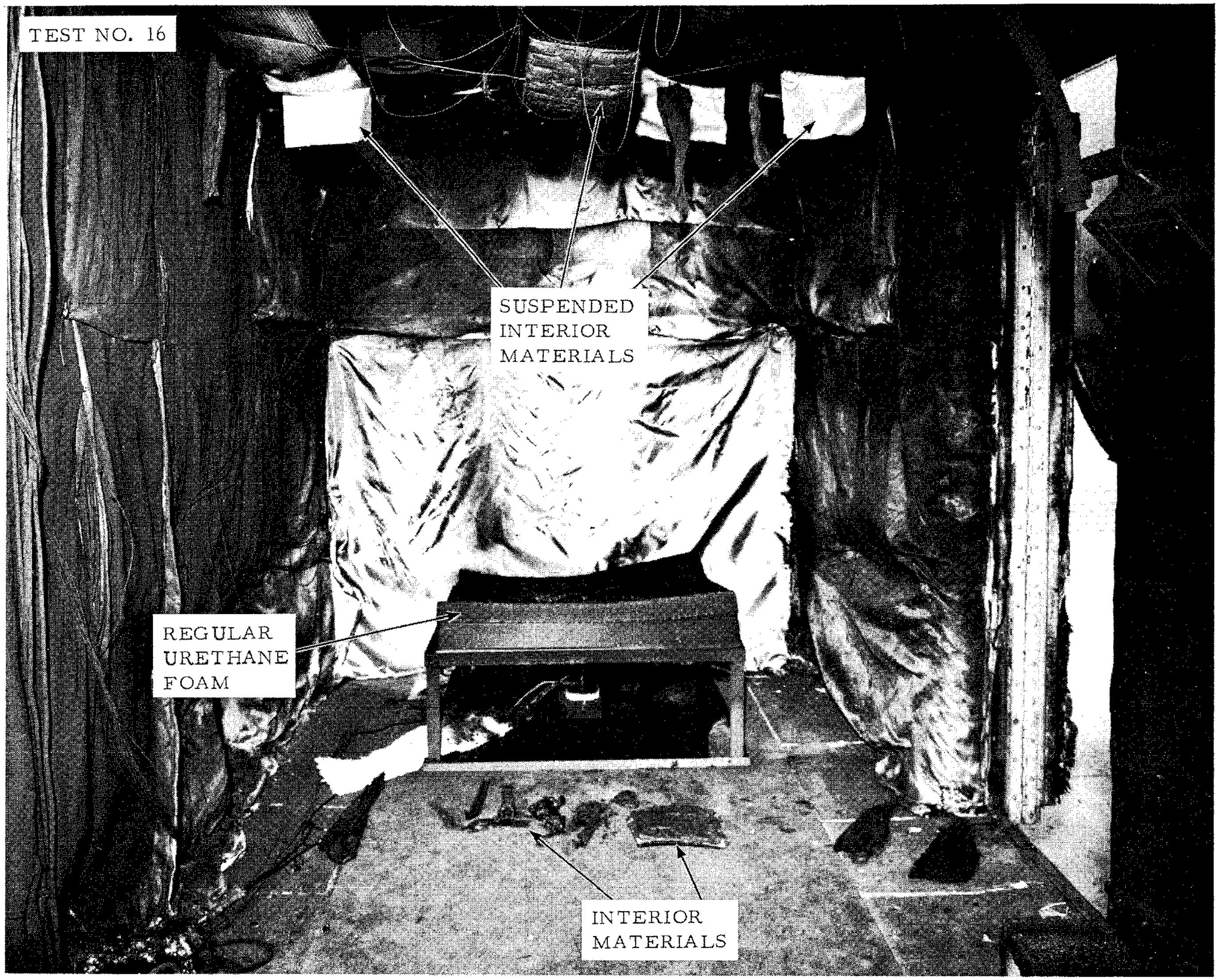

FIG. 15 DAMAGE TO INTERIOR MATERIALS FROM URETHANE FOAM FLASH FIRE

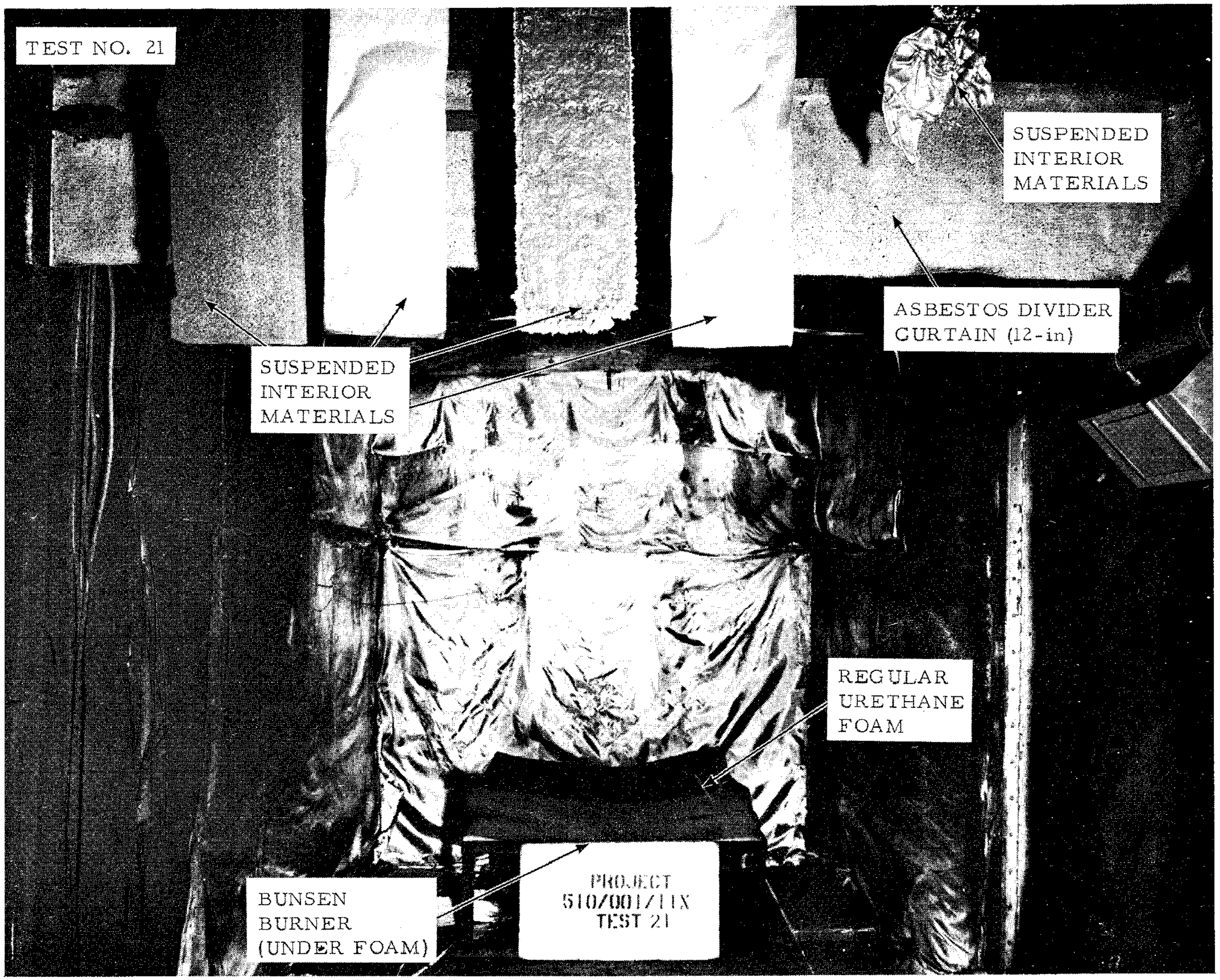

FIG. 16 DAMAGE TO INTERIOR MATERIALS PROTECTED FROM FLASH FIRE BY CURTAIN

temperatures and fire damage recorded were much higher than those in the closed cabin tests. Because of the rapid combustion of the urethane foams, even the largest size openings into the side of the mockup did not prevent the accumulation of smoke and carbon monoxide to a high level. The area of the opening was varied from 1 square foot for the roof vent to 18 square feet for the open door test. In the fire tests, both regular FR urethane foams were compared. Conditions and results of Tests Nos. 13, 23, 24, 25, and 26 are listed in Table 1. The time relation between the six major fire parameters recorded for Tests Nos. 24 and 25 are plotted in Figures 17 and 18. The curves in the two figures illustrate the differences in the fire parameters between regular and FR urethane foams obtained with a 9-square-foot opening in the cabin.

Of major significance to an evaluation of the burning characteristics of different seat foam materials was the unexpected occurrence of the flash-fire phenomena with the FR urethane foam in Tests Nos. 25 and 26. In other tests with the same FR foam used as a fuel load, no flash fire occurred when the foam was ignited in either the closed cabin as in Tests Nos. 10, 11, and 12, or in the roof-vented cabin as in Test No. 13. The only exception was in Test No. 11, in which the foam was heated inside a closed cabin with an incandescent calrod resulting in flash fire. Since both regular and FR urethane have nearly the same flash-point temperatures, of about 600°F as determined under the ideal conditions of the Setchkin Furnace Test, it is apparent that, under certain favorable environmental conditions similar to the tests, FR urethane foam could be expected to flash fire (Reference 8). Conditions conducive to flash fire would be dependent on the particular fire geometry, as this affects the heat balance of the fuel load and the supply of fresh air.

A comparison between the burning characteristics of neoprene and urethane foams was made both outdoors and within an enclosure under different modes of ignition as described in Table 1. Since the neoprene foam subjected to the heat of the 2000W incandescent calrod, in Test No. 22B, did not exhibit flaming as did the FR urethane foam in Test No. 11 under similar conditions of a closed chamber, it can be presumed that the neoprene foam would be much less likely to flash fire in the vented cabin tests or in an actual fire situation. Further evidence that the FR neoprene foam was the safer of the two foams in this respect was furnished by laboratory test results utilizing the Radiant Panel Test Apparatus (References 9 and 10).

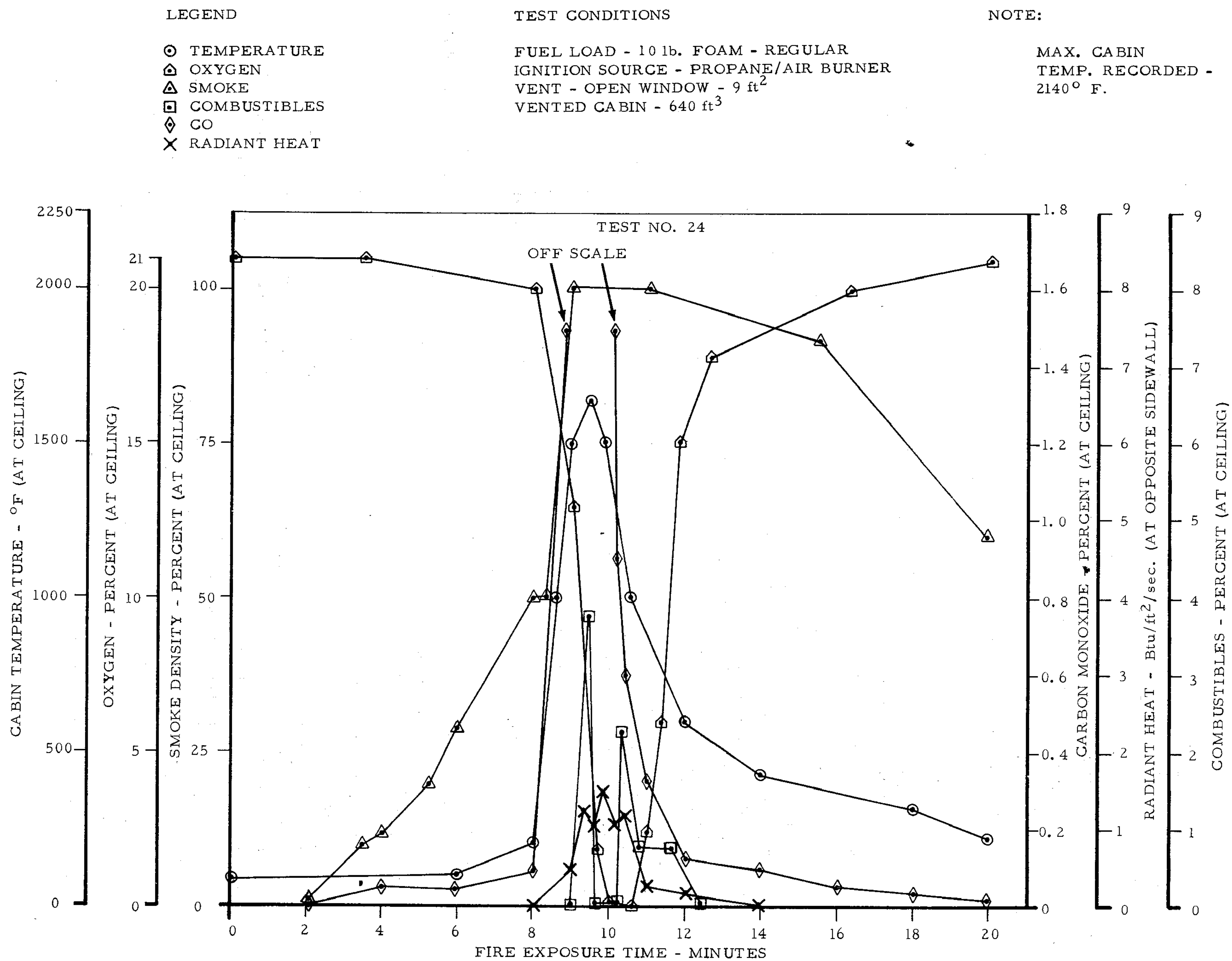

FIG. 17 **REGULAR URETHANE FOAM FIRE PARAMETERS IN WINDOW-VENTED CABIN**

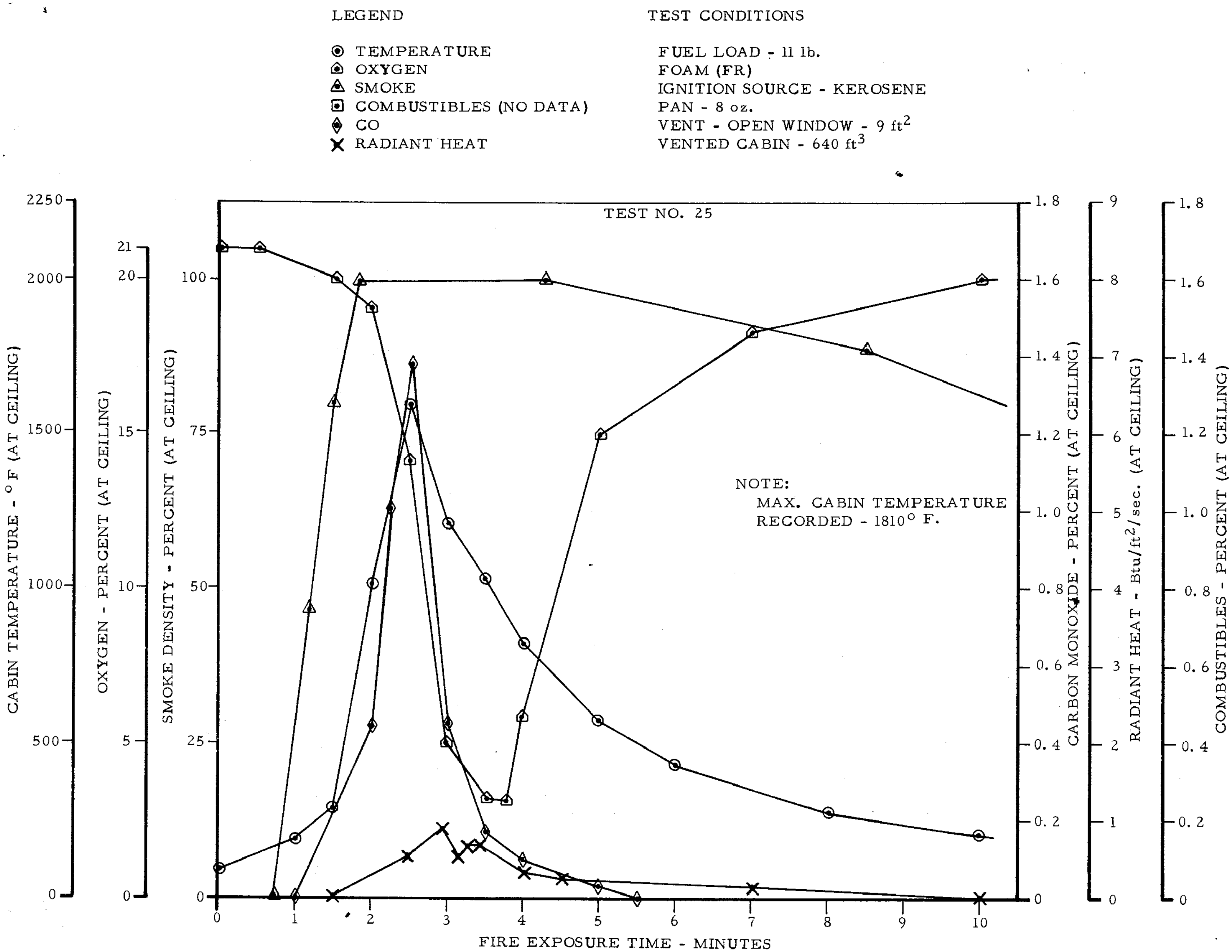

FIG. 18 FLAME-RETARDANT URETHANE (FR) FOAM FIRE PARAMETERS IN WINDOW-VENTED CABIN

Extinguishing Fire Tests

Five tests were conducted to determine the effectiveness of CF_3Br agent as a safe means for securing fire control within an enclosure. In these tests the extinguishing agent was discharged in different ways and amounts; namely, (1) low and high concentrations of about 3.5 percent to 7.0 percent by volume in air, (2) low- and high-rate discharges, and (3) discharge of the agent at different times during the test, before, during, and after the fire. The usefulness of the agent was also evaluated for different types of fires as follows: (1) propane/air mixture, (2) chemicals containing their own oxygen supply such as potassium chlorate, (3) smoldering urethane fires, and (4) open flaming urethane fires. Test conditions and results of fire extinguishing Tests Nos. 5, 6, 7, 8, and 9 are presented in Table 1. The time relation and values of the six fire parameters recorded for Tests Nos. 6 and 9 are shown by the curves plotted in Figures 19 and 20. In Test No. 6, the CF_3Br gas was discharged at a low rate into the cabin over a time period of about 1.5 minutes, starting when flash fire was considered imminent. Maximum cabin temperature recorded at the ceiling was about 300°F. No significant depletion of oxygen content in the air which typifies the flash fire was experienced. Attempts to reignite the foam with the propane/air burner were unsuccessful. Of some interest was the experience that, although the propane/air flame in a 3.6-percent-by-volume CF_3Br atmosphere was readily extinguished, the burner could be reignited sporadically by high voltage sparking. However, when the CF_3Br concentration was doubled by discharging a second bottle in the cabin, ignition of the propane/air burner was no longer possible. This would tend to confirm the results of tests by Creitz at the National Bureau of Standards (Reference 11), which demonstrated that halogenated agents are much more effective on the air side (i.e., putting out the fire) than on the fuel side of the reaction (i. e., preventing the fire from occurring).

In Test No. 9, a high-rate discharge of the extinguishing agent at higher concentration than in Test No. 6 was used. Recordings of the fire parameters with time are shown by the four curves presented in Figure 20. The curves show the very rapid extinguishment of the flaming foam following discharge of the agent after the ceiling temperature had reached about 200°F, at which point a flash fire could be expected to erupt within seconds. Attempts were made to reignite the foam after the discharge of the agent by subjecting it to a very intense chemical fire and also to the heat of a 2000W incandescent calrod. No flaming of the foam

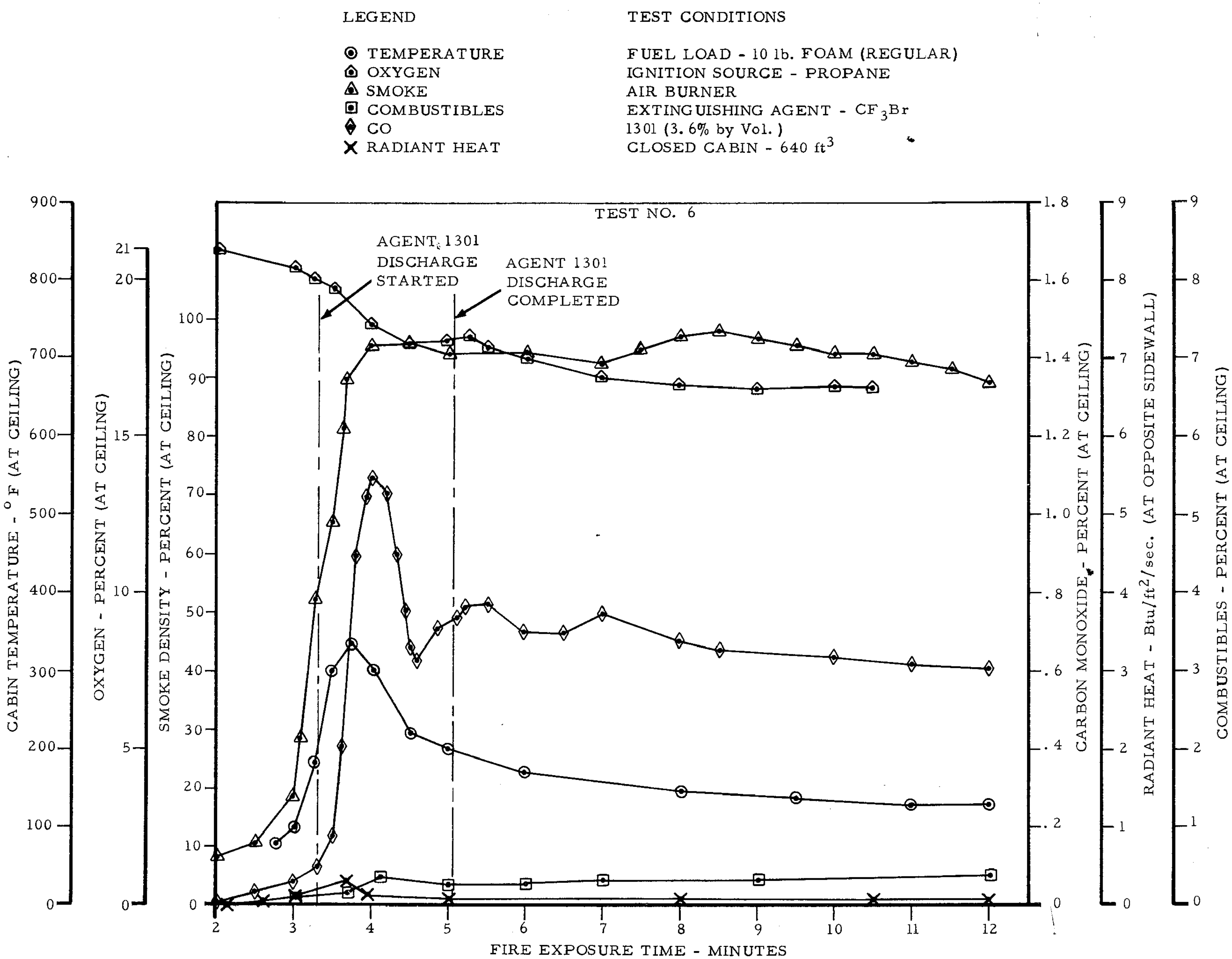

FIG. 19 URETHANE FOAM FIRE EXTINGUISHMENT PARAMETERS (SLOW RATE AGENT DISCHARGE)

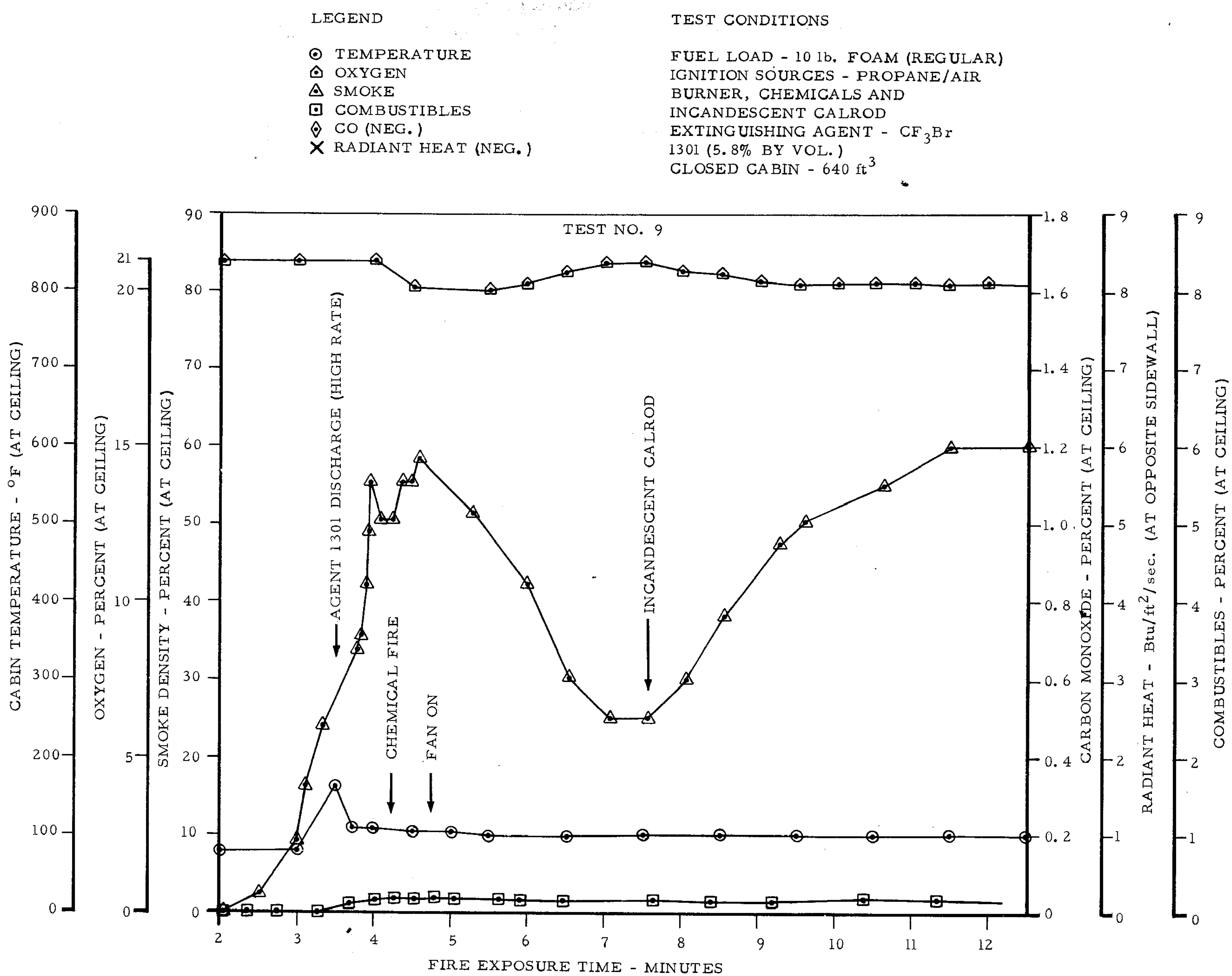

FIG. 20 URETHANE FOAM FIRE EXTINGUISHMENT PARAMETERS (HIGH RATE AGENT DISCHARGE)

pad was observed in either case. However, considerable smoke developed as a result of continued smoldering caused by the heated calrod over a period of 5 minutes as can be seen from the curve in Figure 20.

Very obnoxious bromine-type odors from brownish fumes were experienced when the cabin door was opened following the CF_3Br tests. The odor was particularly objectionable in the slow discharge tests and also in tests employing an incandescent heat source. Such tests would be expected to cause pyrolysis of the halogenated gas into toxic byproducts such as bromine which exceeded 70 parts per million in air in Test No. 7, described more fully in Table 1.

The fact that CF_3Br is not effective on some types of fires, such as chemicals which may furnish their own oxidizers, should be noted as a possible limitation in certain applications.

A fire extinguishment test was conducted on a 5-foot-long wool coatroom drape suspended from the center of the cabin. Attempts to ignite the fabric by either the bunsen burner flame, chemicals, or an incandescent heat source to a self-sustaining fire in the halogenated gas atmosphere were not successful. The only damage to the drape was some charring of the fabric as reported in Table 1.

SUMMARY OF RESULTS

The more significant findings which resulted from mockup-scale testing of aircraft interior materials are presented below.

Seat Fire Tests

The flash-fire type of hazard encountered in confined spaces was investigated for different types of materials, individually and in combination, as in a complete assembly. It was shown that materials with a low flammability rating that were self-extinguishing in laboratory tests would only burn in the area in contact with flame impingement of the ignition sources. No flash fire ensued from the burning of the improved materials and the fire spread and damage was confined to the center portion of the seat assembly. In contrast, the more flammable materials continued to burn at an accelerated rate until the occurrence of a flash fire.

Cabin Partitioning Tests

A curtain shielding interior materials from a urethane foam flash fire was shown to be effective in protecting interior materials from severe fire damage.

Foam Pad Fire Tests

The burning characteristics of seat foams of different flammability ratings were compared under different test conditions. With the flame-retardant urethane and neoprene foams subjected to either a propane flame or kerosene panfire, the burning was limited to the foam in contact with the ignition source. There was no tendency for the fire to spread and develop into a flash fire. Comparing the flame-retardant neoprene to FR urethane, it was shown that the former was superior since it did not flash fire when heated by an incandescent heat source.

Cabin Venting Fire Tests

The effect of openings in the cabin mockup on the burning, smoke emission, and flash-fire characteristics of seat foam materials was investigated. It was shown that a much more severe fire resulted when an opening was provided. Flame-retardant foam which showed no tendency to flash fire in a closed environment could be made to flash fire under certain conditions. Even with relatively large openings, dense smoke and large concentrations of carbon monoxide were able to build up due to the rapid combustion of the foams.

Extinguishing Fire Tests

The effectiveness of bromotrifluoromethane (1301) as an extinguishing agent for cabin fires involving interior materials under different conditions of ignition of the materials and use of the agent was investigated. It was shown that a high-rate discharge system was more effective in bringing the fire under rapid control in order to maintain a survivable environment inside the mockup.

CONCLUSIONS

Based on an analysis of the test results, it has been determined that:

1. The use of self-extinguishing materials in seat construction capable of meeting the improved flammability standards recently proposed by FAA should eliminate in most instances the flash-fire hazard now present in air transport cabins.

2. Burning of flame-retardant urethane foam can result in a flash-fire hazard, but only under extreme environmental conditions.

3. The use of a curtain suspended from the ceiling is effective as a fire barrier to flame propagation along the cabin ceiling.

4. A high-rate discharge system utilizing bromotrifluoromethane (1301) is effective in rapidly extinguishing a urethane foam fire, thus preventing significant buildup of smoke.

5. Prolonged exposure of bromotrifluoromethane (1301) to an incandescent heat source can cause pyrolysis of the agent into toxic gases.

6. Temperatures exceeding 2000°F and extensive fire damage to the cabin interior can result from a ventilated fire such as may occur with an open roof vent to the outside atmosphere.

7. Although standard laboratory tests provide a useful measure of the fire properties of interior materials, where possible, these should be supplemented by cabin mockup or full-scale tests on complete assemblies.

8. Dense smoke develops very rapidly during the early stages of a cabin fire involving cabin materials, well before any significant increase in air temperature or carbon monoxide is experienced that could be harmful.