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ADVANCED CONCEPT IN AIRCRAFT CRASH FIREFIGHTING USING CARBON TETRAFLUORIDE

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16. Abstract

The objective of this effort was to establish the feasibility of replacing a potentially lethal aircraft cabin environment with a cool habitable atmosphere which is nonsupportive of combustion during passenger evacuation in fire emergencies. For this purpose, carbon tetrafluoride (CF_4) was chosen as the fire extinguishant because of its very low toxicity and high molecular stability under thermal insult.

Four large-scale experiments were performed in the completely instrumented cabin of a DC7 aircraft employing both Class A and B combustable materials. Three experiments were performed using the habitable inert atmosphere (27-volume percent CF_4) discharging at the rate of 3,300 cubic feet per minute into the aircraft cabin through a window exit. For comparative purposes, the fourth experiment was performed using neat CF_4 discharged from two simulated points of fuselage penetration by a ballistically-powered aircraft skin penetrator nozzle. Both of these prototype fire extinguishing systems were designed to be employed by airport crash-fire-rescue services to extinguish aircraft cabin and compartment fires.

The CF_4-air atmosphere was capable of extinguishing nonsurvivable Class A and B cabin fires within 125 seconds or less during which time the cabin temperature was rapidly reduced and visual acuity slowly improved by smoke dilution during the Class A fire tests. Fire extinguishment by means of neat CF_4 at the same discharge rate required approximately twice as long, and visibility within the cabin did not improve during the duration of the experiment.

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

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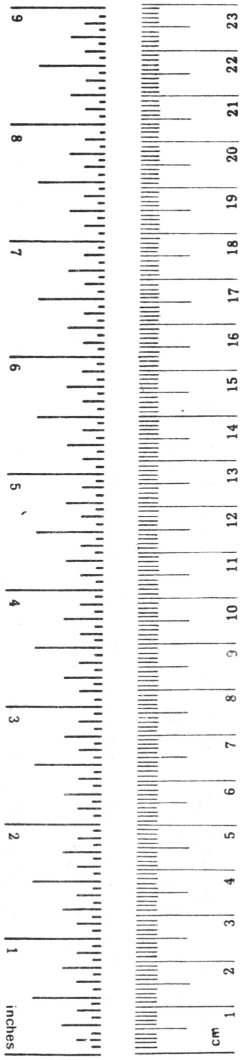
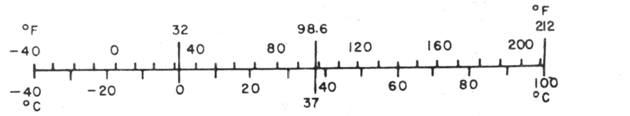
*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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INTRODUCTION

PURPOSE.

The project objectives were: (1) to establish the feasibility of replacing a potentially lethal aircraft cabin environment with a cool, habitable atmosphere containing approximately 75 percent air and 25 percent carbon tetrafluoride (CF_4) by volume, which is nonsupportive of combustion, during fire emergency evacuation procedures, and (2) to determine the fire extinguishing effectiveness of neat CF_4 when it is injected into an aircraft cabin by means of a ballistic skin penetrator nozzle.

BACKGROUND.

One of the principal objectives of the crash-fire-rescue (CFR) services is to respond to aircraft accidents/incidents and extinguish all exterior fires to permit the safe self-evacuation of occupants. However, this limited scope objective is currently being reviewed by experts in the field. Accident reports are existent in which the CFR services accomplished their basic mission, but the aircraft was subsequently lost because of the uncontrollable interior cabin fires which had been ignited by external fuel spill fires. One well-documented example (reference 1), illustrative of these conditions, is the United Airlines DC8 accident at Stapleton Airport, Denver, Colorado, which resulted in 17 fatalities, 16 of which were caused by carbon monoxide poisoning, and the subsequent loss of the aircraft.

From this and similar accident situations it is apparent that the polymeric cabin furnishings which contain carbon, hydrogen, and halogen atoms in combination with lesser amounts of nitrogen, sulfur etc., are potentially capable of high temperature combustion and/or pyrolysis, thereby producing an extremely toxic aircraft cabin environment if the ignition source is of sufficient magnitude. That devastating thermal conditions develop very rapidly was demonstrated in reference 2 in which simulated aviation fuel spill fires adjacent to an aircraft fuselage reached equilibrium burning conditions with flame temperatures between 1,500 and 1,700 degrees Fahrenheit (°F) within 90 seconds causing a 0.125-inch-thick aluminum aircraft skin panel to fail (melt) within 53 seconds. Therefore, serious consideration is being devoted to various means of providing the CFR services with new and more effective tools and equipment to combat complex three-dimensional Class A cabin fires as well as the external aviation fuel spill fires. The principal concern of these efforts is to provide an increase in the safe passenger self-evacuation time and a potential reduction in property loss.

DISCUSSION

COMPOSITION OF HABITABLE ATMOSPHERES WHICH WILL NOT SUPPORT COMBUSTION.

A study of chemical literature indicates that inert atmospheres can be developed which are nonsupportive of the ordinary combustion process, but which are life supporting for animals and humans over more or less extended periods of time. The most attractive candidates from the toxicological standpoint are the first three completely fluorinated members of the methane series of saturated hydrocarbons defined by the general formula $C_nH_{2n}+2$ (where n = a whole number). These agents are identified as tetrafluoromethane (carbon tetrafluoride) CF_4 (Halon 1400), hexafluoroethane C_2F_6 (Halon 2600), and octafluoropropane C_3F_8 (Halon 3800). The agents are physiologically inert in use concentrations of approximately 20 percent or less by volume. A summary of one animal toxicological study is presented in appendix A.

The amount of each of these compounds in air, required to suppress the combustion of tissue paper (reference 3), which was determined to be the most flammable Class A material tested and requires the highest concentration of each agent for combustion suppression was Halon 1400, 20 percent; Halon 2600, 12 percent; and Halon 3800, 10 percent. By comparison, bromotrifluoromethane CF_3Br (Halon 1301), which is commonly employed as a total flooding fire extinguishant (reference 4), required 5 percent by volume of air to suppress the combustion of tissue paper.

An assessment of the potential toxicity of the fluorocarbons (reference 4) was conducted in respiratory studies in which male rats were exposed to atmospheres containing 80 percent of the neat agent and 20 percent of oxygen by volume for 1 hour. The effects of exposure were observed during the testing and for 14 days after exposure. In additional studies, prolonged exposure tests were conducted with rats and guinea pigs in which the animals were exposed continuously for 10 days to air-atmospheres containing each fluorocarbon in its proposed use concentration; i.e., Halon 1400, 20 percent; Halon 2600, 10 percent; Halon 3800, 10 percent; and Halon 1301, 5 percent. The results of both of these studies showed no adverse physiological effects from exposure of the animals to any of these agents.

When male rats were exposed to an environment in which fires had been started and extinguished, dyspnea and other respiratory symptoms (reference 3) were evident in the animals to varying degrees depending upon the extinguishing agent and test conditions employed. Notwithstanding these symptoms, the results of the experiments were favorable for the use of these fluorocarbons in extinguishing fires in confined areas. However, on the basis of the decomposition products produced (appendix A) by the various agents, only Halon 1400 appeared a likely candidate for application in confined habitable areas.

Therefore, a series of experiments was conducted with six male beagle dogs which had been sensitized with epinephrine and exposed to various concentrations of Halon 1400 in air (20 percent CF_4 - 80 percent air) and oxygen

(60 percent CF_4 - 40 percent oxygen). In these experiments, the only observed responses were occasional preventricular contractions in three of the dogs with no arrhythmias occurring. This very mild response to large dosages of epinephrine administered in these animal studies tends to validate the safety aspects of using Halon 1400 to develop habitable atmospheres for use in extinguishing aircraft cabin fires.

PROPERTIES OF CF_4. The use of fire extinguishing agents requires not only a knowledge of their effectiveness, but also an assessment of any potential adverse effects upon the safety and health of aircraft passengers as well as their ecological impact. The fire extinguishing effectiveness and toxicity of Halon 1400 and its pyrolysis products are treated in detail in other sections of this report.

Molecular Stability. The principal reason for investigating the use of Halon 1400 as an aircraft cabin fire extinguishant was its chemical and thermal inertness. The relative stability of Halon 1400 and Halon 2600 is illustrated in table 1 which shows the bond dissociation energies for the weakest bond in the molecule (reference 5); Halon 1301 is included for comparison. From these dissociation energies it is apparent that CF_4 is significantly more stable than the other halogenated hydrocarbons.

TABLE 1. BOND DISSOCIATION ENERGIES FOR THE HALOCARBONS

$CF_4 \longrightarrow CF_3 - F$:	121 kilo calorie (k cal)/mole
$C_2F_6 \longrightarrow CF_3 - CF_3$:	69 k cal/mole
$CF_3Br \longrightarrow CF_3 - Br$:	65 k cal/mole

Additional chemical, physical, thermodynamic, and radiation stability data for Halon 1400 are contained in appendix B.

INERT ATMOSPHERE GENERATING SYSTEM.

The inert atmosphere generating system is composed of a completely self-contained, weather-protected, variable-speed, electrically-driven, centrifugal fan having a variable air capacity between 2,000 and 4,500 cubic feet per minute (ft^3/min). A means was provided for proportioning Halon 1400 into the airstream at variable rates to achieve a concentration from 15 to 35 percent by volume. This atmosphere was dispensed through a 20-foot-long, 12-inch-diameter, flexible air conduit fitted with a diffuser terminal which was capable of a throw range of approximately 60 feet in both directions simultaneously. A diagram identifying the basic components of the aircraft ventilating system is presented in figure 1 with a more detailed specification of each component

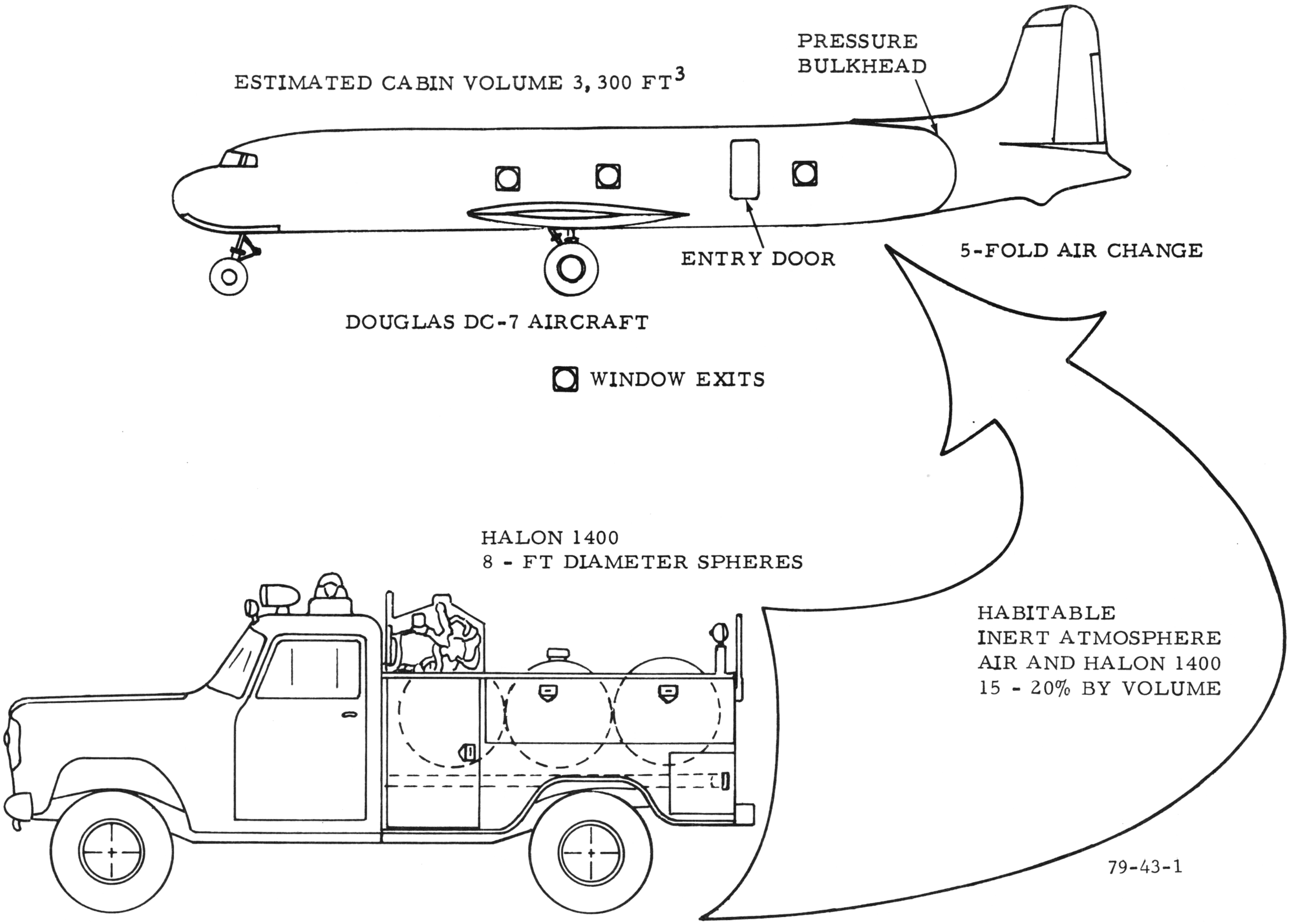


FIGURE 1. CONCEPTUAL DIAGRAM OF THE HALON 1400-AIR CABIN FIRE EXTINGUISHING SYSTEM TO INCREASE PASSENGER SAFE SELF-EVACUATION TIME

provided in appendix C. Figure 2 shows the skid mounted unit on a 1 1/2-ton truck bed in position for discharging the inerted atmosphere into a DC7 aircraft cabin through a window exit.

DC7 AIRCRAFT FIRE TEST BED.

The fire test bed was a DC7 aircraft from which the seats and galley equipment had been removed. A 20-foot-long section within the cabin, between stations 530 and 770 (figure 3) was fire-hardened by means of ceramic fiber insulation and sheet steel. After the existing paneling had been removed, it was replaced with a 2-inch-thick layer of Kaowool® (reference 6) which was supported over the formers by means of 20-gage, 1-inch mesh chicken wire. The ceramic insulation was supported by 2-inch-wide steel strips (figure 4) and subsequently covered with 24-gage cold rolled steel. To prevent direct flame impingement on this structure, a concentric metal flame deflector shield was suspended 9 inches below the ceiling, directly over the fire load. In addition, a welded steel pan 6 feet by 7.66 feet by 6 inches deep was provided in the fire-hardened area to contain any flaming Class A or Class B materials during each test sequence.

ANCILLARY FIRE PROTECTION SYSTEMS IN THE DC7 AIRCRAFT. To preclude the possibility of a catastrophic fire developing in those sections of the aircraft cabin which were not fire hardened, three ancillary fire protection systems were installed. The ceiling and sidewall panels were protected from possible ignition by a series of seven foam/water sprinkler heads of the type shown in figure 5 and installed at the stations indicated in figure 6. This system was capable of discharging a solution of Aqueous-Film-Forming-Foam (AFFF) at the rate of 90 gallons per minute through an external coupling to a foam firefighting vehicle.

In an attempt to inhibit or delay the development and propagation of an overhead flash fire during the tests, a series of seven flame barriers was constructed by suspending 30 mesh wire screens vertically from the ceiling at the stations indicated in figure 6 and in the manner shown in figure 7. Although this conceptual means of controlling the propagation of flash fires in an aircraft is new and therefore unproven, the principle was proven to be eminently successful in preventing flaming, combustible gases from propagating through wire mesh grids of the proper size by Sir Humphry Davy in 1803. Prior to installing the flame barriers, laboratory experiments were conducted. The data from these experiments were utilized to obtain the proper mesh configuration which was employed in this testing.

Although the first two systems were believed capable of providing adequate overall cabin fire protection, the first line of defense in a runaway fire situation was considered to be two spray nozzles, one of which was positioned on either side of the fire load (figure 8) 44 inches above floor level at fuselage station 637 (figure 6). Each nozzle was capable of discharging AFFF solution at the rate of 40 gallons per minute. AFFF was the agent of choice for this application because its low surface tension (15 dynes per centimeter)

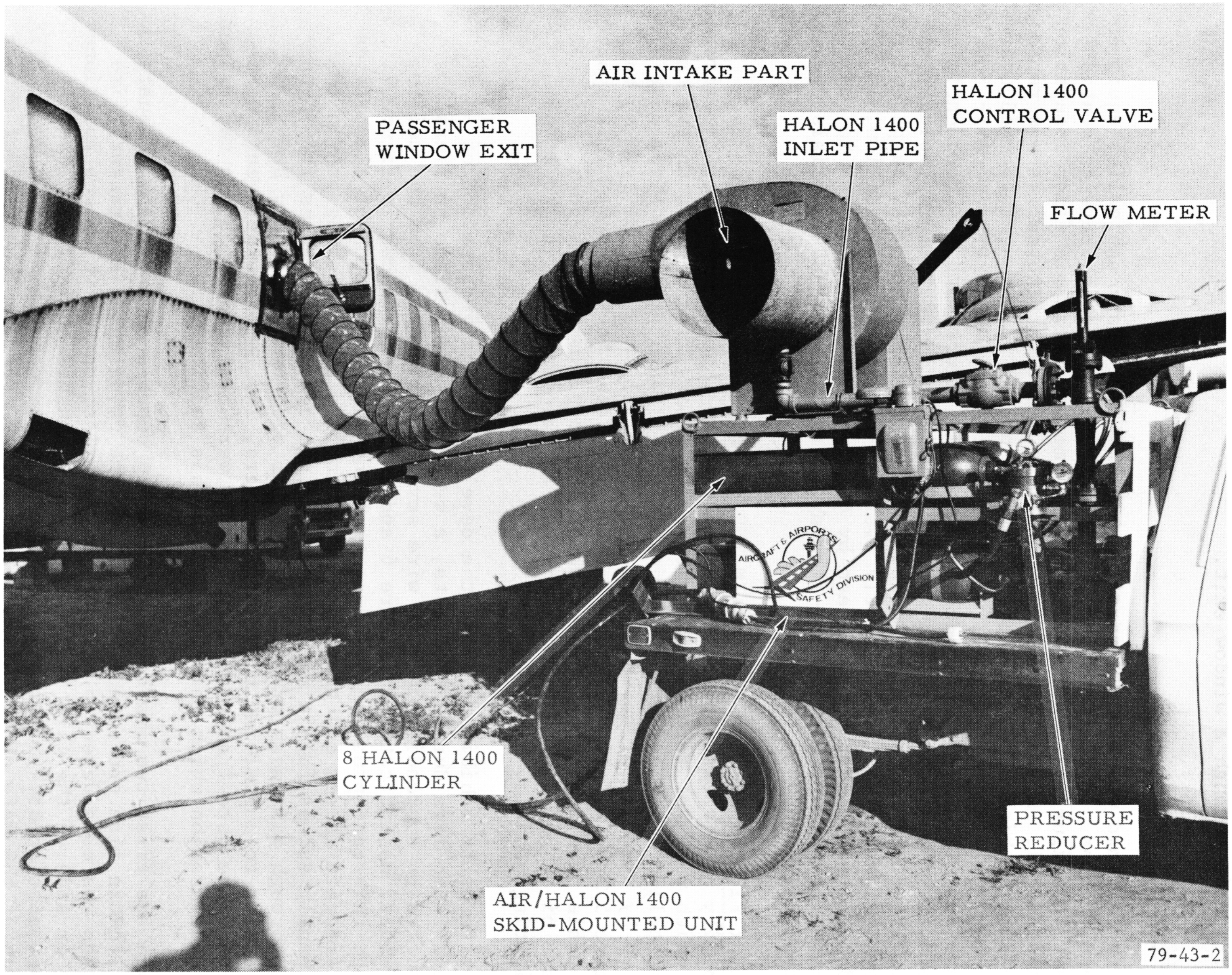


FIGURE 2. AIRCRAFT CABIN HALON 1400-AIR FIRE EXTINGUISHING SYSTEM IN POSITION FOR USE

FIGURE 3. VIEW OF THE DC7 AIRCRAFT FIRE-HARDENED AREA DURING CONSTRUCTION

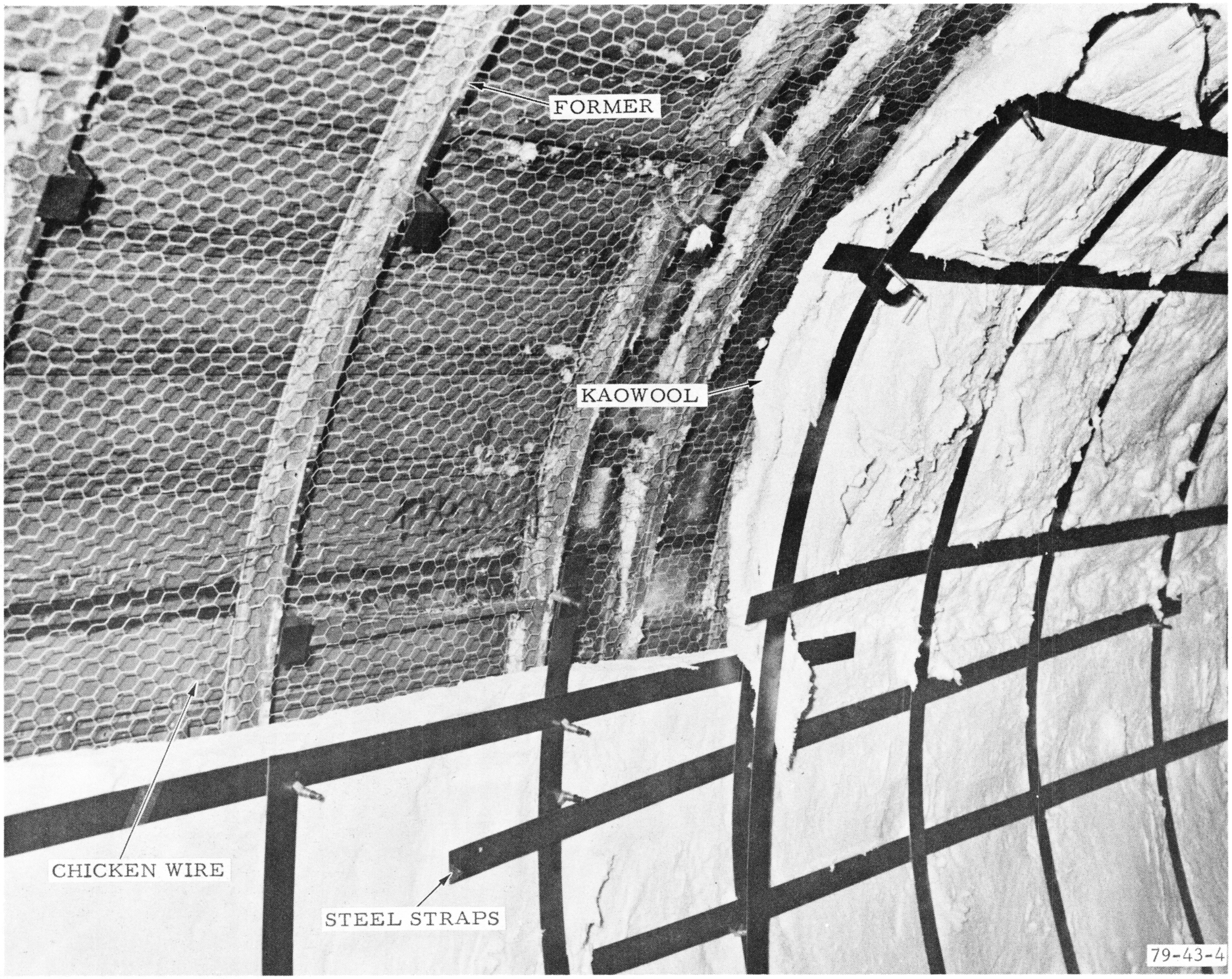


FIGURE 4. CONFIGURATION OF THE FIRE-HARDENED AREA

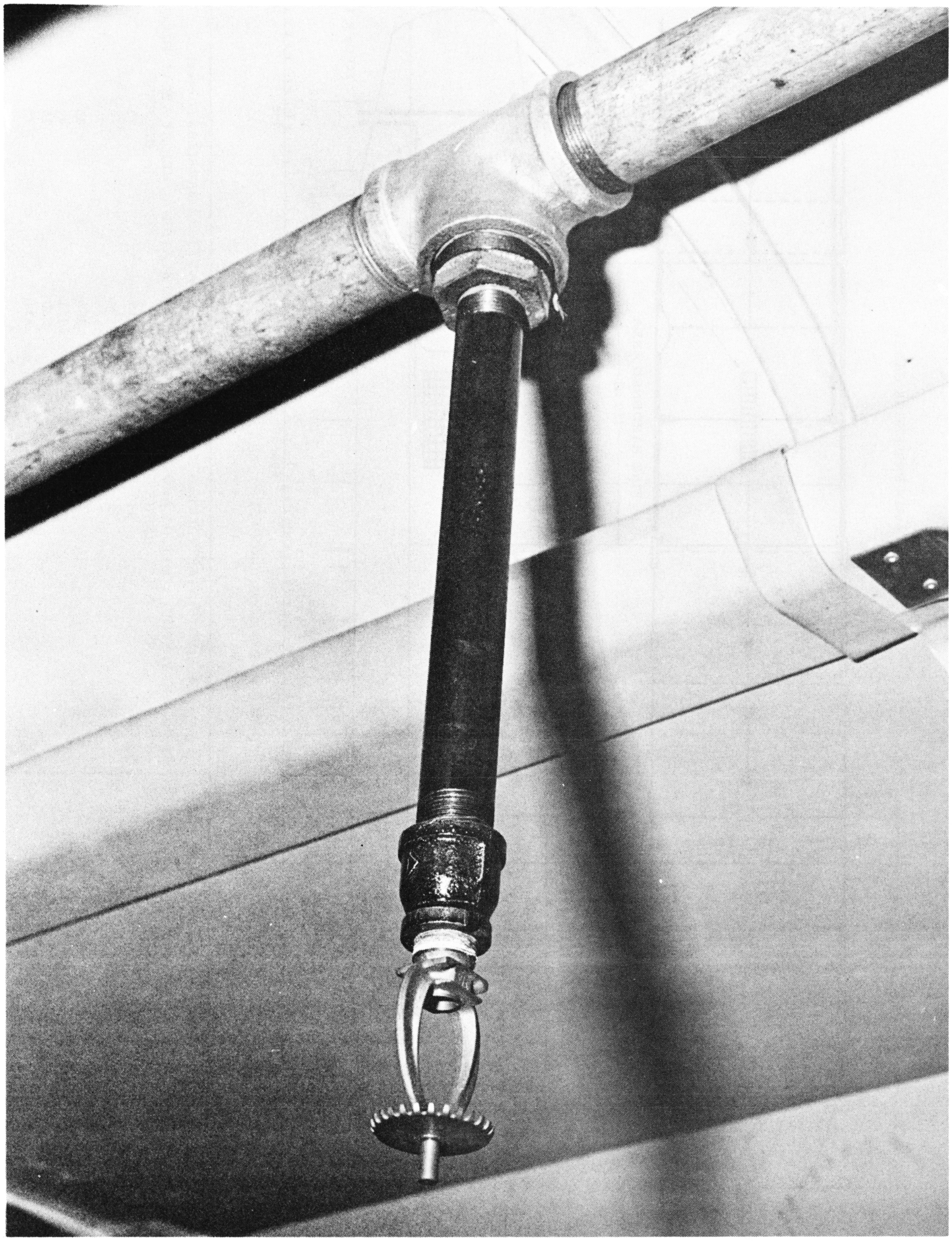
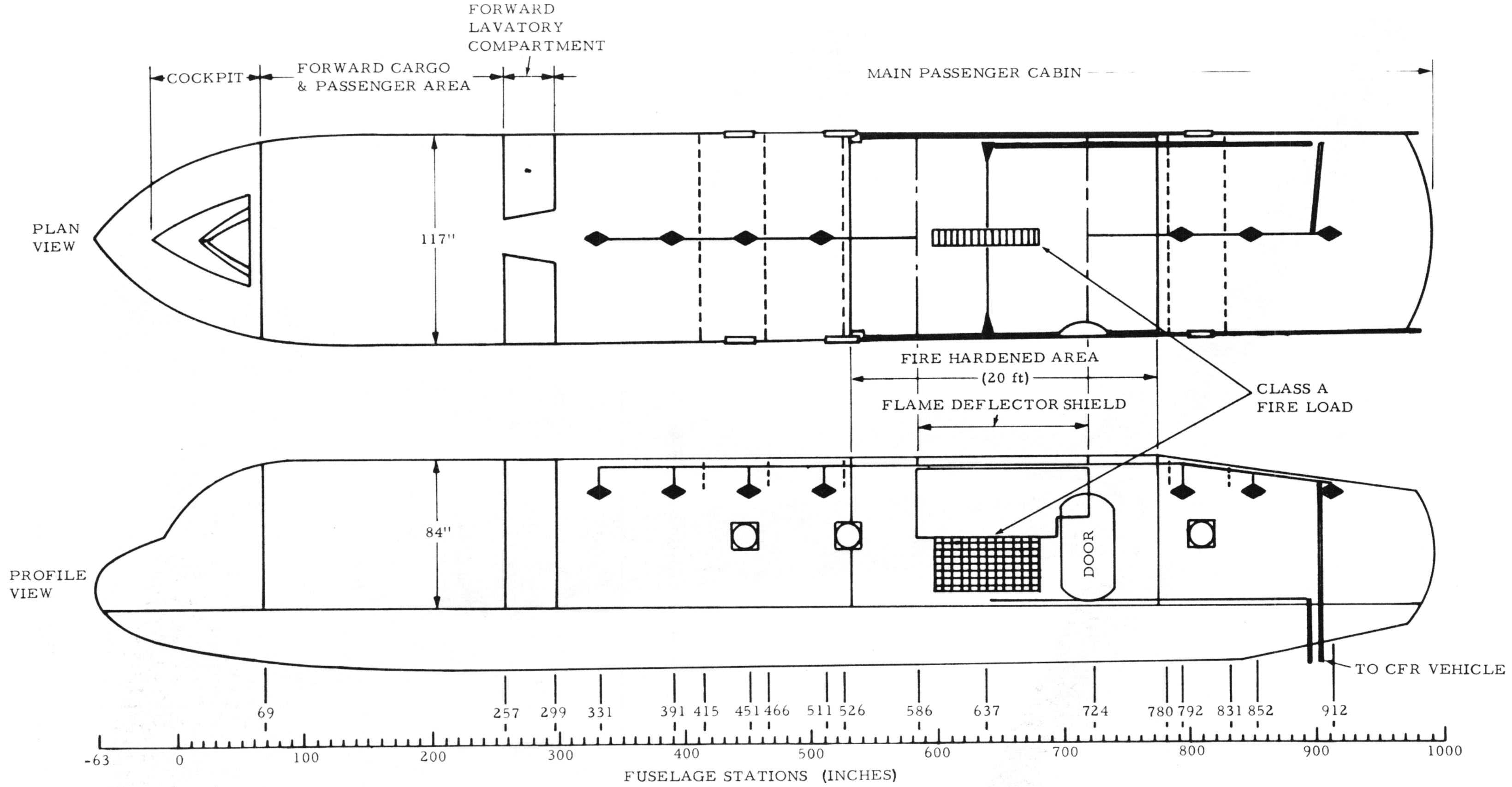


FIGURE 5. FOAM-WATER (AFFF) SPRINLKER HEAD



◆ - ONBOARD AFFF OVERHEAD SPRINKLERS (7 each)

FUSELAGE STATION	HEIGHT ABOVE FLOOR (INCHES)
331	72
391	72
451	72
511	72
792	72
852	72
912	72

▲ - AFFF FOAM WATER NOZZLES (2 each)

FUSELAGE STATION	HEIGHT ABOVE FLOOR (INCHES)
637	44
637	44

¦ - FLASH FIRE BARRIERS (7 each)

FUSELAGE STATION	HEIGHT ABOVE FLOOR (INCHES)
415	75
466	75
526	75
586	80
724	80
780	75
831	75

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FIGURE 6. DC7 AIRCRAFT CABIN ANCILLARY FIRE PROTECTION SYSTEM

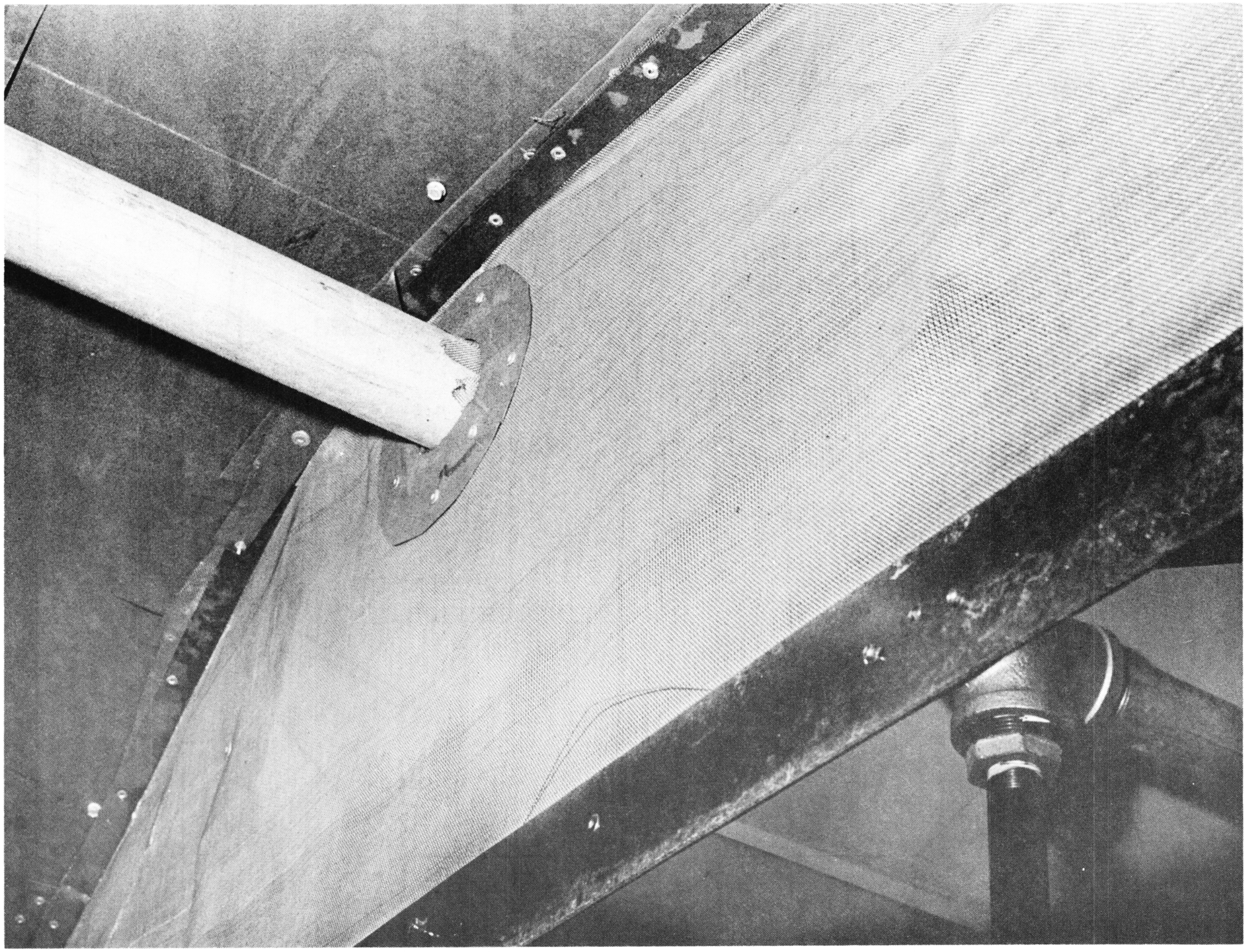


FIGURE 7. ONE OF SEVEN FLASH-FIRE RETARDING SCREENS INSTALLED IN THE CEILING OF THE DC7 AIRCRAFT

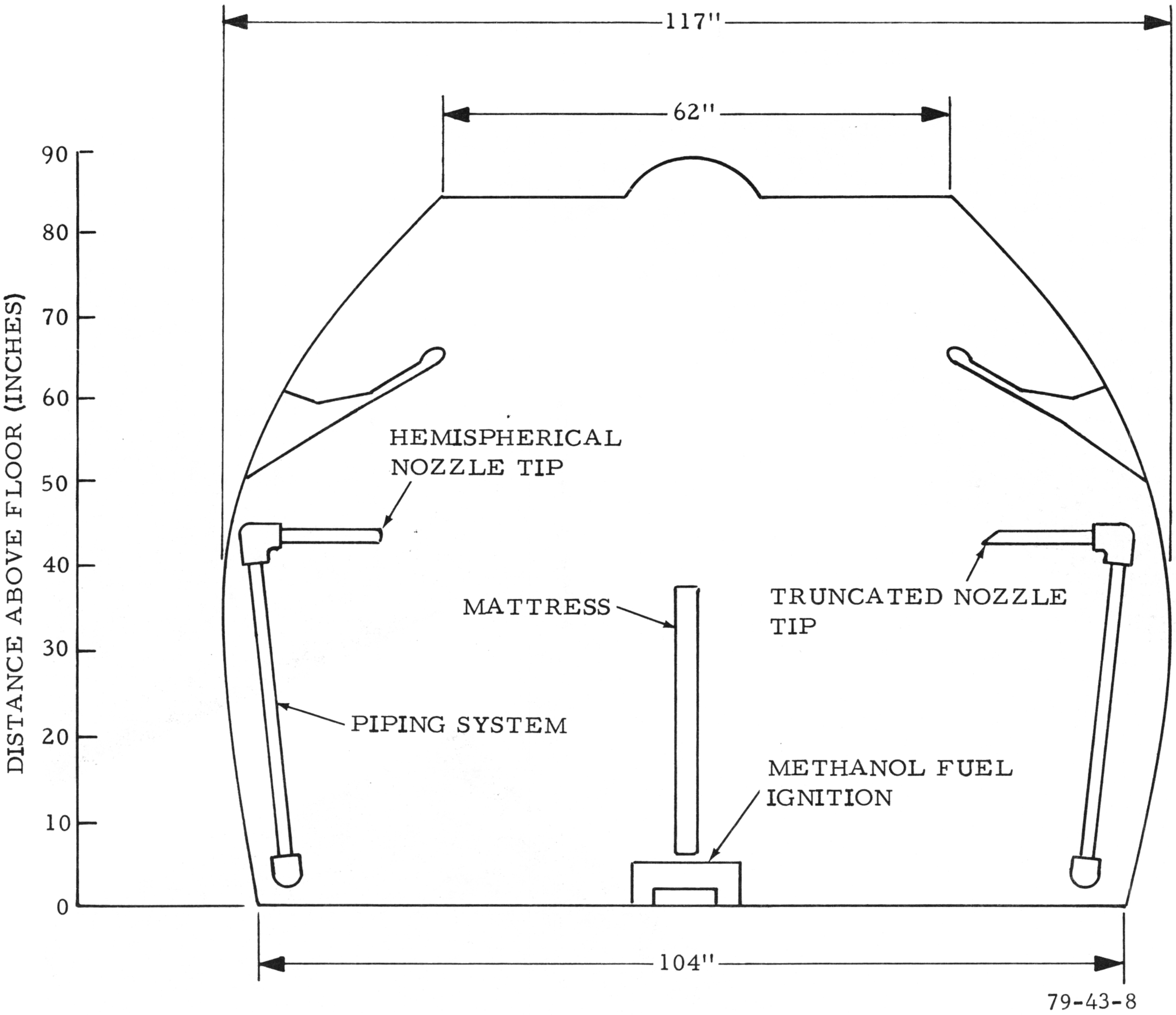


FIGURE 8. SECTIONAL DIAGRAM THROUGH THE DC7 AIRCRAFT CABIN AT STATION 637 SHOWING THE AFFF NOZZLE INSTALLATIONS

permitted rapid wetting and penetration of the Class A combustibles as well as providing a foam blanket and aqueous film over the surface of the Class B fuel.

These two AFFF nozzles were subsequently used to simulate two points of fuselage penetration by the United States (U.S.) Air Force's penetrator nozzle to extinguish a Class A (mattress) fire by means of neat Halon 1400.

INSTRUMENTATION.

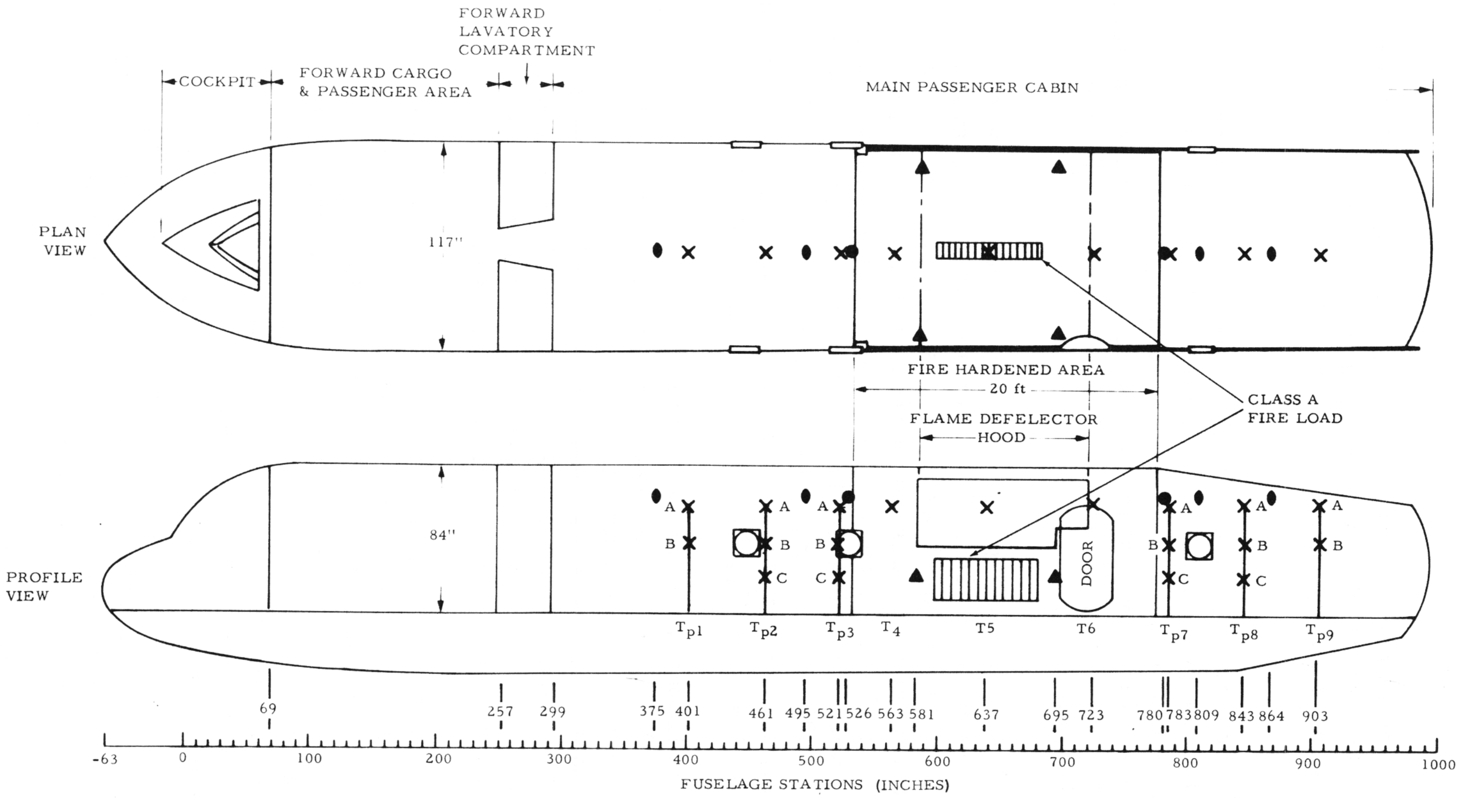
General. The thermal effects of the fires on the interior environment of the aircraft were monitored principally by means of thermocouples, radiometers, calorimeters, and smoke meters positioned strategically within the cabin (figure 9). Additional instrumentation included a video tape camera, instrumentation cameras, and gas sampling apparatus. The position of each of these elements is identified in figure 10.

Thermocouple Positions. Nineteen thermocouples (chromel-alumel) were strategically distributed throughout the aircraft cabin in various arrays and at different elevations above floor level as indicated in figure 9. One of the principle uses of the thermocouples was to monitor the cabin environment in terms of human survival during the fire buildup period. Unsurvivable conditions were considered to exist when from 1/4 to 1/3 of the cabin atmosphere rose to temperatures between 290° to 300° F. To maintain uniform test condition, insofar as practicable, the Halon 1400-air fire extinguisher was energized when any one of the thermocouples at stations T_4, T_5, or T_6 reached 290° F.

Thermal Radiation. Four radiometers were positioned on either side of the fire-hardened section of the test bed at stations 581 and 645. This location was 25 inches above floor level and approximately 77 inches from the center of the fire load. Additional thermal data were obtained from two calorimeters positioned along the centerline of the fuselage, 67 inches above floor level at stations 562 and 780. The calorimeters were used principally as backup instrumentation for assessing human tolerance, if required.

In addition to the thermocouples, the radiometers were also employed to monitor the aircraft cabin in terms of passenger survival during evacuation. A practical estimation of the intensity of thermal radiation may be made by considering the fact that approximately 0.10 British thermal unit per square foot per second (Btu/ft^2-sec) is delivered by the sun, at sea level, during the summer months in the temperate zone. Also, exposure to 0.2 Btu/ft^2-sec for periods in excess of 30 seconds will cause severe pain in humans. Accordingly, 0.2 Btu/ft^2-sec was established as a radiation level capable of contributing significantly to prolonging passenger self evacuation. Fire extinguishment was therefore, initiated when either the air temperature reached a minimum of 290° F or the radiation level was 0.2 Btu/ft^2-sec or above when measured within the fire-hardened section.

Determination Of Smoke Density. Two methods were employed to assess the relative visual obscuration of the aircraft cabin interior by smoke as the fire progressed. Four photoelectric cell, smoke-density meters were installed along the centerline of the aircraft cabin 68 inches above floor level at the



● SMOKE METERS (4 each)

FUSELAGE STATION	HEIGHT ABOVE FLOOR (INCHES)
375	68
495	68
809	68
864	68

× THERMOCOUPLES (19 each)

FUSELAGE STATION	HEIGHT ABOVE FLOOR (INCHES)		
	A	B	C
401	66	40	
461	66	40	20
521	66	40	20
563	66		
637	66		
723	66		
783	66	40	20
843	66	40	20
903	66	40	

▲ RADIOMETERS (4 each)

FUSELAGE STATION	HEIGHT ABOVE FLOOR (INCHES)
581	25
581	25
695	25
695	25

● CALORIMETERS (2 each)

FUSELAGE STATION	HEIGHT ABOVE FLOOR (INCHES)
526	67
780	67

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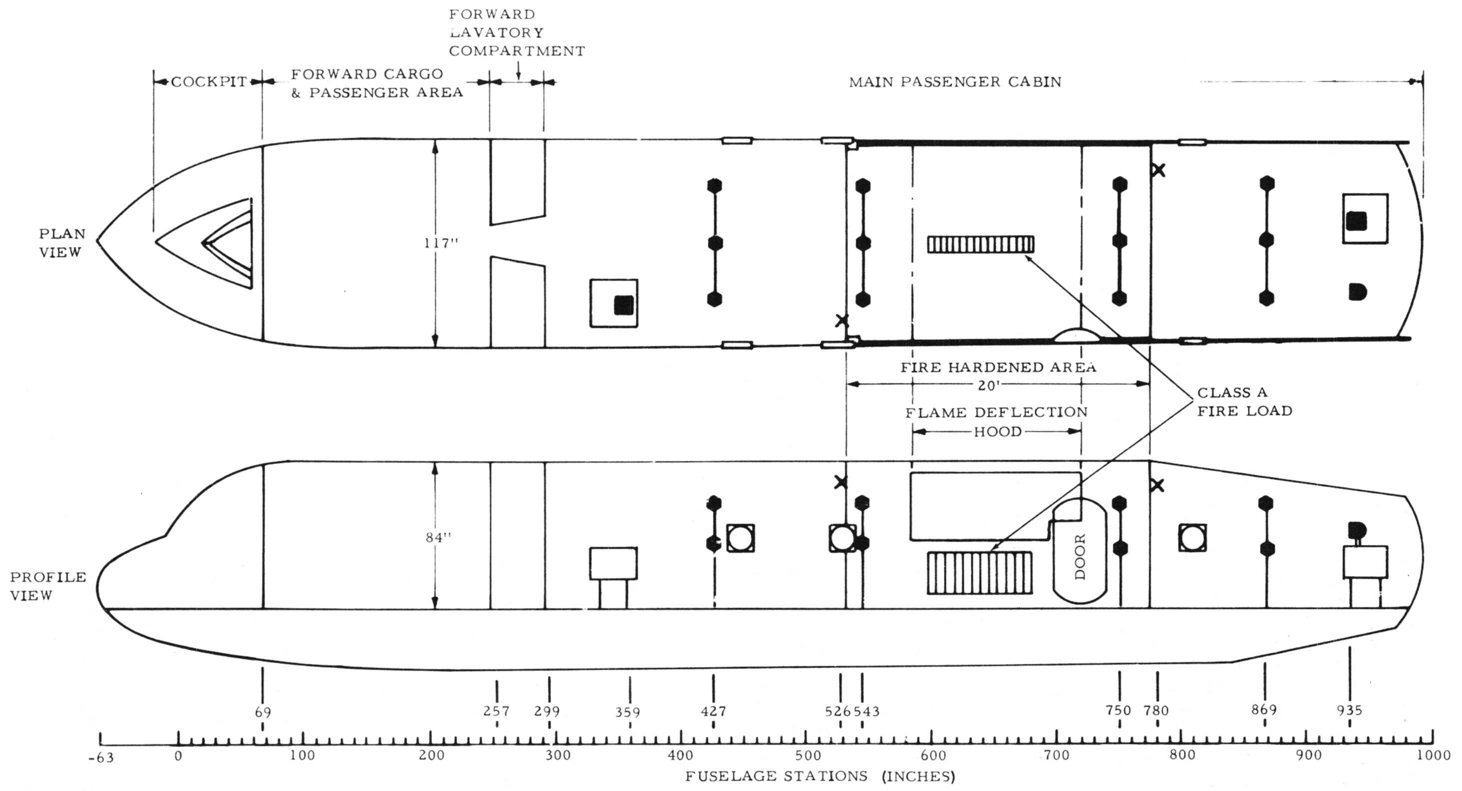
FIGURE 9. SMOKE METER AND THERMAL INSTRUMENTATION FUSELAGE STATIONS



■ INSTRUMENTATION CAMERAS

FUSELAGE STATION	HEIGHT ABOVE FLOOR (INCHES)
359	30
935	30

NOTE:
EACH CAMERA BOX CONTAINED ONE MOTION PICTURE AND ONE 35mm CAMERA

◗ VIDEO TAPE CAMERA

FUSELAGE STATION	HEIGHT ABOVE FLOOR (INCHES)
935	66

× EXIT SIGNS

FUSELAGE STATION	HEIGHT ABOVE FLOOR (INCHES)
526	74
780	74

⬢ CHEMICAL SAMPLER LOCATIONS

FUSELAGE STATION	HEIGHT ABOVE FLOOR (INCHES)
427	66, 42, 42
543	66, 42, 42
750	66, 42, 42
869	66, 42, 42

79-43-10

FIGURE 10. PHOTOGRAPHIC AND CHEMICAL SAMPLING EQUIPMENT FUSELAGE STATIONS

stations indicated in figure 9. These instruments along with two pen recorders were used to sense and continuously record the reduction in light transmission over a 1-foot distance for the duration of each test. A typical smoke meter installation is shown in figure 11.

To assess the relative visual obscuration of the cabin interior by smoke, two illuminated EXIT signs were established at stations 526 and 780, 74 inches above floor level within the optical range of two thermally insulated cameras located at stations 359 and 935 (figure 9). Each camera installation contained one instrumentation motion picture camera exposing 16-millimeter (mm) color film at 24 frames per second and one 35-mm, time-sequenced still camera which recorded at 2-second intervals. The camera lens were all positioned 30 inches above floor level forming an angle between the floor and the EXIT signs of approximately 15°. This provided a direct line of sight of approximately 15 feet forward and approximately 13 feet to the rear of the fire.

ENVIRONMENTAL GAS SAMPLING APPARATUS. Samples of the cabin atmosphere were collected and analyzed for Halon 1400, carbon monoxide (CO), carbon dioxide (CO_2), hydrogen fluoride (HF), and oxygen (O_2). The results of the analysis along with a description of the procedures are presented in the following discussion. A detailed description of the analytical method employed to determine the concentration of HF is presented in appendix D.

Sampler Design. Twelve sampling stations were designed and constructed for gathering atmospheric samples. Each station comprised two sampling points: one for Halon 1400, CO, CO_2, O_2, the other for HF (figure 10).

The HF sampler consisted of a glass "midget bubbler" containing 0.1 normal (N) sodium hydroxide solution (figure 12). The body of the bubbler was a Pryex® test tube fitted with a two-hole rubber stopper. A Teflon® tube was inserted through the stopper and into the collection medium. The portion of the Teflon tube in the solution was fitted to allow for optimum mixing, while the other end was connected to a Milipore® filter to keep solid particles from being collected in the solution. A second Teflon tube was inserted through the rubber stopper, but not permitted to come in contact with the collection medium. The outside end of this tube was connected to a calibrated orifice which was subsequently connected to a vacuum source. By this means the volume of gas passing through the collection solution could be accurately measured.

The other sampling device (figure 12) consisted of two evacuated test tubes held in place by a wooden bracket. An electric solenoid containing two hypodermic needles was placed below the test tubes. By manually closing the electrical circuit, the solenoid was made to push the syringe needles into the evacuated test tubes for sample collection.

Sampler Locations. Four sampler "trees" each containing three sampling stations were placed inside the aircraft fuselage (figure 13). One station designated "A" was located in the "aisle" at an elevation of 64 inches to approximate the position of a person standing. Samplers "B" and "C" were positioned at a height of 42 inches to simulate the respiratory level of a person seated in the aircraft.

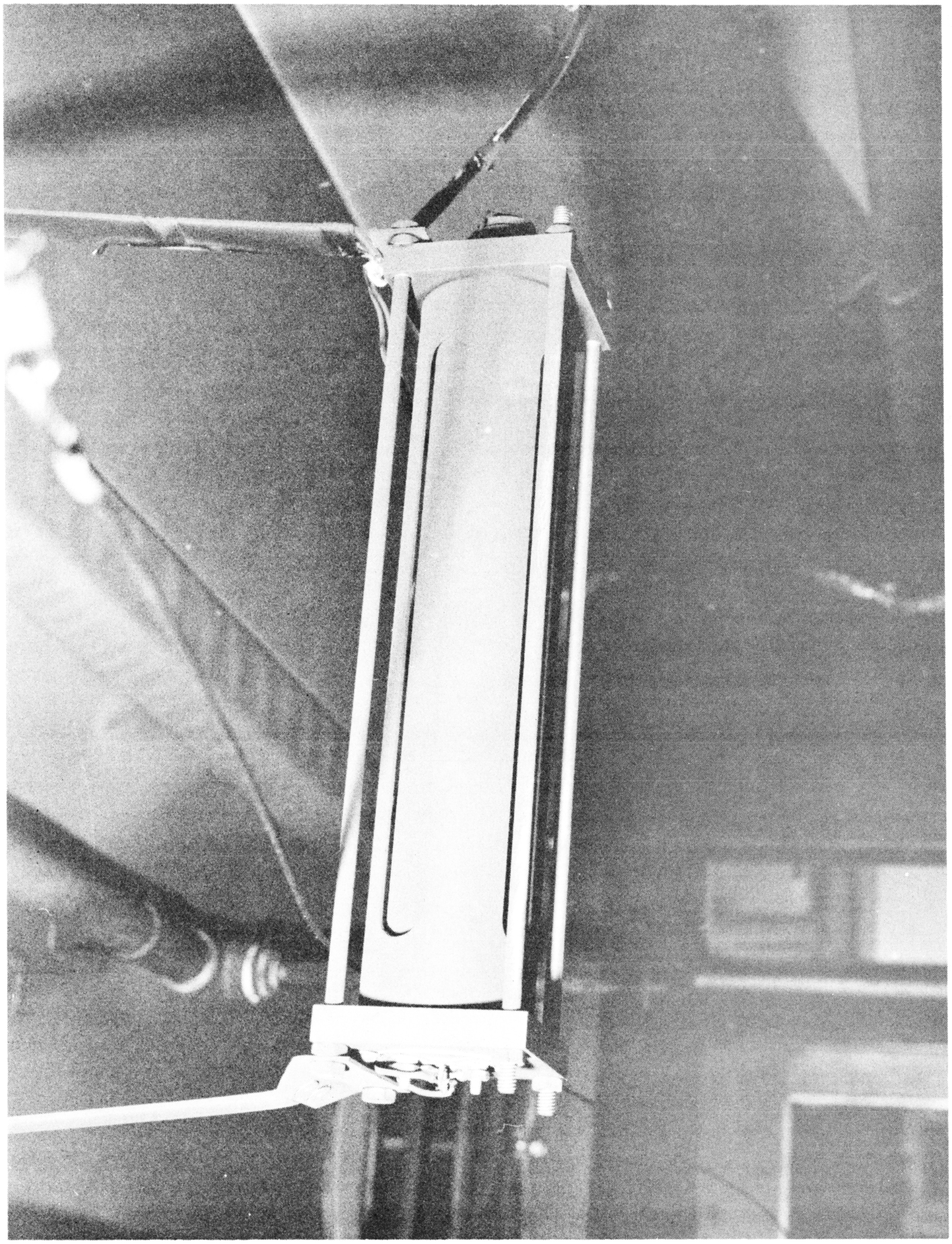


FIGURE 11. TYPICAL PHOTOELECTRIC SMOKE DENSITY METER INSTALLATION

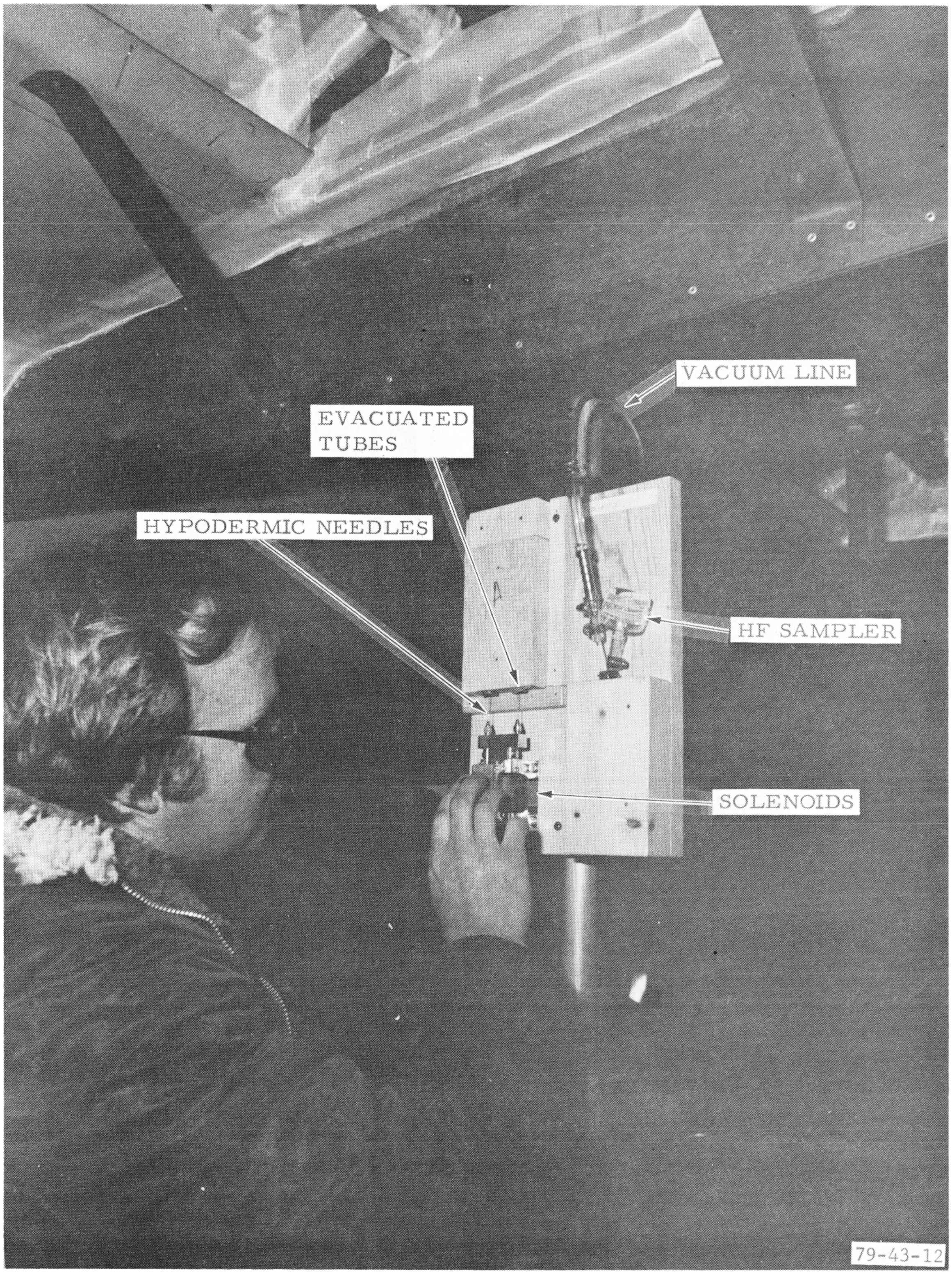


FIGURE 12. TYPICAL GAS SAMPLING INSTALLATION

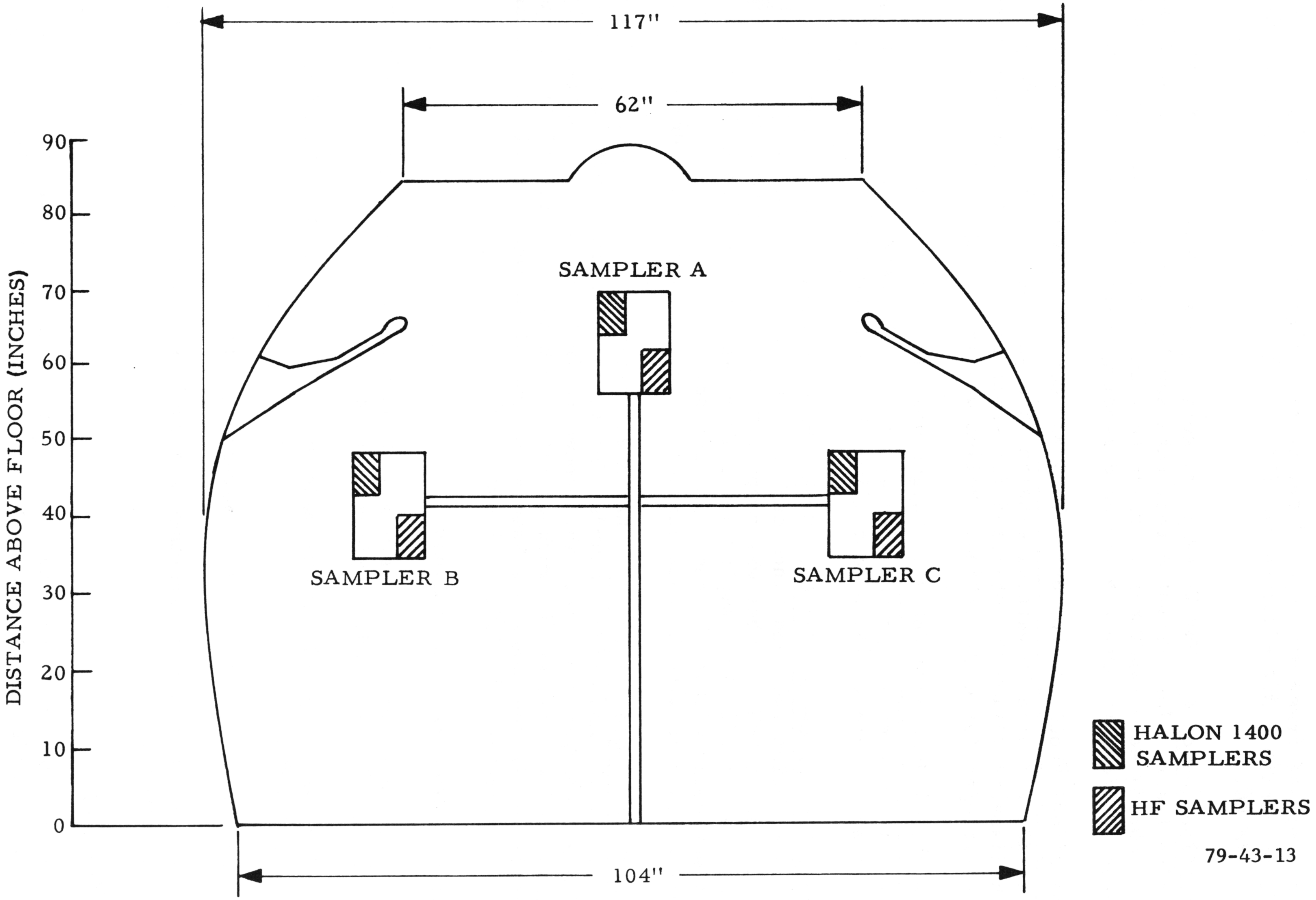


FIGURE 13. GAS SAMPLER LOCATIONS VIEWED FROM THE DC7 COCKPIT

The sampling trees were spaced two on each side of the fire-hardened area in order to obtain a distribution profile of Halon 1400 as well as the toxic gases HF and CO.

Sampling Sequence. The HF samplers were run continuously during the fire suppression tests. The evacuated test tube samplers were activated at 30-second intervals during each experiment. Prior to each fire suppression test, samples were taken in order to obtain background readings within the aircraft fuselage.

Analytical Procedure For Halon 1400 and CO_2. A Varian model 3700 gas chromatograph was used to determine Halon 1400 and CO_2. A 12-foot, Porapak QS, 1/8-inch-diameter column was utilized for separation and a thermal conductivity detector employed for quantitation. Helium was used as the carrier gas.

Analytical Procedure For O_2. Oxygen was also determined by gas chromatography using a thermal conductivity detector. The separation was performed using a molecular sieve, 5A, 6-foot 1/4-inch column at 100° C.

Analytical Procedure For CO. Since the concentration of CO was low in comparison to Halon 1400 and since each sample was only 15 milliliters (ml), a procedure using Dräger tubes was adapted to determine the CO content. In order to obtain sufficient sample volume 10 ml were drawn from each sampler that was activated within the same time period. For example, all A samples (4 sampling stations with 2 tubes/station) were tested with one Dräger tube.

Analytical Procedure For HF. National Institute for Occupational Safety and Health (NIOSH) Analytical Methods, Set L, dated January 1976, were used to determine hydrogen fluoride. The procedure in this set was numbered S176. This technique is based on the work of Elfers and Decker entitled "Determination of Fluoride in Air and Stack Gas Samples by Use of an Ion Specific Electrode," Analytical Chemistry, 40 (11), p. 1,658, 1968.

The general procedure is as follows:

1. A known volume of air is drawn through a midget bubbler containing 10 ml of 0.1 N sodium hydroxide to trap HF.

2. The resulting solution is made up to 25 ml using 0.1 N sodium hydroxide.

3. Twenty-five milliliters of buffer are added.

4. The diluted samples are then analyzed using a fluoride specific ion electrode.

TEST PROCEDURES.

Prior to conducting any large-scale fire tests in the DC7 aircraft, the airflow pattern was assessed for uniformity by incorporating theatrical smoke from burning candles positioned in the intake manifold of the centrifugal blower. By adjusting the louvers in the discharge plenum, it was possible to direct the airflow both horizontally and vertically to achieve uniform distribution. Final adjustment of the airflow pattern was accomplished by means of movable vanes in the diffuser terminal and observing the intensity and direction of movement of the paper streamers suspended horizontally across the cabin interior and open exits as indicated in figure 14. The flow rate of the Halon 1400-air inerted atmosphere was determined to be approximately 3,300 cubic feet per minute by means of a metal coated thermal sensor (Thermo-Systems, Inc., TSI 1650 air velocity meter).

The effect of open exits (windows and door) upon the interior airflow patterns varied widely with the external ambient wind direction and intensity. However, minimal disruptive effects were observed when the wind direction was approximately perpendicular to the right side of the fuselage and maximal when it impinged upon the left or exit side of the aircraft.

After the desired flow pattern had been established, a series of experiments was performed to determine the pressure at which the Halon 1400 had to be discharged into the blower manifold to obtain a concentration of 25- to 30-percent volume with air. The results of these experiments are indicated by the profile presented in appendix E in which the Halon 1400 manifold pressure is plotted as a function of its concentration in the Halon 1400-air atmosphere. From this information it was estimated that the Halon 1400 manifold pressure necessary to obtain the required Halon 1400-air concentration was approximately 128 pounds per square inch gauge (psig).

The information required to assess the feasibility of employing the Halon 1400-air ventilating system is indicated in the data matrix presented in table 2. Additionally, the table identifies the area in which information was obtained using neat Halon 1400 dispensed from the U.S. Air Force's aircraft skin penetrator nozzle from two simulated points of entry.

Table 2 indicates that three large-scale fire modeling experiments were planned using Class A flammable materials, two of which employed the Halon 1400-air atmosphere and the third used a neat Halon 1400 discharge. Since the established fire test parameters required a fire load sufficient to produce a thermally uninhabitable environment within one-quarter to one-third of the total volume of the DC7 aircraft cabin within approximately 60 seconds after fuel ignition, a suitable Class A fuel had to be determined.

Although many different types of Class A combustibles may be present on military and civil aircraft, the one which appeared to offer the greatest potential in providing reproducible test results was a bunk mattress comprising a sponge pad and cover. To validate this assumption, a test was conducted using a surplus military mattress suspended vertically over a trough containing methanol. The results of this test are presented in appendix F. From these data it was concluded that all of the fire load requirements could be met by employing this configuration.

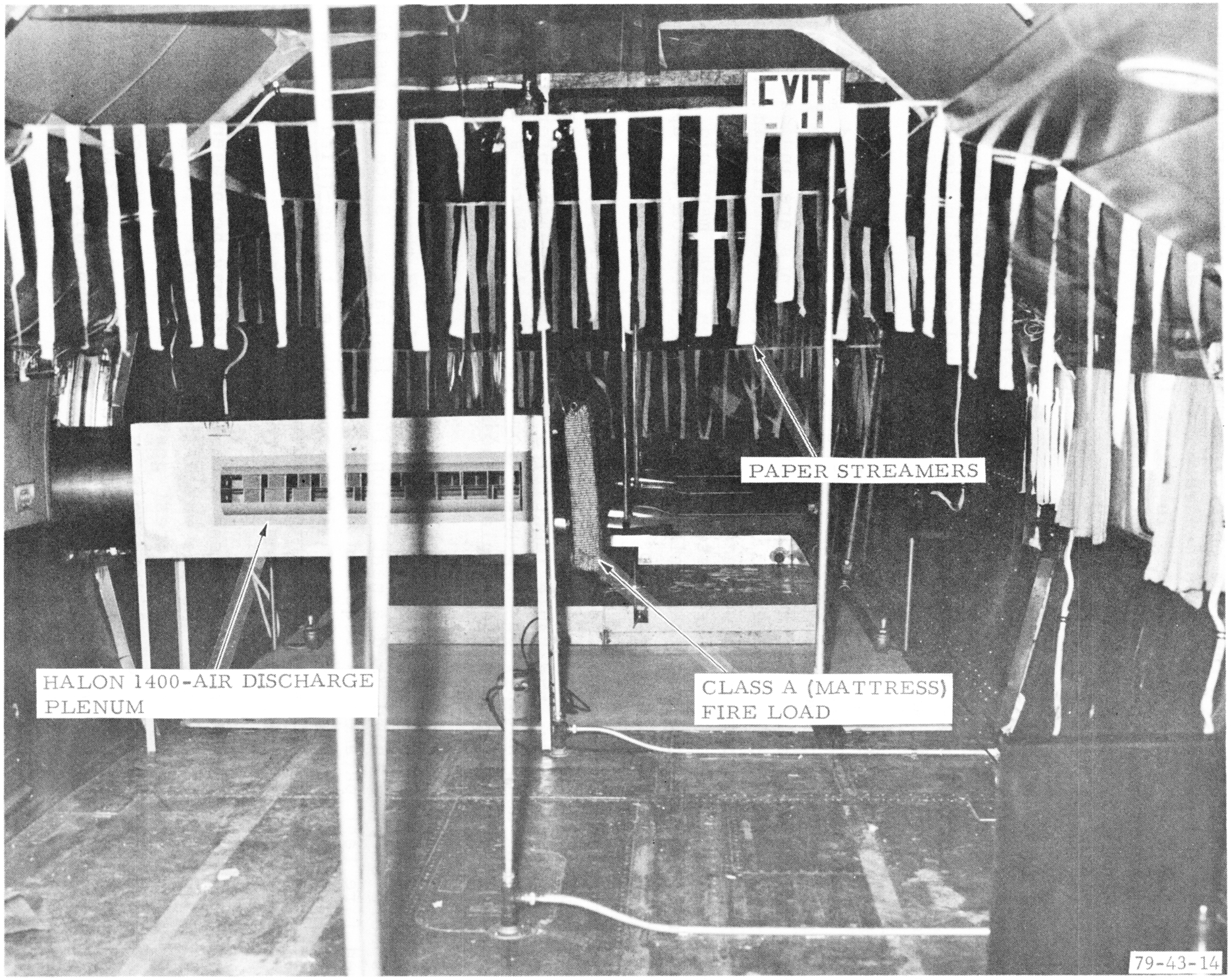


FIGURE 14. PAPER STREAMERS USED TO OPTIMIZE THE HALON 1400-AIR DISCHARGE PATTERN WITHIN THE DC7 AIRCRAFT CABIN

TABLE 2. TEST DATA MATRIX

			Heat Flux			DC7 Cabin Atmosphere				
Test No.	Fire Class	Temperature	Radiometer	Calorimeter	Smoke	CF_4	CO_2	CO	O_2	HF
1	A	X	X	X						
2	A	X	X	X	X	X	X	X	X	X
3	B	X	X	X	X	X	X	X	X	X
U.S. Air Force Skin Penetrator Nozzle										
4	A	X	X	X	X					

The first two large-scale fire tests were conducted within the fire-hardened area of the DC7 cabin by duplicating the equipment and procedure indicated in appendix F. Methanol was employed as the ignition source in all Class A fuel experiments to preclude the development of smoke and combustion products other than the carbon dioxide and water produced by burning methyl alcohol.

The experiment was initiated by igniting the alcohol with a high voltage spark which was synchronized with the electronic recording equipment and activated remotely from the instrumentation trailer which was adjacent to the aircraft.

Additionally, a photoflash bulb was incorporated in the circuitry and positioned in the center of the fuselage to serve as a visual marker for timing the photographic coverage of events.

After fuel ignition, the fire load was permitted to burn freely until any one of the thermocouples at stations T4, T5, or T6 reached 290° F or the radiometers at stations 581 and 695 reached 0.2 Btu/ft^2-sec. When either of these criterion was met, the fire extinguisher system was activated and the discharge continued until the fire was extinguished.

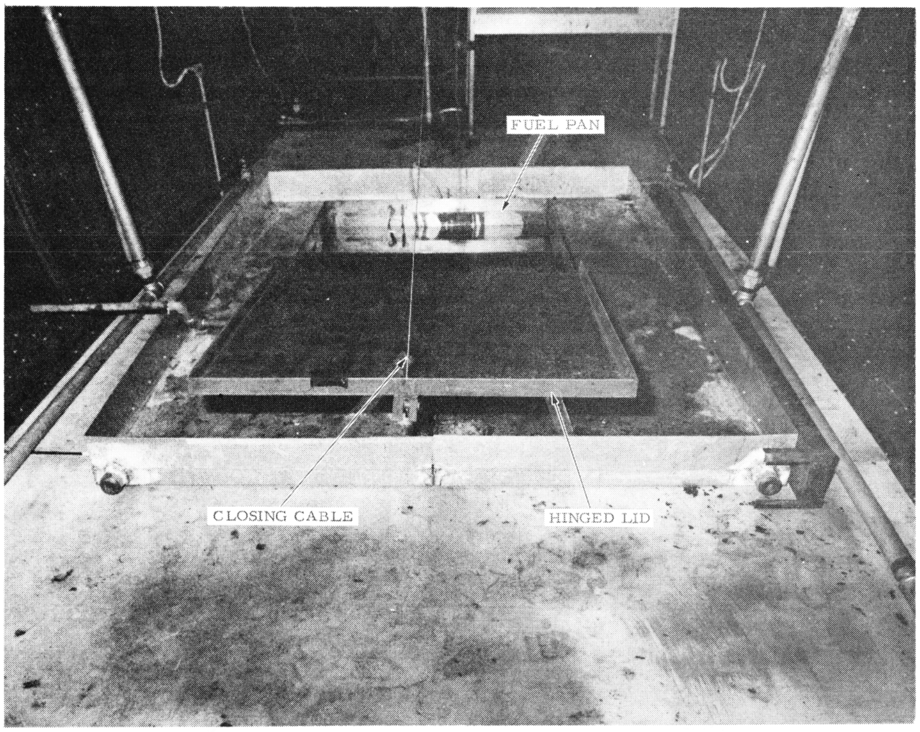
Fire control of the Class A flammables was considered to have been achieved when either the ambient air temperature was reduced to 150° F or the heat flux was 0.2 Btu/ft^2-sec or less. Fire extinguishment was recorded as that time when the environmental temperature was reduced to 100° F or the heat flux was 0.10 Btu/ft^2-sec or below.

The third experiment employed a Class B fire load positioned in the center of the fire-hardened area. Fuel was contained in a 3-foot by 3-foot by 4-inch-deep steel pan. This pan incorporated a hinged steel lid which could be closed over the pan by means of a steel cable activated from an observation post in the aircraft cockpit area. Figure 15 shows the configuration of the fuel pan, hinged lid, and electrical ignition system.

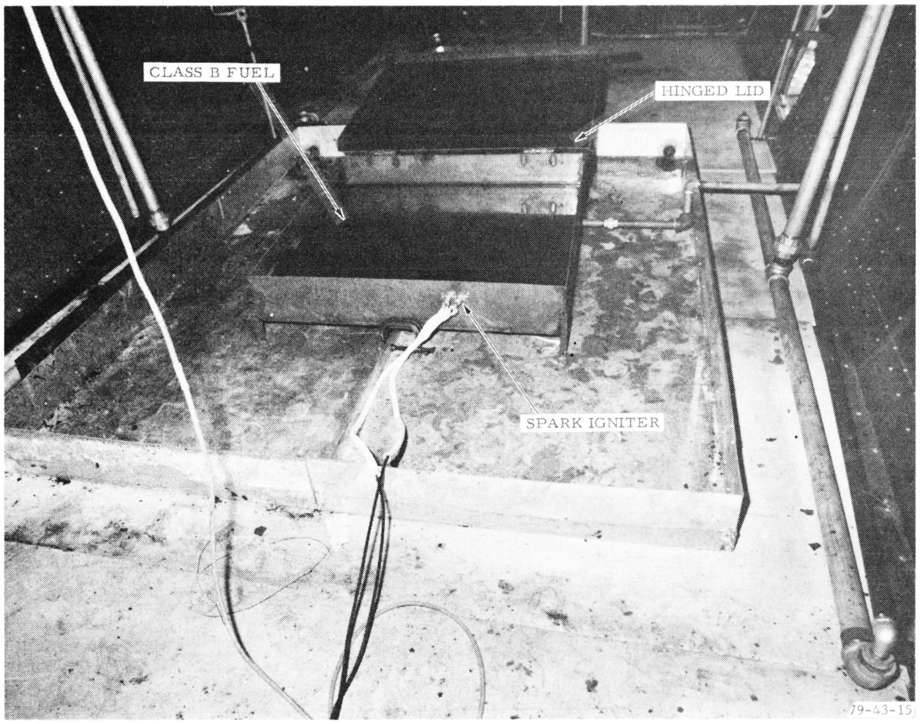
After fuel ignition, the cabin interior very rapidly reached unsurvivable conditions after which the Halon 1400-air system was activated and the fire extinguished. However, as a consequence of the increased burning intensity of the Class B fire over the Class A material, it was necessary to establish 400° F and 300° F as the fire control and extinguishing times, respectively.

FIRE EXTINGUISHING EFFECTIVENESS OF THE HALON 1400-AIR ATMOSPHERE. The principal means of assessing the effectiveness of the Halon 1400-air atmosphere was by determining the time required to obtain control and extinguishment of the fire after activation of the extinguishing system. In all experiments, the fire control and extinguishing times were based upon the temperature and thermal radiation levels developed within the fire-hardened area.

Test 1--Class A (Mattress) Fire. The fire control and extinguishing times obtained with the Halon 1400-air ventilating system during the first Class A fire test in terms of reductions in temperature and radiation levels are indicated on the profiles presented in figures 16 and 17, respectively.



FUEL PAN, HINGED LID AND CLOSING MECHANISM



SPARK IGNITER SYSTEM

FIGURE 15. CONFIGURATION OF THE CLASS B FUEL TEST BED

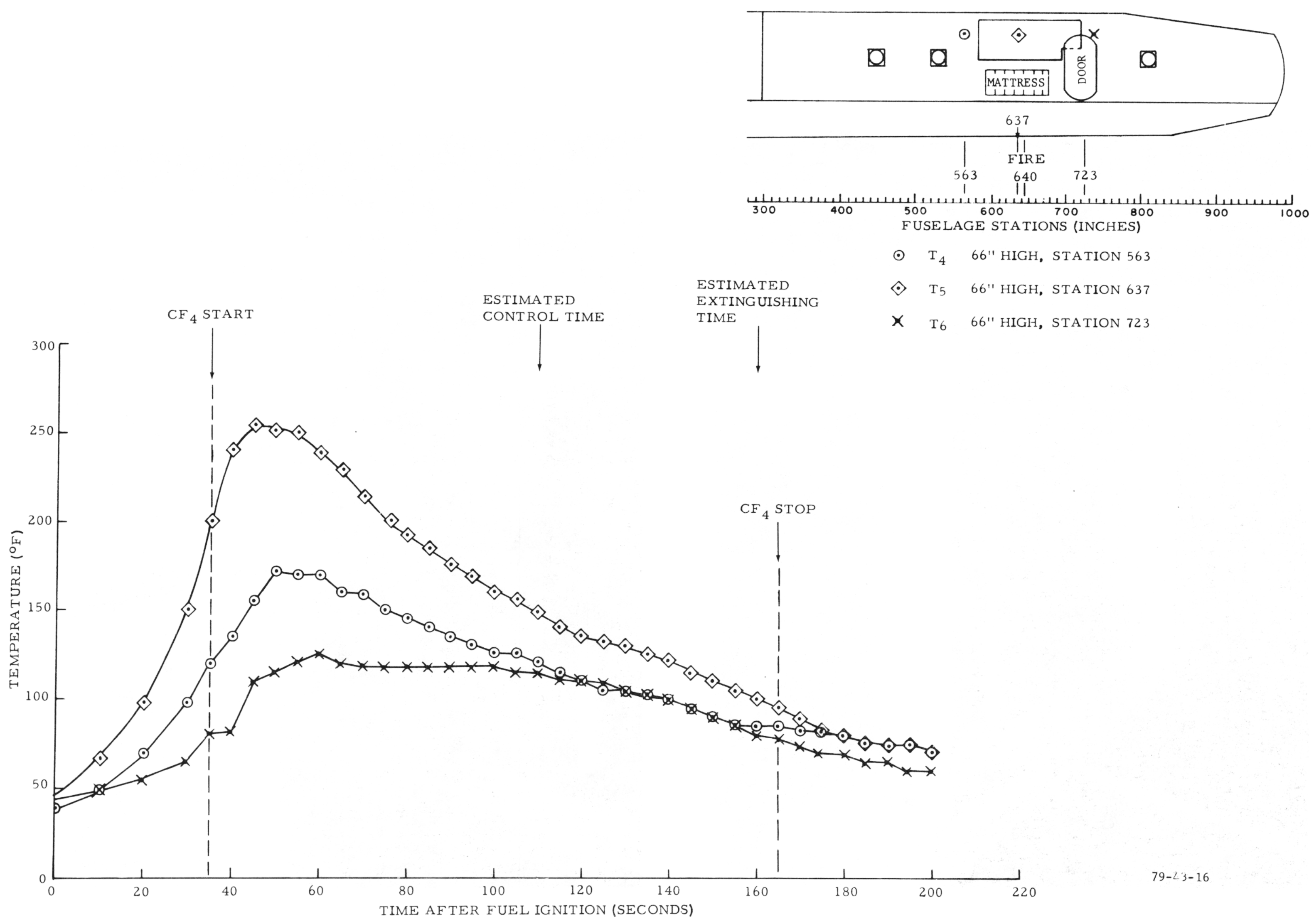


FIGURE 16. TEST 1--AMBIENT AIR TEMPERATURES WITHIN THE FIRE-HARDENED AREA AFTER FUEL IGNITION (CLASS A FIRE)

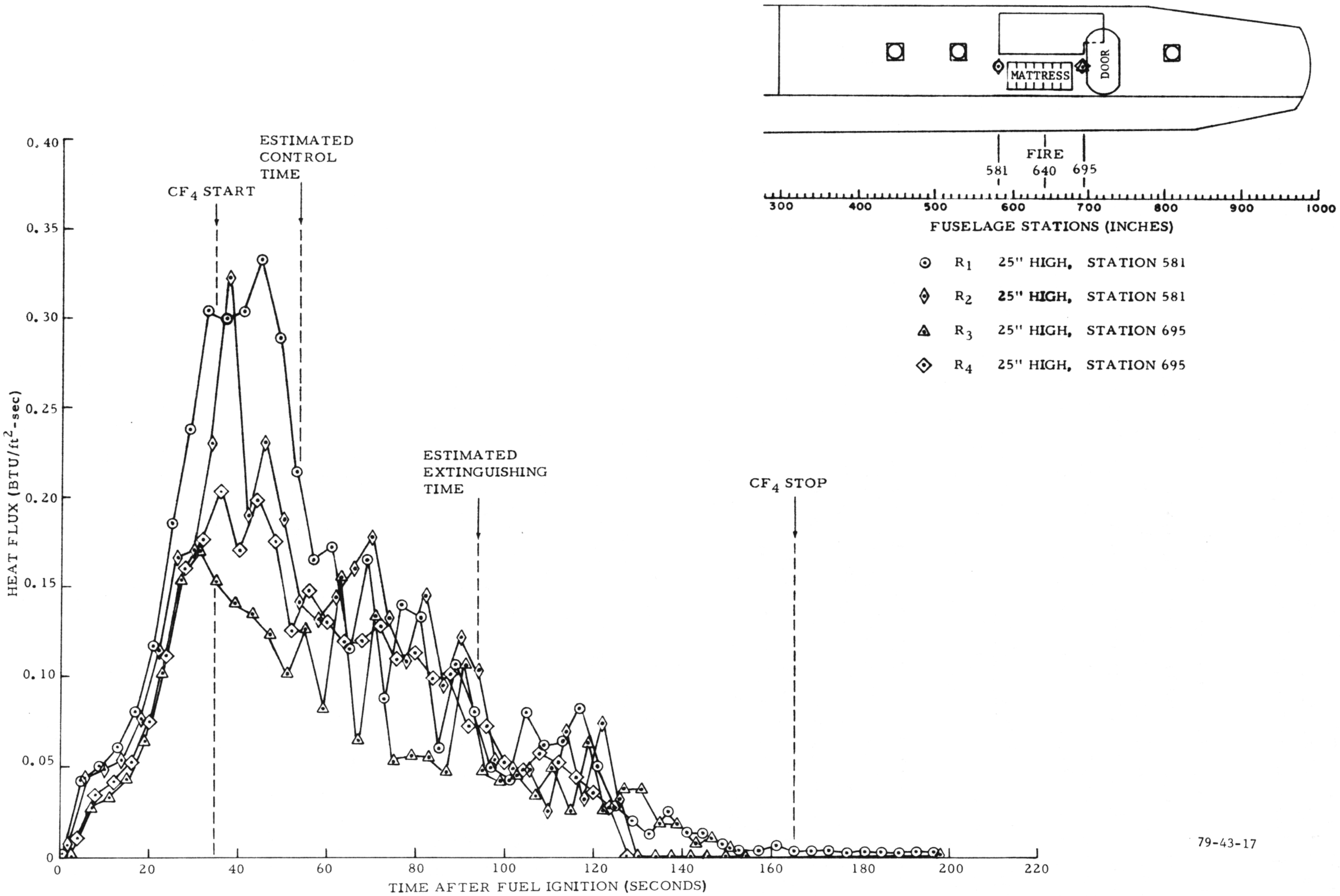


FIGURE 17. TEST 1--THERMAL RADIATION LEVELS WITHIN THE FIRE-HARDENED AREA AFTER FUEL IGNITION (CLASS A FIRE)

These data show that in terms of temperature, fire control was obtained in 75 seconds and extinguishment in 125 seconds, respectively. The corresponding radiation levels indicated control in 19 seconds and extinguishment in 59 seconds.

Additional thermal data are provided in appendix G which show the temperature and radiation levels both forward and aft of the fire-hardened area. In general, these data show that the forward section of the cabin sustained higher ambient air temperatures and radiation levels than the section aft of the fire-hardened area. However, the thermal conditions in either section of the cabin were insufficient to impair the safe self-evacuation of passengers.

Test 2--Class A (Mattress) Fire. The second experiment was essentially a duplication of the first except that an analysis of the cabin atmosphere was made in terms of the concentration of Halon 1400, CO, CO_2, O_2, and HF.

The fire control and extinguishing times using the Halon 1400-air atmosphere are shown on the time-temperature profiles in figure 18 and by the heat flux-time profiles in figure 19. Based upon the temperature data, fire control was obtained in 54 seconds and extinguishment in 124 seconds after activation of the Halon 1400-air extinguishing system. However, in terms of thermal radiation, fire control and extinguishment were obtained in 48 seconds and 75 seconds, respectively, based on a reduction in heat flux to 0.20 and 0.10 Btu/ft^2-sec.

It is noteworthy that in this experiment, as well as in the first, the ambient environmental temperature, in terms of human tolerance levels, may be the more persistent parameter limiting passenger safe self-evacuation.

Additional thermal data are presented in appendix H which show the environmental cabin conditions forward and aft of the fire-hardened area. These data indicate, as in the previous experiment, that the most severe thermal environmental conditions were maintained in the forward section of the aircraft cabin and that these conditions could seriously impair passenger evacuation if not controlled.

Test 3--Class B (JP-4 Fuel) Fire. Aviation fuel fires are significantly more devastating than the Class A fuels generally involved in aircraft accidents. However, Class A fires may pose special problems because of their 3-dimensional burning characteristics.

A comparison of the thermal data presented in figures 20 and 21 for test 3 with those obtained in tests 1 and 2 (mattress fires) illustrates the devastating effects produced by the Class B fuel in a confined space. During this experiment, two separate attempts were made to extinguish the fire. In the first attempt, the Halon 1400-air system was shut down prematurely because no flames were visible through the extremely dense black smoke which developed in the cabin within 20 seconds after fuel ignition. When this error was detected, the Halon 1400-air system was reactivated and the fire extinguished.

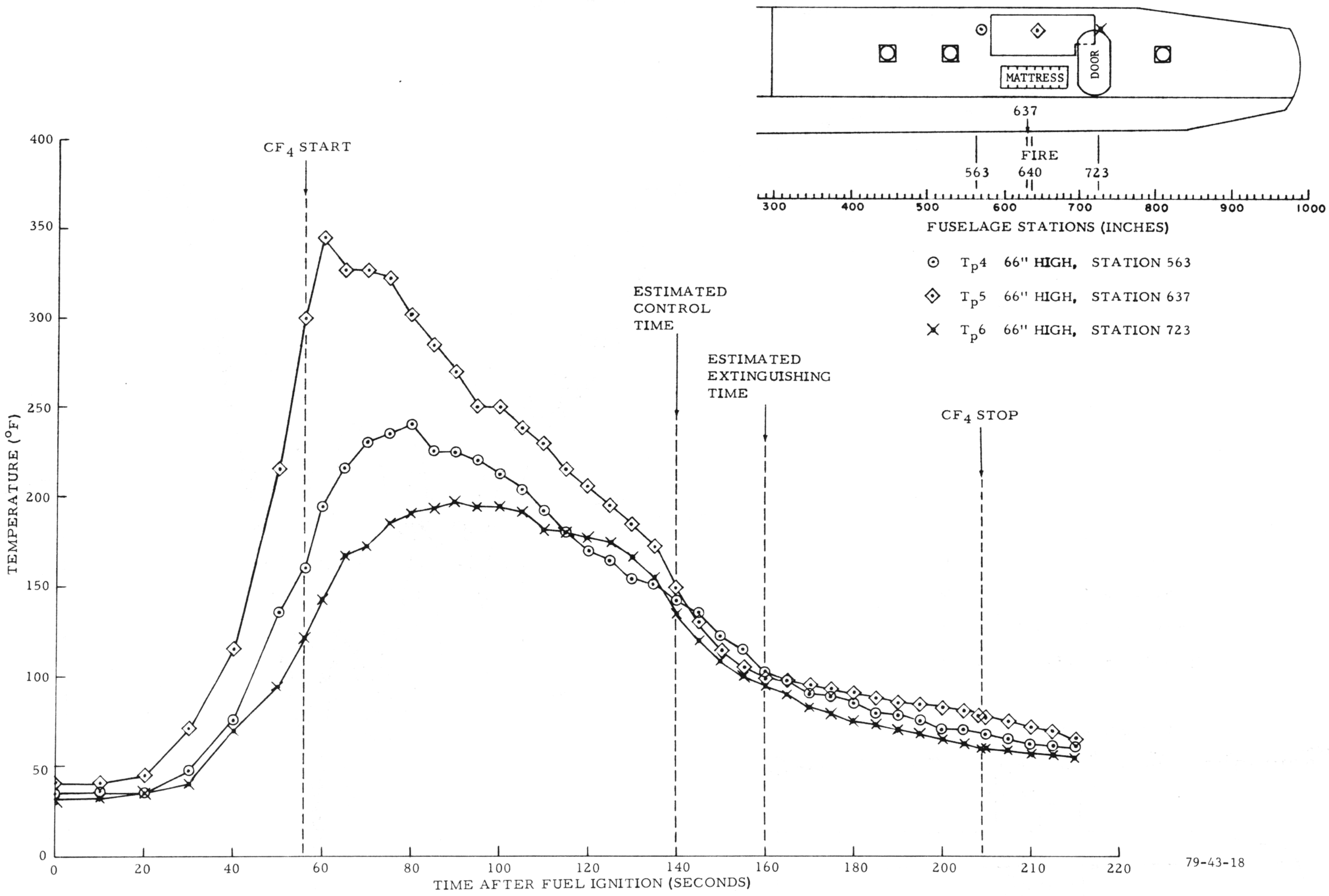


FIGURE 18. TEST 2--AMBIENT AIR TEMPERATURES WITHIN THE FIRE-HARDENED AREA AFTER FUEL IGNITION (CLASS A FIRE)

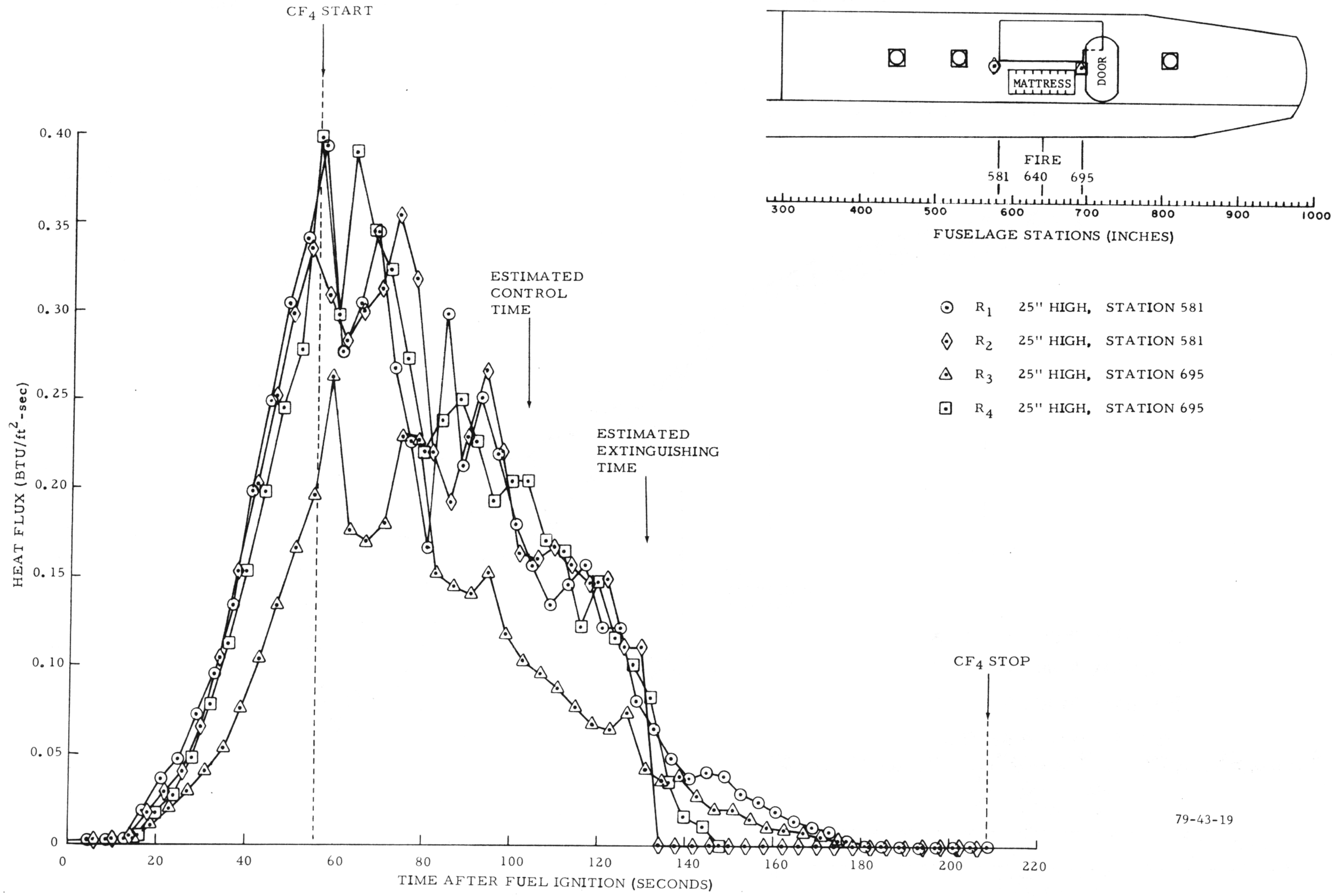


FIGURE 19. TEST 2--THERMAL RADIATION LEVELS WITHIN THE FIRE-HARDENED AREA AFTER FUEL IGNITION (CLASS A FIRE)

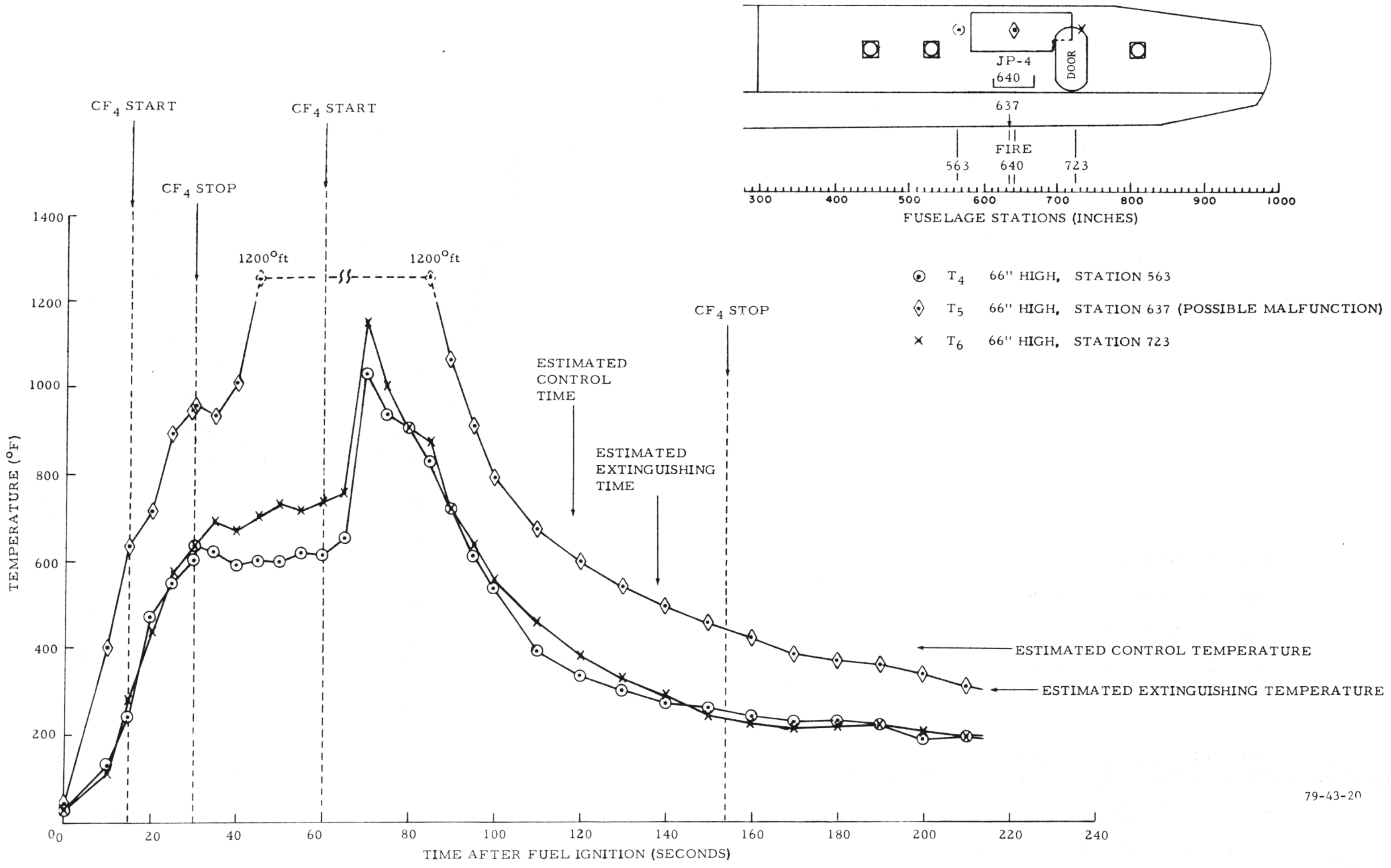


FIGURE 20. TEST 3--AMBIENT AIR TEMPERATURES WITHIN THE FIRE-HARDENED AREA AFTER FUEL IGNITION (CLASS B FIRE)

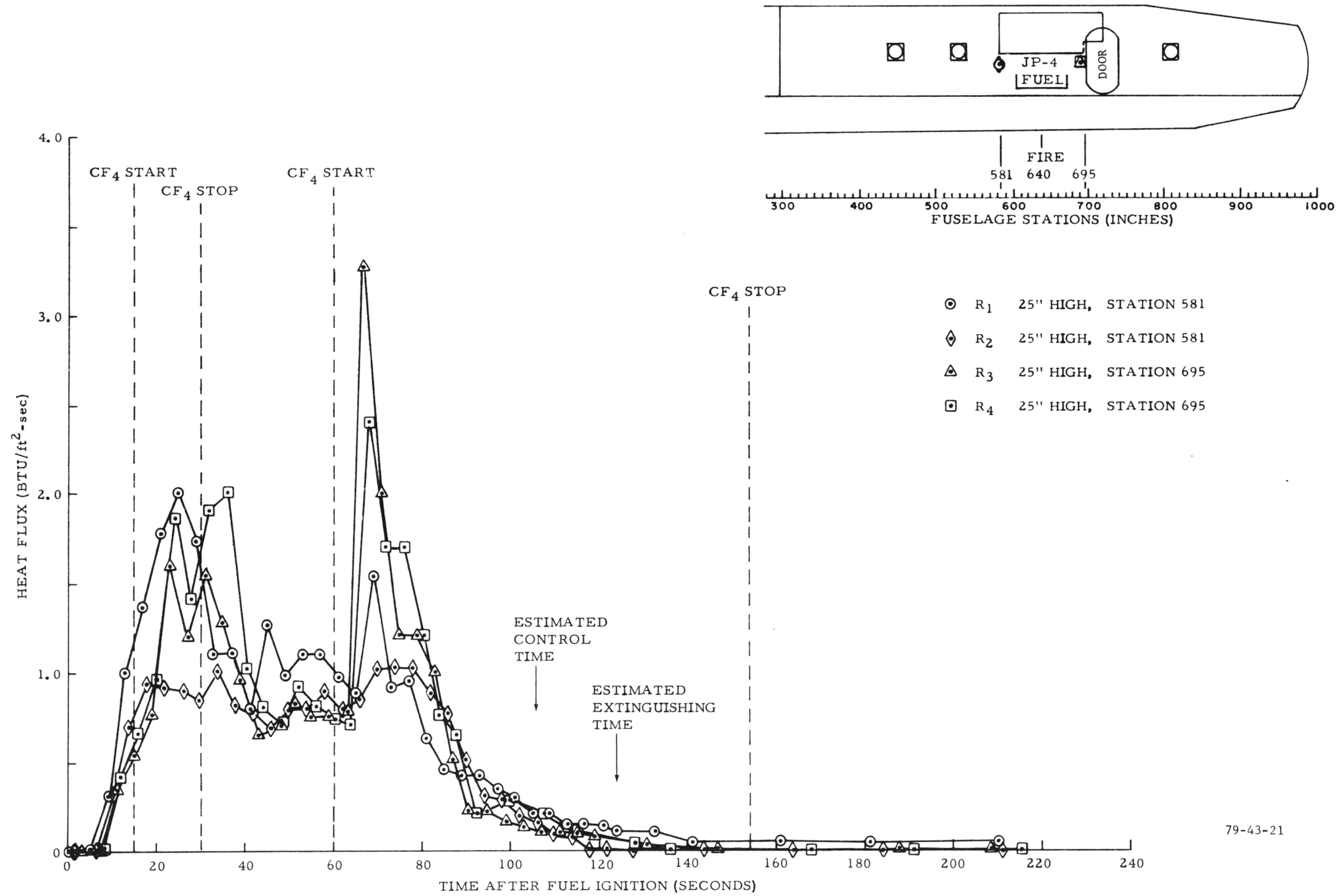


FIGURE 21. TEST 3--THERMAL RADIATION LEVELS WITHIN THE FIRE-HARDENED AREA AFTER FUEL IGNITION (CLASS B FIRE)

Consequently, the total time required to control and extinguish the fire in terms of temperature and radiation intensity is recorded as the sum of the two sequential discharge periods.

The data show that in terms of temperature, fire control was obtained in 73 seconds and extinguishment in 93 seconds, while the thermal radiation-time profiles indicate fire control in 61 seconds and extinguishment in 79 seconds. A comparison of these values with similar data developed for the Class A fires tends to show that the ambient air temperature was somewhat below that produced by the Class A fire, while the radiation intensity was somewhat higher. Additional thermal data taken forward and aft of the fire-hardened area are presented in appendix I.

From an evaluation of all of the thermal data obtained throughout the DC7 aircraft cabin during test 3, it was considered probable that all occupants who had not evacuated within 30 seconds after fuel ignition would be incapable of safe self-evacuation. It is considered significant that even under the devastating thermal-environmental conditions in the cabin which occurred durning the Class B fire, there was no evidence of charring or flamming combustion of any of the paneling. Figure 22 illustrates the severe blistering of the ceiling panels between fuselage stations 466 and 526 without evidence of active combustion. Paint blistering was minor or nonexistent in other sections of the cabin ceiling between the flash fire barrier screens. However, it is speculated that under these conditions passengers would probably have succumbed as a consequence of thermal insult, smoke, and/or toxic gases without the interior paneling having contributed to the conflagration.

These facts emphasize the need for rapid fire intervention and extinguishment by the CFR services in aircraft accidents in which the integrity of the fuselage is lost due to impact forces or the aluminium skin has been melted by the fuel-spill fire.

ANALYSIS OF THE CABIN SMOKE DATA. A major parameter limiting the safe, rapid egress of passengers from an aircraft in a fire emergency is the early release of excessive amounts of smoke and pyrolysis products during fire development. Visual acuity may be further reduced by the lachrymatory effects induced by the combustion products from various polymeric interior cabin furnishings. One of the anticipated advantages to be derived through the use of the inert habitable atmosphere is a significant reduction in the concentration of smoke, toxic gases, and pyrolysis products by dilution, thereby enabling passengers to evacuate more readily and safely.

To assess the overall practicability of this concept, two methods were employed to determine the relative obscuration time of the aircraft cabin by smoke. One system required photoelectric measurements, and the second employed motion picture and still cameras to view remote and illuminated "EXIT" signs during fire extinguishment.

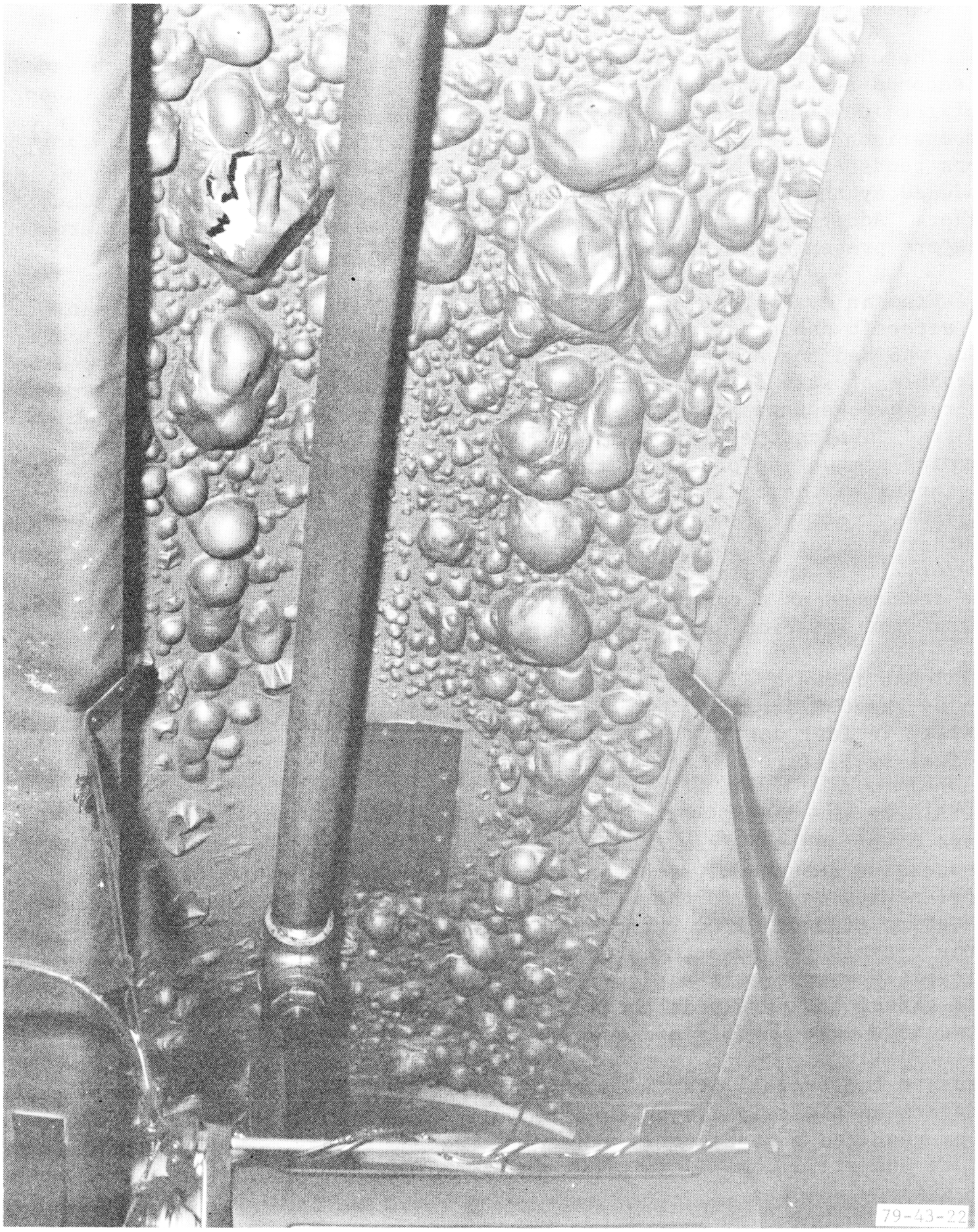


FIGURE 22. SEVERE BLISTERING OF THE CEILING PANELS BETWEEN FUSELAGE STATIONS 466 AND 526 WITHOUT EVIDENCE OF FLAMING

Class A Materials (Mattress) Fires. During the first Class A experiment, the smoke meters were inoperative due to an equipment malfunction. However, an analysis of the optical instrumentation data shows that at no time during the test were the EXIT signs completely obscured when viewed from either of the two camera positions. The blue-grey smoke that was generated was distributed uniformly (no stratification) throughout the cabin by the Halon 1400-air discharge. The smoke slowly increased in density during fire control and extinguishment which lasted from 35 to 125 seconds after fuel ignition. The Halon 1400-air ventilating system was turned off 40 seconds after the fire was extinguished.

The second Class A material test was a repetition of the first experiment in which all of the parameters remained constant. The profiles presented in figure 23 show the reduction in specific light transmission as a function of time after fuel ignition for each of the two sets of smoke meters located forward and aft of the fire. These data indicate that the average specific light transmittance throughout the cabin rose from approximately 50 percent to 58 percent within 49 seconds after fire extinguishment. From the standpoint of passenger visual acuity, the optical instrumentation data indicated that an evacuation route would be discernable when the light transmittance increased to approximately 45 to 55 percent. This, however, would vary with the type of smoke and the intensity of the EXIT sign illumination.

Class B Material (JP-4) Fire. Because of the potentially devastating effects of a runaway Class B fire (9 square feet) in the relatively small cabin of the DC7 aircraft, only one experiment was scheduled in this class.

The adverse environmental impact produced by the JP-4 fuel fire in terms of visual obscuration, which may seriously delay passenger evacuation, is dramatically indicated by the profiles presented in figure 24. The profiles show that complete light obscuration, as determined from the smoke meter data, occurred within 80 seconds after fuel ignition, and that this condition did not improve within the monitoring time frame of the test. An analysis of the optical instrumentation data, in general, tends to corroborate these findings in that the EXIT signs were obscured within 18 seconds after fuel ignition and that total obscuration of the cabin interior occurred a few seconds later.

Based upon these data, it may be speculated that small Class B fires occurring within an aircraft, or flames from a fuel-spill fire which penetrate the cabin through a fuselage rupture and/or open doors and exit windows may severely impede passenger evacuation procedures by visual obscuration of the surroundings.

COMPOSITION OF THE DC7 AIRCRAFT CABIN ATMOSPHERE DURING FIRE EXTINGUISHMENT. The major concern in assessing the feasibility of employing the Halon 1400-air fire extinguishing system to provide a cool habitable atmosphere during passenger self-evacuation in fire emergencies, lies in the resulting composition

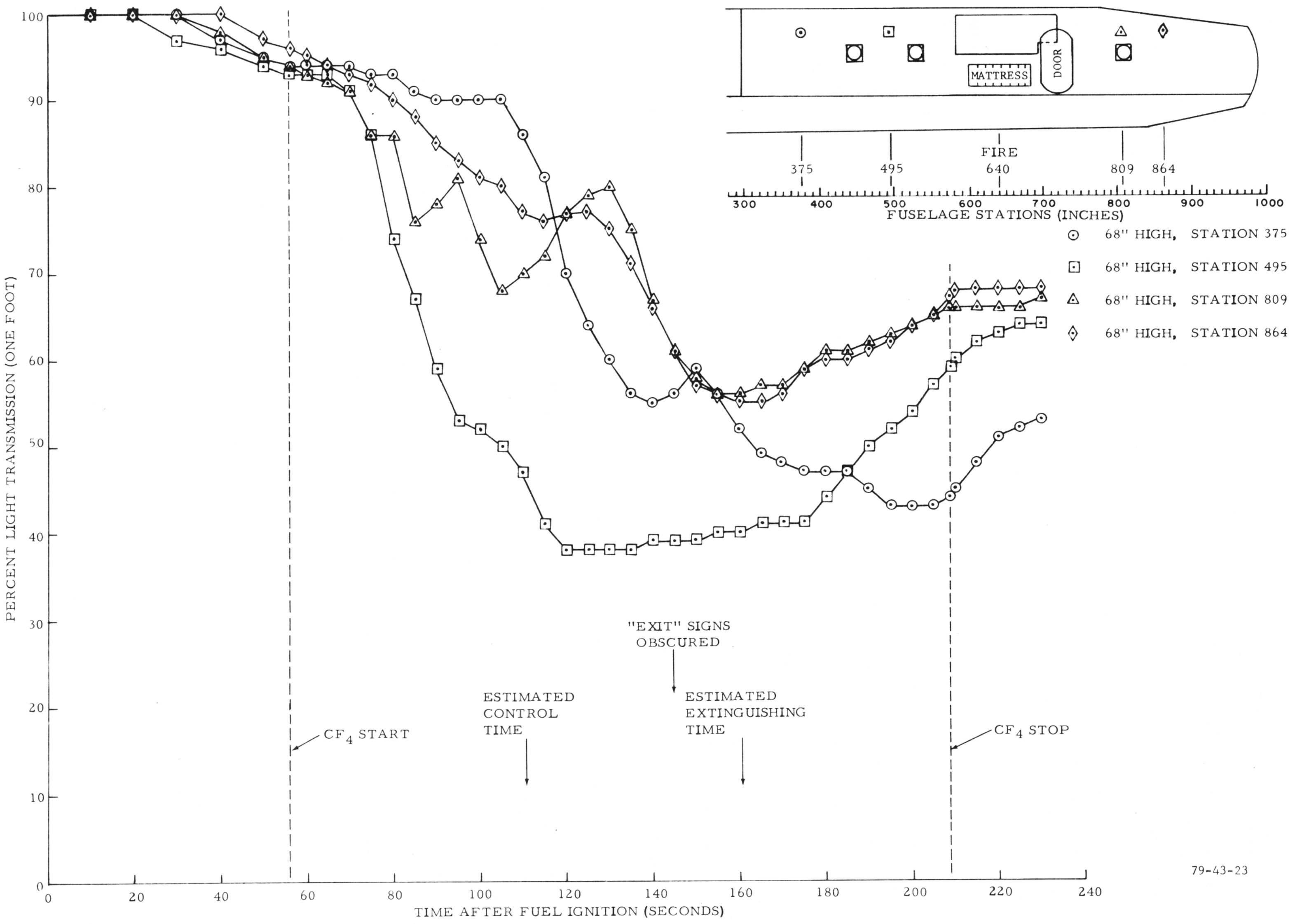


FIGURE 23. TEST 2--SMOKE LEVELS USING THE HALON 1400-AIR EXTINGUISHING SYSTEM (CLASS A FIRE)

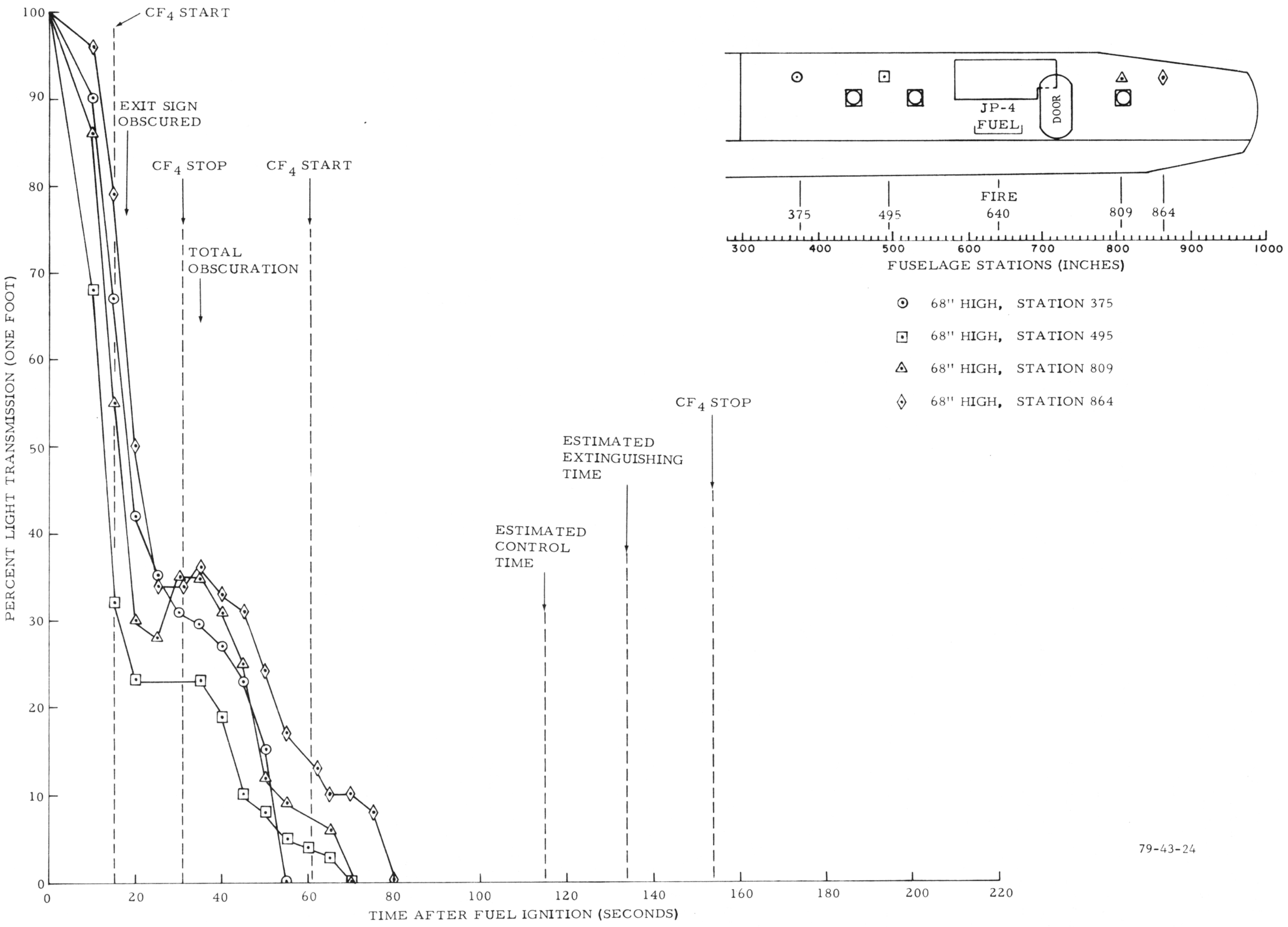


FIGURE 24. TEST 3--SMOKE LEVELS USING THE HALON 1400-AIR EXTINGUISHING SYSTEM (CLASS B FIRE)

of the cabin environment both during and after fire extinguishment. In this context a successful extinguishing system would comprise one which is either capable of maintaining an existing survivable atmosphere or of improving upon an unacceptable one.

To investigate the full capabilities of the Halon 1400-air extinguishing system, fires were established in the DC7 aircraft which were considered unsurvivable to humans if not brought rapidly under control or extinguished. Additionally, the most severe conditions from the toxicological standpoint were adopted by limiting the quantity of air entering or leaving the cabin to that provided by the ventilating system and the closed, but not locked, cabin door and exit windows.

Only two of the four fire tests conducted in the aircraft were monitored to determine the concentration of the principle components in the atmosphere which included Halon 1400, CO_2, CO, O_2, and HF. The concentration of each of these gases was considered of value in assessing the overall effectiveness of the life support system provided by the Halon 1400-air mixture.

The concentration of the five critical gases taken from each of the 12 sampling points during tests 2 and 3 are summarized in figures 25 and 26 and presented graphically in figures 27 and 28. These data show that the average O_2 concentration in the aircraft cabin varied between 18.9 (test 2) and 19.1 (test 3) percent by volume which was well above the minimum level of 15 percent at which muscular skills are impaired (appendix J). The maintenance of this relatively high O_2 level is attributable in part to the air provided by the Halon 1400-air discharge.

It is apparent from figures 25 and 26 that the average CO_2 concentration (1.89 percent) produced in test 3 (Class B fuel) exceeded that obtained (0.41 percent) in test 2 (Class A fire) by a significant margin. This is accounted for by the differences in the burning characteristics of the two fuels. Although the average concentration of CO_2 in the cabin during test 3 exceeded the maximum exposure permitted by the Occupational Safety and Health Administration (OSHA) of 5,000 parts per million (ppm) (8-hour weighted average), it was not considered a critical parameter limiting passenger evacuation which was estimated to be 50,000 ppm (appendix K).

In contrast with CO_2, the average concentration of CO produced during test 2 (26 ppm) and test 3 (33 ppm) was well below the maximum 50 ppm for the 8-hour weighted average exposure permitted by OSHA. A comparison of the CO and CO_2 concentrations within the cabin tends to indicate that the Halon 1400 air mixture may favor the formation of CO_2 over the more toxic CO during fire extinquishment.

The concentration of Halon 1400 at each fuselage station is presented in figures 25 and 26 and plotted in figures 27 and 28. The average Halon 1400 concentration in the aircraft cabin after fire extinguishment during tests 2 and 3 was 10.4- and 6.47-volume percent, respectively. This was significantly below the 15-volume percent estimated to be required (table 3, reference 3). The lower Halon 1400 requirement in these experiments may be

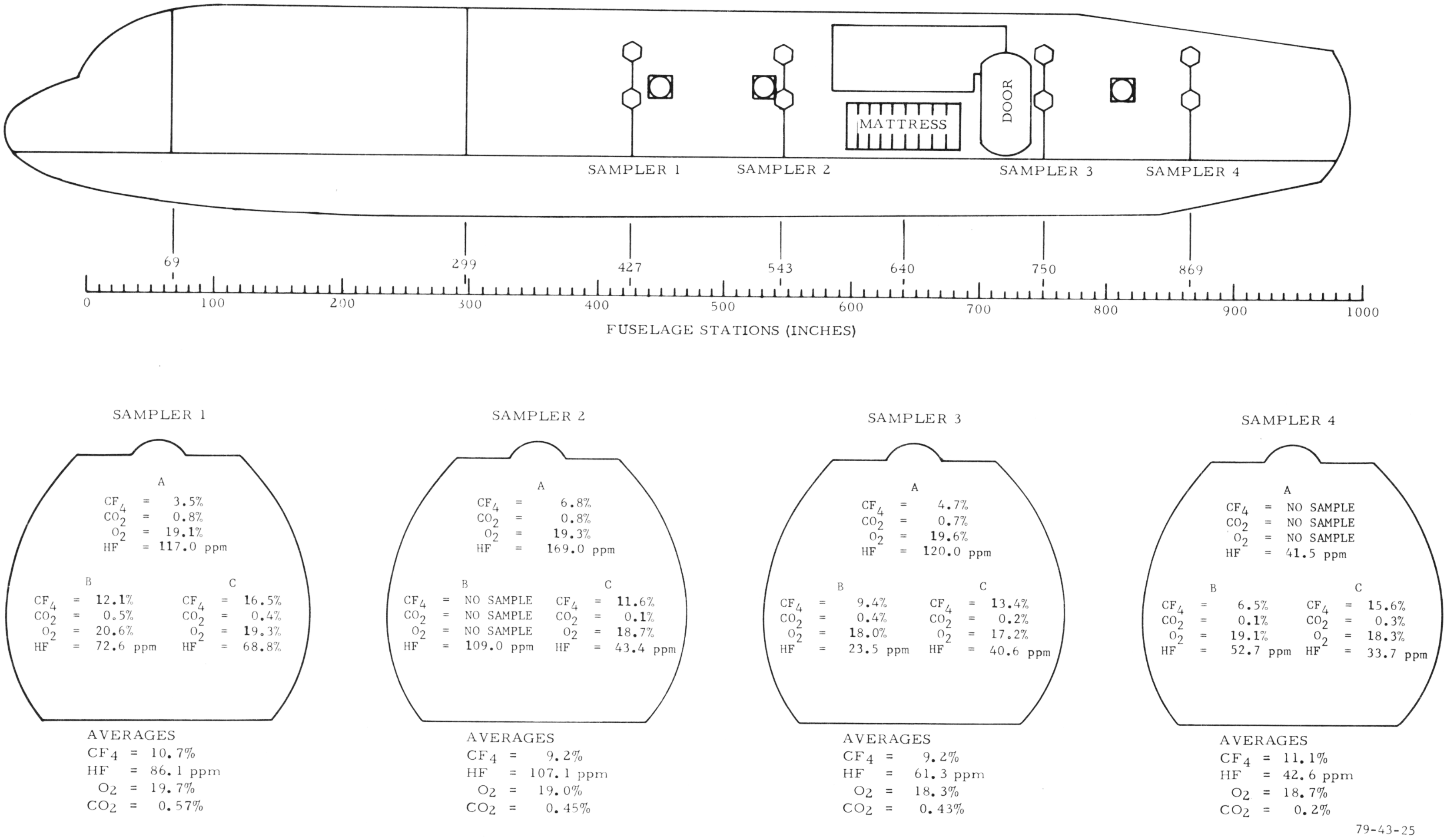


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FIGURE 25. TEST 2--COMPOSITION OF THE DC7 CABIN ATMOSPHERE (CLASS A FIRE)

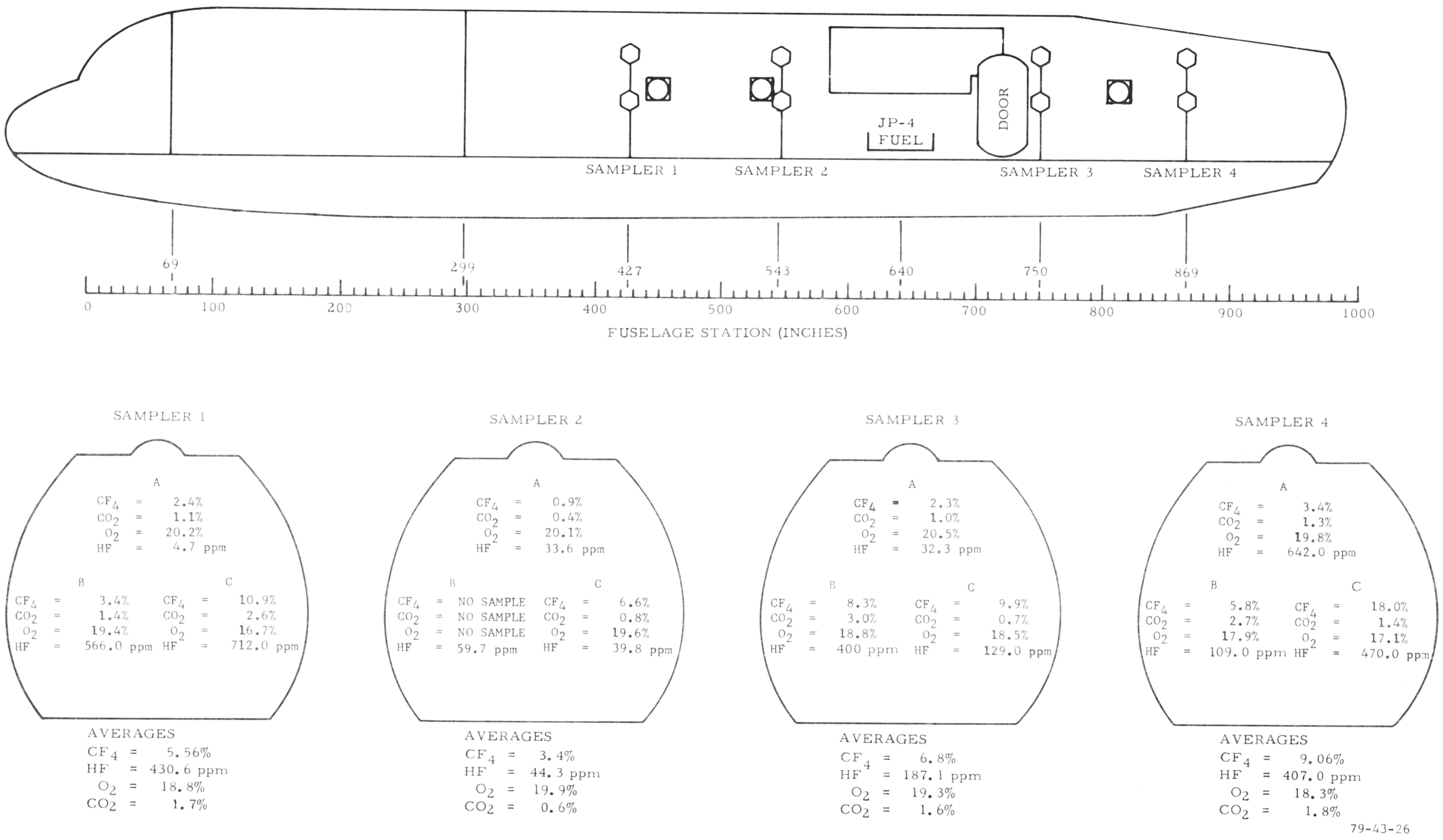


FIGURE 26. TEST 3--COMPOSITION OF THE DC7 CABIN ATMOSPHERE (CLASS B FIRE)

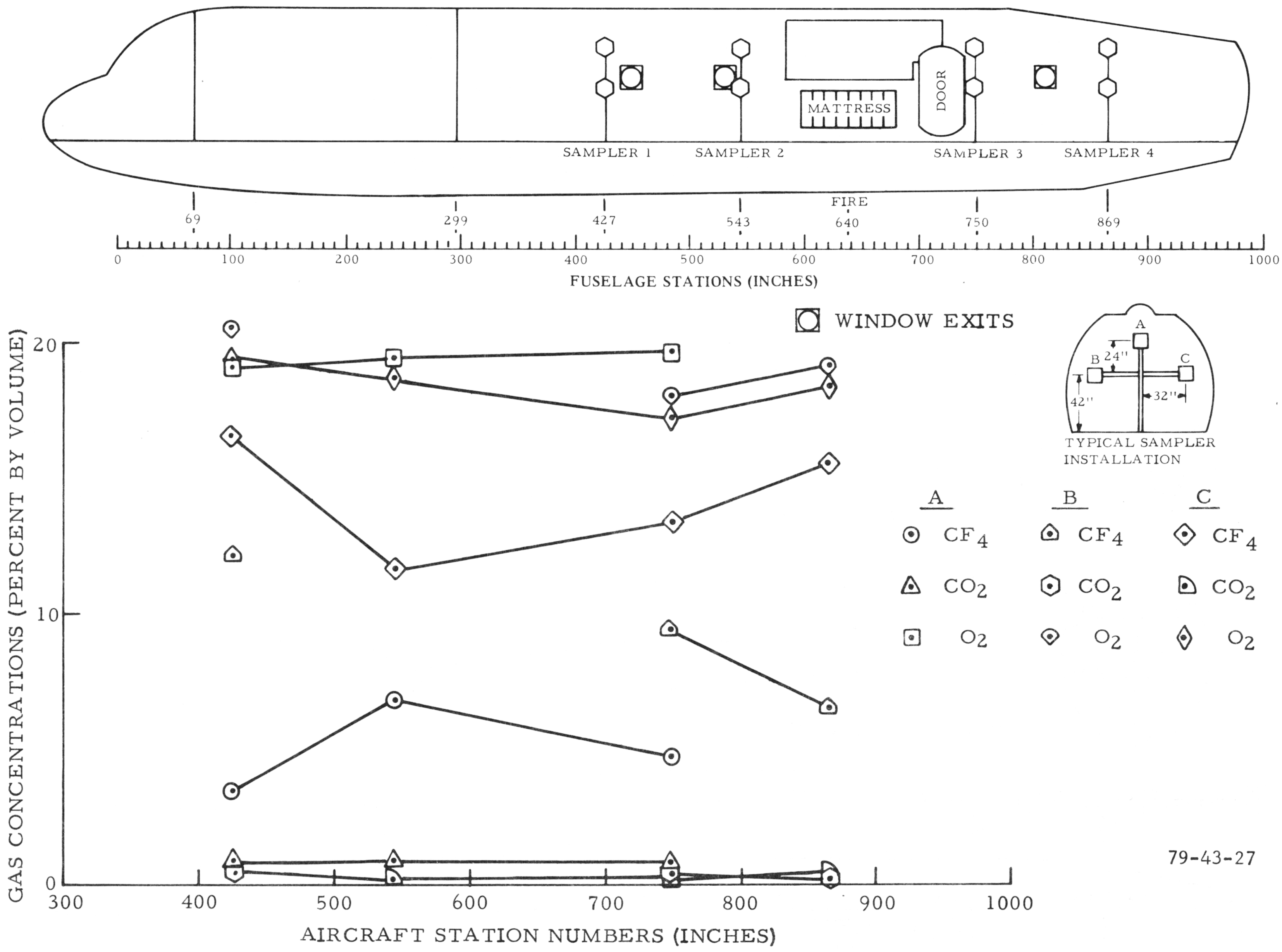


FIGURE 27. TEST 2--CONCENTRATIONS OF CF_4, CO_2, O_2 AT FOUR SAMPLER LOCATIONS (CLASS A FIRE)

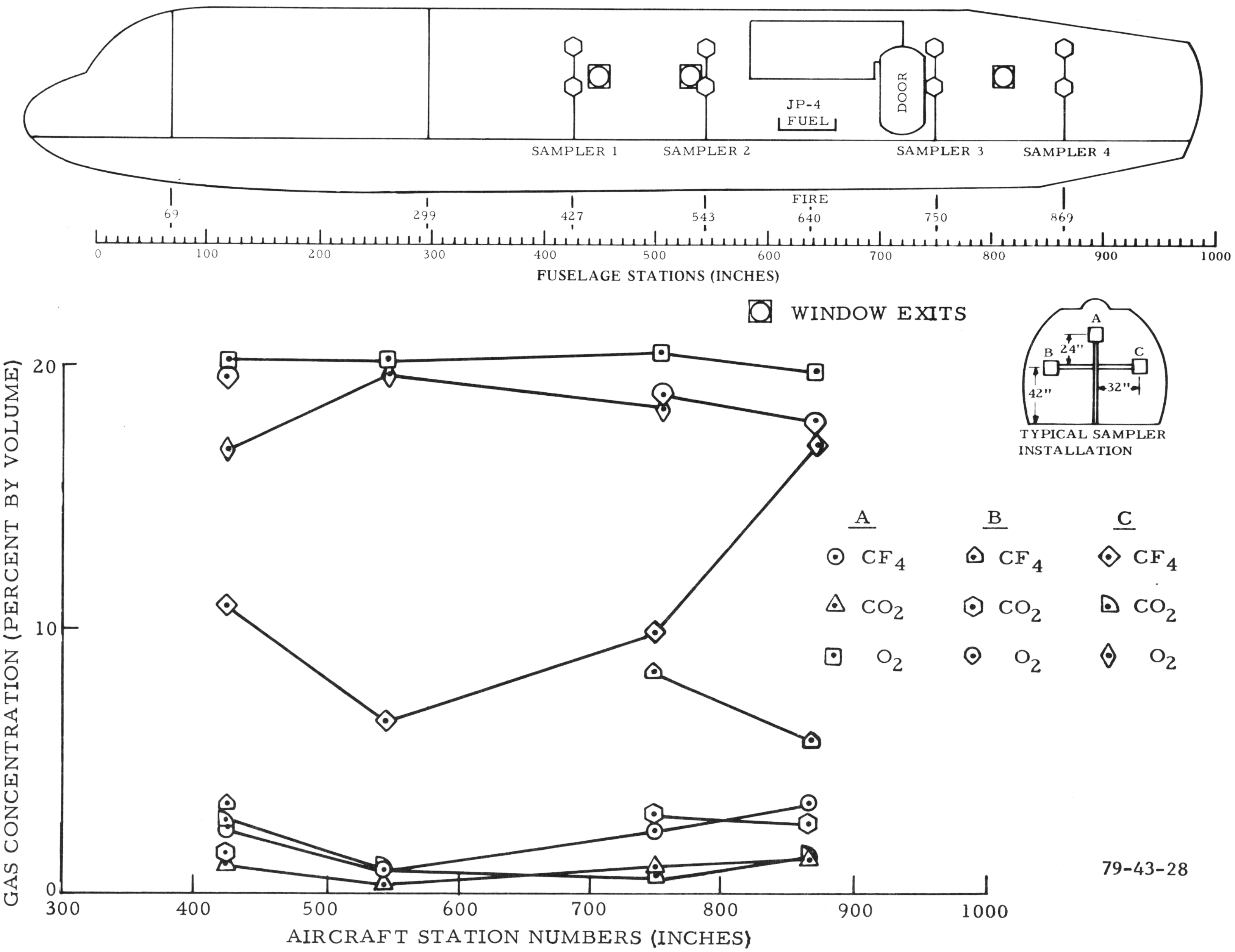


FIGURE 28. TEST 3--CONCENTRATIONS OF CF_4, CO_2, O_2 AT FOUR SAMPLER LOCATIONS (CLASS B FIRE)

attributed, in part, to the difference in test dynamics. The agent concentrations shown in table 2 were obtained from relatively small fuel samples contained in a 3.2 cubic foot (ft^3) hermetically sealed steel chamber which tended to establish stagnant environmental burning conditions. By contrast, the large-scale experiments in the DC7 cabin provided a dynamic situation in which the thermal energy released in the flame plume was more effectively removed by the relatively cool Halon 1400-air atmosphere as it was circulated in the cabin thereby retarding the rate of thermal feedback to the fuel which resulted in more rapid fire extinguishment.

TABLE 3. RESULTS OF FLAMMABILITY TESTS ON VARIOUS MATERIALS*

(Atmospheres contained fluorocarbon agents only added to air in volumetric percentages indicated)

	Percent Agent To Prevent Burning			
Material	CF_4	C_2F_6	C_3F_8	CF_3Br
Tissue Paper	21	12	10	5
Cotton Flannel	19	11	10	5
Canvas	12	8	9	-
Cardboard	15	8	8	-
Kerosene	15	8	7	3
Acetone	13	7	8	3
Ethyl Alcohol	17	8	8	4

*Extracted from reference 4

Although many of the combustion and pyrolysis products generated during the fire tests were noxious, the principal gaseous toxicant was HF, the concentration of which served to indicate the approximate quantity of Halon 1400 decomposed during fire extinguishment. The estimated quantity of Halon 1400 decomposed during tests 2 and 3, assuming the complete destruction of the molecule, was approximately 0.00186- and 0.00666-volume percent, respectively. The HF concentration varied widely throughout the cabin in each experiment with the highest average concentration occurring during test 3 in which the largest flame front and highest temperatures prevailed. The relative flame size produced by the Class A and B fires is shown in figure 29. The accumulative concentration of HF determined at various sampler locations taken over periods of 4 and 5 minutes during test 2 and 3, respectively, are presented in figures 30 and 31. These profiles show the random distribution of HF

A. CLASS A MATERIAL (MATTRESS) FIRE

B. CLASS B MATERIAL (AVIATION FUEL) FIRE

FIGURE 29. RELATIVE FLAME SIZE PRODUCED BY THE CLASS A AND B MATERIALS

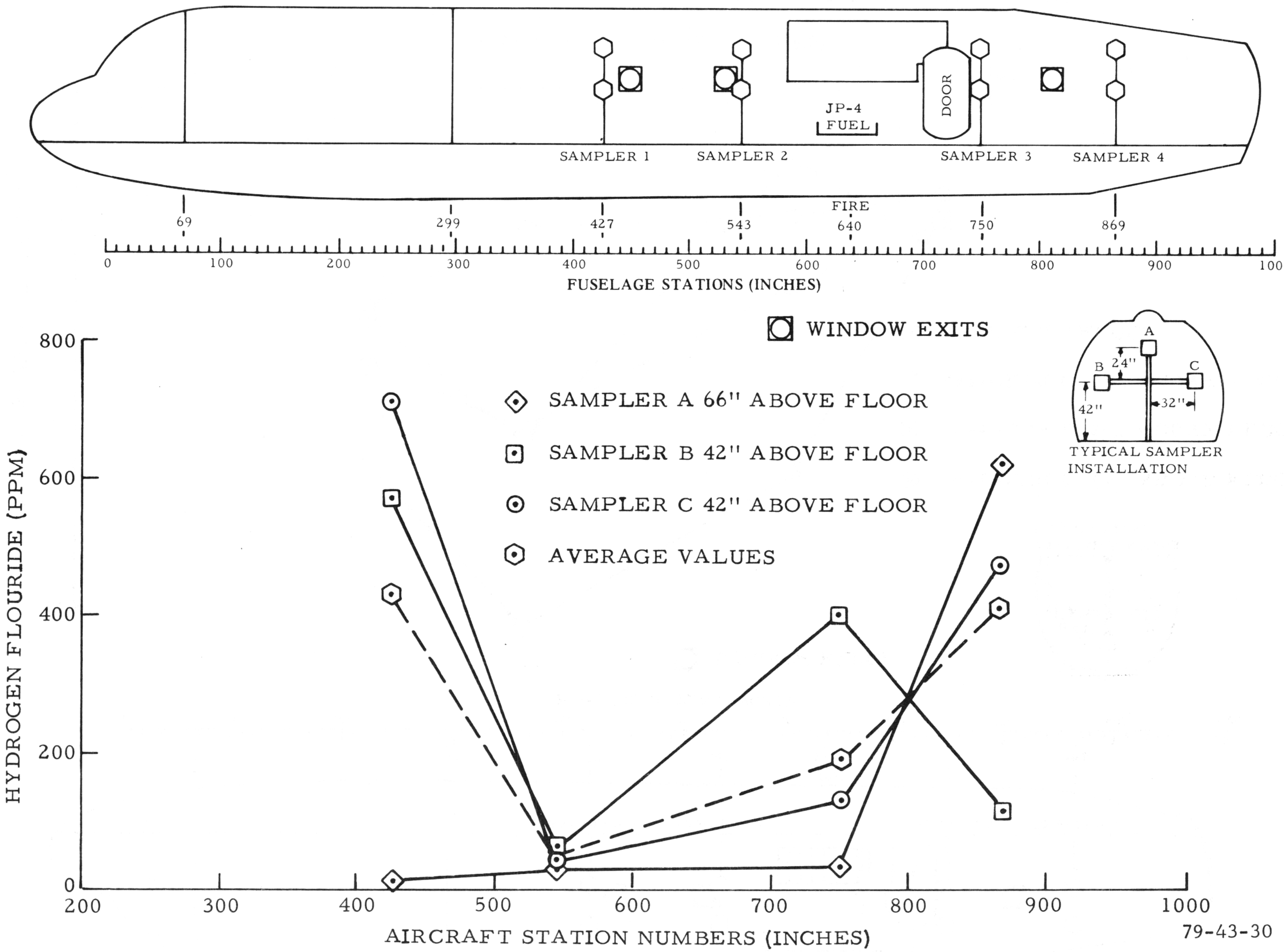


FIGURE 30. TEST 2--HYDROGEN FLUORIDE CONCENTRATIONS AT FOUR SAMPLER LOCATIONS (CLASS A FIRE)

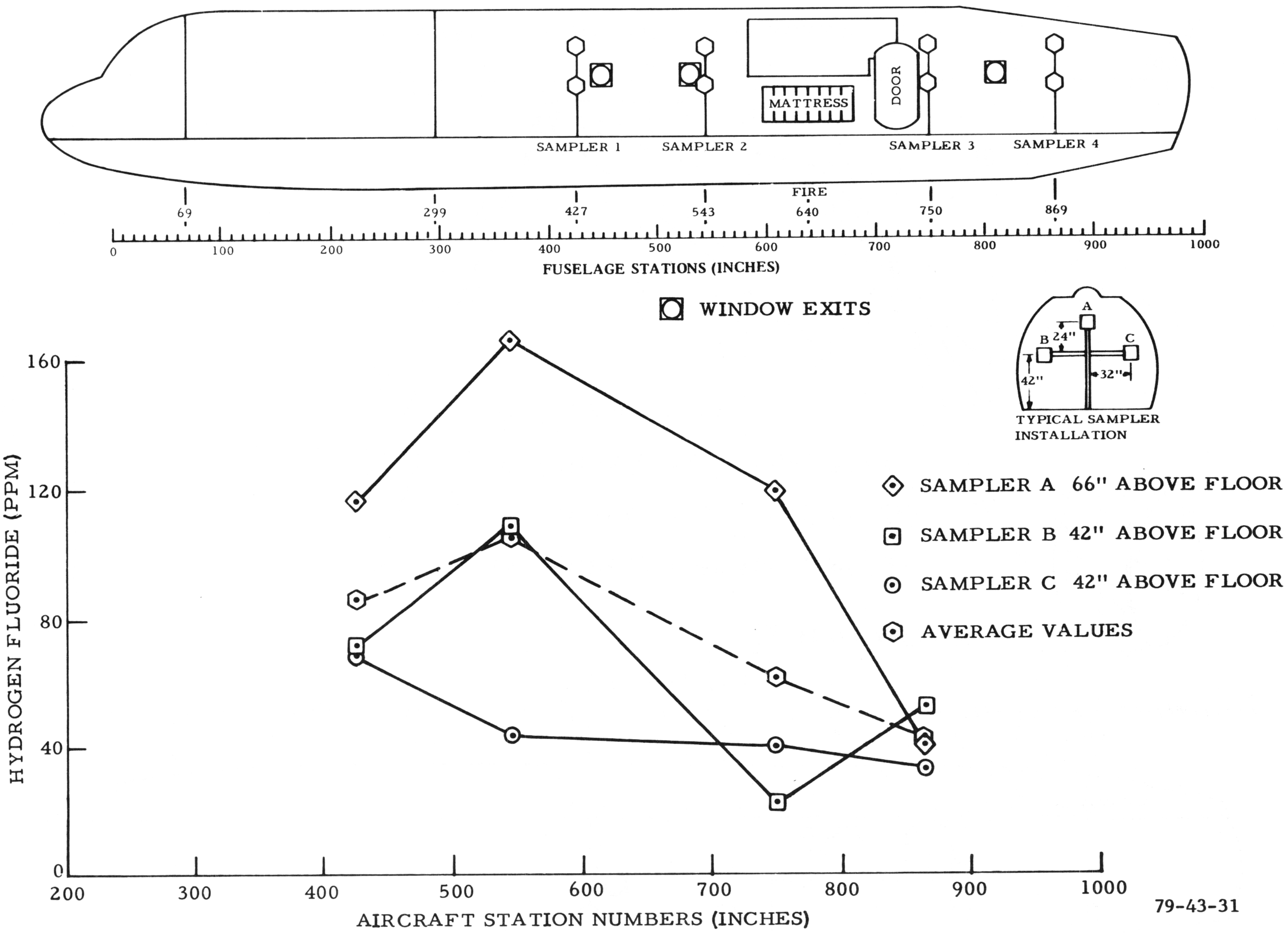


FIGURE 31. TEST 3--HYDROGEN FLUORIDE CONCENTRATIONS AT FOUR SAMPLER LOCATIONS (CLASS B FIRE)

throughout the cabin which probably resulted from the interaction of the convective currents produced by the fire with the Halon 1400-air atmosphere. The lines connecting similar sampling points at each of the four stations in the cabin should not be construed as indicating the concentration of HF at any intermediate station.

The average concentration of HF in the aircraft cabin during tests 2 and 3 was 74.26 and 266.5 ppm, respectively. Although these concentrations are above the value established by OSHA (table 4) for an 8-hour weighted average exposure, they are both significantly below the approximate lethal concentration (ALC) for a 15-minute exposure (reference 7) of 1,500 ppm for HF. The 15-minute time frame defining human survival in terms of toxicant concentration is valid for survivable aircraft accidents involving fire in that accident experience indicates that safe self-evacuation by passengers is generally accomplished within 10 minutes or less.

Table 4 lists the ALC values for several toxic gases which may be associated with the Halon 1400-air extinguisher as well as that for other halogens and halogen acids for comparison. For shorter periods of exposure, these ALC values would be expected to be greater.

TABLE 4. APPROXIMATE LETHAL CONCENTRATIONS OF VARIOUS TOXIC GASES OR VAPORS FOR 15-MINUTE EXPOSURE PERIODS

Toxic Vapor	ALC (15 minute) (ppm)	OSHA (8 hr. weighted average) (ppm)
Carbon dioxide (asphyxiant)	> 5 percent	5,000
Carbon monoxide	1,500	50
Hydrogen fluoride	2,500	3
Hydrogen chloride	4,750	5
Hydrogen bromide	4,750	3
Fluorine	375	0.1
Chlorine	350	1
Bromine	550	0.1

THE U.S. AIR FORCE SKIN PENETRATOR NOZZLE AS A MEANS FOR INJECTING HALON 1400 INTO AN AIRCRAFT CABIN.

BACKGROUND. Heat, smoke, and toxic gases have been identified as the most serious environmental factors influencing safe passenger evacuation in aircraft accidents involving fire. The currently available auxiliary firefighting equipment at U.S. certificated airports does not provide for sufficiently rapid access to aircraft cabin interiors or airframe voids where access ports are limited or not provided. Commercial aircraft configurations employing high tensile strength alloys make forcible entry into some of these areas by the crash-fire-rescue (CFR) services difficult and time consuming. Therefore, to provide a means for overcoming some of these difficulties, a lightweight hand-operated and ballistically-powered firefighting agent dispensing nozzle was developed under contract by the U.S. Air Force to the AAI Corporation (reference 8).

One potential application of the aircraft skin penetrator nozzle is illustrated in figure 32. This photograph shows the firefighter in position for injecting Halon 1400 or some other agent into an aircraft cabin between the seats.

NOZZLE DESIGN AND CAPACITY. The penetrator nozzle is fabricated entirely of heat-treatable stainless steel. The device is 26.25 inches long and weighs 12.2 pounds. Two subsystems are incorporated in the basic design, a ballistic cutter system and a firefighting agent dispensing system. The ballistic system comprises a barrel, firing mechanism, cutter, and a 12-gauge blank cartridge to drive the cutter (figure 33). The agent dispensing system consists of a nozzle, nozzle depth control lever, and a valve with a quick disconnect fitting for attaching to a 3/4-, 1-, or 1 1/4-inch agent supply line. The device is operated by means of the nozzle which serves as a trigger when it is pressed against the surface to be penetrated. This contact fires the cartridge (figure 34) that propels the cutter through the panel.

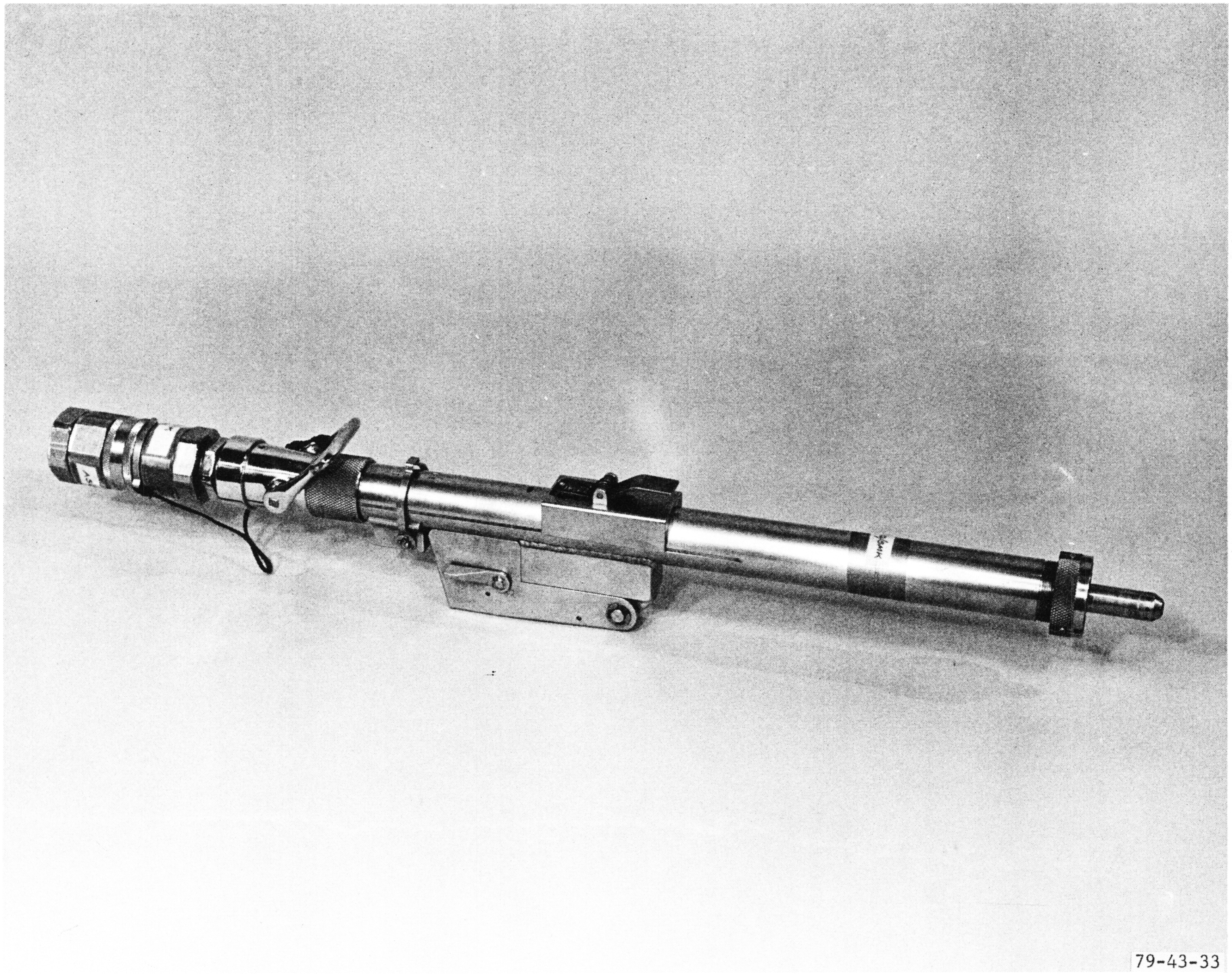
Various construction materials that have been successfully penetrated with the device include:

1/4-inch Fiberglass (MIL-P-25421)
1/4-inch 7075-T6 Aluminum
3/32-inch 7075-T6 Aluminum
3/16-inch 2024-T4 Aluminum
1/16-inch Ti-6Al-4V Annealed Titanium

The device is capable of discharging water, vaporizing liquids, and gaseous fire extinguishing agents. Foam firefighting agents and water can be discharged at the rate of 40 gallons per minute, liquid CO_2 at 100 pounds per minute, bromochloromethane (Halon 1011) at 20 gallons per minute, and Halon 1400 at approximately 810 cubic feet per minute.

TEST PROCEDURES. One large-scale test was conducted with the aircraft skin penetrator nozzle using neat Halon 1400 to extinguish a Class A fuel fire. The fire load comprised a mattress similar to that employed in the previous Halon 1400-air extinguishing experiments. Two nozzle configurations were

FIGURE 32. ONE METHOD OF EMPLOYING THE BALLISTIC AIRCRAFT SKIN PENETRATOR NOZZLE TO CONTROL AND EXTINGUISH AIRCRAFT CABIN FLOW



79-43-33

FIGURE 33. THE U.S. AIR FORCE'S AIRCRAFT SKIN PENETRATOR NOZZLE

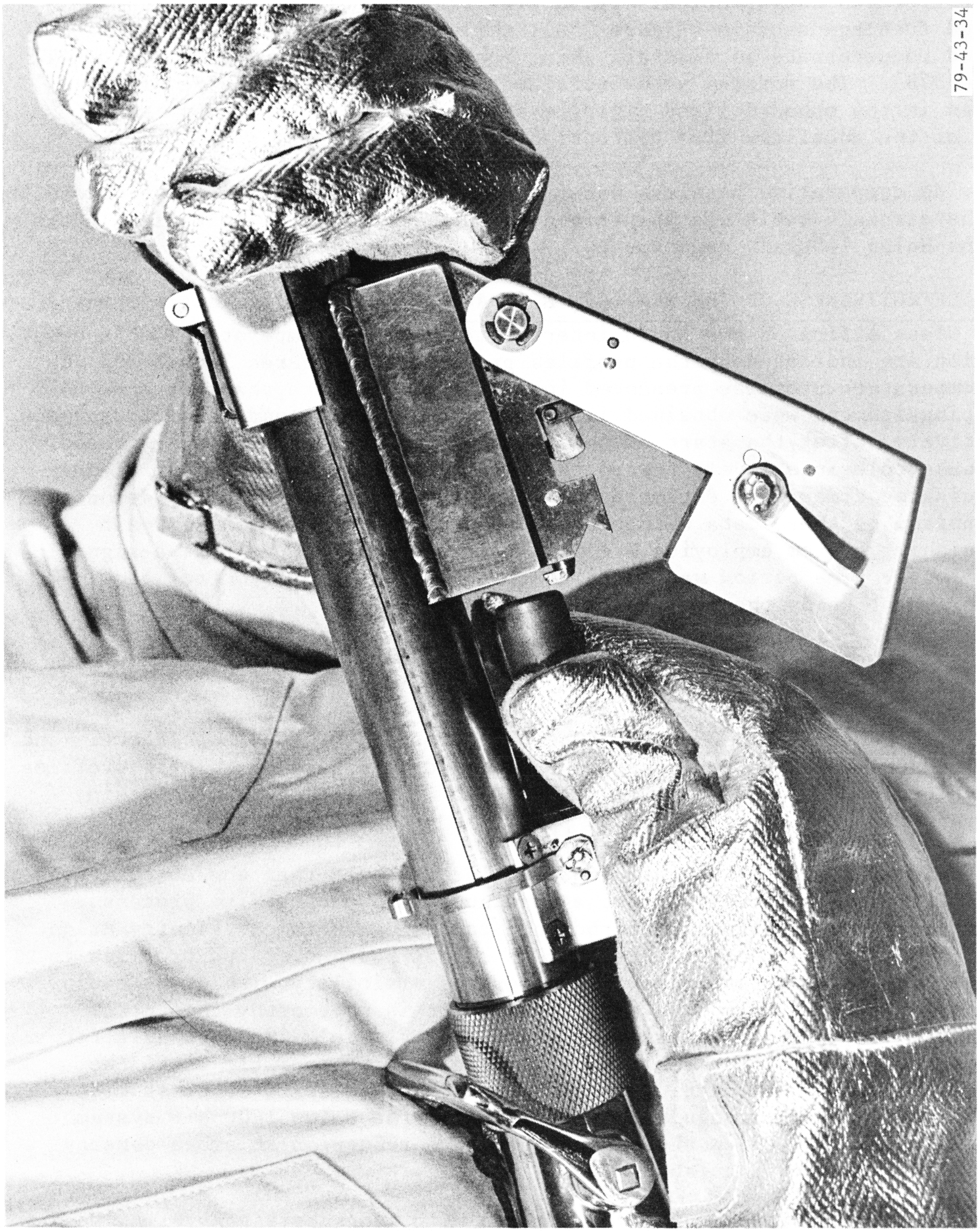


FIGURE 34. BLANK CARTRIDGE (12-GAGE) BEING LOADED INTO THE BREECHBLOCK OF THE PENETRATOR NOZZLE

used to simulate the Halon 1400 discharge within the aircraft cabin: one had a perforated hemispherical tip to penetrate and discharge through an unbacked fuselage section (figure 35A); while the other had the truncated tip required to penetrate an aircraft skin, backed by both insulation and paneling (figure 35B). The nozzles were installed with one on either side of the mattress in the onboard fixed piping system (figure 36) previously employed as one of the ancillary fire protection systems (figure 8).

To provide comparative baseline data, the discharge rate of the neat Halon 1400 into the aircraft cabin was maintained at the same level as that used in the previous Halon 1400-air experiments.

TEST 4 EFFECTIVENESS OF THE NEAT CF_4 DISCHARGE. The environmental impact of the Class A fire on the cabin interior in terms of temperature and thermal radiation are indicated by the profiles presented in figures 37 and 38. The time-temperature profiles presented in figure 37 indicate that fire control and extinguishment were obtained in approximately 186 seconds and 225 seconds, respectively, after the start of the Halon 1400 discharge. However, based upon human tolerance levels toward thermal radiation, the fire control and extinguishing times were estimated to be approximately 145 and 169 seconds. A comparison of these data with those obtained using the Halon 1400-air extinguishing system employing a similar fire load indicates that a significantly longer time period was required to obtain both fire control and extinguishment using the neat Halon 1400 discharge.

Additional thermal data both forward and aft of the fire-hardened area are contained in appendix L.

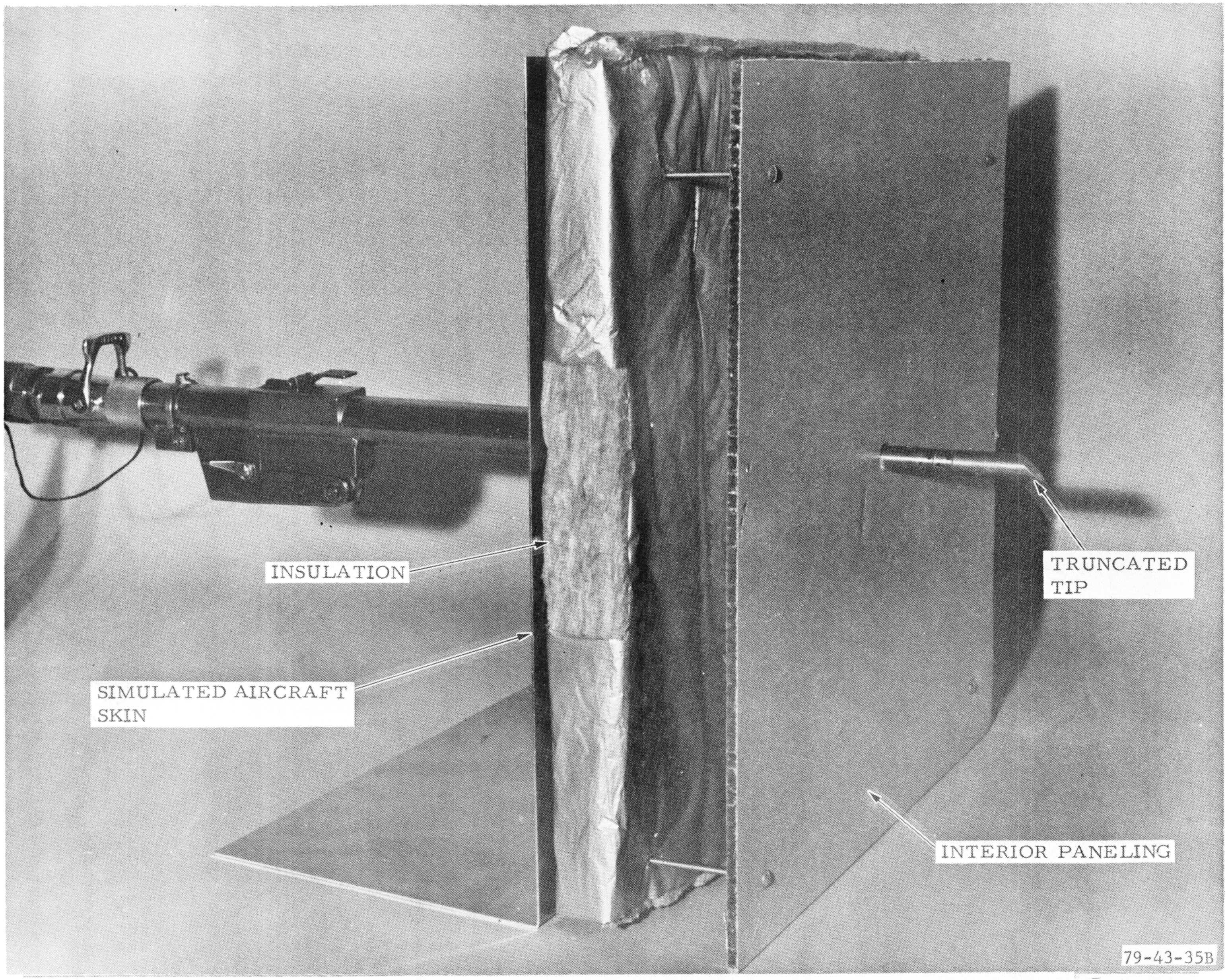
ANALYSIS OF THE CABIN SMOKE DATA. The data provided by the photoelectric and optical instrumentation equipment is summarized in figure 39. These profiles show the prolonged period of time required for fire extinguishment during which large quantities of smoke and pyrolysis products were generated.

An analysis of the optical instrumentation data showed that the obscuration of the EXIT signs by smoke was not a continuous and progressive process, but varied as a consequence of turbulence caused by the high velocity Halon 1400 discharge. The photographic data is superimposed over the profiles in figure 36 and illustrates the cyclic nature of visibility within the cabin as recorded by the forward and aft cameras. It is noteworthy that total obscuration of the cabin interior occurred approximately 196 seconds after fuel ignition and that the smoke density continued to increase until the conclusion of the experiment. This performance is in sharp contrast with that observed during extinguishment by means of the Halon 1400-air system (test 2, figure 23), which showed a progressive reduction in smoke density after the fire was extinguished.

FIRE EXTINGUISHING EFFECTIVENESS OF THE U.S. AIR FORCE SKIN PENETRATOR NOZZLE WHEN USED TO DISPENSE AFFF. Although AFFF was not included for evaluation with the skin penetrator nozzle in this effort, it was considered expedient to conduct one experiment to determine the efficacy of the system as a potential aircraft cabin fire extinguishant under the same environmental conditions as

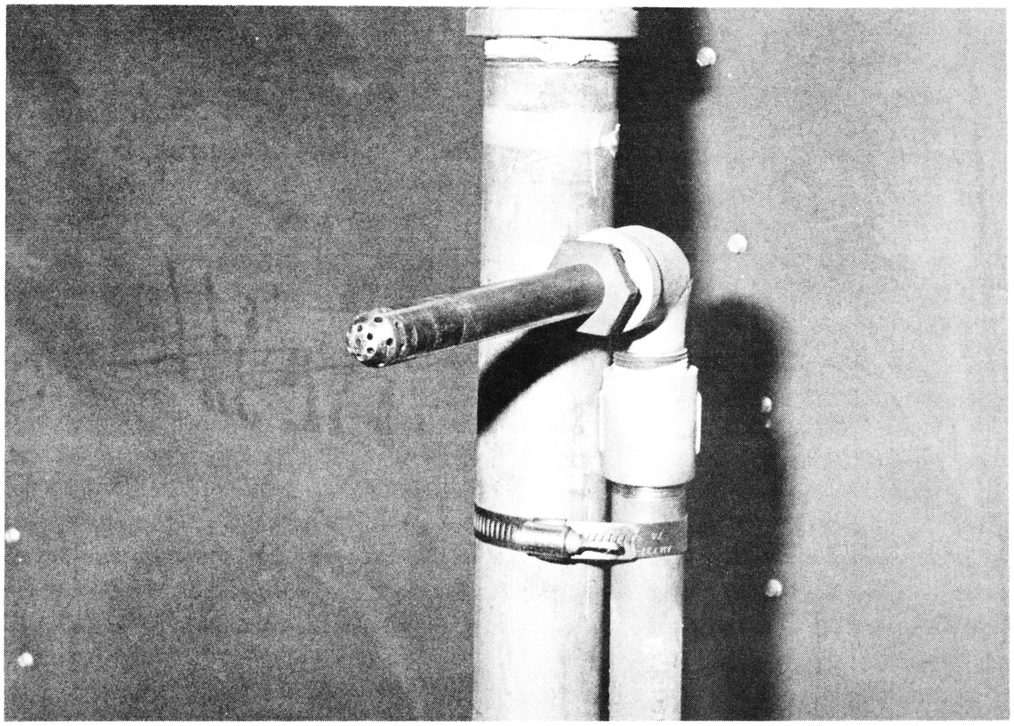
A. HEMISPHERICAL NOZZLE TIP PENETRATING METAL

FIGURE 35. AIRCRAFT SKIN PENETRATOR NOZZLE TIP DESIGNS (SHEET 1 OF 2)

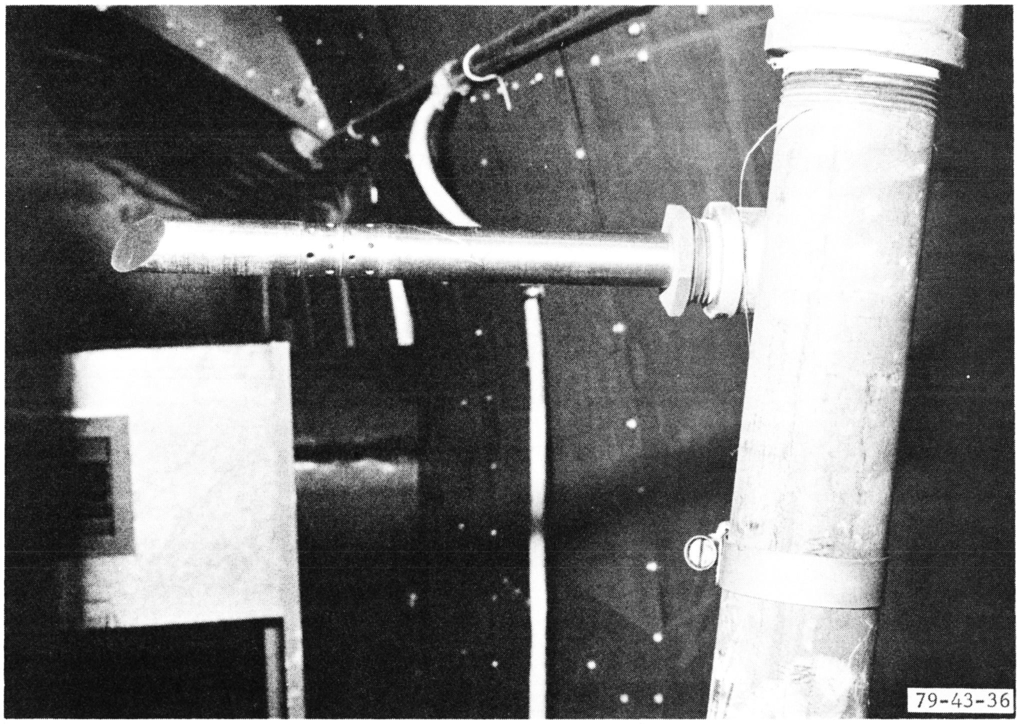


B. TRUNCATED NOZZLE TIP REQUIRED TO PENETRATE ALUMINUM SKIN, INSULATION, AND PANELING

FIGURE 35. AIRCRAFT SKIN PENETRATOR NOZZLE TIP DESIGNS (SHEET 2 OF 2)



A. HEMISPHERICAL NOZZLE TIP CONFIGURATION



B. TRUNCATED NOZZLE TIP CONFIGURATION

FIGURE 36. INSTALLATION SIMULATING TWO POINTS OF FUSELAGE PENETRATION BY THE BALLISTIC NOZZLE

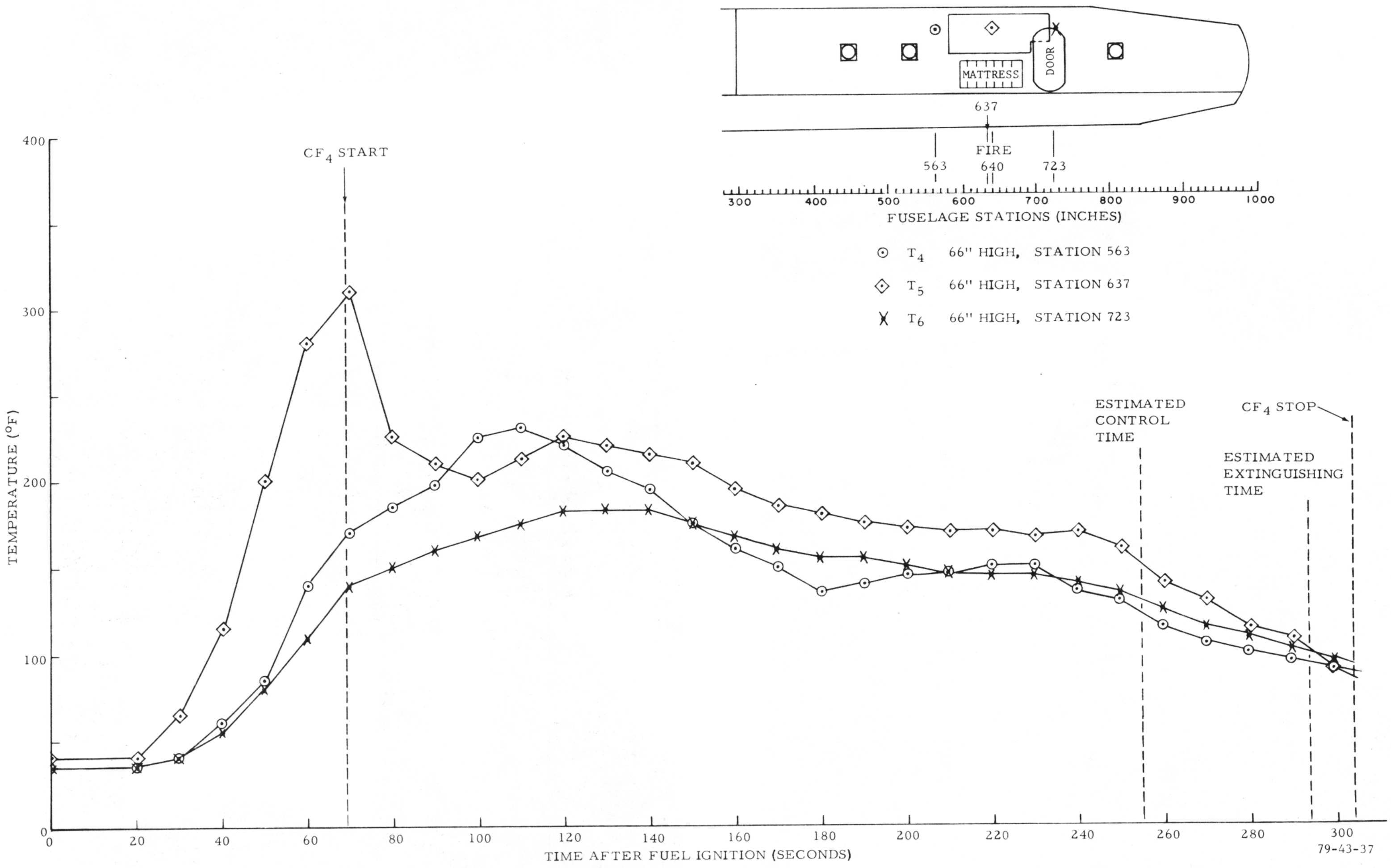


FIGURE 37. TEST 4--AMBIENT AIR TEMPERATURE WITHIN THE FIRE-HARDENED AREA AFTER FUEL IGNITION (CLASS A FIRE)

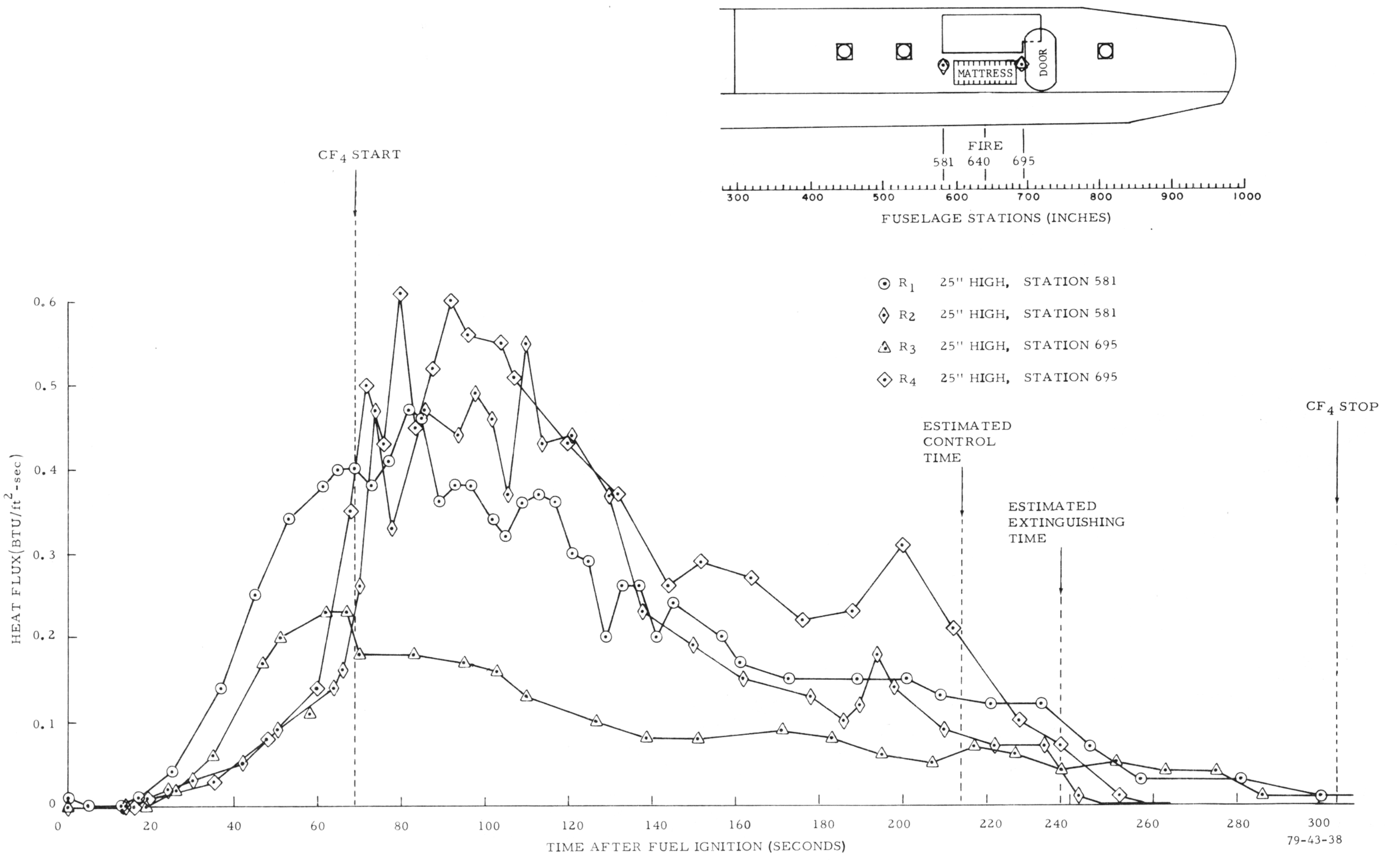


FIGURE 38. TEST 4--THERMAL RADIATION LEVELS WITHIN THE FIRE-HARDENED AREA AFTER FUEL IGNITION (CLASS A FIRE)

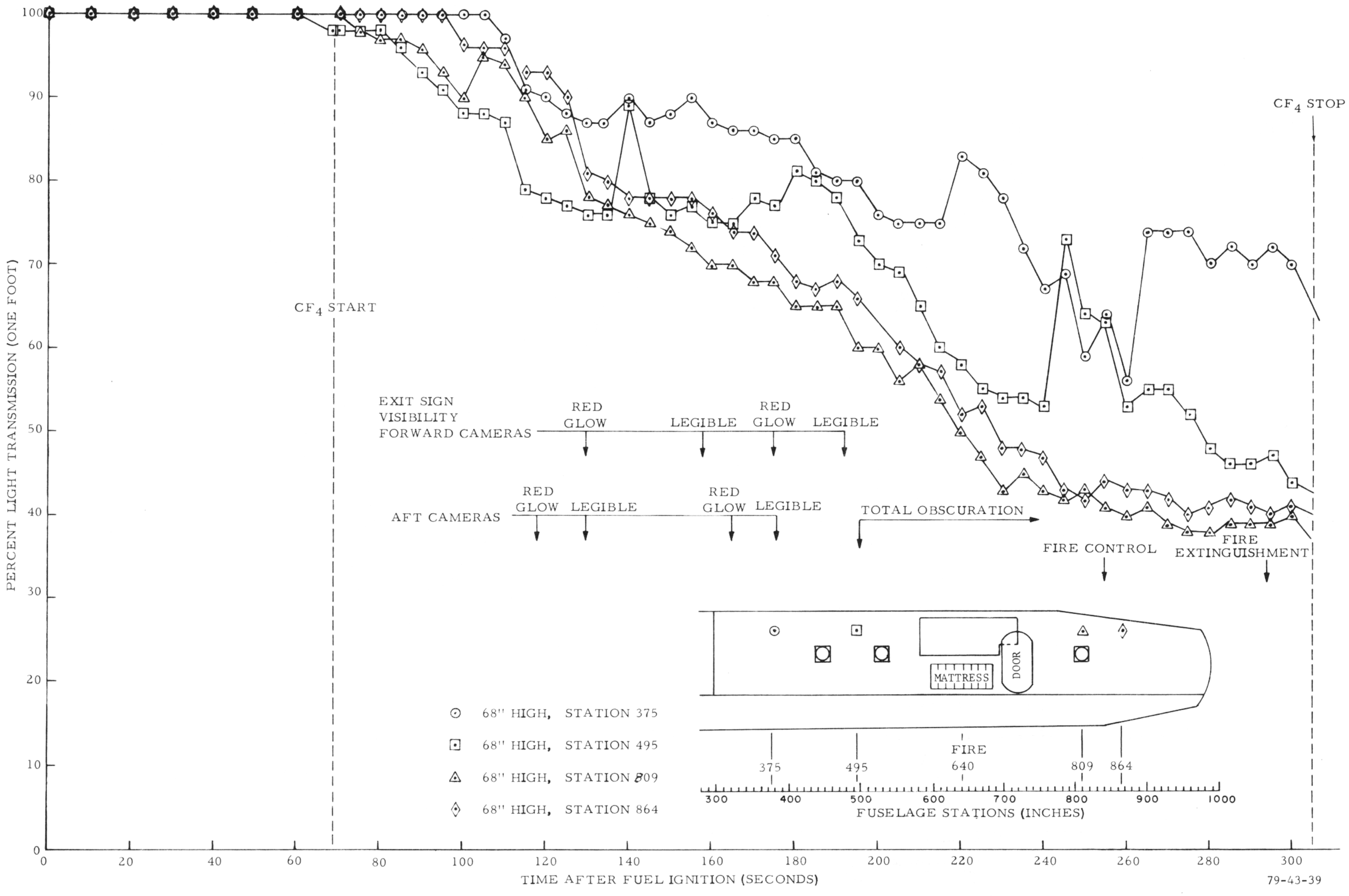


FIGURE 39. TEST 4--SMOKE LEVELS USING NEAT HALON 1400 FROM TWO DISCHARGE POINTS (CLASS A FIRE)

those employed with the Halon 1400-air system. Accordingly, one experiment was performed in which AFFF was dispensed on the established Class A (mattress) fire from two simulated points of fuselage penetration with one located on either side of the mattress. The progress of fire extinguishment was monitored by the same instrument system as that employed in the previous Halon 1400-air fire tests.

The total quantity of AFFF solution impinging on the mattress was approximately 4.13 gallons per minute (gal/min) which resulted in an average application density of 0.123 gal/min-ft^2 of surface area. After ignition, the mattress was permitted to burn freely for 63 seconds prior to the activation of the extinguishing system. During this preburn cycle, severe thermal environmental conditions occurred which were considered to preclude the safe self-evacuation of passengers.

At the moment the AFFF dispensing system was activated, the ambient air temperature within the fire-hardened area reached 335° F , which rose to 350° F during the following 4 seconds and then rapidly declined. Fire control was determined to be 10 seconds based on the reduction in environmental temperature to 150° F, and extinguishment was achieved within 12 seconds when the temperature had been further reduced to 100° F. This relatively rapid reduction in the ambient air temperature is attributable in part to the cooling effect produced through sensible and latent heat absorption by the AFFF spray.

The fire control and extinguishing times determined by the reduction in heat flux from the maximum (0.47 Btu/ft^2-sec) measured by the radiometers to 0.2- and 0.1-Btu/ft^2-sec, respectively, which were considered maximum to assure safe self-evacuation of passengers, required 20 and 40 seconds, respectively.

The quantities of AFFF solution required to obtain control and extinguishment of the mattress fire in terms of temperature reduction were 0.688 and 0.826 gallons, respectively, while 1.376 and 2.752 gallons were employed to achieve the desired reduction in the radiation level. These relatively low solution discharge rates and application densities tend to demonstrate the effectiveness of AFFF in extinguishing one type of Class A material fires.

SUMMARY AND DISCUSSION.

Carbon tetrafluoride was chosen for investigation because of its high molecular bond energies and relatively low animal toxicity when compared with other halogenated fire extinguishing agents. Although Halon 1301 is a more effective extinguishing agent (table 3) than Halon 1400, it is both chemically and biologically more active. However, because of its superior extinguishing effectiveness, Halon 1301 is considered a viable candidate for use in the Halon-air system and worthy of evaluation.

The information presented in table 5 summarizes the more significant data obtained during the four large-scale fire tests in which Halon 1400 was used as the extinguishant. The data show that the Halon 1400-air system was more effective than anticipated in terms of the residual concentration in the

TABLE 5. SUMMARY OF FIRE TEST DATA

							CF_4 Fire Performance					
							Air Temperature		Heat Flux			
Test No.	Fire Class	Fire Load	Sampling Time Load	Average CF_4 Concentration in Atmosphere (percent)	Total CF_4 Discharge Time (sec)	Average CF_4 Concentration in Cabin (sec)	Control Time (150°F) (sec)	Exting. Time (100°F) (sec)	Control Time (0.20 BTU/ft2-sec) (sec)	Exting. Time (0.10 BTU/ft2-sec) (sec)	Average HF Concentration (ppm)	Average CO Concentration (ppm)
1	A	mattress	--	--	130	--	75	125	19	59	--	—
2	A	mattress	300	26.9	153	10.40	84	124	48	75	74.2	26.7
3	B	JP-4	240	27.9	109	6.47	Cont.@ 400°F 73	Ext.@ 300°F 93	61	79	265.1	33.3
U.S. AIR FORCE SKIN PENETRATOR NOZZLE												
4	A	mattress	--	neat CF_4 discharge	247	--	186	225	145	169	--	--

cabin atmosphere after fire extinguishment. This effect may be attributed in part to the dynamic conditions established by the Halon 1400-air stream which tends to accelerate the heat transfer from the fire plume to the extinquishing medium which serves principally as a heat sink. The measured concentration of Halon 1400 in the cabin atmosphere was 10.40 percent for the Class A fire and 6.47 percent for the Class B fire which may be considered survivable over a prolonged time period (reference 4).

Although neat Halon 1400 poses no significant toxicity problems in concentrations of 20-volume percent or less, its pyrolysis products which are principally CO and HF must be considered. Because human tolerance levels to these compounds cannot be determined directly, the recorded levels are based upon animal studies. A very large body of data in this regard has been developed and will probably continue into the predictable future.

The concentrations of HF in the DC7 aircraft cabin varied from 74.2 ppm for the Class A fire to 265 ppm for the Class B fire; while the concentration of CO was 26.7 ppm for the Class A fire and 33.3 ppm for the Class B fire. A comparison of these data with those presented in table 4 tends to indicate that the concentration of HF and CO in terms of time-concentration survival time for a 15-minute exposure does not pose a significant human toxicity problem. However, the concentration values shown for CO (1,500 ppm) and HF (2,500 ppm) tend to indicate that CO is significantly more toxic than HF and that the concentrations of both toxicants are well below those obtained in either of the Halon 1400-air extinguishing tests in the DC7 aircraft.

SUMMARY OF RESULTS

The results obtained from the large-scale aircraft cabin fire extinguishing experiments using the Halon 1400-air and neat Halon 1400 discharge on Class A and B material fires are:

1. The concentration of Halon 1400 in the Halon 1400-air fire extinguishing system was 26.90- and 27.90-volume percent for the Class A and B combustibles, respectively.

2. The average concentration of Halon 1400 in the aircraft cabin after extinguishment of the Class A and B fires was 10.40- and 6.47-volume percent, respectively.

3. The cabin EXIT signs were obscured by smoke during the second Class A fire test within 145 seconds after fuel ignition, while it required only 18 seconds to obscure the signs using the Class B fuel (test 3).

4. The average concentration of hydrogen fluoride (HF) in the aircraft cabin during test 2 (Class A fuel) using the Halon 1400-air extinguishing system was 74.2 parts per million (ppm), which rose to 265.1 ppm during test 3 (Class B fuel).

5. The average concentration of carbon monoxide (CO) in the DC7 aircraft cabin was 26.7 ppm during test 2 (Class A fuel) and 33.3 ppm during test 3 (Class B fuel).

6. At no time during tests 2 (Class A fuel) or test 3 (Class B fuel) was the oxygen (O_2) content of the cabin atmosphere below 18.9 percent by volume.

7. The fire control and extinguishing times of the Class A fire (test 2) were 84 and 124 seconds, respectively, based upon the estimated temperature tolerance level of humans, while Class B fuel times were 73 and 93 seconds (test 3).

8. The fire control and extinguishing times based upon human tolerances to thermal radiation were 48 and 75 seconds for test 2, and 61 and 79 seconds for test 3, respectively.

9. Based upon the optical instrumentation data, visibility within the DC7 aircraft during the neat Halon 1400 discharge (test 4) became seriously impaired within 118 seconds after fuel ignition and the EXIT signs were totally obscured within 196 seconds.

10. Based upon the DC7 aircraft cabin temperatures, fire control and extinguishing times for the Class A fire (test 4) while discharging neat Halon 1400 from two simulated points of fuselage penetration were 186 seconds and 225 seconds, respectively.

11. Fire control and extinguishing times were 145 and 169 seconds, respectively, based upon the estimated radiation levels of human tolerances during the neat Halon 1400 discharge.

CONCLUSIONS

Based upon the results of the Class A and B fire tests conducted in the DC7 aircraft cabin using the Halon 1400-air system and neat Halon 1400 discharge, it is concluded that:

1. The Halon 1400 proportioning system was adequate to produce and maintain the required Halon 1400-to-air ratio during the experiments.

2. The concentration of Halon 1400 in the aircraft cabin after fire extinquishment was below that estimated to be required for the Class A and B fires.

3. The quantity of smoke, in terms of optical density, produced by the Class B fire (test 3) greatly exceeded that produced by the Class A fires in these experiments.

4. A significantly higher concentration of hydrogen fluoride (HF) was produced in test 3 as a consequence of higher temperatures and a larger flame front.

5. The approximate lethal concentration (ALC) of HF (2,500 parts per million (ppm)) for a 15-minute exposure was not exceeded in these experiments. However, the 8-hour weighted average concentration of HF (3 ppm) established by Occupational Safety and Health Administration (OSHA) was greatly exceeded.

6. The concentration of carbon monoxide (CO) established by OSHA of 50 ppm (8-hour weighted average) was not exceeded in either the Class A fire (test 2) or the Class B fire (test 3) conducted in the DC7 cabin.

7. Anoxia would not have been a controlling parameter inhibiting passenger safe, self-evacuation from the DC7 aircraft in there experiments.

8. A comparison of the fire control and extinguishing times based upon the temperature and radiation data tends to indicate that the radiation levels drop within human tolerance levels somewhat more rapidly than the environmental temperatures during extinguishment by the Halon 1400-air system.

9. Fire control and extinguishment of the Class A fire (test 4) required a significantly longer application time when neat Halon 1400 was discharged at the same rate as that used in the Halon 1400-air system.

RECOMMENDATIONS

Based upon the results obtained during the performance evaluation of the Halon 1400-air fire extinguishing system, it is recommended that:

1. Comparative fire tests be conducted in the DC7 aircraft cabin in which Halon 1400 and Halon 1301 are proportioned at 20 and 5 percent by volume with air.

2. Comparative fire tests be conducted with Halon 1400 and Halon 1301 to determine the residual concentration of Halon 1400, Halon 1301, carbon dioxide (CO_2), carbon monoxide (CO), oxygen (O_2), hydrogen fluoride (HF), and hydrogen bromide (HBr) within the DC7 aircraft cabin after the extinguishment of Class A and B materials.

3. An assessment of the benefit-cost relationship be made between Halon 1400 and Halon 1301 in terms of fire extinguishing effectiveness and the relative toxicity of the ensuing cabin atmosphere.

4. The practicability of the Halon 1400-air extinguishing system be assessed by conducting full-scale fire modeling experiments based upon accident experience and the established 90-second passenger evacuation time frame.

5. The halocarbon-air-type fire extinguishing system be evaluated as a total flooding system under environmental conditions from which occupants cannot immediately evacuate themselves such as railroad cars, buses, boats, etc.

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5. Cotrell, T.L., The Strength of Chemical Bonds, Academic Press, 2nd Edition, New York, 1958.

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APPENDIX A

TOXICITY OF HALOCARBON PYROLYSIS PRODUCTS

In laboratory fire extinguishing experiments, CF_4, C_2F_6, and C_3F_8 were determined (reference 2) to be effective fire extinguishing agents at concentrations below their toxicity level. However, in all of the experiments, a portion of the extinguishing agent was pyrolysed producing principally carbon monoxide (CO) and hydrogen fluoride (HF). The quantity of CO produced during the 10-second fire extinguishing period would not present a significant toxicity hazard to humans. However, the concentrations of HF produced along with the CO by the three fluorocarbons are presented in table A-1.

TABLE A-1. QUANTITY OF HF PRODUCED BY THE THERMAL DECOMPOSITION OF THE FLUOROCARBONS

	Extinguishing Agents			
Pyrolysis Product (ppm)	Halon 1400 (CF_4)	Halon 2600 (C_2F_6)	Halon 3800 (C_3F_8)	Baseline Halon 1301 (CF_3Br)
HF	6.6	280	430	50

These data show that an unacceptably high level of HF is produced by Halon 2600 and Halon 3800 in situations where personnel may be required to remain in the post-fire environment. However, the relatively low concentration of HF produced by Halon 1400 tends to indicate that this agent would be acceptable from this standpoint.

APPENDIX B

PHYSICAL, CHEMICAL, THERMODYNAMIC, AND RADIATION STABILITY OF HALON 1400

PHYSICAL.

Carbon tetrafluoride is an odorless, colorless gas with a low order of toxicity and is nonflammable. It is handled as a gas in steel cylinders. Some of its vital characteristics are as follows:

Molecular Weight	88.005
Boiling Point	-198.32° F
Critical Temperature	-50.2 ° F
Critical Pressure	543.2 psia
Critical Volume	0.0256 ft^3/lb

CHEMICAL.

The following selected data tend to emphasize the chemical stability of CF_4 (E. I. Dupont de Nemours).

PYROLYSIS. It is extremely stable.

$$CF_4\ (g) \longrightarrow CF_3\ (g) + 1/2\ \ F_2\ (g)$$

Keg = 3 x 10^{-22} @ 1000° K (calculated from
data in NBS Report 1439)

ELECTRIC ARC. It reacts only slightly to give C_2F_6 and C_2F_4.

HYDROLYSIS. It is thermodynamically unstable. Kinetically stable in reactions with gaseous water. (W. A. Wilson, Ph. D. Thesis, Pennsylvania State College 1950)

THERMODYNAMIC.

Halon 1400 reactions with metals and oxides are analyzed in tables B-1, B-2, and B-3.

TABLE B-1. REACTIONS WITH METALS AND OXIDES

Metals/Oxides	Temperature	Effect
Cu, Ni, Mo, Ag, Si, Sb, Cr, Fe, Pt, MgO, Be_2O_3, CrO_3, MoO_3, WO_3	softening point of glass	none
Alkali metals	400° C	MF + C
Magnesium (liquid)	700° C	slow reaction
SS, W	1000° C	reacts

(Simons, "Fluorine Chemistry," Vols. I and II)

TABLE B-2. CORROSION OF CARPENTER 304 SS

Time (hrs)	Temperature (°C)	Pressure (psi)	Result
20	425	400	pale brown discoloration
20	500	400	much more noticeable attack--dull grey film

(MacCormack and Schneider, J. Chem. Phys., 19, No. 7 846, 1951)

TABLE B-3. GENERAL REACTIONS

Agent	Temperature	Effect
Carbon	<1200° K	none
	>5000° K (arc)	slight--C_2F_2, C_2F_6
CO_2	1000° C	forms COF_2, Keg (Calc.) = 0.466
H_2	900° C	Cu catalyst--none
	spark	none
Air	gas flame	noncombustible nonflammable

RADIATION STABILITY.

Very little experimental data are available on the radiation stability of carbon tetrafluoride.

Dick, et al., (Helv. Physica Acta, 20 357) have determined stopping power (2.70 in.) and work of ionization (31.1 ev) by alpha particles from ThC. Steidlitz, et al., (J. Phys. Chem. 56 1010, 1952) found that alpha particles from U-234 produced 1.44 x 10^{-5} ion pairs per alpha particle. This was the lowest value obtained for a number of fluorocarbon gases.

Recent work at Du Pont with 2 MEV electrons indicates that CF_4 undergoes 1-2 mole percent decomposition (to C_2F_6) when exposed to 10^8 rads. The gas was contained in a cooled aluminum capsule at 20 psig.

P. Y. Feng of Armour Research Institute has reported the results of gamma-ray irradiation of benzene solutions of carbon tetrafluoride (A/Conf. 15/P/922-). G-values, using diphenylpicrylhydrazyl, were low (0.8-1.0) and the principal decomposition products were ΦF and ΦCF_3.

APPENDIX C

COMPONENT SPECIFICATIONS FOR THE HALON 1400-AIR AIRCRAFT CABIN FIRE EXTINGUISHER SYSTEM

FAN UNIT.

Shall comprise a variable speed centrifugal fan with nonoverloading backward curved aluminum wheel, self-aligning pillow block bearings, split taper lock housing, adjustable V-belt drive sized for 150 percent of normal horsepower rating, static and dynamic balancing of unit, complete drive protection inlet screen and drain.

The nominal test flow rate shall be 3,000 cubic feet per minute with a variation of ±5 percent due to adjustable drives. Larger variations in the airflow rate shall be capable of being accomplished by a complete drive package change, in the field, from stock items.

HALON 1400 INJECTOR.

The fan unit shall incorporate a system for injecting variable quantities of Halon 1400, from 15 to 25 percent by volume into the airstream during operation. Means shall be provided to measure and control the volume of Halon 1400 injected within ±1.0 percent of the calculated quantity based on the airflow rate.

FLEXIBLE DUCT.

The air duct shall be of all metal construction, bonded, two-ply, laminated, and semirigid for ease of handling, capable of continuous operation at 350° F, and able to withstand operating pressures of 20 inches of water with a crushing strength of 110 pounds per foot.

DIFFUSER TERMINAL.

The diffuser terminal at the end of the flexible duct shall be constructed so as to allow the mixture of air and Halon 1400 to be distributed in a pattern which can be varied from full forward to full aft or any percentage desired forward or aft. The diffusion device shall be adjustable for variations in throw paths of 80° up/down and not less than 160° left/right which may be accomplished by spread control members and a vane dividing members. The diffuser must be capable of a throw of at least 60 feet in both directions simultaneously.

APPENDIX D

DETERMINATION OF HYDROGEN FLUORIDE

Analyte:	Hydrogen Fluoride	Method No.:	S176
Matrix:	Air	Range:	1.33-4.50 mg/cu m
OSHA Standard:	3 ppm (2.45 mg/cu m)	Precision ($\overline{CV}_T$):	0.057
Procedure:	Bubbler collection in 0.1 N sodium hydroxide, ion specific electrode	Validation Date:	8/1/75

1. Principle of the Method (Reference 11.1)

   1.1 A known volume of air is drawn through a midget bubbler containing 10 ml of 0.1 N sodium hydroxide to trap hydrogen fluoride.

   1.2 The resulting solution is made up to 25 ml with 0.1 N sodium hydroxide and transferred to a 50-ml polyethylene beaker.

   1.3 The sample is diluted with 25 ml total ionic strength activity buffer (TISAB).

   1.4 The diluted samples are analyzed using a fluoride ion specific electrode.

2. Range and Sensitivity

   2.1 This method was validated over the range of 1.33-4.50 mg/cu m at an atmospheric temperature and pressure of 22°C and 761 mm Hg, using a 45-liter sample. The probable useful range of this method is 0.245-7.35 mg/cu m for 45-liter samples.

   2.2 The upper limit of the range of the method is dependent on the collection efficiency of the midget bubbler. If higher concentrations than those tested are to be sampled, smaller sample volumes should be used. The collection efficiency for hydrogen fluoride was determined to be 0.991 ± 0.004 when sampled for 30 minutes at 1.5 liters per minute from a test atmosphere containing 4.50 mg/cu m.

3. Interference

3.1 When interferring compounds are known or suspected to be present in the air, such information, including their suspected identities, should be transmitted with the sample.

3.2 Hydroxide ion is the only significant electrode interference; however, addition of the TISAB eliminates this problem. Very large amounts of complexing metals such as aluminum may result in low readings even in the presence of TISAB.

4. Precision and Accuracy

4.1 The Coefficient of Variation ($\overline{CV}_T$) for the total analytical and sampling method in the range of 1.33-4.50 mg/cu m was 0.057. This value corresponds to a standard deviation of 0.14 mg/cu m at the OSHA standard level. Statistical information and details of the validation and experimental test procedures can be found in Reference 11.2.

4.2 A collection efficiency of 0.991 ± 0.004 was determined for the collecting medium. On the average the concentrations obtained at the OSHA standard level using the overall sampling and analytical method were 5.5% higher than the "true" concentrations for a limited number of laboratory experiments. Any difference between the "found" and "true" concentrations may not represent a bias in the sampling and analytical method, but rather a random variation from the experimentally determined "true" concentration. Therefore, no recovery correction should be applied to the final result in paragraph 10.4.

5. Advantages and Disadvantages of the Method

5.1 The samples collected in bubblers are analyzed by means of a quick, instrumental method.

5.2 There are no known disadvantages to the method.

6. Apparatus

6.1 Sampling Equipment. The sampling unit for the bubbler collection method consists of the following components:

6.1.1 A glass "midget bubbler" containing the collection medium (Section 7.3). Bubbler stem unit consists of a two-hole rubber stopper to fit 1/8-in O.D. Teflon tubing.

6.1.2 A prefilter unit which consists of the filter media and a polystyrene 37-mm, 2-piece cassette filter holder. The filter is a 37-mm mixed cellulose ester membrane filter with a 0.8-micrometer pore size. A cellulose backup pad should not be used, but care must be taken to insure that the filter is sealed tightly to avoid air leaks during sampling.

6.1.3 A pump suitable for delivering at least 1.5 liters per minute for 30 minutes. The sampling pump is protected from splashover or solvent condensation by a 5-cm long by 6-mm I.D. glass tube loosely packed with a plug of glass wool and inserted between the exit arm of the bubbler and the pump.

6.1.4 An integrating volume meter such as a dry gas or wet test meter.

6.1.5 Thermometer.

6.1.6 Manometer.

6.1.7 Stopwatch.

6.2 Volumetric flasks: 25-ml or convenient sizes.

6.3 Pipets: 1, 2, 4, and 5 ml.

6.4 Orion Model 94-09 fluoride specific ion electrode, or equivalent.

6.5 Reference electrode, Orion 90-01 single junction, or equivalent calomel or silver/silver chloride electrode.

6.6 Expanded scale millivolt-pH meter, capable of measuring to within 0.5 millivolt.

6.7 Polyethylene beakers, 50-ml capacity.

6.8 Magnetic stirrer and stirring bars for 50-ml beakers.

7. Reagents

All chemicals must be ACS reagent grade or equivalent. Polyethylene beakers and bottles should be used for holding and storing all fluoride-containing solution.

7.1 Doubly distilled water.

7.2 Glacial acetic acid.

7.3 Collection Medium: 0.1 N sodium hydroxide solution. Dissolve 4 g of sodium hydroxide in 1 liter distilled water.

7.4 Sodium hydroxide, 5 N solution. Dissolve 20 g of sodium hydroxide in sufficient distilled water to give 100 ml of solution.

7.5 Sodium chloride.

7.6 Sodium citrate.

7.7 Total Ionic Strength Activity Buffer (TISAB). Place 500 ml of doubly distilled water in a 1-liter beaker. Add 57 ml of glacial acetic acid, 58 g of sodium chloride, and 0.30 g of sodium citrate. Stir to dissolve. Place beaker in water bath (for cooling) and slowly add 5 N sodium hydroxide until the pH is between 5.0 and 5.5. Cool to room temperature and pour into a 1-liter volumetric flask and add doubly distilled water to the mark.

7.8 Sodium fluoride, for preparation of standards.

7.9 Standard Fluoride Solution.

7.9.1 Dissolve 12.06 mg sodium fluoride in 0.1 N sodium hydroxide (prepared from doubly distilled water) and dilute to 100 ml with 0.1 N sodium hydroxide. This solution is equivalent to 0.0546 mg/ml F^-. One ml of this solution contains the amount collected at the 0.5X OSHA level, when sampling at 1.5 liters per minute for 30 minutes. The 0.5X level standard is made by spiking 10 ml of 0.1 N sodium hydroxide with 1 ml of the standard stock solution. Likewise, the 1X level standard is prepared with 2 ml, and the 2X level is prepared with 4 ml of the standard stock solution. The standards are diluted to 25 ml with 0.1 N sodium hydroxide and 25 ml TISAB is added prior to analysis with the fluoride ion specific electrode.

8. Procedure

8.1 Cleaning of Equipment. All glassware and plastic ware are washed in detergent solution, rinsed in tap water, and then rinsed with doubly distilled water.

8.2 Calibration of Personal Sampling Pumps. Each pump should be calibrated by using an integrating volume meter (Section 6.1.3) or other means.

8.3 Collection and Shipping of Samples

8.3.1 Pour 10 ml of the collection medium (Section 7.3) into the midget bubbler, using a graduated cylinder to measure the volume.

8.3.2 Assemble the prefilter unit in the 2-piece filter cassette holder and close firmly to insure that the center ring seals the edge of the filter. A backup pad should not be used.

8.3.3 Connect the bubbler (via the adsorption tube) to the prefilter assembly and the vacuum pump with a short piece of flexible tubing. The minimum amount of tubing necessary to make the joint between the prefilter and bubbler should be used. The air being sampled should not pass through any other tubing or other equipment before entering the bubbler.

8.3.4 Bubbler stem unit consists of a two-hole rubber stopper to fit 1/8-in O.D. Teflon tubing. One piece of tubing conducts the analyte vapor below the level of the collection medium where the analyte is trapped. The short outlet tube is connected to the sampling pump.

8.3.5 Turn the pump on to begin sample collection. Care should be taken to measure the flow rate, time and/or the volume as accurately as possible. Record the atmospheric pressure and the temperature. If the pressure reading is not available, record the elevation. The sample should be taken at a flow rate of 1.5 liters per minute for 30 minutes. The flow rate should be known with an accuracy of ±5%.

8.3.6 The pump rotameter should be observed frequently, and sampling should be terminated at any evidence of a problem.

8.3.7 Terminate sampling at the predetermined time and note sample flow rate and collection time.

8.3.8 After sampling, the bubbler stem may be removed and cleaned. Tap the stem gently against the inside wall of the bubbler bottle to recover as much of the sampling solution as possible. Wash the stem with 1-2 ml of the collection medium, adding wash to the bubbler. Transfer the contents of the bubbler to a 50-ml polyethylene bottle. Rinse the bubbler with 2-3 ml of the collection medium and seal the bottle tightly for shipment.

8.3.9 Care should be taken to minimize spillage or loss by evaporation at all times. Refrigerate samples if analysis cannot be done within a day.

8.3.10 Whenever possible, hand delivery of the samples is recommended. Otherwise, special bubbler shipping cases designed by NIOSH should be used to ship the samples.

8.3.11 A "blank" bubbler should be handled in the same manner as the bubblers containing samples (fill, seal, and transport) except that no air is sampled through this bubbler.

8.3.12 The filter may be discarded since the method is designed to measure gaseous hydrogen fluoride only.

8.4 Analysis of Samples

8.4.1 The sample in each bubbler is analyzed separately.

8.4.2 Quantitatively transfer the contents of the polyethylene bottle to a 25-ml volumetric flask. Make up to volume with 0.1 N sodium hydroxide.

8.4.3 Transfer the sample to a 50-ml polyethylene beaker. Add 25 ml of TISAB and stir with a magnetic stirrer.

8.4.4 Lower the fluoride ion specific electrode and reference electrode into the stirred solution and record the resulting millivolt reading (to the nearest 0.5 mv) after it has stabilized (drift less than 0.5 mv/min).

9. Calibration and Standards

9.1 Prepare three fluoride standard solutions as described in Section 7.9 at each of three levels (0.5X, 1X, and 2X the standard).

9.2 Insert the fluoride ion specific electrode and the reference electrode into one of the standards at the 0.5X level, and stir the solution with the magnetic stirrer.

9.3 Record the resulting millivolt reading to the nearest 0.5 millivolt.

9.4 Repeat steps 9.2 and 9.3 for the remaining standard solutions.

9.5 Calibration standards at each level should be repeated twice daily.

9.6 Average the six millivolt readings at each level.

9.7 Prepare the standard curve by plotting the three averaged millivolt readings vs mg F^- on semilog paper. Plot the mg F^- on the log axis.

10. Calculations

10.1 Read the weight in mg corresponding to each millivolt reading from the standard curve. No volume corrections are needed, because the standard curve is based on mg/50 ml volume, and the volume of the samples is identical to the volume of the standards.

10.2 Corrections for the blank must be made for each sample.

$$\text{mg} = \text{mg sample} - \text{mg blank}$$

where:

mg sample = mg found in sample bubbler

mg blank = mg found in blank bubbler

10.3 Calculate the mg of hydrogen fluoride by multiplying the mg fluoride ion found (Section 10.2) by 1.05, which is a conversion factor to convert mg F^- to mg HF.

10.4 The concentration of the analyte in air sampled can be expressed in mg/cu m.

$$\text{mg/cu m} = \frac{\text{mg (Section 10.3) X 1000 liter/cu m}}{\text{Air volume sampled (liter)}}$$

10.5 Another method of expressing concentration is ppm.

$$\text{ppm} = \text{mg/cu m} \times \frac{24.45}{\text{M.W.}} \times \frac{760}{P} \times \frac{T + 273}{298}$$

where:

P = pressure (mm Hg) of air sampled
T = temperature (°C) of air sampled
24.45 = molar volume (liter/mole) at 25°C and 760 mm Hg
M.W. = molecular weight (g/mole) of analyte
760 = standard pressure (mm Hg)
298 = standard temperature (°K)

11. References

11.1 Elfers, L.A. and C.E. Decker, "Determination of Fluoride in Air and Stack Gas Samples by Use of an Ion Specific Electrode," Anal. Chem., 40 (11), p. 1658 (1968).

11.2 Documentation of NIOSH Validation Tests, NIOSH Contract No. CDC-99-74-45.

APPENDIX E

CONCENTRATION OF HALON 1400 IN THE INERT ATMOSPHERE AS A FUNCTION OF THE HALON 1400 MANIFOLD PRESSURE

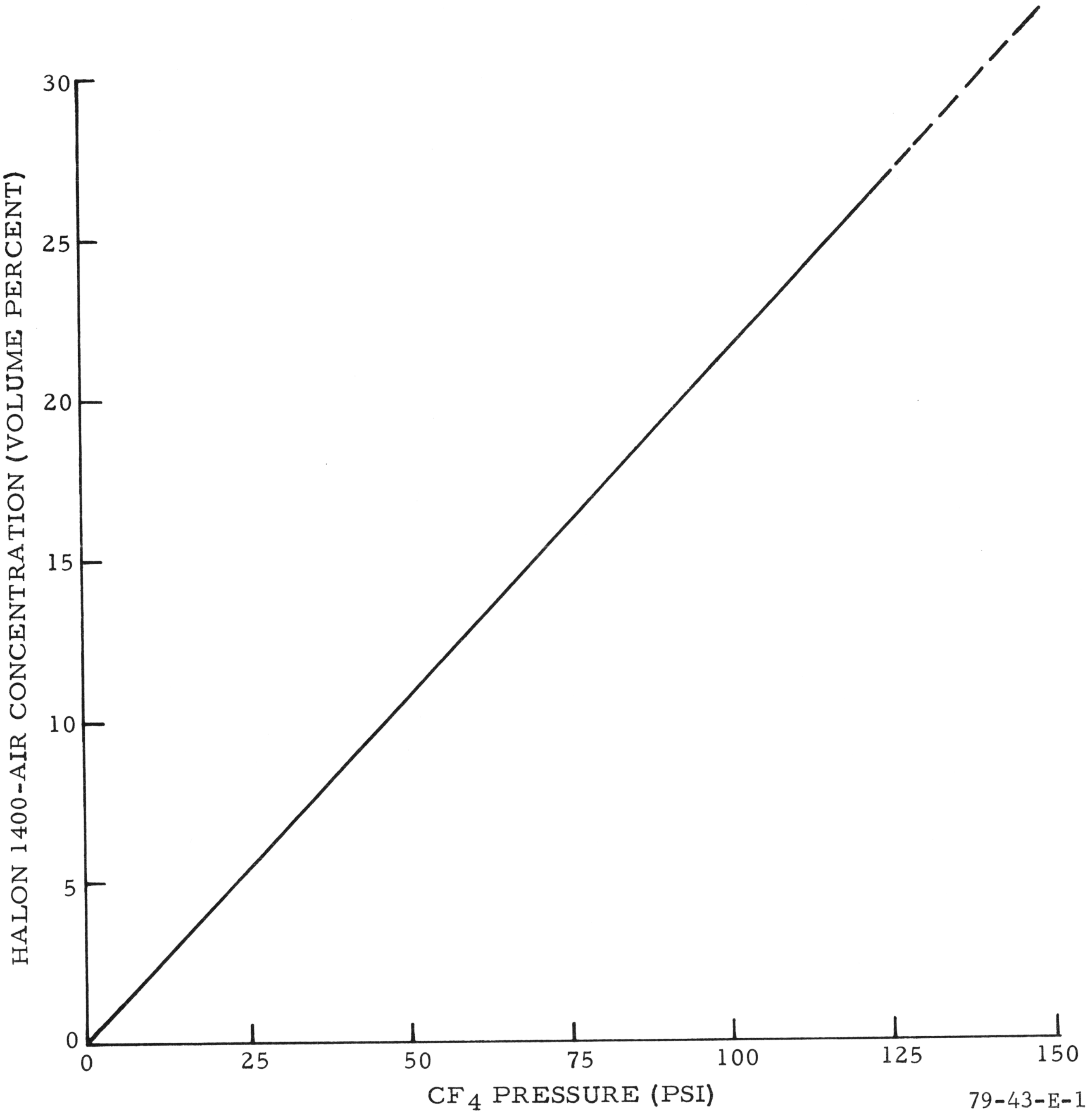


FIGURE E-1. CONCENTRATION OF HALON 1400 IN THE INERT ATMOSPHERE AS A FUNCTION OF THE HALON 1400 MANIFOLD PRESSURE

APPENDIX F

METHOD FOR EVALUATING THE CLASS A FIRE HAZARD

GENERAL.

To assess the fire extinguishing effectiveness of Halon 1400-inerted atmosphere, it was considered essential to establish a realistic fire load within the fire-hardened area of the DC7 aircraft. To this end, thermally uninhabitable environmental conditions were considered to maintain when the ambient air temperature reached 300° F and the radiant heat flux from the conflagration was 0.20 Btu/ft^2-sec or above. The time frame within which these conditions were to be accomplished was established as 90 seconds to correspond with the maximum passenger evacuation time required for aircraft certification (reference 9).

TEST PROCEDURE.

The fire load configuration comprised a 30-inch-wide by 76-inch-long by 4-inch-thick, cloth-covered, foam mattress wrapped with a single layer of chicken wire and suspended edgewise 10 inches above a 84-inch-long by 6-inch-wide by 1 3/4-inch-deep trough containing 2 gallons of neat methanol (figure F-1). A shallow pan was placed beneath the mattress and trough to catch and retain any flaming material or char that might fall as the test progressed. A 4-inch by 8-foot plywood sheet containing a 1-foot-square grid was positioned 8 feet behind the mattress for estimating the flame height as the fire progressed.

The electronic fire monitoring equipment comprised two thermocouples and one radiometer positioned around the test bed as indicated in figure F-1. Visual monitoring of the flame spread rate and height was obtained from both still and instrumentation motion picture cameras.

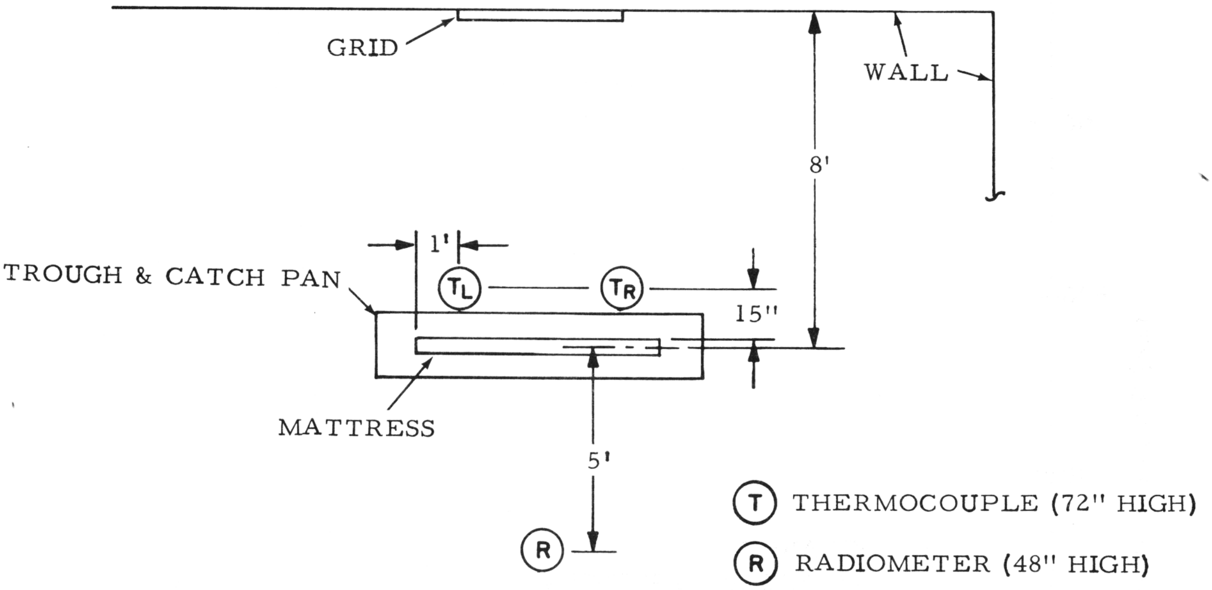
TEST RESULTS.

The data obtained from the electronic fire monitoring equipment are presented in figures F-2 and F-3. The profiles presented in figure F-2 show the thermocouple temperatures as a function of time after fuel (methanol) ignition. The vertical dashed line at 15 seconds identifies the time at which the mattress became uniformly ignited along its lower edge. These profiles indicate that the flame temperatures on the left side of the mattress reached 320° F approximately 82 seconds after fuel ignition and within 67 seconds after the mattress became uniformly ignited. The low temperatures experienced on the right side of the mattress resulted from an open door which caused the flame to drift to the left. Flames accompanied by copious quantities of black acrid smoke rose approximately 6 feet above the top of the mattress.

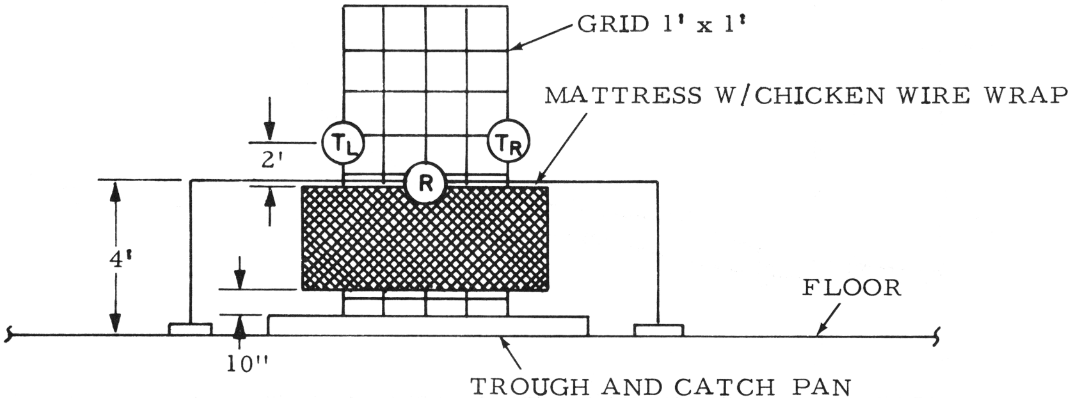
The heat flux experienced by the radiometer positioned 5 feet from the center-top edge of the mattress is indicated by the profile presented in figure F-3.

These data show that the radiation level reached 0.20 Btu/ft^2-sec in approximately 70 seconds after fuel (methanol) ignition. This corresponds to approximately 55 seconds after the mattress became uniformly ignited along its lower edge.

The results of this experiment indicated that this Class A fire load would produce an uninhabitable thermal environment in the DC7 aircraft cabin within 90 seconds after fuel ignition.



A PLAN VIEW



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B PROFILE VIEW

FIGURE F-1. SCHEMATIC DRAWING OF THE FIRE TEST BED

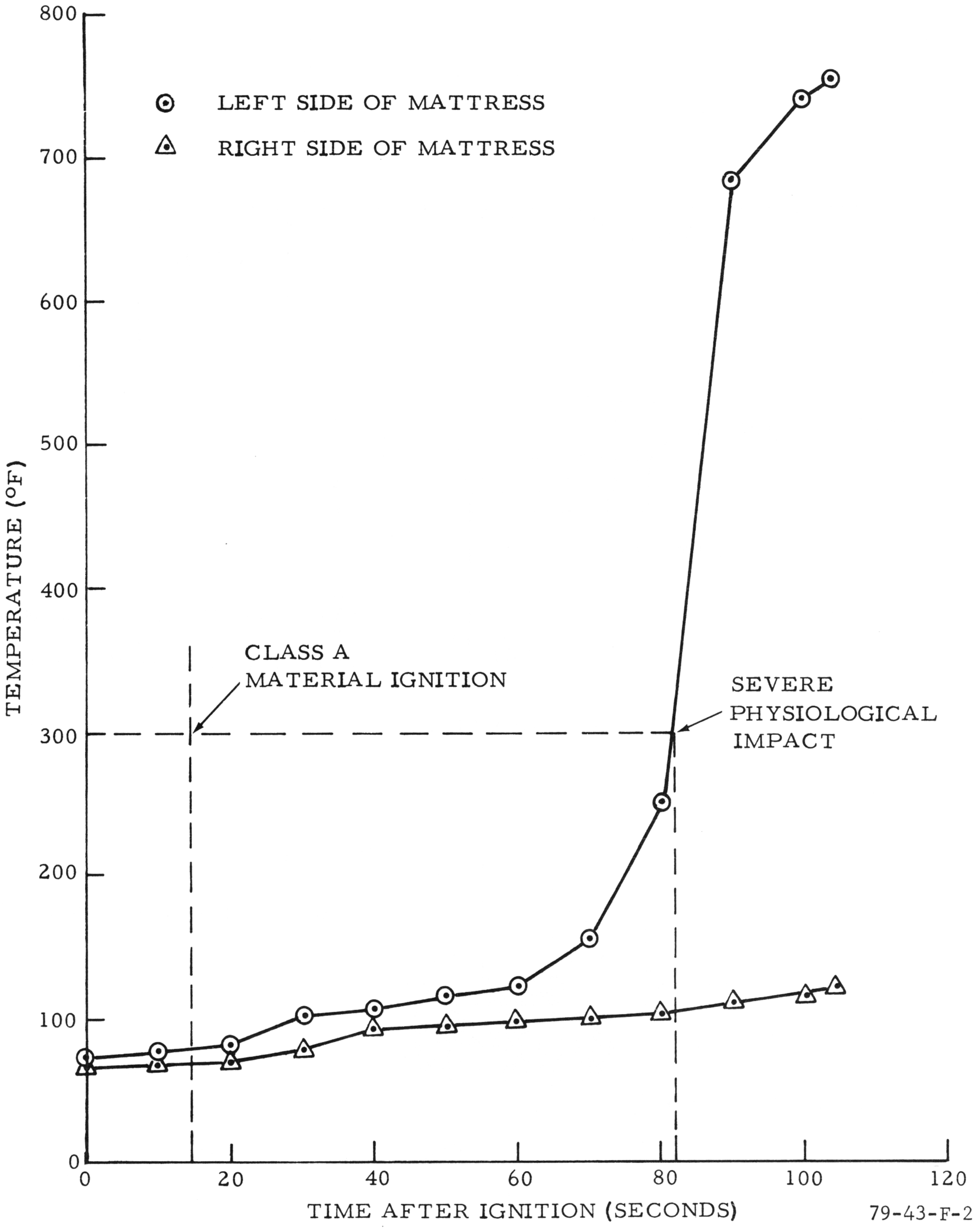

FIGURE F-2. CLASS A MATERIAL (MATTRESS) EVALUATION SHOWING TEMPERATURE AS A FUNCTION OF TIME AFTER FUEL IGNITION.

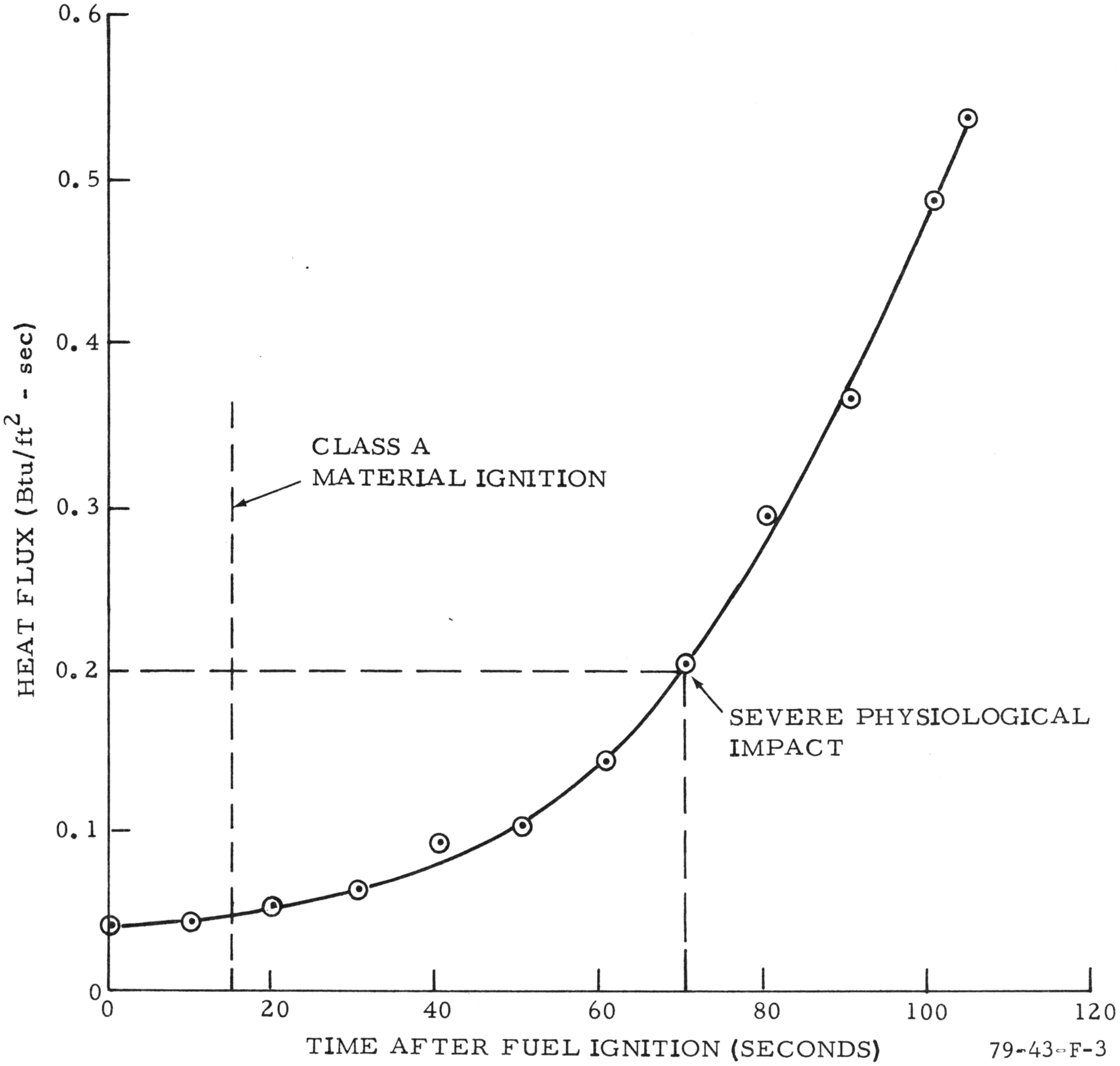

FIGURE F-3. CLASS A MATERIAL (MATTRESS) EVALUATION SHOWING HEAT FLUX AS A FUNCTION OF TIME AFTER FUEL IGNITION

APPENDIX G

TEST 1--AMBIENT THERMAL ENVIRONMENTAL CONDITIONS IN THE DC7 AIRCRAFT CABIN (CLASS A FIRE)

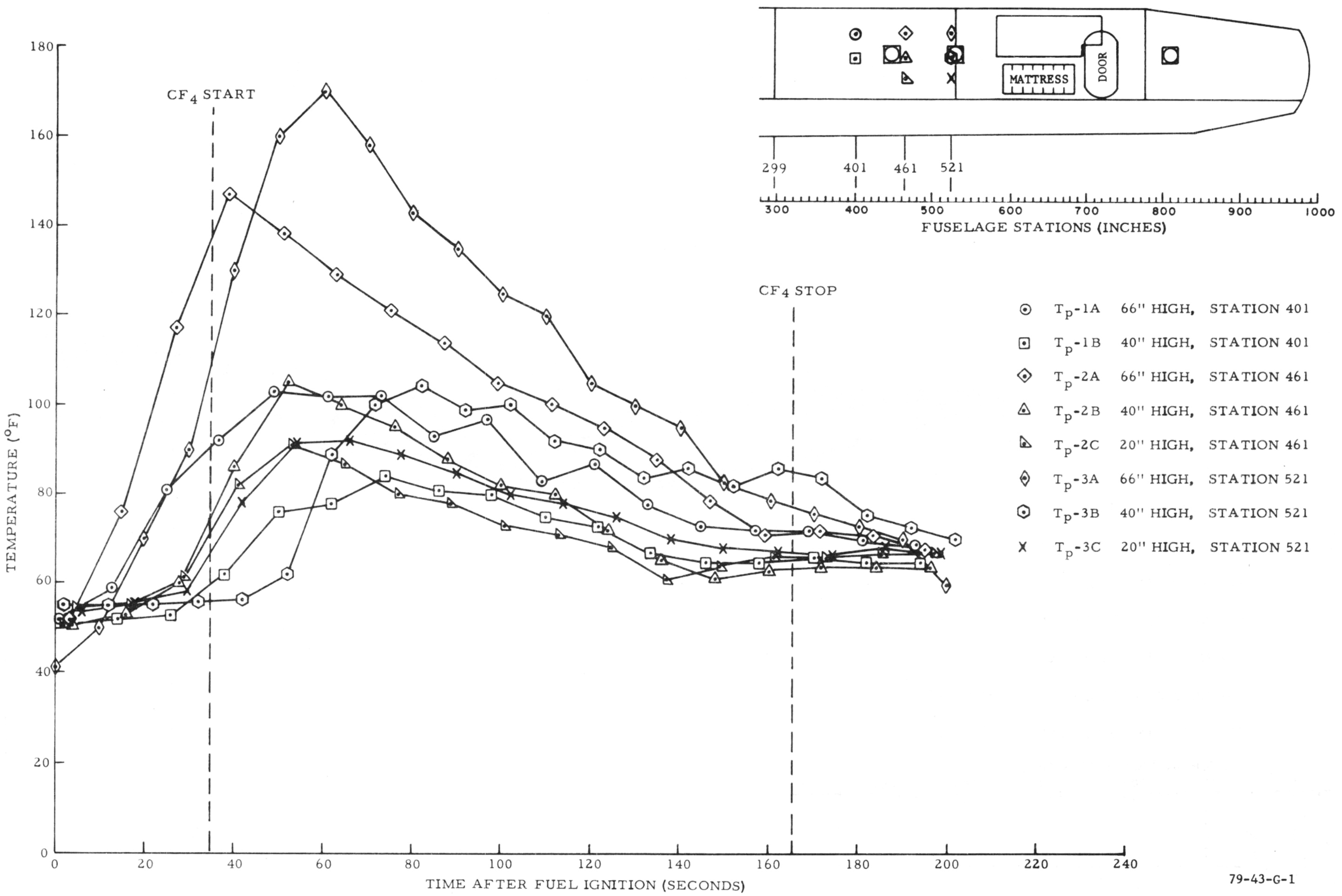

FIGURE G-1. TEST 1--AMBIENT AIR TEMPERATURE FORWARD OF THE FIRE-HARDENED AREA AFTER FUEL IGNITION (CLASS A FIRE)

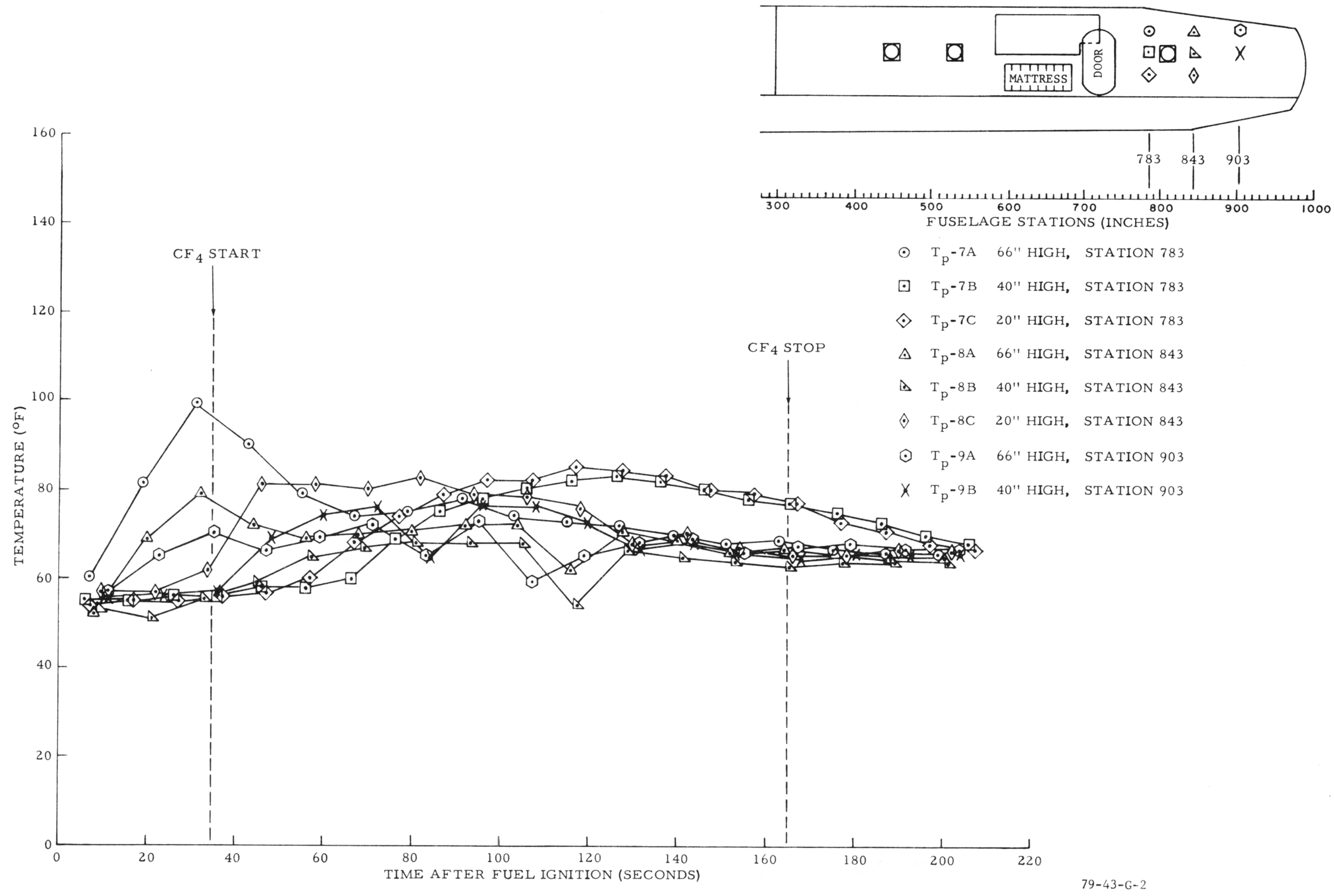

FIGURE G-2. TEST 1--AMBIENT AIR TEMPERATURE AFT OF THE FIRE-HARDENED AREA AFTER FUEL IGNITION (CLASS A FIRE)

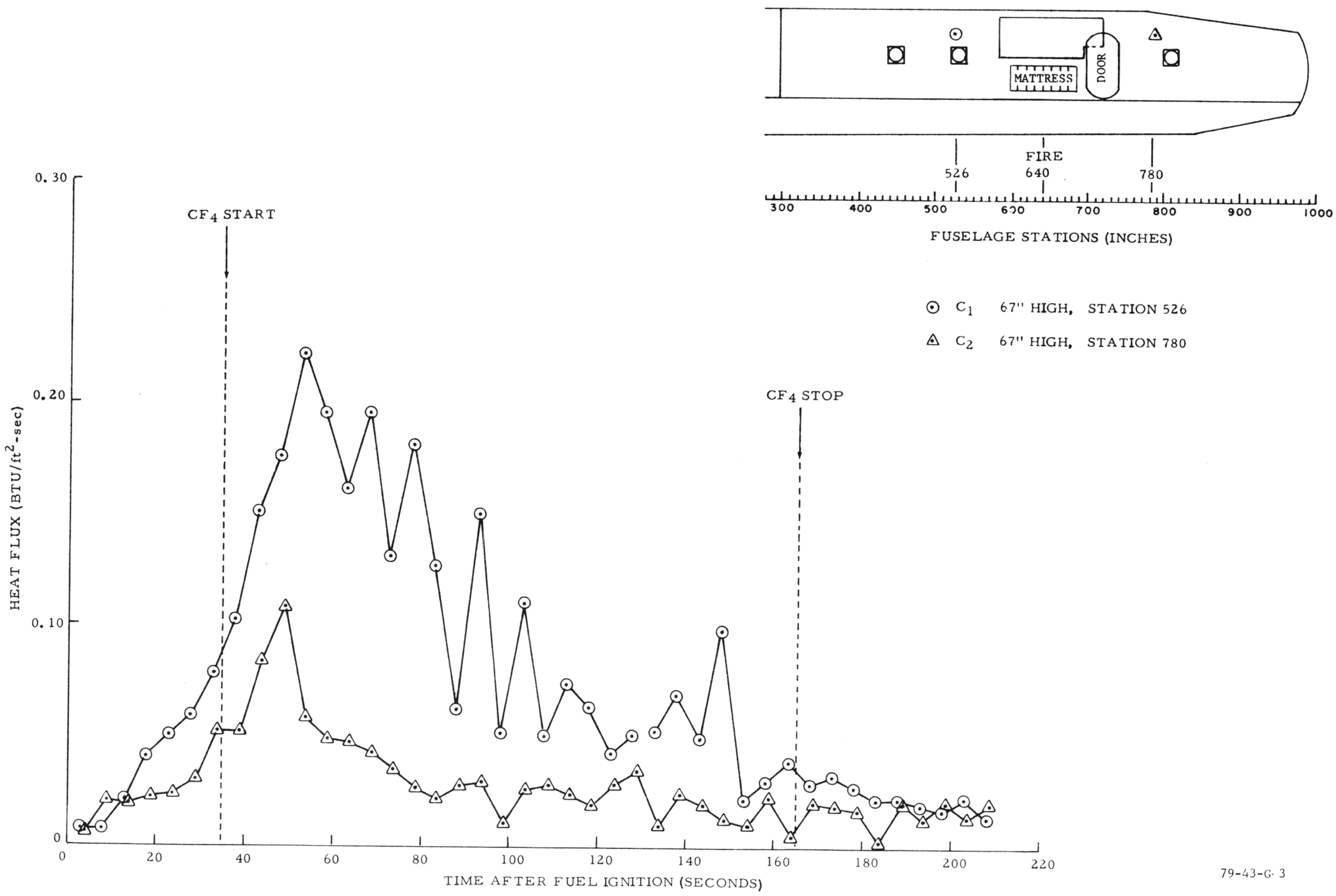

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FIGURE G-3. TEST 1--TOTAL QUANTITY OF THERMAL ENERGY MEASURED FORWARD AND AFT OF THE FIRE-HARDENED AREA AT APPROXIMATELY HEAD LEVEL (CLASS A FIRE)

APPENDIX H

TEST 2--AMBIENT THERMAL ENVIRONMENTAL CONDITIONS IN THE DC7 AIRCRAFT CABIN (CLASS A FIRE)

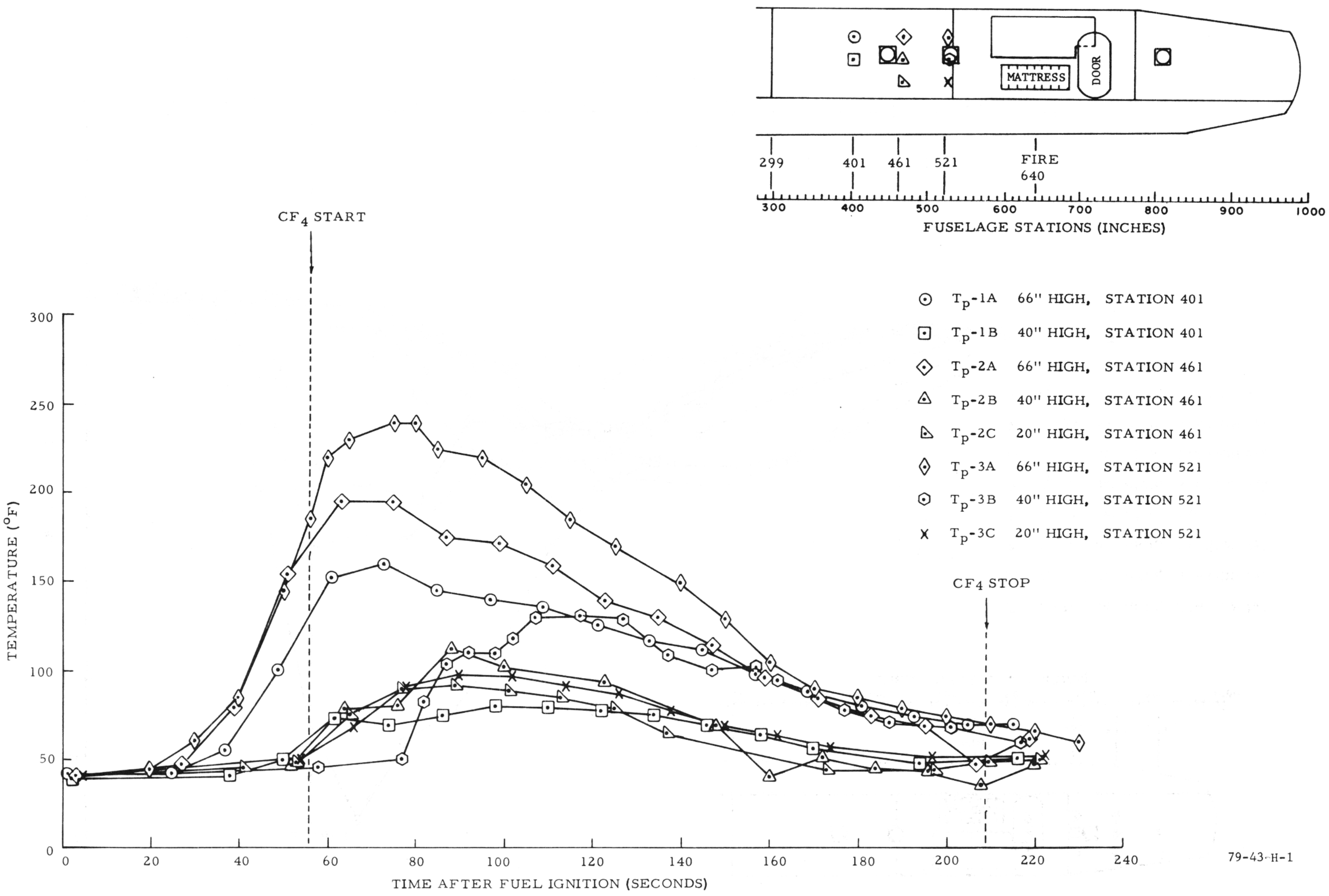

FIGURE H-1. TEST 2--AMBIENT AIR TEMPERATURES FORWARD OF THE FIRE-HARDENED AREA AFTER FUEL IGNITION (CLASS A FIRE)

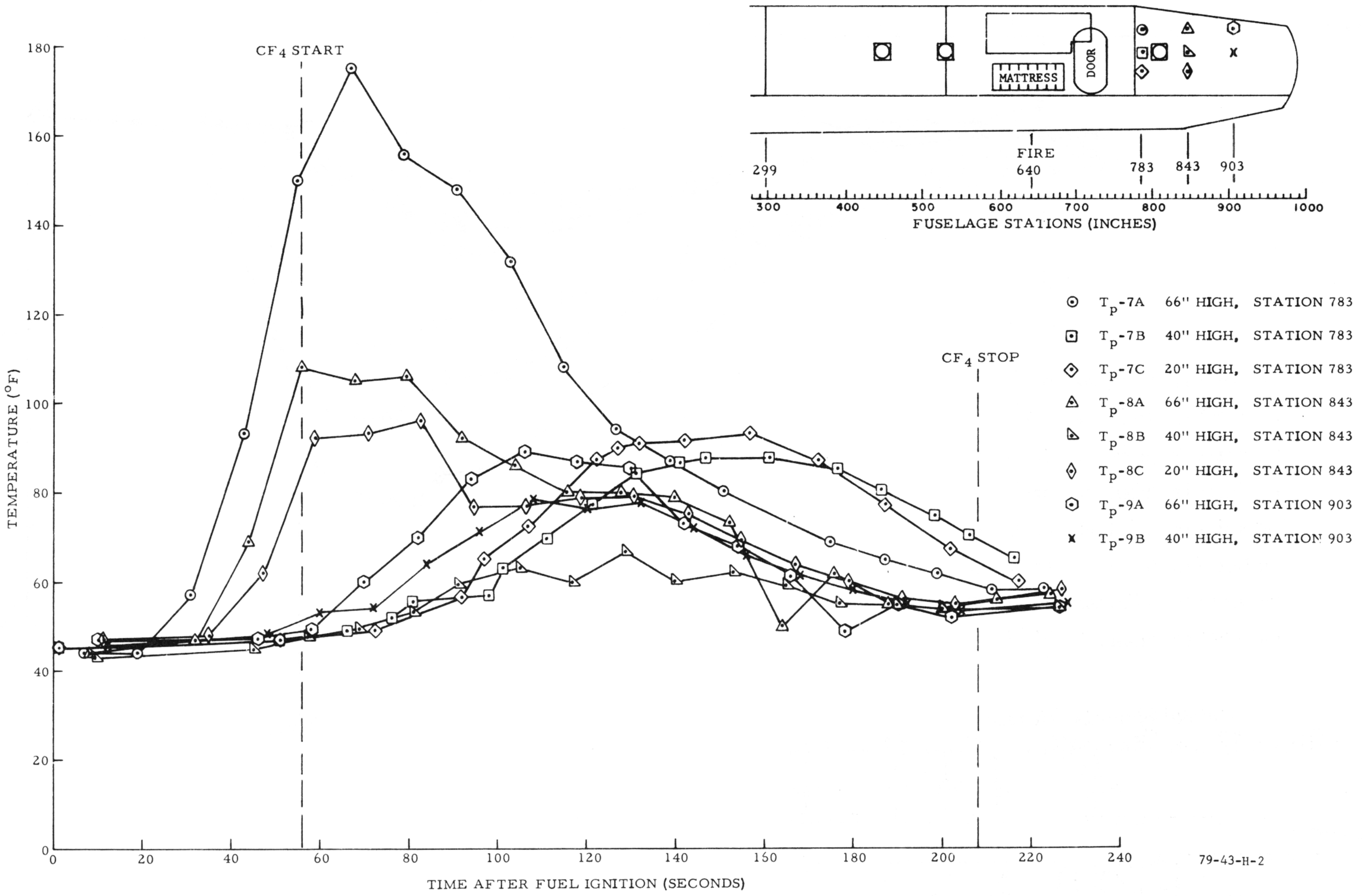

FIGURE H-2. TEST 2--AMBIENT AIR TEMPERATURES AFT OF THE FIRE-HARDENED AREA AFTER FUEL IGNITION (CLASS A FIRE)

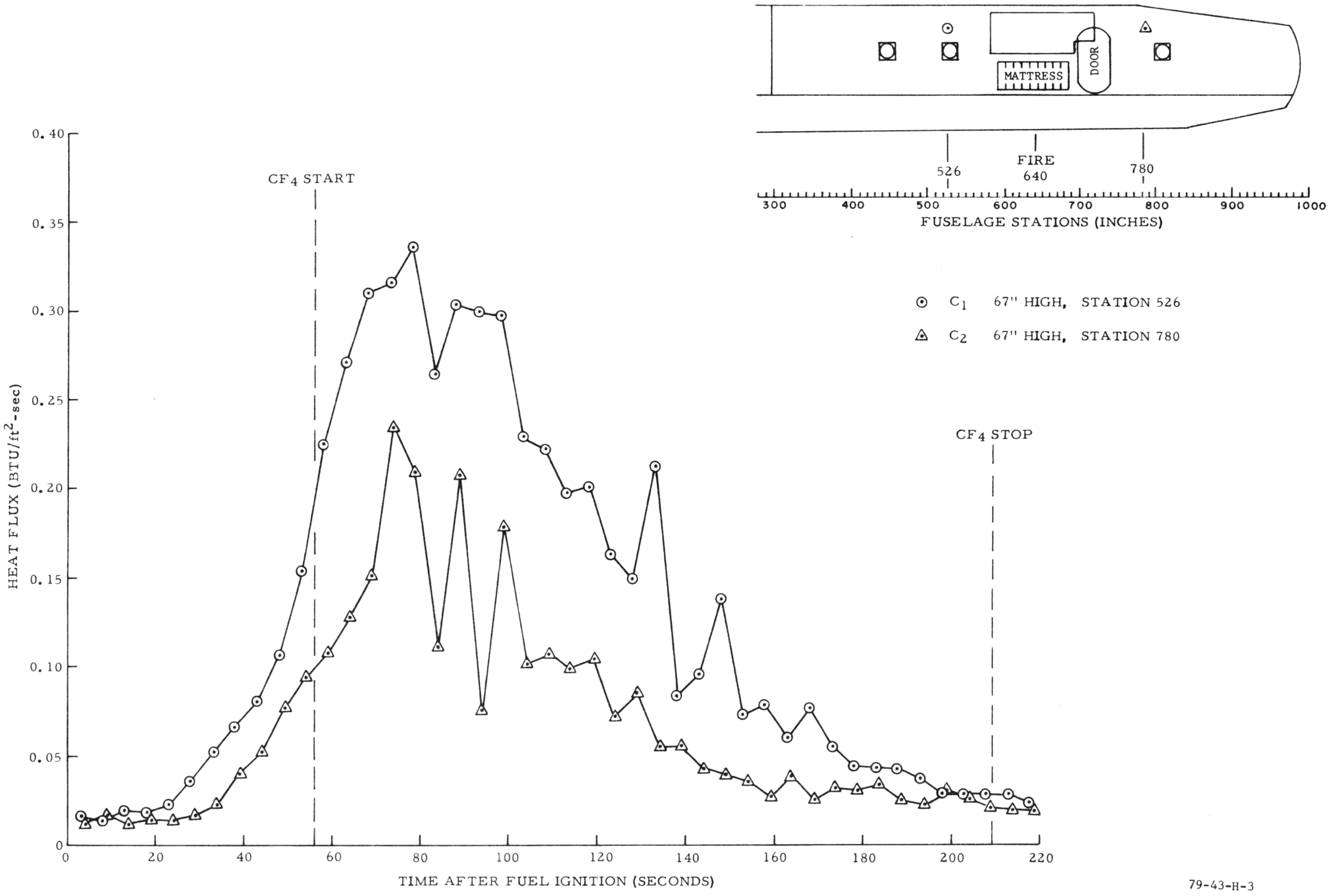

FIGURE H-3. TEST 2--TOTAL QUANTITY OF THERMAL ENERGY MEASURED FORWARD AND AFT OF THE FIRE-HARDENED AREA AT APPROXIMATELY HEAD LEVEL (CLASS A FIRE)

APPENDIX I

TEST 3--AMBIENT THERMAL ENVIRONMENTAL CONDITIONS IN THE DC7 AIRCRAFT CABIN (CLASS B FIRE)

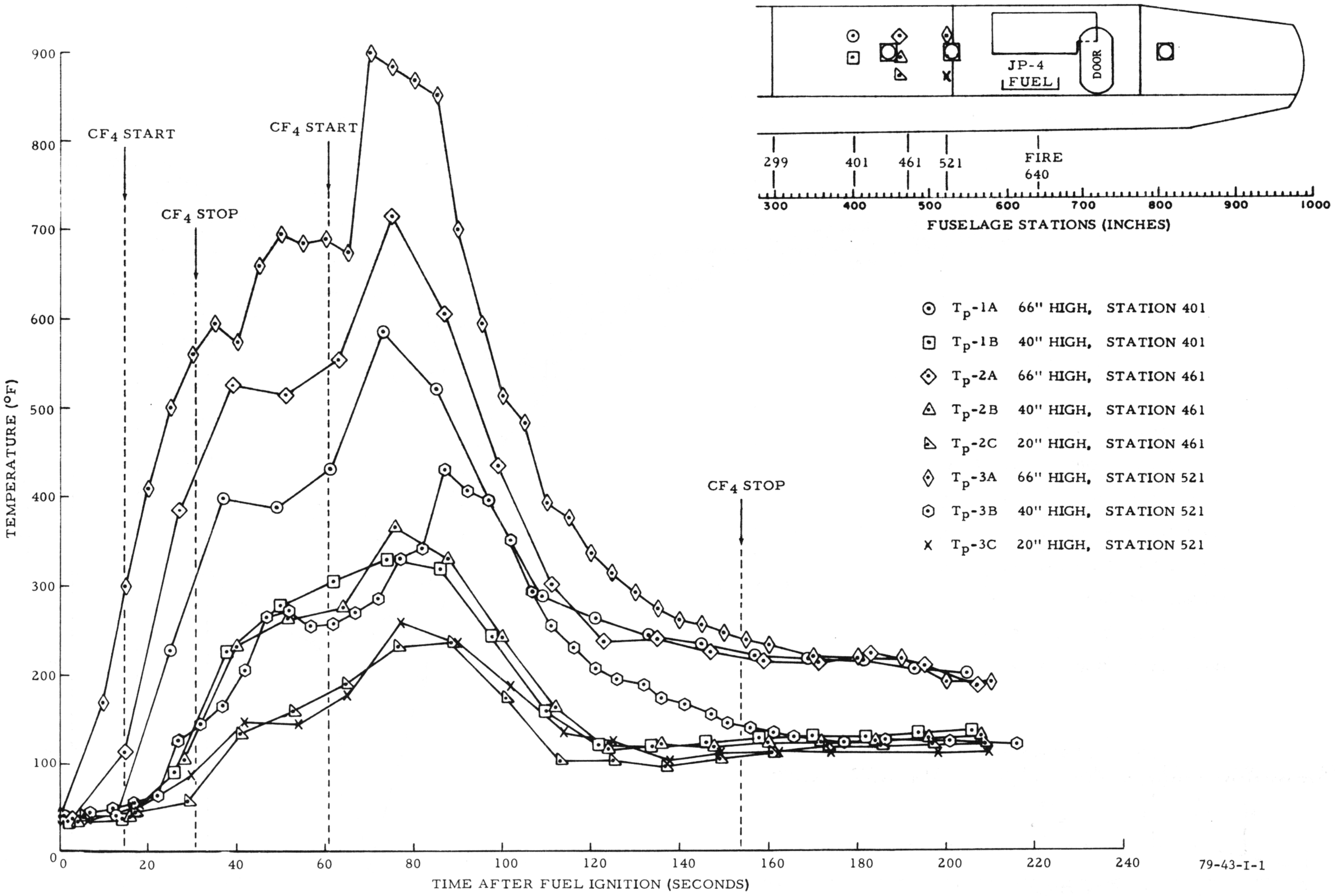

FIGURE I-1. TEST 3--AMBIENT AIR TEMPERATURES FORWARD OF THE FIRE-HARDENED AREA AFTER FUEL IGNITION (CLASS B FIRE)

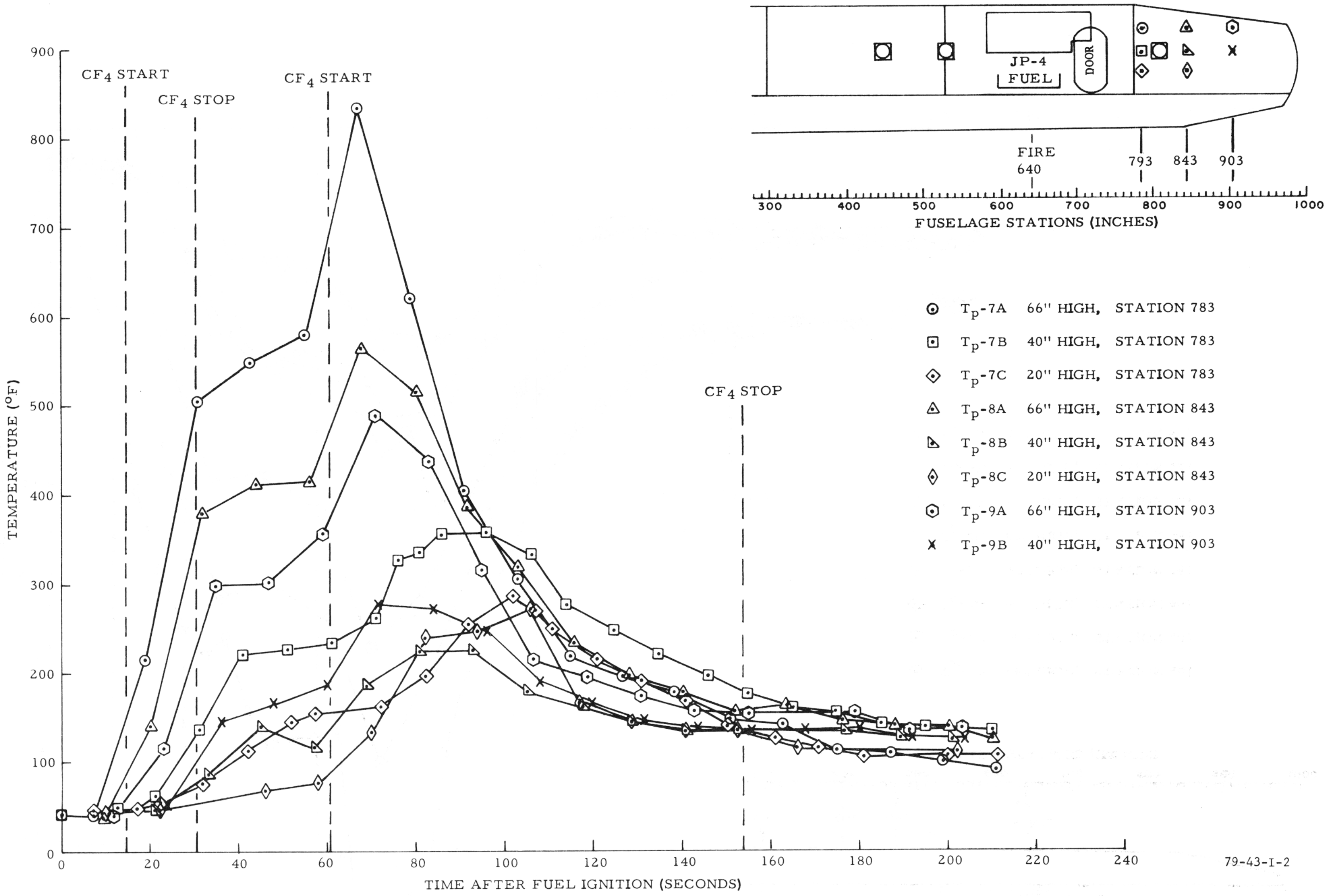

FIGURE I-2. TEST 3—AMBIENT AIR TEMPERATURES AFT OF THE FIRE-HARDENED AREA AFTER FUEL IGNITION (CLASS B FIRE)

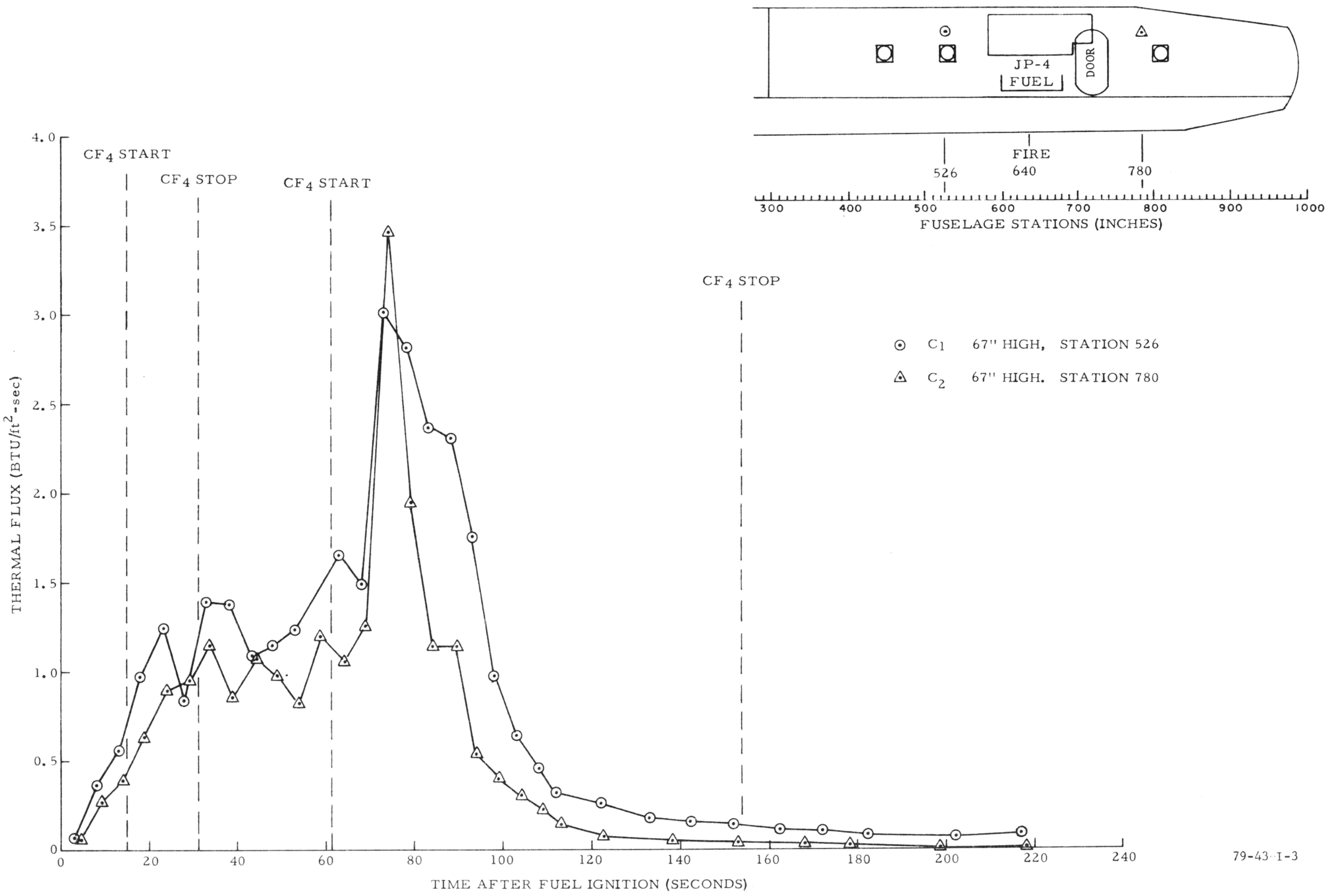

FIGURE I-3. TEST 3--TOTAL QUANTITY OF THERMAL ENERGY MEASURED FORWARD AND AFT OF THE FIRE-HARDENED AREA AT APPROXIMATELY HEAD LEVEL (CLASS B FIRE)

APPENDIX J

EFFECTS OF OXYGEN DEPLETION (ANOXIA) ON MAN (NATIONAL FIRE PROTECTION ASSOCIATION (NFPA) HANDBOOK)

GENERAL.

When atmospheric oxygen (O_2) falls from its usual level of 21 percent to 15 percent, muscular skill is diminished. As the concentration is further reduced from 14 percent to 10 percent, the victim may remain conscious but is subject to faulty judgment and the early onset of fatigue. Additional decreases in oxygen from 10 to 6 percent brings on unconciousness and a general collapse; however, the victim can be revived by providing additional oxygen or removal to fresh air.

SOME IMMEDIATE SYMPTOMS OF ANOXIA (E.I. DUPONT de NEMOURS DATA).

O_2 Percent By Volume	Signs And Symptoms Of O_2 Deficiency At Rest
12 to 14	respiration deeper, pulse up, coordination poor
10 to 12	giddiness, poor judgment, blue lips
8 to 10	nausea, vomiting, unconsciousness, ashen face
6 to 8	8-minute exposure--100 percent of animals die. 6-minute exposure--50 percent die, 50 percent recover with treatment. 4- to 5-minute exposure--all recover with treatment.
4	Coma in 40 seconds, convulsions, respiration ceases, death.

APPENDIX K

TOLERANCE TO SELECTED COMBUSTION PRODUCTS

TABLE K-1. TOLERANCE TO SELECTED COMBUSTION PRODUCTS

Combustion Products	Hazardous Levels for Times Indicated			
	Minutes	1/2 Hour	1-2 Hours	8 Hours
Heat (°F)	284	212	150	120
Oxygen (%)	6	11	14	15
Carbon Dioxide (ppm)	50,000	40,000	35,000	32,000
Carbon Monoxide (ppm)	3,000	1,600	800	100
Sulphur Dioxide (ppm)	400	150	50	8
Nitrogen Dioxide (ppm)	240	100	50	30
Hydrogen Choloride (ppm)	1,000	1,000	40	7
Hydrogen Cyanide (ppm)	200	100	50	2

NOTE: Data from table 1 in C.H. Yuill, "Pysiological Effects of Products of Combustion," American Society of Safety Engineers Journal 19 (1974): 36-42. Author notes that table is substantially that set forth in A.J. Pryor and C.H. Uill, Mass Fire Life Hazard, OCD Work Unit 2537A Final report (San Antonio, Texas: Southwest Research Institute, 1968), and that there is considerable variation among investigators as to what level of a particular gas does constitute a life hazard.

APPENDIX L

TEST 4--AMBIENT THERMAL ENVIRONMENTAL CONDITIONS IN THE DC7 AIRCRAFT CABIN (CLASS A FIRE)

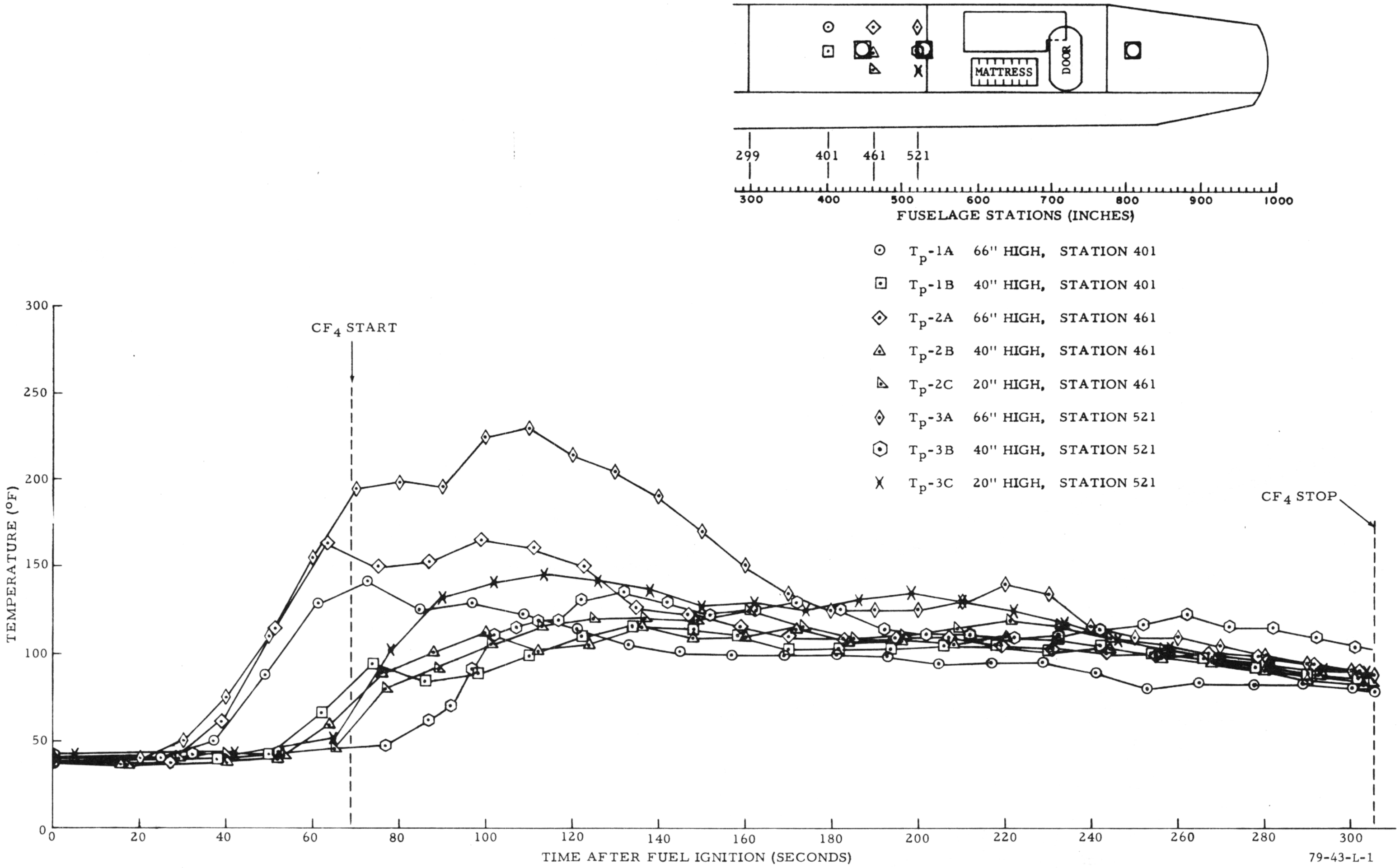

FIGURE L-1. TEST 4--AMBIENT AIR TEMPERATURE FORWARD OF THE FIRE-HARDENED AREA AFTER FUEL IGNITION (CLASS A FIRE)

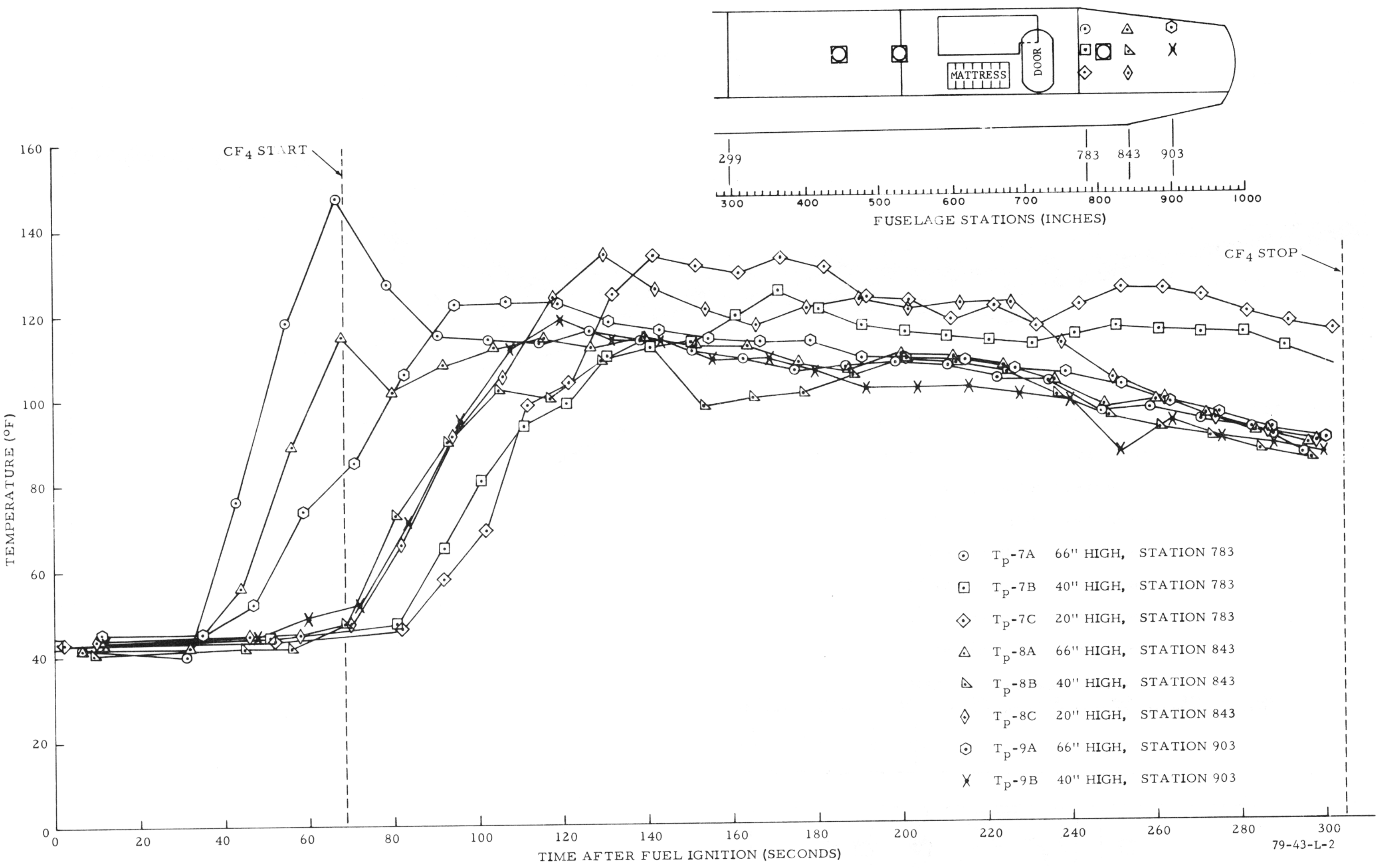

FIGURE L-2. TEST 4--AMBIENT AIR TEMPERATURE AFT OF THE FIRE-HARDENED AREA AFTER FUEL IGNITION (CLASS A FIRE)

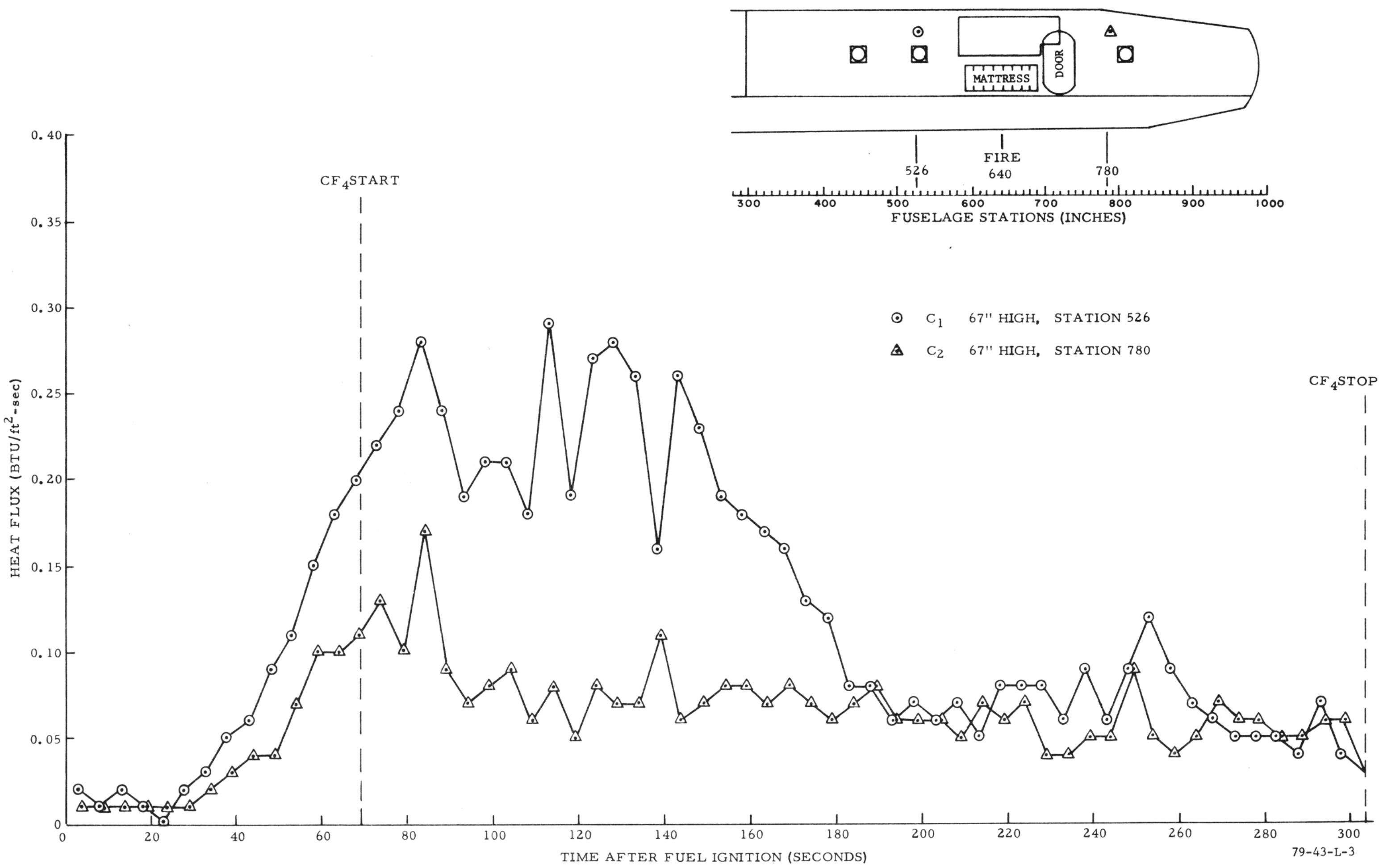

FIGURE L-3. TEST 4--TOTAL QUANTITY OF THERMAL ENERGY MEASURED FORWARD AND AFT OF THE FIRE-HARDENED AREA AT APPROXIMATELY HEAD LEVEL (CLASS A FIRE)