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Aviation Committee

of the NATIONAL FIRE PROTECTION ASSOCIATION

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August 1971
Price: $2.50

Aviation Bulletin No. 387

AIR TRANSPORT CABIN MOCKUP FIRE EXPERIMENTS

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As presented at the Aviation Seminar held in conjunction with the 75th Annual Meeting of the National Fire Protection Association
San Francisco, Calif., May 17, 1971

Background

This is the third time since the Aviation Seminar held in Dallas in 1964 that I have been honored by being asked to speak before this distinguished gathering of fire experts on some of the more recent activities of the FAA, in the field of Aircraft Fire Protection conducted at its experimental center - NAFEC located at Atlantic City. My particular interest and work in this field has been with the study of cabin fires and how these arise and are related to the combustible characteristics of interior materials used in aircraft construction and furnishing.

Ever since 1947 when the first regulation was issued limiting burn rate to 4 inches per minute, the degree of flammability, smoke and toxic gases emission of the materials has been the cause of increased concern over passenger safety, especially following a survivable crash landing. However, it has only been since aviation has become a mass transportation media this past decade with the introduction of ever larger capacity airplanes, that more attention was drawn to minimizing the danger of fire by raising the flammability standards of the materials. This growing concern over the role of materials in the overall fire safety program in aviation parallels that elsewhere in surface transportation, building construction, furnishings and special clothing. This follows from a general desire, backed in part by legislation, to provide a safer and more healthful environment for mankind.

Responsible for much of the development of new materials and requirements was the B-727 Salt Lake City crash in November of 1965,* followed within about one year by the Apollo disaster. The shock of these events served to mobilize on a crash basis the vast technical resources of the nation, both within the government, (including the FAA and NASA) as well as within private industry.

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* See NFPA Fire Journal Reprint FJ66-18 (50 cents per copy) and the September 1966 issue of Fire Journal, pages 5 to 10.

The results of these combined efforts have made it possible for FAA to revise its flammability standards to require that all materials with minor exemptions be self-extinguishing within a burn length of either 6 or 8 inches depending upon their use and location in the aircraft. In addition to the more severe flammability regulations, FAA is now proposing a new rule that would set limits for smoke emission at acceptable visibility levels. It is of interest to note that the aviation industry in anticipation of new federal regulations has largely adopted the new proposals for the materials used in the wide-bodied jet transport aircraft. This is reflected in the extensive use in this airplane of Nomex Honeycomb paneling, flame-retardant foam, and low-smoke thermoplastics such as polysulfone, polycarbonate, nylon, and fluorocarbons.

Although new materials developed by NASA for use in spacecraft exceed FAA's flammability standards because of the more severe high oxygen environment, these materials may not be suitable or readily adaptable for use in commercial aviation because of other considerations besides fire safety--decor, comfort, cost, service life and maintenance.

Introduction

The results of the tests I am reporting are covered more completely in report No. FAA-RD-70-81, titled, "Air Transport Cabin Mockup Fire Experiments" published in December 1970.

From its inception the overall program has mainly emphasized the conduct of laboratory tests on new materials to justify improved standards. In contrast, the work described at this time will be concerned with large-scale testing on selected materials which are most critical to fire safety, in particular seat upholstery and foam padding. It is well known that fire officials, with good reason, are reluctant to accept at face value without supporting evidence the results of laboratory scale tests in trying to predict the behavior of materials in a typical large fire. Thus, one of the main objectives of the project was to compare laboratory test data with that obtained under large-scale fire conditions on the same materials.

Materials studied were those believed to be most hazardous in view of their relative abundance in cabins and greater combustibility. Because of the large costs and efforts needed for conducting series of full-scale tests on fuselages, this approach was not possible or practical. Instead, a relatively small enclosure designed specifically to resist fire was used to conduct some 30 tests on materials and components. In these tests anyone of several parameters could be selected for study and varied independently to evaluate its particular effect on the evolution of the fire. Even so, because of the complex nature of fire, and lack of scientific data, it has been difficult to generalize too far on the phenomena. Fire technology as a new science is largely empirical and as such is surrounded by much controversy over the interpretation of the fire tests and the relative importance of the factors which control fire. It is hoped that this presentation will promote a better understanding of how materials with different flammability ratings ignite and burn inside a cabin enclosure.

Cabin Mockup and Instrumentation

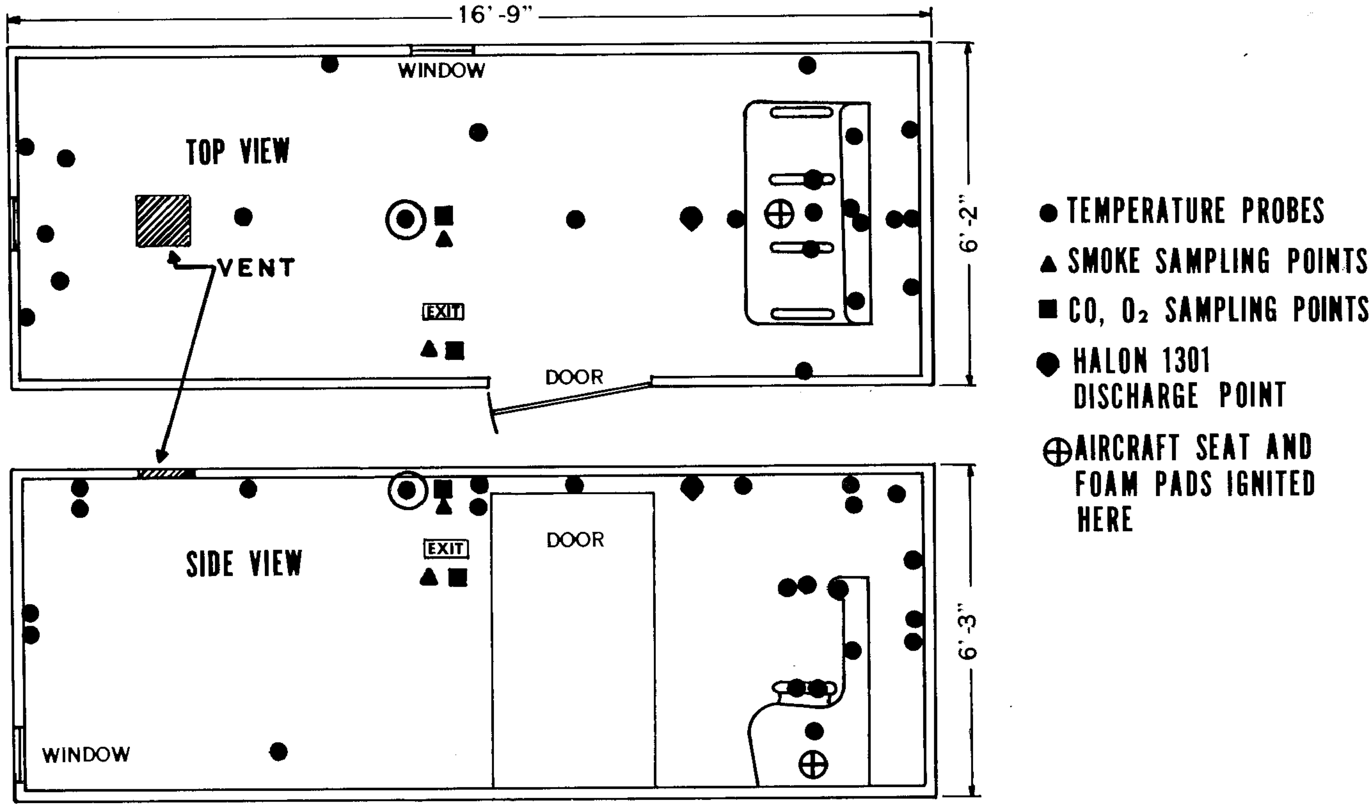


Figure 1 shows a schematic of the cabin mockup used in the tests. The steel enclosure is insulated and lined with high temperature inert materials with no combustibles and has a volume of 640 cubic feet. It is equipped with four windows which were used for observing and photographing the fire from outside the cabin from different angles. One of the windows opposite the exit sign was used to monitor the decrease in visibility of the target caused by the smoke. Various size openings to the outside air were provided by blocking off the 18-square foot area of the door space. In addition, a 1-foot square vent hole was cut in the roof to provide ventilation to the fire in separate tests. Temperature probes at 24 different locations are shown by the circles. Continuous temperature recordings were taken of the aircraft seat and throughout the cabin as shown by the scattering of circles. However, except for the next Figure, only the temperatures recorded at the mid-ceiling point will be presented in the Figures that follow. The locations of the sampling points for smoke are shown by the triangles and for oxygen and carbon monoxide by the squares. Smoke density in percent was measured by the attenuation of a beam of light over a distance of 1 foot using a photocell with response similar to that of the eye. Oxygen was measured by a paramagnetic type of detector and carbon monoxide by an infrared type of detector. The location of the Halon 1301 discharge port used in the fire extinguishing tests is shown on Figure 1. Also shown is the location of the fuel load at one end as well as the location of the ignition source under the foam pads or triple seat assembly as shown by the circled cross. Other instrumentation and sampling points used in the tests, but not shown in Figure 1, measured carbon dioxide, combustibles, pressures, heat flux, and toxic gases, other than carbon monoxide.

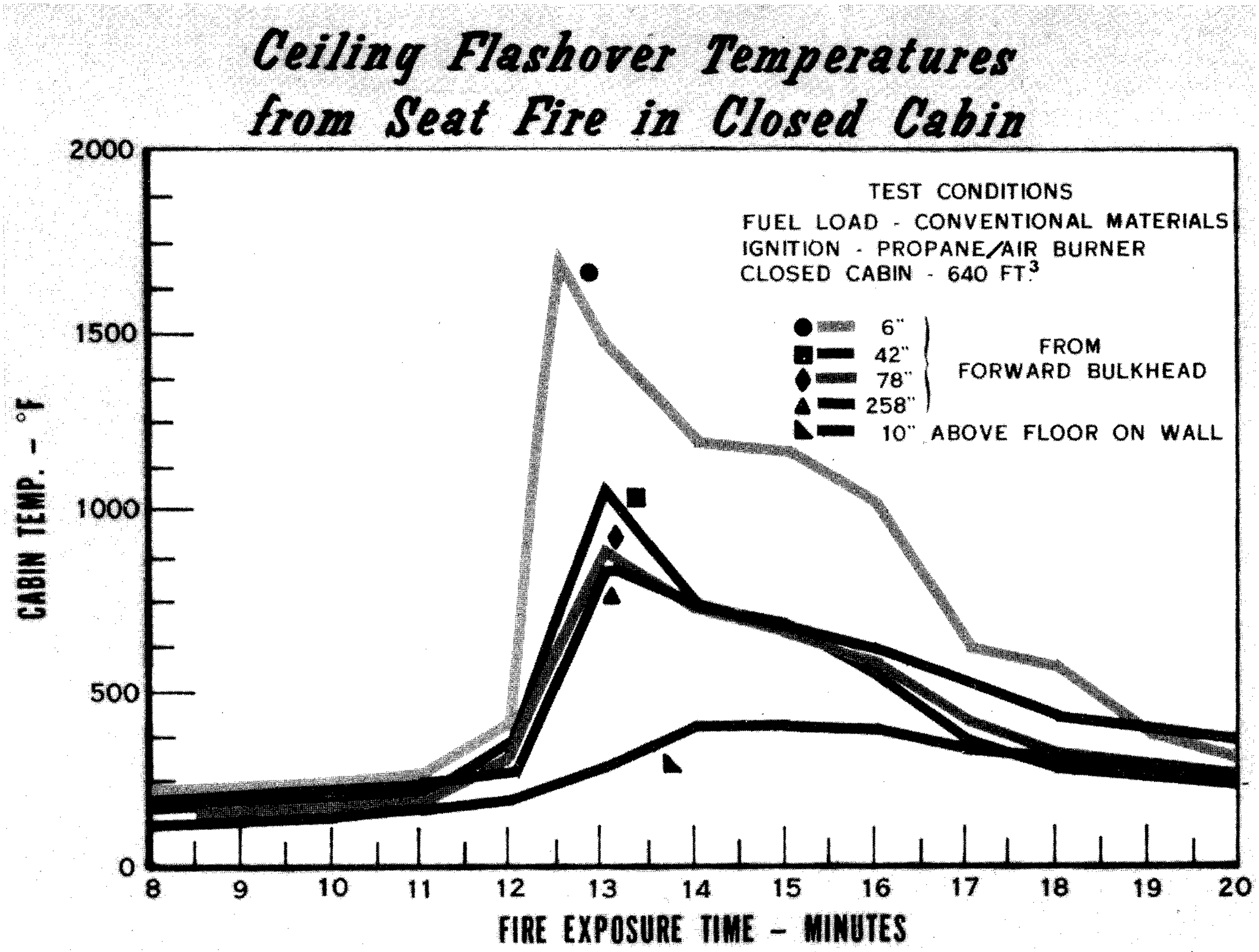


Figure 2 shows a series of temperature curves taken of a fire burning a triple seat constructed of materials currently in use in aviation. The seat was ignited from below by a small propane flame held in contact with the center bottom cushion for a time period of 1 minute and then shut off. By this time the nylon upholstery had caught fire and started to burn of its own accord. The temperature curves show the very slow rate of burning for the first 11 minutes, at the end of which the maximum cabin temperatures are not much over 200°F. Of particular interest is the extremely rapid rise in temperatures at 12 minutes. During the initial phase of burning the foam pad is apparently heated to a temperature at which it rapidly decomposes and generates large quantities of combustible gases which escape burning at the source and accumulate, being lighter than air, under the ceiling. When the concentration of these gases in air reach their lower flammable limit, a flash fire suddenly occurs which rapidly propagates over the ceiling area. The displacement of the curves with time give some indication of the transient nature of the phenomena. Thermocouples located at lower levels such as No. 18, 10 inches above floor which register only moderate increase in temperature, show that the flash fire is restricted to the upper part of the cabin.

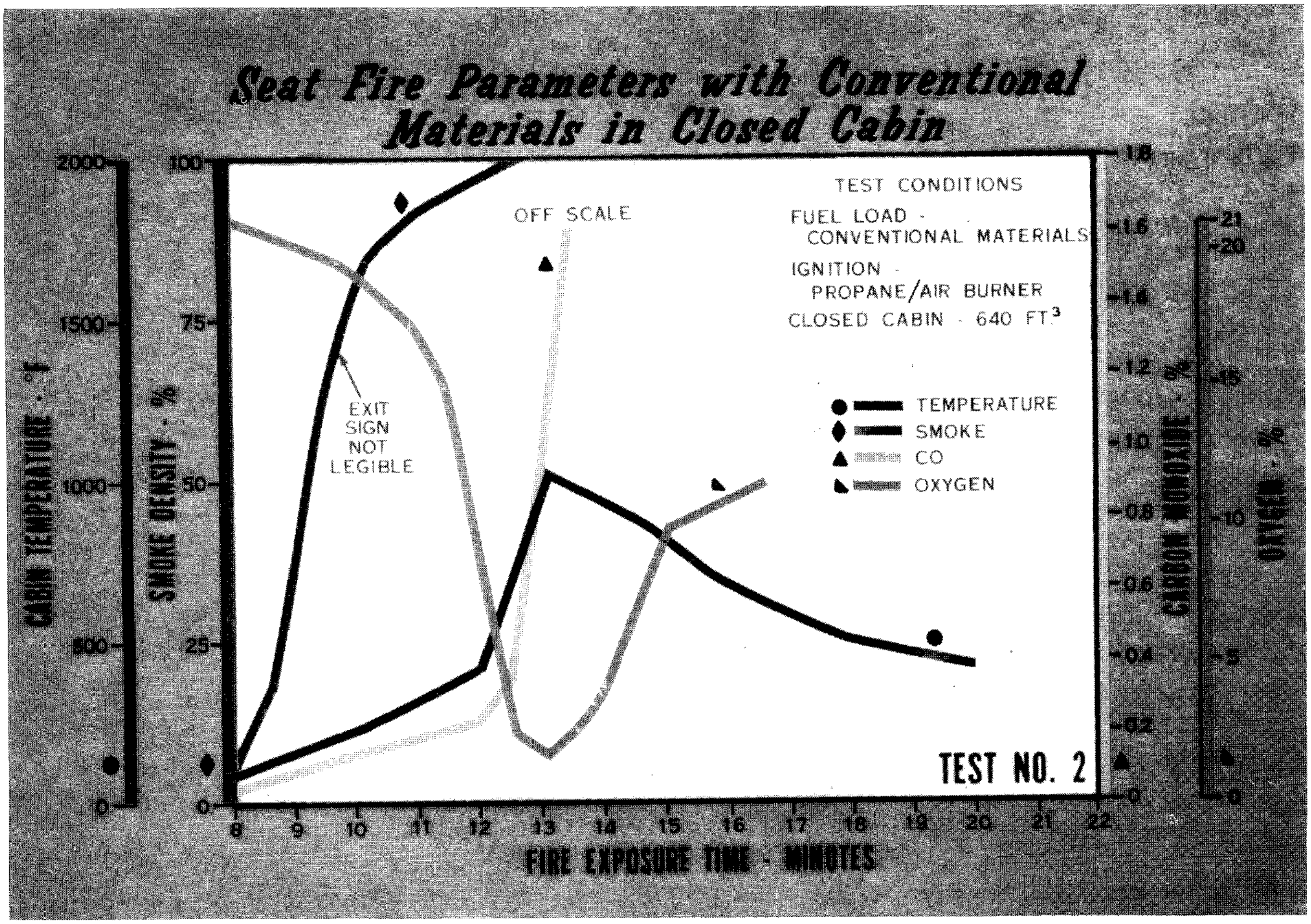


Figure 3 shows a series of curves of the fire parameters of an aircraft seat with conventional materials burning inside the closed mockup. Cabin ceiling temperature, smoke density in terms of percent light obscuration, carbon monoxide and oxygen content in the air are plotted against time. The curves show that up to 8 minutes no significant buildup of smoke, temperature or carbon monoxide is yet apparent. After 8 minutes, smoke develops very rapidly and within 2 minutes the exit sign is completely obliterated. During this time, the rise in temperature and carbon monoxide are both very gradual as is the corresponding drop in the oxygen content of the air. At 12 minutes, the temperature suddenly jumps to about 1000°F and smoke builds up to almost 100 percent, carbon monoxide goes off scale at 1.5 percent, and the oxygen is rapidly depleted and drops to about 3 percent. At this point open flaming ceases because of lack of oxygen after the flash fire has terminated. This rapid sequence of events lasts only about 2 minutes. Fire damage in this test was limited by the amount of available oxygen. Only about 2 pounds of combustible materials were consumed in the closed mockup.

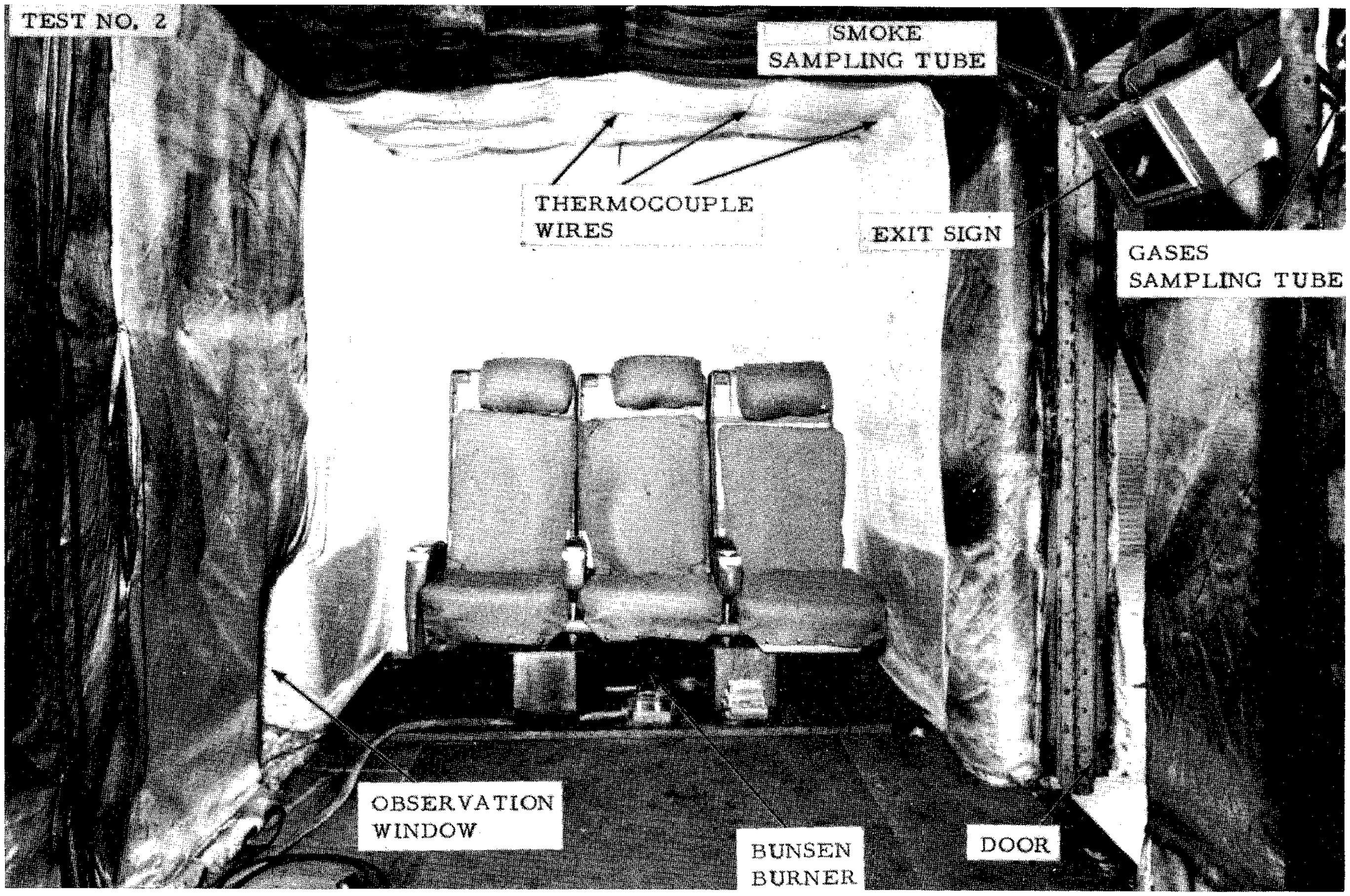


Figure 3A

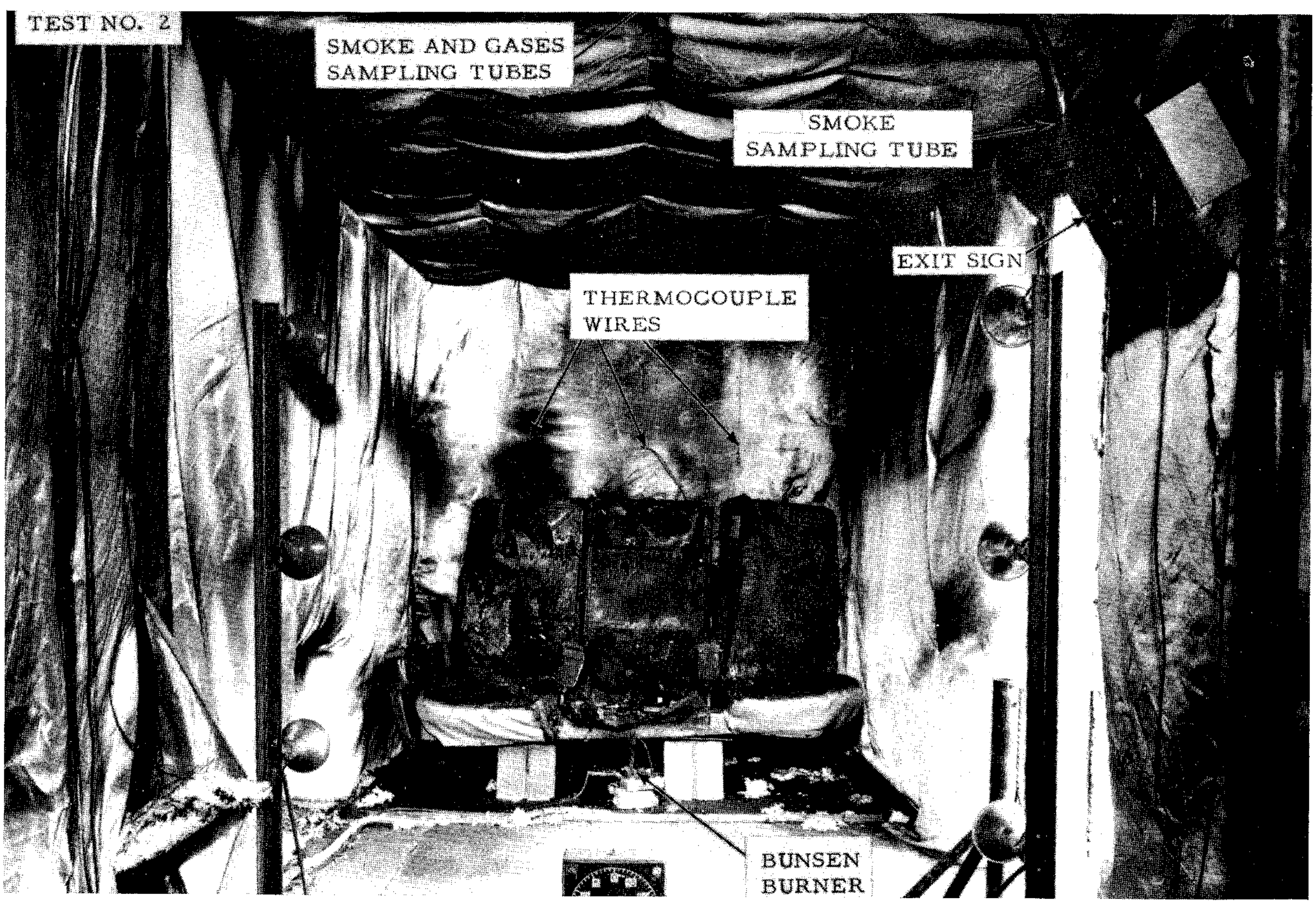
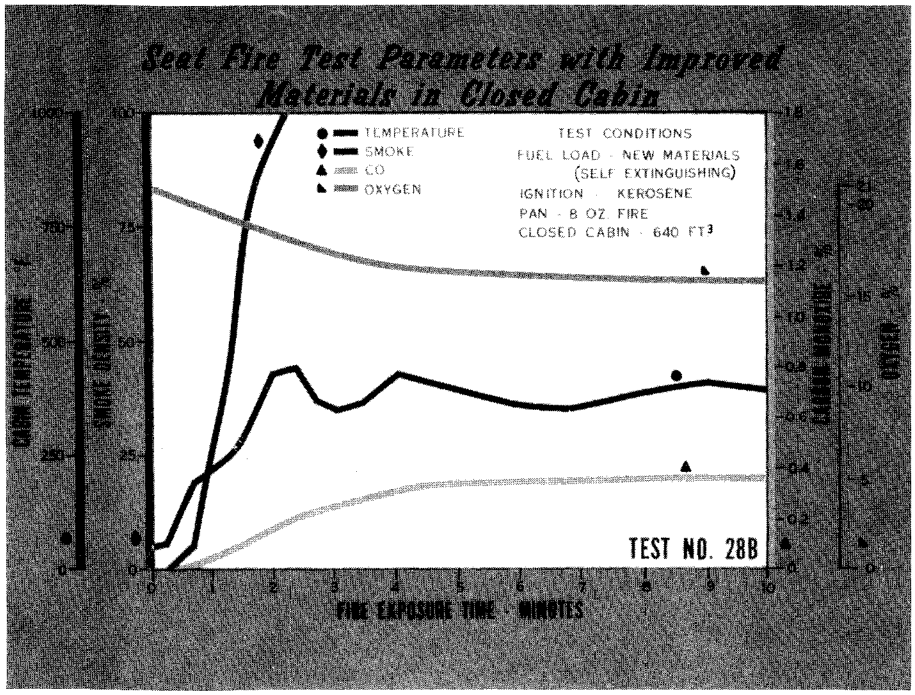
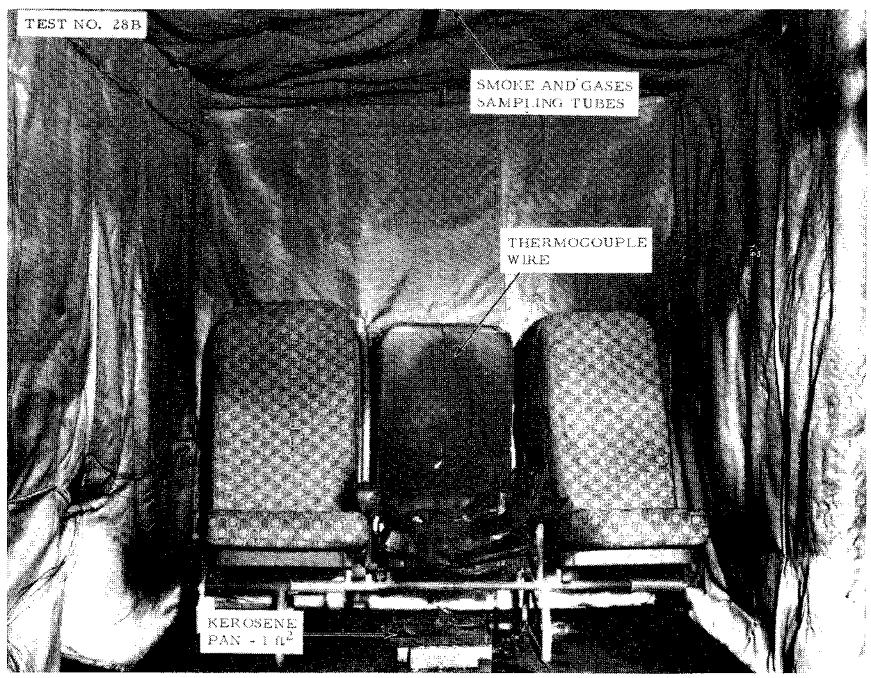


Figure 3B





In Figure 4 the only difference in the test conditions from that recorded by the previous slide is that the seat was constructed of self-extinguishing materials consisting of flame-retardant urethane foam for the cushions and Nomex for the upholstery fabric. Also since very little burning was obtained using a propane flame as in the previous slides, instead a kerosene fire was built under the seat to ignite the materials. With the much larger ignition source, smoke develops very rapidly and there is complete obscuration of the exit sign within less than 2 minutes. Maximum carbon monoxide only reaches 0.4 percent, while maximum ceiling temperature only reaches 400^{o}F. There is no flash fire as evidenced by the gradual decline of the oxygen curve. Although the kerosene flames were large, only the middle seat suffered some fire damage The two adjoining seats of the assembly sustained almost no damage.

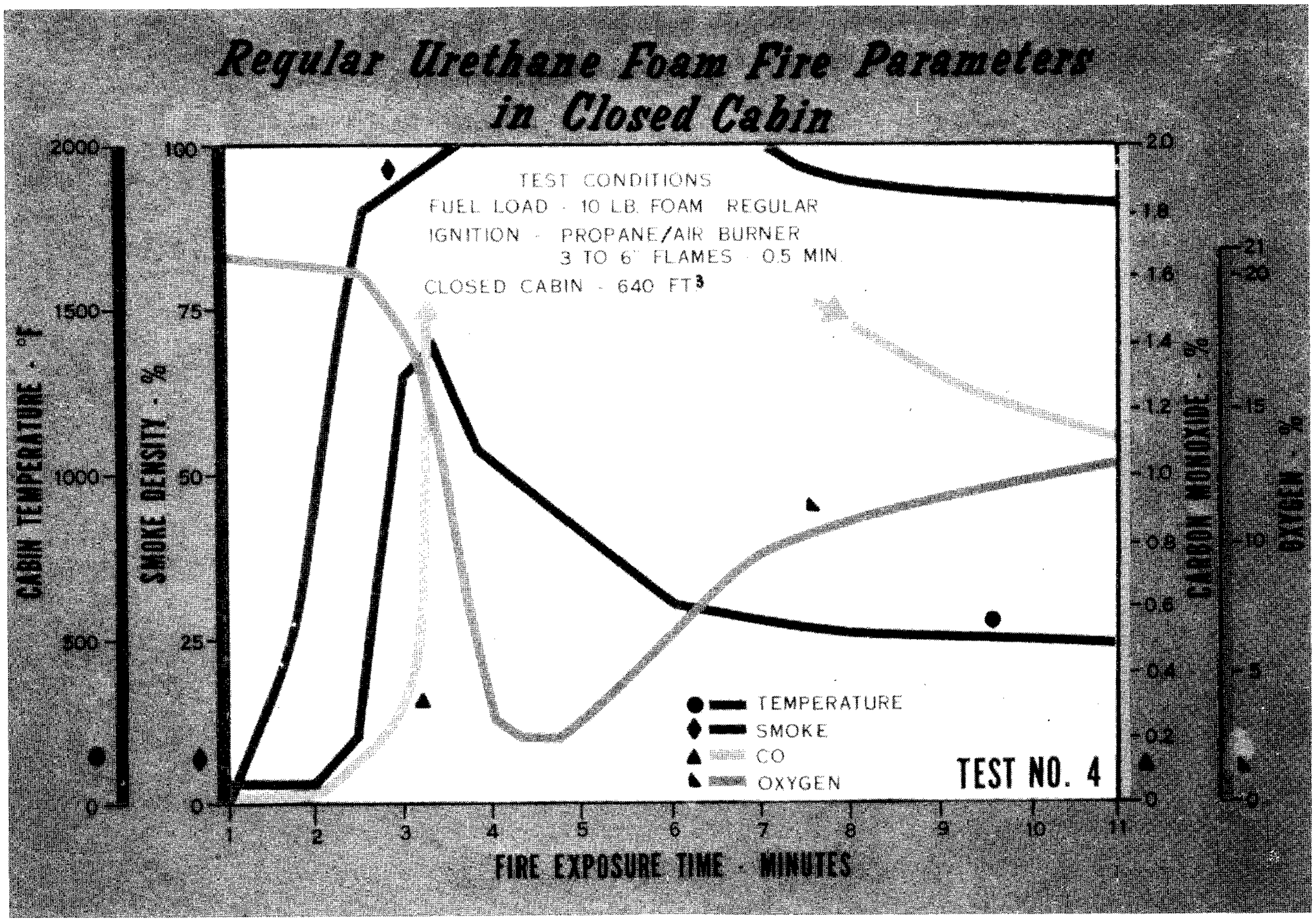


Figure 5 shows a series of curves of a urethane foam pad fire ignited from below by a small propane torch. After 60 seconds, when self-flaming of the foam had occurred, the ignition source was extinguished. Rapid generation of smoke occurred after 1 minute. Another minute was required before the cabin ceiling temperature and carbon monoxide began to register in increase. At about 2.5 minutes, when smoke had reached the 90% obscuration level, both temperature and carbon monoxide experienced a very rapid rise, with temperature going up to 1500°F and carbon monoxide going off scale at 1.5%. A corresponding rapid depletion of oxygen in the air to about 3 percent occurs during the same period which is typical of the flash fire.

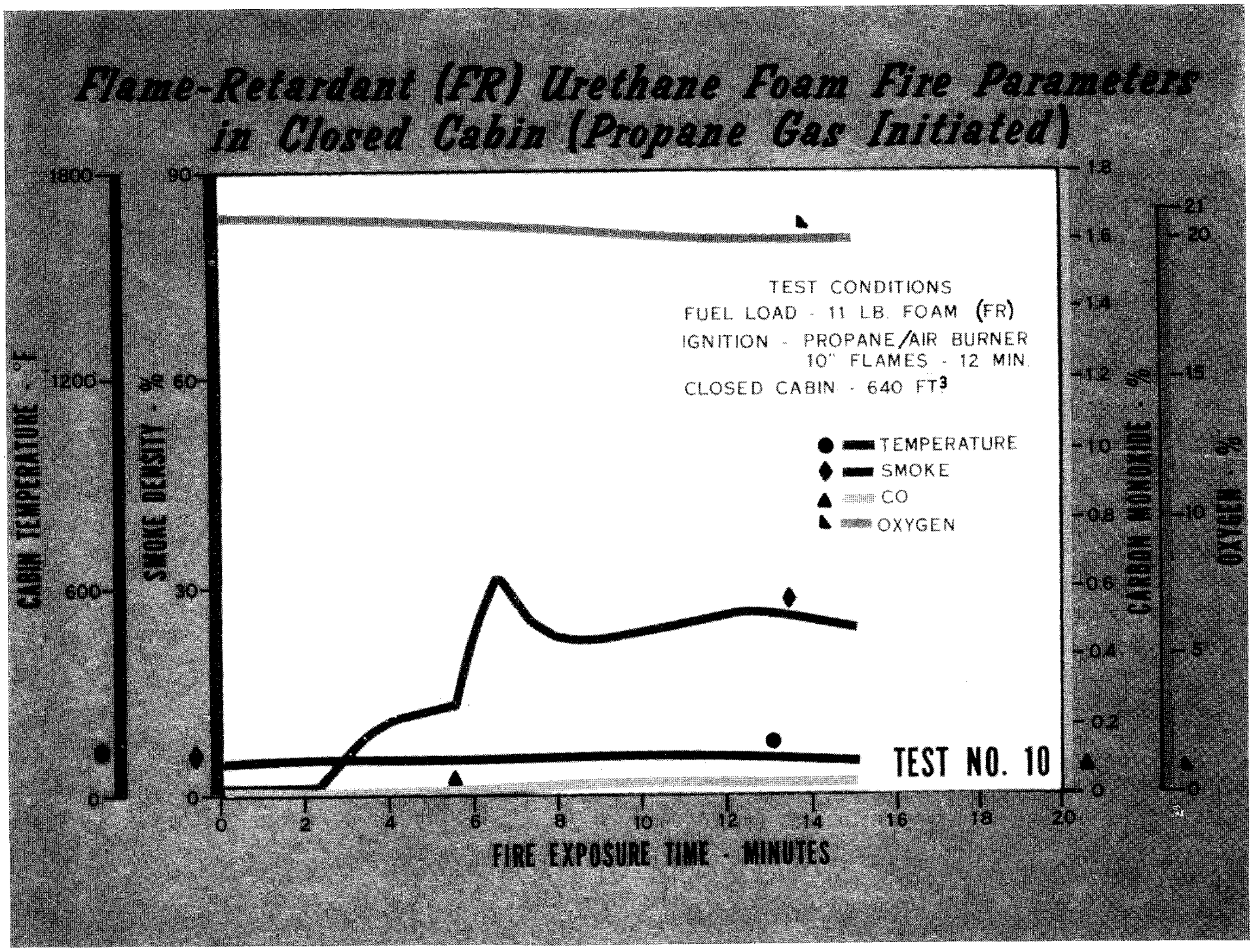
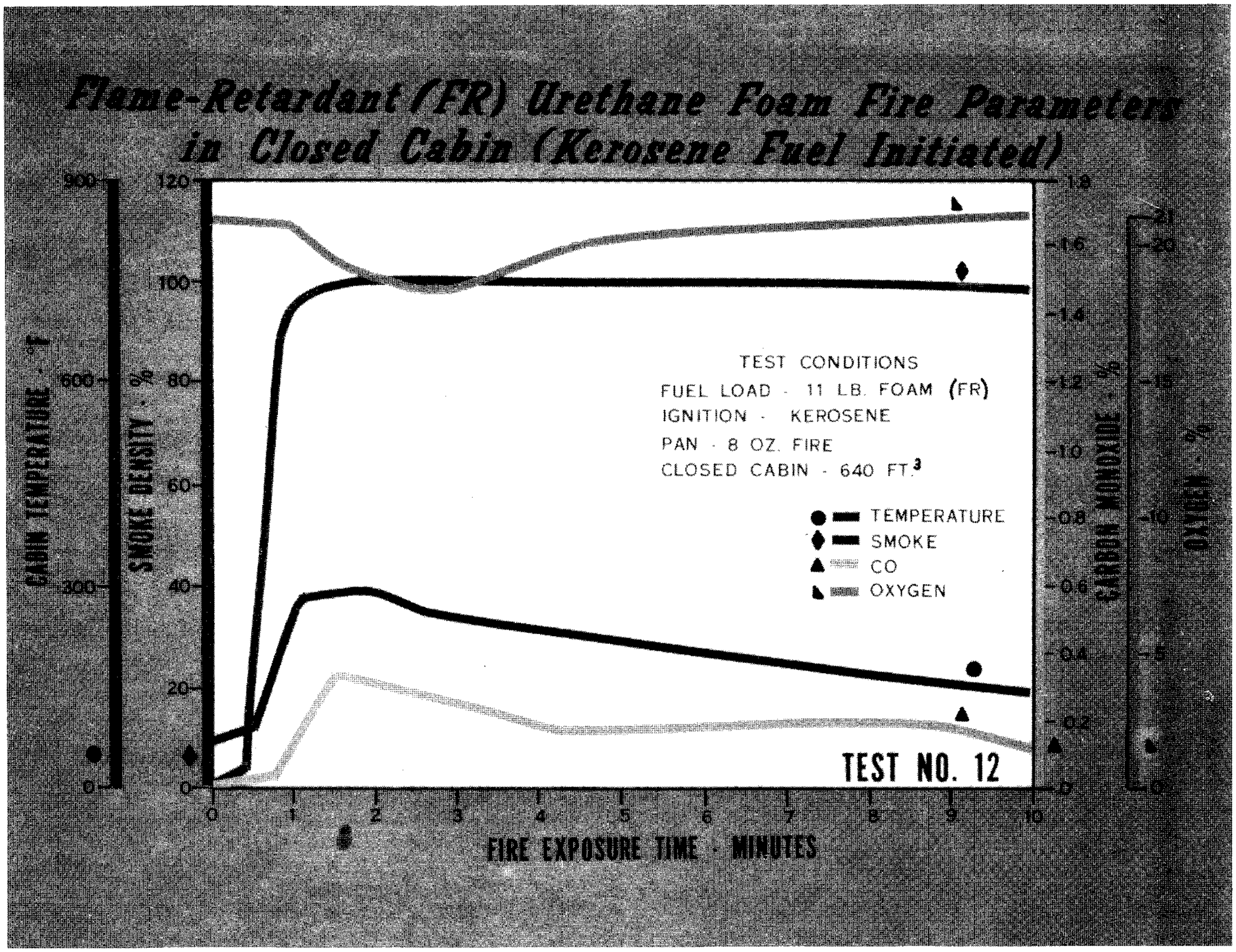
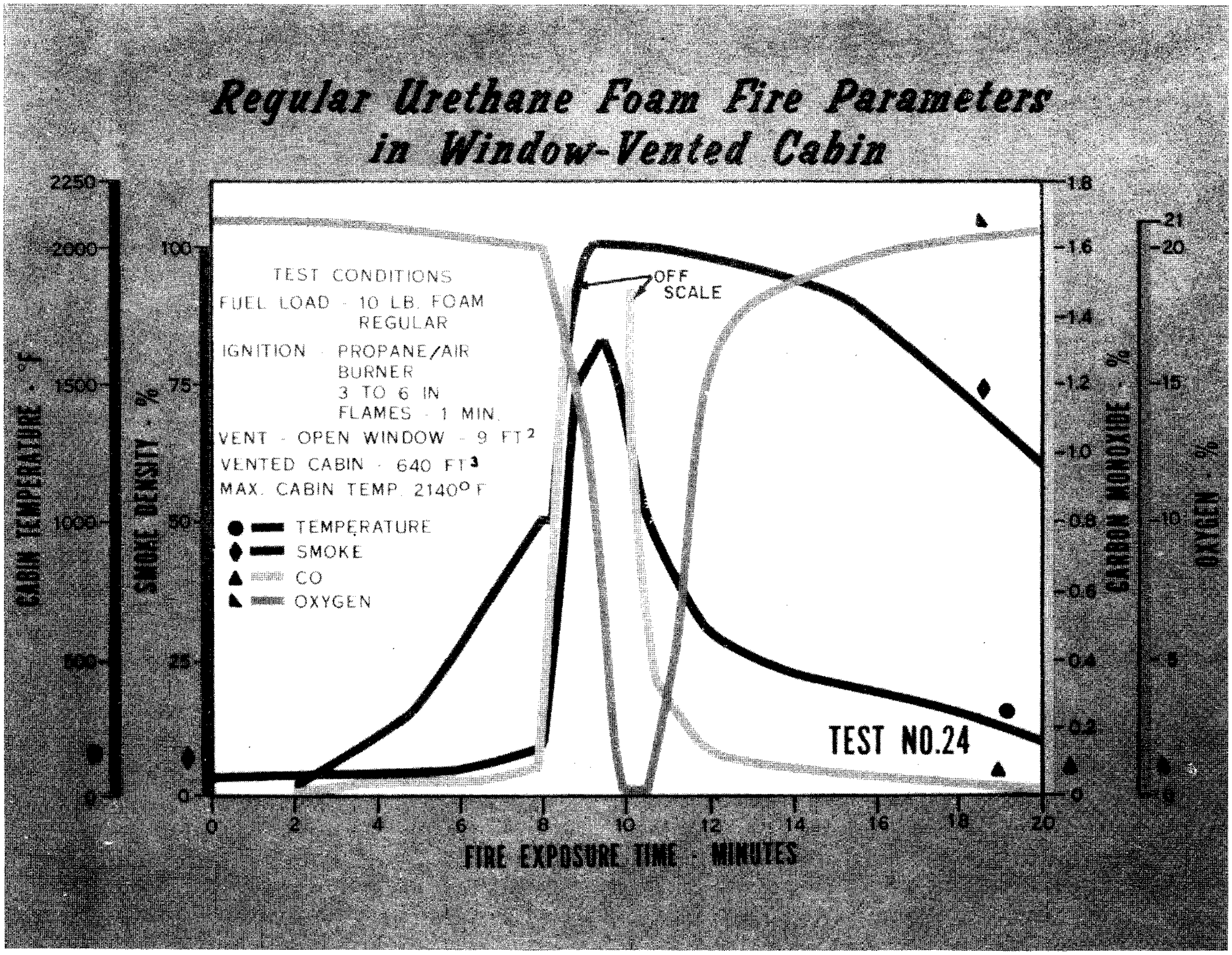


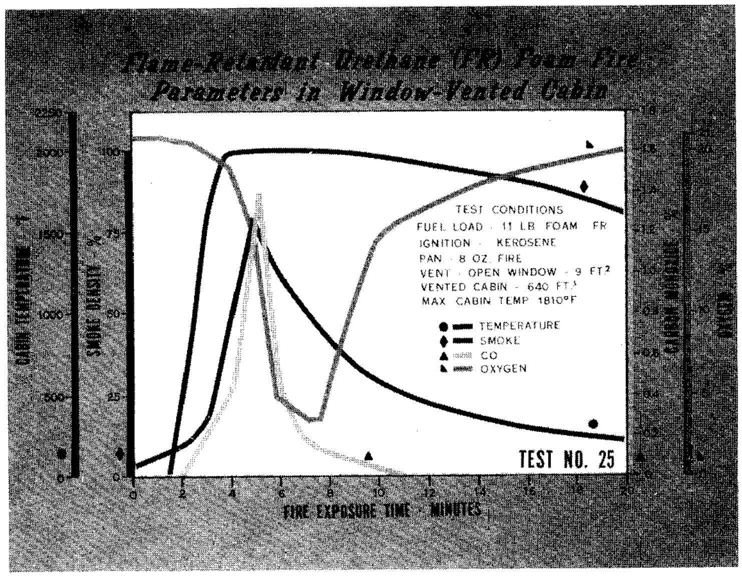
Figure 6 shows a series of curves of a flame-retardant (FR) urethane foam fire in the closed mockup. The foam is very similar in appearance and feel to the foam used to produce the experience shown in Figure 5, except that it has been treated with chemical additives to make it self-extinguishing. This foam is being used in the new wide-bodied jet transports, although as yet there is no official FAA requirement for its use. In the test the propane flame, 10 inches in height and held in contact for 12 minutes with the underside of the pad, only succeeded in burning a 3- to 6-inch circular hole through the 8-inch thick pad. There was no tendency for the foam to burn outside the area of direct burner flame impingement. The curves show no increase in temperature, and a very slight effect on oxygen content or carbon monoxide. The only significant parameter to register any increase is smoke. This reaches a 30 percent level which was not high enough to obscure the exit sign.



In Figure 7, the test conditions were the same as in the previous slide (FR urethane foam) except that a much larger ignition source--a kerosene fire--was used for burning the foam. Smoke is shown to develop very rapidly and completely obscures the cabin within a half minute. Temperature reaches a maximum of 300°F. Oxygen drops to only 18 percent. Carbon monoxide increases to 0.3 percent. Drop in temperature and increase in oxygen from cabin leakage show that the combustion of the foam ceased after the kerosene was consumed in about 3 minutes. There was no flash fire in this test.



In Figure 8, the test conditions differ from those in the previous slide in that the burning of the non-treated foam took place in a vented cabin instead of in a closed cabin. The effect of the 9-foot square open window is seen by the more gradual increase that takes place in both the temperature and carbon monoxide during the early phase of the fire, especially after 6 minutes when smoke had reached a 50-percent obscuration level. Of particular interest, is the sharp increase in temperature, smoke and carbon monoxide which occurs at 8 minutes with a corresponding rapid drop in oxygen down to zero. It is surprising that even with a 9-foot square open window that combustible gases could accumulate at the ceiling in sufficient concentrations to develop into a severe flash fire. Rapid recovery of oxygen, decrease in temperature, smoke and carbon monoxide as shown by the curves, after the flash fire, indicate the effect of the opening in allowing the products of combustion to be expelled and fresh air admitted. Very high temperatures of over 2000°F were recorded and the foam was totally consumed within a few minutes.



In Figure 9, the test conditions were the same as in the previous slide except that FR urethane foam instead of the untreated foam was burned in the vented cabin. The curves are similar to those obtained in the fire tests on the regular foam. The very rapid rise in temperature from 250°F to 1700°F within 1 minute accompanied by a rapid drop in oxygen down to 3 percent is typical of the flash fire. Complete destruction of the FR foam and very high temperatures were obtained for the ventilated cabin. The results were unexpected on the basis of outdoors fire tests on the same foam materials. In the outdoor tests, the FR foam was self-extinguishing to a kerosene fire and was only partially consumed in the area of direct flame impingement.

Note: Mr. Marcy presented a film presentation of some of the tests conducted. The first test series shown were with wool upholstery and regular urethane padding with a 30 second ignition from a propane-air burner. The second test series shown were with nylon upholstery and regular urethane padding using a 60 second ignition from a propane-air burner. The third test series shown were with the improved seat using Nomex upholstery and flame-retardant urethane padding using a 10 minute ignition from a propane-air burner. The last test series used the same improved seat but the ignition was from a kerosene fire (8 ounces in a 1 foot-square pan) giving about a 3 minute burn time.

CONCLUSIONS.....

1. Flashover (i.e. Flash Fire) hazards within an airplane cabin from seat fires can largely be eliminated by the use of self-extinguishing materials.
2. Burning of flame-retardant (FR) foam can result in a flash fire, but only under conditions of severe heating with induced air drafts in a vented cabin.
3. Extensive damage and temperatures over 2000° F can result from a ventilated cabin fire.
4. Dense smoke develops very rapidly during the early stages of a cabin fire involving seat materials, well before any significant increases in air temperature and carbon monoxide are experienced that could be considered harmful.
5. Although laboratory tests provide useful data on the fire hazards of materials, these tests should be supplemented by tests on complete assemblies inside a cabin mockup.

Figure 10 shows the conclusions derived from the fire tests in which aircraft seats and urethane foam pads were burned under various controlled conditions.