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CHARACTERISTICS OF HALON 1301 DISPENSING SYSTEMS FOR AIRCRAFT CABIN FIRE PROTECTION

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FINAL REPORT

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16. Abstract

Two Halon 1301 dispensing systems, modular nozzle and perforated tube, were designed and installed in an obsolete but completely furnished CD7 passenger cabin. For each system, agent distribution was continuously measured during discharge and for a period of 10 minutes at approximately 20 locations throughout the unpressurized cabin. The effect of Halon 1301 discharge on cabin temperature, noise, pressure, and visibility was also measured. The modular system was judged to be best by virtue of its producing more rapid and effective agent distribution resulting in greater potential fire-protection capability. Installation of the Halon 1301 dispensers along the ceiling for both systems minimized the known possible transient adverse effects upon passengers from agent concentration overshoot, discharge noise, over-pressure, and reduced temperature. Halon 1301 was found to rapidly permeate all cabin airspaces, including those shielded from the discharge streamlines. The effect of agent leakage through opened emergency exits was investigated. It was determined that even under such unfavorable conditions of operation, a high-rate discharge system would provide a reasonably good degree of inerting protection over a representative evacuation period.

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PREFACE

A special recognition and gratitude is owed to James Demaree, who diligently calibrated the gas analysis instrumentation and reduced much of the voluminous data, and Richard Johnson, who ably assisted in the preparation and conduct of the test program from beginning to end.

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INTRODUCTION

PURPOSE.

The purpose of this program was to design and develop a Halon 1301 fire protection system for use in an aircraft passenger cabin with the capability for rapid and effective distribution of agent throughout the cabin airspace, but without impairing the safety of occupants. Tests were also conducted to determine the system performance characteristics in a closed cabin and examine the effect of open emergency exits on the time of inerting protection.

BACKGROUND.

For purposes of discussion, cabin fires may be divided into three general categories: (1) postcrash, (2) in-flight, and (3) ramp.

Fatalities or injuries related to the hazards arising from a cabin fire are usually only experienced in the postcrash category. An analysis of 16 impact-survivable postcrash fires by the Aerospace Industries Association of America (AIA) in 1968 indicated that for most cases the cabin was set afire by flames originating from a large external fuel fire entering the cabin through a rupture or open door, while the remainder of the fuselage was otherwise intact (reference 1). Complete fuselage separation was experienced in six of these accidents; however, it is unlikely that any cabin-fire protection measures could have increased passenger survivability for this severe fire exposure condition. More recent examples of impact-survivable cabin-fire accidents are as follows: (1) United Airlines (UA) 737 at Chicago on December 8, 1972, (2) North Central DC9 at Chicago on December 20, 1972, (3) Trans World Airlines (TWA) 707 at Los Angeles on January 16, 1974, (4) Pan American Airlines 707 at Pago Pago on January 30, 1974, and (5) Eastern DC9 at Charlotte on September 11, 1974. These five accidents have in common the fire destruction of the cabin interior, although the fuselage impact damage ranged from minimal, for the North Central DC9, Pan American Airlines 707, and TWA 707, to complete multiple separation for the Eastern DC9. Thus, the former accidents are those in which additional fire protection measures would have been of most benefit.

Some indication of the severity and large thermal gradients characteristic of many cabin fires is shown in figure 1, which is a forward view of a gutted TWA 707 compared with that of a sister ship. The ceiling vinyl cover was completely consumed by fire, acrylontrile-butadiene-styrene (ABS) passenger service units melted and dripped, cotton/rayon seat covers were burned away in some areas and charred in others, yet the modacrylic/acrylic carpet was undamaged. The obviously large temperature difference that existed between the ceiling and floor indicates that this section of the cabin sustained a flashover condition. Impact-survivable postcrash cabin fires involving United States (U.S.) carriers appear to occur at the rate of about one or two per year.

FIGURE 1. INTERIOR COMMERCIAL TRANSPORT PASSENGER CABIN BEFORE (BELOW) AND AFTER (ABOVE) A SEVERE FIRE

The majority of in-flight fires occurring in the occupied sections of commercial transports have originated in either the galley or lavatory areas and have been detected early and extinguished with minimal hazard. The occupants of an airplane provide excellent early fire detection and, until the Varig 707 accident near Paris on July 11, 1973 (reference 2), the known occurrence of an uncontrollable in-flight fire originating in an occupied area was practically nonexistent. This fine record on the control of small fires can be at least partially attributed to Federal Aviation Administration (FAA) flammability regulations for cabin interior furnishings and materials that were made more effective on May 1, 1972, by requiring that materials be "self-extinguishing" in a vertical orientation after ignition by a small flame (reference 3) as exists in most in-flight or ramp fires. However, experience shows that flame-retardant materials alone cannot prevent flame spread under high-energy in-flight, ramp, or postcrash ignition sources.

A third category of cabin fires is the ramp fire. This fire occurs when the aircraft is parked at an airport ramp and is being serviced or left unattended. In recent years, ramp fires have either originated from faulty electrical circuits or devices, ignition of organic deposits in oxygen systems during emergency oxygen recharging operations, or have been of unknown cause (reference 4). An example of the latter was the TWA L1011 cabin fire at Boston on April 20, 1974 (reference 5). Although furnished and lined with improved materials, the passenger cabin of this airplane was destroyed by a fire of unknown origin (no aviation fuel involvement) and vividly demonstrated that even flame-retardant polymeric materials will indeed burn completely when exposed to a sufficiently intense ignition source. During the past 5 years, U.S. commercial transport cabins have been destroyed by ramp fires at the rate of about one per year. Some reduction in this type of fire experience may be expected from the use of advanced cabin interior materials.

Two basic conceptual approaches can be taken to provide fire protection in a commercial transport airplane, building, or home; i.e., (1) passive and (2) active.

The former involves, for example, utilization of fire-retardant materials or sound engineering design judgments to separate ignition sources from combustible materials. An example of passive fire protection is the FAA flammability regulation for interior materials. However, if the ignition source is intense enough to create a self-sustaining condition as previously mentioned in a real fire, then the immediate danger to life is often imposed by the smoke and toxic products of combustion. Recognizing this problem, the FAA has proposed to establish standards for the smoke emission characteristics of compartment interior materials (reference 6) and is considering similar action for the toxic gas emissions of these materials (reference 7).

The toxicity of burning polymeric materials is being studied at a number of governmental, industrial, and academic institutions using a wide variety of approaches, with perhaps the broadest effort at the University of Utah (reference 8). The toxicity problem is very complicated, due at least in part to the multiplicity of different gases produced by different materials that can be quantitatively and qualitatively dependent upon the combustion temperature and environmental conditions, as well as to the scarcity of data on the responsiveness of humans or animals to singular, acute (5-minute) gas exposures. (Multiple gas exposure data is almost nonexistent.) Furthermore, some "experts" are expressing concern that materials inherently or chemically treated to prevent flame spread from small ignition sources may emit much higher levels of toxic gases in intense fires than untreated materials which burn more freely (reference 9). Finally, couple the aforementioned difficulties with the questionable relevancy of laboratory-scale test methods to a "real fire" situation (reference 10), and one may conclude that passive fire protection by regulating the combustion characteristics (flammability, smoke, and toxic and combustible gases) of materials at best, may only be a partial solution to the problem. Instead, an active fire-extinguishing system may be the most expedient and effective method for providing the additional capability needed to control cabin fires.

This report describes the first of a three-phase effort to determine the degree of protection provided by a Halon 1301 cabin fire extinguishing system (reference 11). The second phase will be basically an evaluation of the hazards associated with pyrolysis of Halon 1301 versus those of a typical cabin fire. The third phase will be a determination of the safety provided in an environment inerted with Halon 1301 for the condition of an external-fuel fire entering the cabin through a crash rupture or exit opening.

DISCUSSION

HALON 1301.

Halon 1301 chemically is bromotrifluoromethane, $CBrF_3$. Under normal atmospheric conditions, Halon 1301 is a colorless, odorless, electrically nonconductive gas with a density approximately five times that of air. Halon 1301 liquifies upon compression and is stored and shipped at this condition. A list of some important physical properties of Halon 1301 is given in table 1.

TABLE 1. PHYSICAL PROPERTIES OF HALON 1301*

Chemical Name	Bromotrifluoromethane
Chemical Formula	$CBrF_3$
Molecular Weight	148.9
Boiling Point at Atmospheric Pressure	-72° F
Vapor Pressure at 70° F	199 psig
Liquid Density at 70° F	97.8 lb/ft^3
Superheated Vapor Density at 70° F	0.391 lb/ft^3
Heat of Vaporization at Boiling Point	51.08 Btu/lb

*For source, see reference 12.

Halon 1301 is an effective fire-extinguishing agent against surface fires on solid materials and fires involving flammable liquids or gases. It is particularly attractive for use in total flooding extinguishing systems which consist of the release of a predetermined amount of agent into an enclosure to develop a uniform extinguishing concentration throughout the air space. The advantages of total flooding Halon 1301 systems are: (1) compact storage volumes and long storage life, (2) low vision obscuration, (3) lack of particulate residue, (4) rapid mixing with air, (5) accessibility to blocked or remote spaces, and (6) low toxicity of the extinguishing atmosphere (reference 13).

For total flooding extinguishment of surface flaming from cellulosic and plastic materials, a Halon 1301 concentration of 5 percent is recommended (reference 14), although extinguishment is attained with concentrations as low as 3 percent (reference 13). In this concentration range, testing at NAFEC has demonstrated a capability for cabin fire extinguishment and inerting (reference 15) and cargo compartment fire protection for at least 2 hours (reference 16).

It appears that Halon 1301 extinguishes by a chemical action. The halogen compound reacts with the transient products of the combustion process. This action is in contrast to the usual mechanisms of either cooling, oxygen depletion, or separation of fuel and oxidant for the common extinguishants. As such, Halon 1301 is much more effective than carbon dioxide (CO_2), nitrogen, or water vapor in quenching the flames of hydrocarbons and other gaseous fuels (reference 17). In total flooding, Halon 1301 is three times as effective as CO_2 on a unit weight basis (reference 18).

When used properly under the guidelines established by the National Fire Protection Association (NFPA), Halon 1301 can be safely used in occupied areas (reference 14). However, some toxicity studies have indicated a hazard "under the worst conceivable circumstances" (reference 19). Based on medical research involving both humans and test animals, NFPA recommends that occupant exposures to Halon 1301 concentration levels of 7 percent or less not exceed 5 minutes (reference 14). For the majority of postcrash fire accidents, the safe evacuation of passengers from a commercial transport should be completed well before the recommended Halon 1301 exposure time limit. If Halon 1301 were used for in-flight protection, the cabin pressurization system can be expected to rapidly dilute the agent concentration (reference 20).

DC7 TEST ARTICLE DESCRIPTION.

The test article used for this investigation was an obsolete DC7 fuselage with a completely furnished passenger cabin. The fuselage was housed inside a heated building. Halon 1301 protection was provided to the entire passenger cabin which, as shown in figure 2, extended from the forward slope bulkhead to the rear pressure bulkhead and included the forward "B" lounge, two opposite lavatories, the main passenger cabin, galley, and aft lounge. The length of the protected cabin was approximately 72 feet and the volume of airspace was calculated to be 4,000 cubic feet.

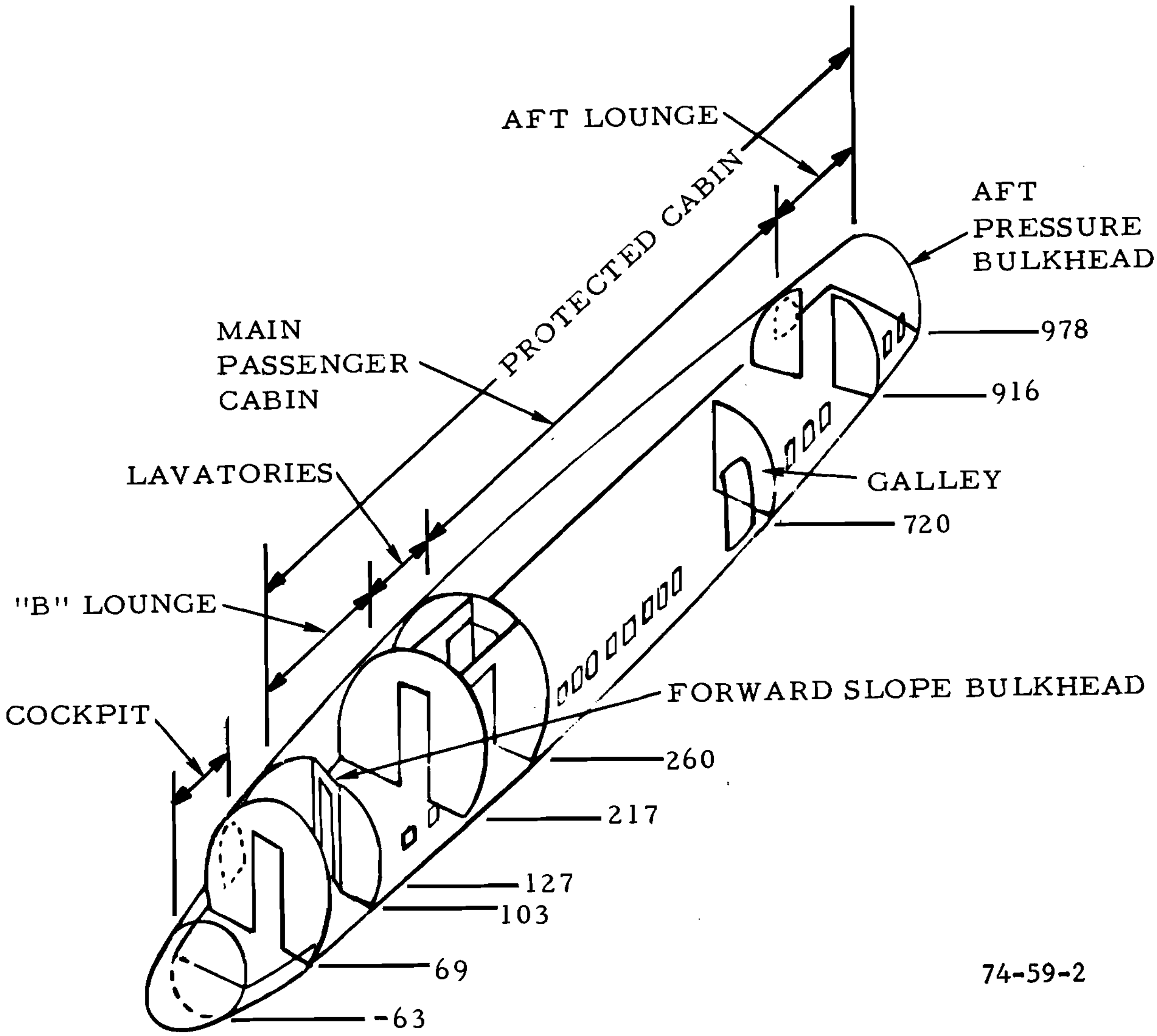


FIGURE 2. AREA OF DC7 FUSELAGE PROTECTED WITH SUPPRESSION SYSTEM

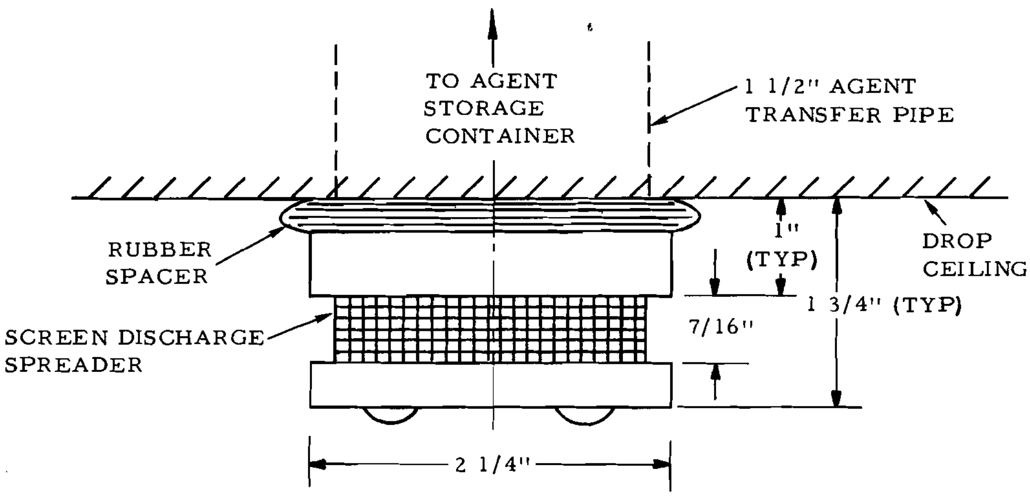
The cabin ventilation system was inoperative. For an enclosure of this size, the weight of Halon 1301 required to produce a uniform volumetric concentration of 5 percent was 80 pounds. This value was based on an equation recommended by NFPA that compensates for agent (Halon 1301) loss through small openings during discharge overpressure by assuming that the agent was lost at the design concentration (reference 14). When analyzing the data, it is well to remember that theoretically a Halon 1301 design concentration of 6 to 7 percent could have been selected to provide a longer inerting time without impairing the health of any individuals exposed to the natural agent.

CANDIDATE AGENT DISPENSING SYSTEMS.

Two basically different Halon 1301 dispensing systems were evaluated: (1) modular and (2) continuous perforated tube. The systems did have in common, however, the discharge of agent from a location immediately below the cabin drop ceiling at the fuselage symmetry plane.

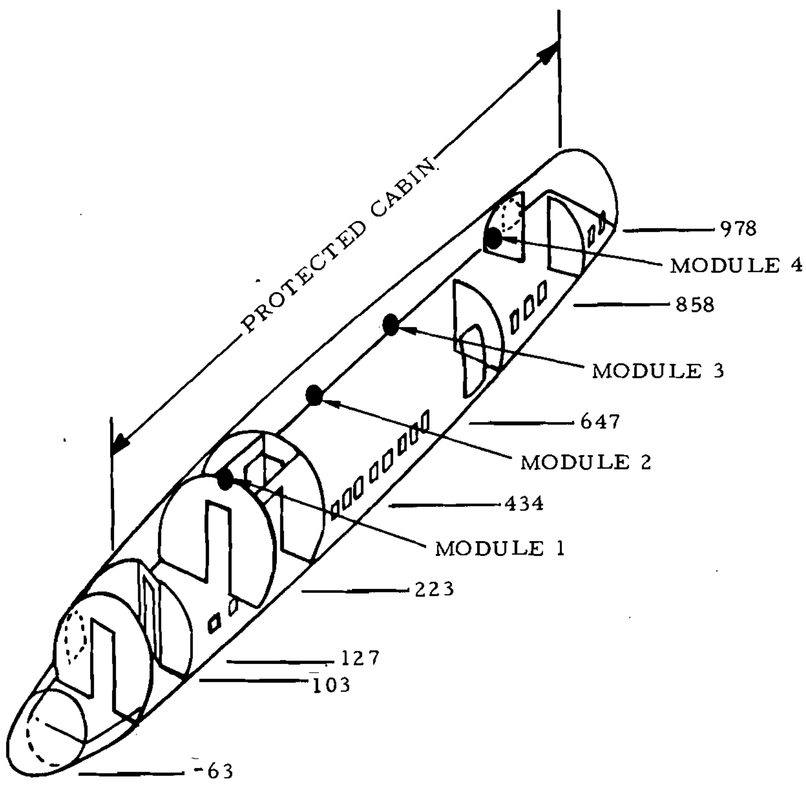
The modular system was designed so that only the discharge spreader head was visible from within the cabin. This feature could probably be configured to meet the aesthetic demands of a production installation. Halon 1301 discharges through a cylindrical spreader head which provides a radial horizontal pattern designed to minimize direct agent impingement upon passengers. A drawing of the agent discharge spreader head is shown in figure 3A, and the four module locations within the DC7 cabin are illustrated in figure 3B. The cabin was divided into four equivalent volumetric zones and one module was placed at the approximate center of each zone. A module consisted of an agent discharge spreader head, a 25-inch-long transfer pipe extending through the top of the fuselage, and a spherical storage container mounted on top of the fuselage. In an operational system, the storage containers and actuating devices would be placed in the void space between the drop ceiling and fuselage skin. For this system, Halon 1301 discharge was activated by a pyrotechnic device inside the neck of the storage container. When fired electrically, this device produced a localized pressure that ruptured a frangible disk in the container neck and released the agent. Discharge was simultaneously initiated from the four modules manually.

Conceptually, the perforated discharge tube promised a more effective and safe "continuous" release of Halon 1301 along the entire fuselage length in contrast to the point discharge from the modular system. The perforated tube system is illustrated in figure 4 and consisted of two main elements: (1) a 3/4-inch inner tube containing two 0.0468-inch-diameter through holes rotated 90° every 6-inches of tube length (four holes per foot) and (2) a 1-inch outer tube containing two 0.187-inch-diameter through holes rotated 90° every 3-inches of tube length (eight holes per foot). Initially, for several tests, a third element consisting of a 1/4-inch-thick open cell foam, incorporated for discharge noise suppression, discharge jet diffusion, and decorative appearance, covered the outer tube; however, the foam was discarded for subsequent tests after it was found to reduce extinguishing effectiveness and produce an unsafe condition (see tests 5 and 6 results). The inner tube is designed to serve



NOTE: 0.690-IN^2 ORIFICE AREA

A. AGENT DISCHARGE SPREADER HEAD



B. MODULE LOCATION

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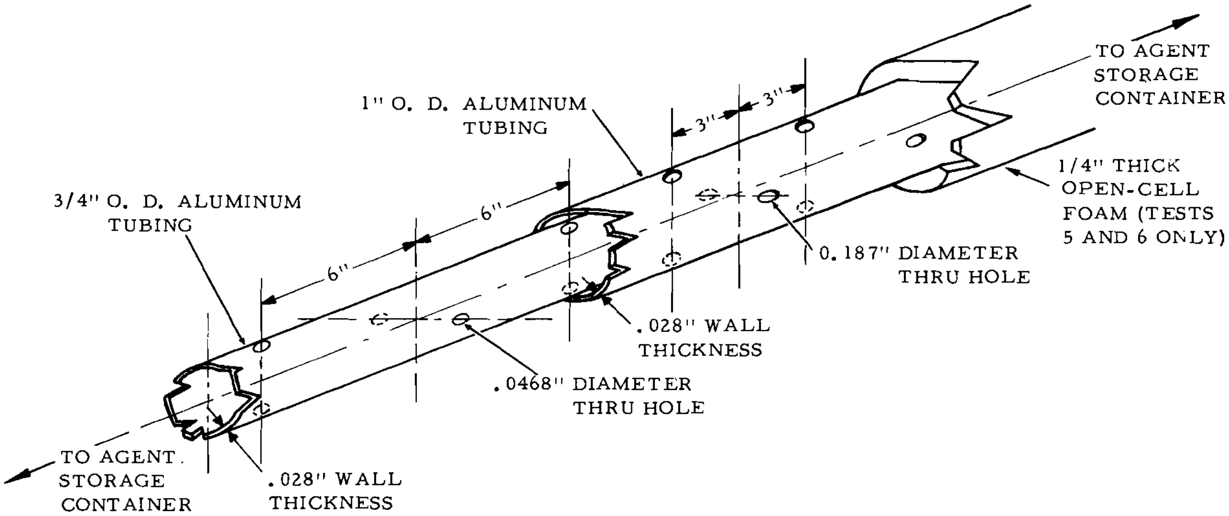
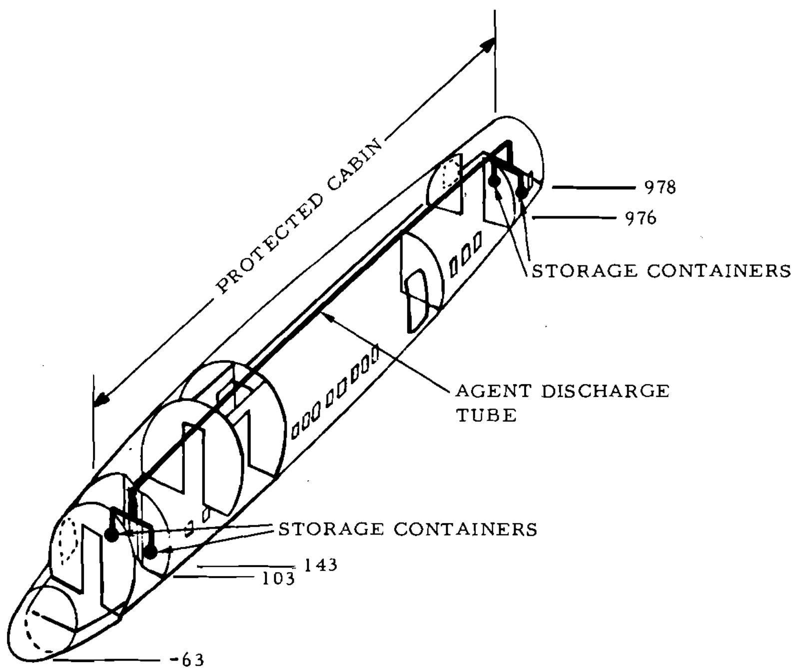
FIGURE 3. MODULAR HALON 1301 FIRE-SUPPRESSION SYSTEM



A. AGENT DISCHARGE TUBE



B. LOCATION IN CABIN

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FIGURE 4. PERFORATED TUBE HALON 1301 FIRE-SUPPRESSION SYSTEM

as a plenum chamber discharging agent from the relatively small 0.0468-inch-diameter orifices at critical flow conditions (reference 21). Developmental tests demonstrated that the pressure was uniform along the entire length of the inner tube (reference 21). Because of the slightly lower ceiling adjacent to the galley and lavatories, the perforated tubes as suspended parallel to the ceiling extended 7-1/4-inches from its centerline to the ceiling along most of the cabin, except near the ends where the fuselage is tapered. When discharge was initiated, equivalent quantities (40 pounds) of Halon 1301 were simultaneously supplied to each end of the inner tube from pneumatically activated storage containers. The perforated discharge tube was about 70 feet long, extending from fuselage station (FS) 143 to 976.

As recommended by NFPA (reference 14), each storage container was "super-pressurized" with nitrogen to a total pressure of 360 pounds per square inch gage (psig) at 70° Fahrenheit (F). This additional pressurization above the vapor pressure of the agent itself (199 psig at 70° F) helped to maintain the agent in the liquid state during discharge.

INSTRUMENTATION.

During the course of the investigation, the following instrumentation was used: (1) Halon 1301 agent concentration recorders, (2) thermocouples, (3) pressure transducers, (4) a noise meter, and (5) motion picture cameras. The only measurements taken for all 17 tests were those of the concentration of Halon 1301 within the protected cabin.

The concentration of Halon 1301 was measured with two similar specially designed agent concentration recorders, models GA-2 and GA-2A, each containing 12 channels for a total capability of 24 channels. Each channel provided a continuous concentration measurment at a relatively fast response rate; 95-percent full-scale is attained in 0.10 second (reference 22). The Halon 1301 concentration in air was determined by measuring the differential pressure across a porous plug maintained at constant flow by a downstream critical orifice (reference 23). This instrument had also been used to measure the concentration of CO_2, methyl bromide, and bromochloromethane, each separately in air, and in principle, it can be used to measure the concentration of any binary gas mixture. A least-squares power law curve fit was generated for each channel in the Halon 1301 concentration range of zero to 20 percent, using five certified Halon 1301 - air calibration mixtures (appendix). Sampling lines were made up of identical 10-foot lengths of 1/4-inch-outer-diameter (o.d.) copper tubing in order to equalize the sampling lag time for each channel. This size of tubing utilized with the Statham gas analyzers produces a lag time of 1.4 seconds (reference 23). Data were recorded with two 24-channel, model 1108, Minneapolis-Honeywell oscillograph recorders. After the test, the galvanometer deflections on the oscillograph paper were tabulated at selected time intervals corrected for the sampling lag time of 1.4 seconds, and a concentration-versus-time curve was plotted for each channel using the appropriate calibration curve stored in a Hewlett-Packard computer, model 9100A, coupled to a 9125A plotter.

The cabin air temperature was continuously measured with fine 30 American wire gage (AWG) iron-constantan thermocouples to minimize thermal lag. Twelve thermocouples were used, usually to measure the temperature at the head level of a seated or standing passenger.

Two pressure transducers, zero to 0.10 psig and zero to 5.0 psig, continually monitored the cabin air pressure. The pressure in the Halon 1301 storage container was also measured, using a zero to 500 psig transducer, to provide an indication of the time required to expel the agent into the cabin.

Temperature and pressure were recorded with an 18-channel, type 5-124, CEC oscillograph recorder. This data was reduced and plotted by hand.

The noise created by the rapid discharge of 80 pounds of Halon 1301 into the cabin was measured with a Bruel and Kjaer precision sound level meter, type 2203, using a condenser microphone, type 4131, and windscreen, type UA 0082. This is an internationally standardized instrument, fulfilling the requirements of the International Electrotechnical Commission. In order to approximate the response of the human ear, the instrument was operated with the standardized "A" frequency weighting network and "fast" readout characteristic. The sound level was recorded on a Bruel and Kjaer sound level recorder, type 2305, operated within the cabin by a technician wearing an ear protector and breathing through a Scott Air Pac.

Some indication of the discharge pattern and forces and misting or fogging of the air following a rapid decrease in temperature on discharge was obtained with two motion picture cameras using 16-millimeter (mm) color film. One camera was operated at a normal speed of 24 frames per second and provided an overall view of the cabin looking aft from about FS 300. Kerosene lanterns were hung in the aisle and below the hatrack to provide visual evidence of the achievement of an extinguishment concentration for kerosene of about 2.5 percent (reference 14). A high-speed camera operated at 200 frames per second viewed the upper torso of a seated anthropomorphic dummy to provide a very crude indication of discharge forces.

TEST RESULTS AND ANALYSIS

GENERAL.

A description of the 17 tests and major observations is summarized in table 2. The thirteenth test was discarded after the reduced data appeared unreasonably low and a loose connection was later discovered in the vacuum manifold.

System effectiveness and safety was determined with all cabin exits closed (tests 1-11, 17); the remaining four tests examined the dependency of inerting on cabin openings (tests 12, 14-16). The majority of tests (10) were conducted with the modular system. Halon 1301 was measured at about 20 cabin locations for all 16 successful tests and was by far the most extensive measurement taken and analyzed. Gas sampling was generally taken throughout the fuselage symmetry plane; however, also included were peripheral, hatrack, under-seat, seated passenger, cargo compartment, galley, lavatory, and open exit locations.

TEST 1.

The primary objective of this test was to determine the uniformity of Halon 1301 distributed within a closed cabin for a period of 10 minutes after activation of agent discharge from the modular system. Halon 1301 was measured about every 3 feet in the fuselage symmetry plane at a height of 5 feet above the floor (figure 5).

The concentration-time curves measured at the various aisle locations converged closely in about 3 to 4 seconds and varied similarly to one another for the remainder of the test. The time at which the concentration became invariant with measurement location corresponded to the completion of agent mixing within the cabin. Three curves representative of the extreme in Halon 1301 concentration-time behavior immediately following discharge (3 to 4 seconds) but typical thereafter are compared in figure 6. The measurement location in the narrow (compared to the cabin cross section) hallway between lavatories, FS 217 to FS 260, exhibited the highest overshoot in concentration because of the discharge of module 1 into this constricted area. In an operational system, the expulsion of a large quantity of Halon 1301 into a confined occupied area would have to be avoided in order to eliminate an overshoot of this kind. Throughout the main cabin, the concentration-time behavior was dependent only on the sampling probe location relevant to the nearest module. Midway between two successive modules, agent discharge streamlines from each module crossed, causing an extremely brief overshoot to about twice the design concentration (e.g., GA-2A #11), whereas beneath the module the concentration builds up gradually to the design value since the discharge streamlines first bounce around inside the hatrack before indirectly reaching the measurement location (e.g., GA-2A #9). The behavior at other locations lie in the area formed by the "midway between modules" and "beneath module" curves.

TABLE 2. SUMMARY OF DESCRIPTION OF TESTS AND OBSERVATIONS (continued)

	Dispensing System			Initial Cabin Conditions			Measurements							
Test No.	Modular	Foam-Covered Perforated Tube	Perforated Tube	Temperature (°F)	Relative Humidity (Percent)	Exit Configuration	Halon 1301	Temp.	Pressure	Noise	Motion Picture	Halon 1301 Sampling Line Location	Observations
10	X			77	88	Same as test 8.	X					Head level of seated passengers. Galley shelves. Similar locations in each lavatory. LHS lavatory door open; RHS lavatory door closed.	Complete obscuration as occurred in test 9. Window across cabin from point of observation became visible at about 45 seconds. Garbage-like odor outside of fuselage during test.
11			X	82	73	Same as test 8.	X					Same as test 10.	No odor inside or outside of fuselage. Total obscuration at 7 secs.; 100 percent visibility returned by about 1 min. Considerable moisture on discharge tube and cabin ceiling.
12	X			80	83	All exits initially closed as in previous tests. Galley exit door opened at 10 secs. after discharge activation.	X					Sampling lines at 4 heights above the floor at 5 fuselage stations at symmetry plane and adjacent to galley door.	Cabin foggy observed through opened galley door. Fog dissipated on contact with warm building air. Rotten egg odor. No odor when cabin entered at 10 mins.
13													Voided test results since instrumentation malfunction.
14	X			77	56	Similar to test 12 except 4 LHS emergency exit windows in addition to galley door opened at 10 secs. after discharge activation.	X					Sampling lines at 4 heights above the floor at 5 symmetry plane fuselage stations. Lines adjacent to opened window and opposite side of cabin.	No cabin obscuration as observed in tests 9 - 12.
15	X			78	48	LHS galley door and 4 emergency exit windows open at time of discharge activation.	X					Same as test 14.	High noise level for split sec. Odor. No cabin fogging.
16			X	78	44	Same as test 15.	X					Same as test 14.	Vaporous discharge jets about 1 ft. long. Cooling effect near exits. No odor.
17	X			84	44	Same as test 8 (all fuselage exits closed for test duration).	X					Potential fire areas in LHS lavatory. Lavatory door open.	Rotten egg odor.

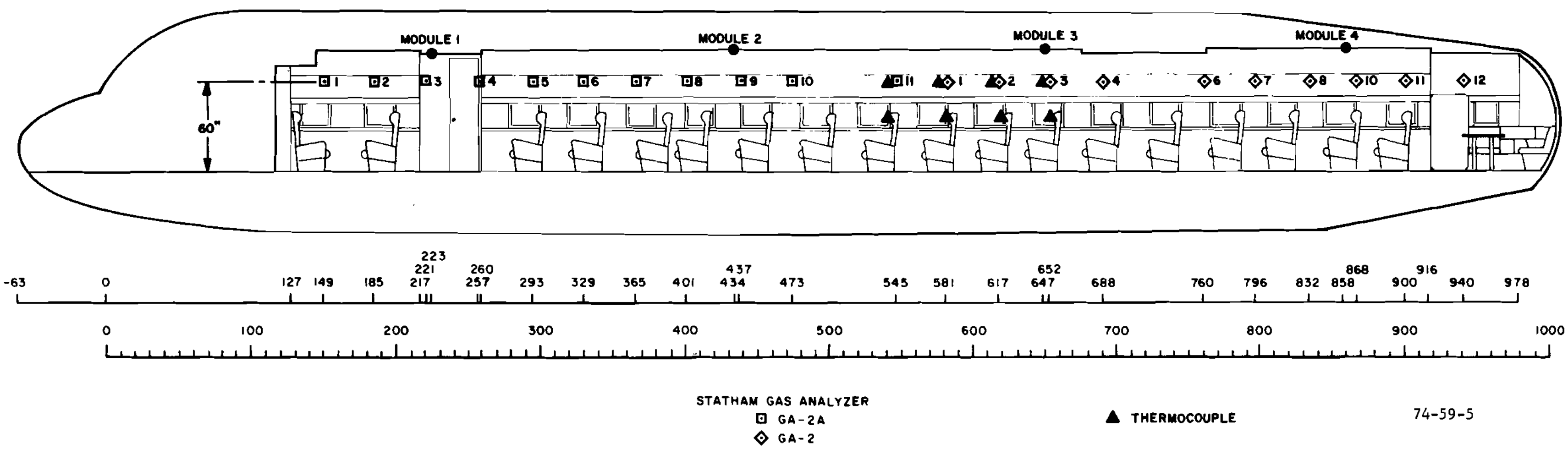

FIGURE 5. LOCATION OF HALON 1301 SAMPLING LINES IN THE FUSELAGE SYMMETRY PLANE AND THERMOCOUPLES FOR TEST 1

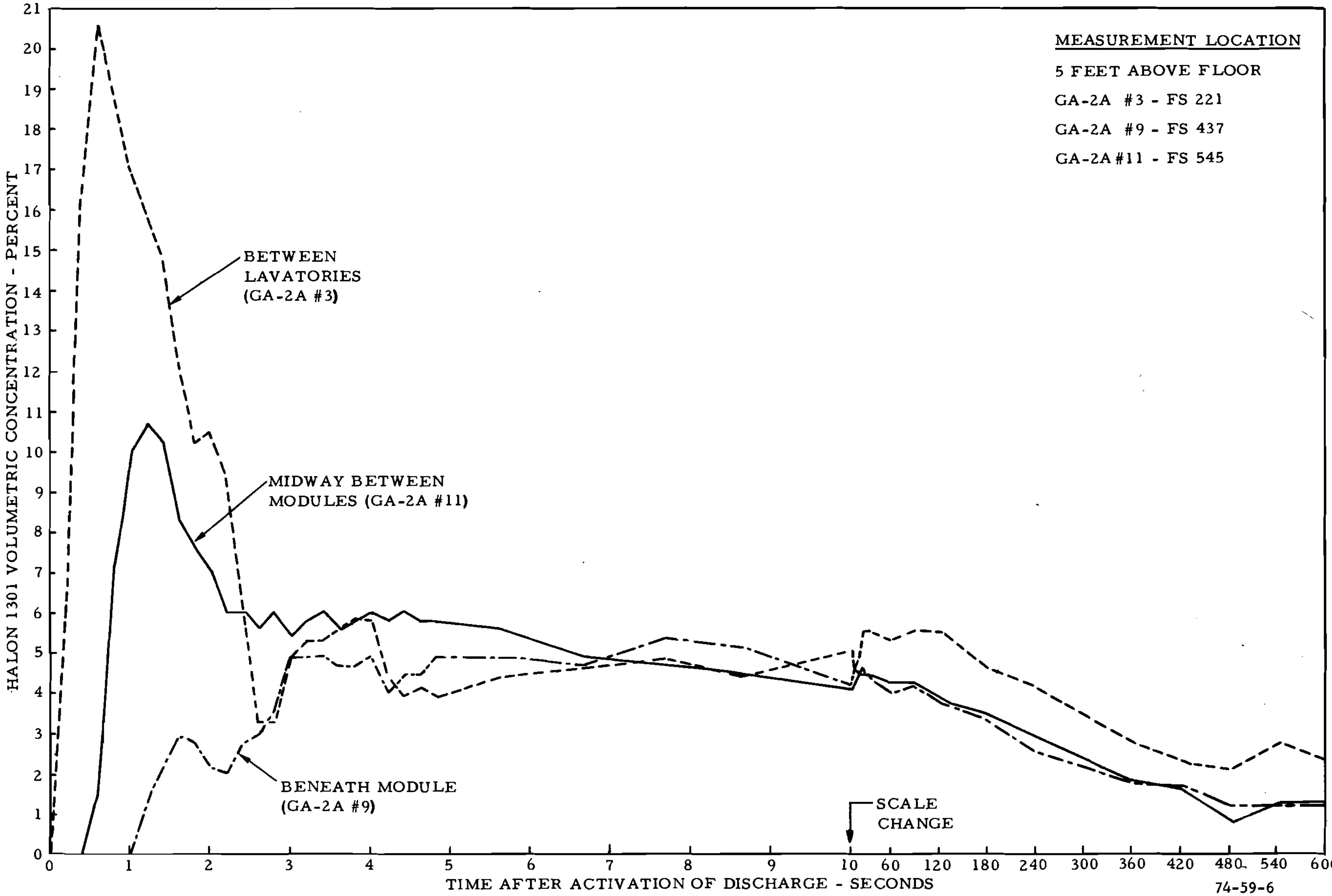

FIGURE 6. EXTREME HALON 1301 CONCENTRATION-TIME PROFILES IN THE FUSELAGE SYMMETRY PLANE FOR THE MODULAR SUPPRESSION SYSTEM (TEST 1)

The concentration of Halon 1301 along the fuselage symmetry plane at selected times from 10 seconds to 10 minutes is shown in figure 7. A relatively uniform concentration existed along the entire length of protected cabin, differing at the most by a concentration of about 1.5 percent at any given time during the test. Uniform agent distribution throughout the cabin to cover all locations is necessary for inerting protection. Although the profiles are similar at 5 and 10 minutes, indicating some relationship with locality, this characteristic appears more a result of measurement technique, especially at low agent concentrations, than dependency upon position relative to the nearest discharge module or fuselage cross section. At 2 minutes, the concentration exceeded a level of 3 percent at all measurement locations but one, and the average concentration was 4.2 percent.

A total of 12 thermocouples were placed near the location of the head of seated passengers in four rows of double seats on the right-hand side (RHS) of the cabin and at the location of the heads of standing passengers in the aisle adjacent to the seat rows (figure 5). The variation of temperature with time behaves somewhat like an inverted image of the agent concentration-time profile. This mutual dependency is shown in figure 8 for the measurement location in the aisle at FS 545. A rough attempt was made to determine if the Halon 1301 concentration was predictable from temperature. It was assumed that agent concentration was proportional to temperature change, i.e.,

$$\text{Concentration} = A\ (-\Delta T) \qquad (1)$$

Using the values of maximum concentration and minimum temperature at FS 545 from figure 8, A was calculated to be 0.324 percent/°F, and equation 1 can be written as

$$\text{Concentration} = -0.324\ (\Delta T) \qquad (2)$$

The applicability of equation 2 was evaluated at the aisle measurement location at FS 617. Figure 9 demonstrates that the agreement between the agent concentration measured and that calculated from the temperature data, and the above empirical formula is good for the first 10 seconds, but depreciates appreciably later in the test. This behavior is reasonable since in the beginning of the test the temperature is related to agent concentration directly by the heat of vaporization; however, as heat becomes transferred from the cabin surfaces and furnishings, this relationship becomes invalid.

The temperature decreased the most at FS 545, midway between modules 2 and 3, to a value about 30° F below ambient in about 1 second. An average maximum temperature drop of 21° F was measured by the 12 thermocouples. There was no appreciable difference in temperature between the aisle and passenger seat measurement locations (e.g., figure 10) at a given fuselage station, although the temperature change was less close to the discharge module. Thus, the Halon 1301 concentration at the head level of a seated passenger was probably very close to that measured in the aisle.

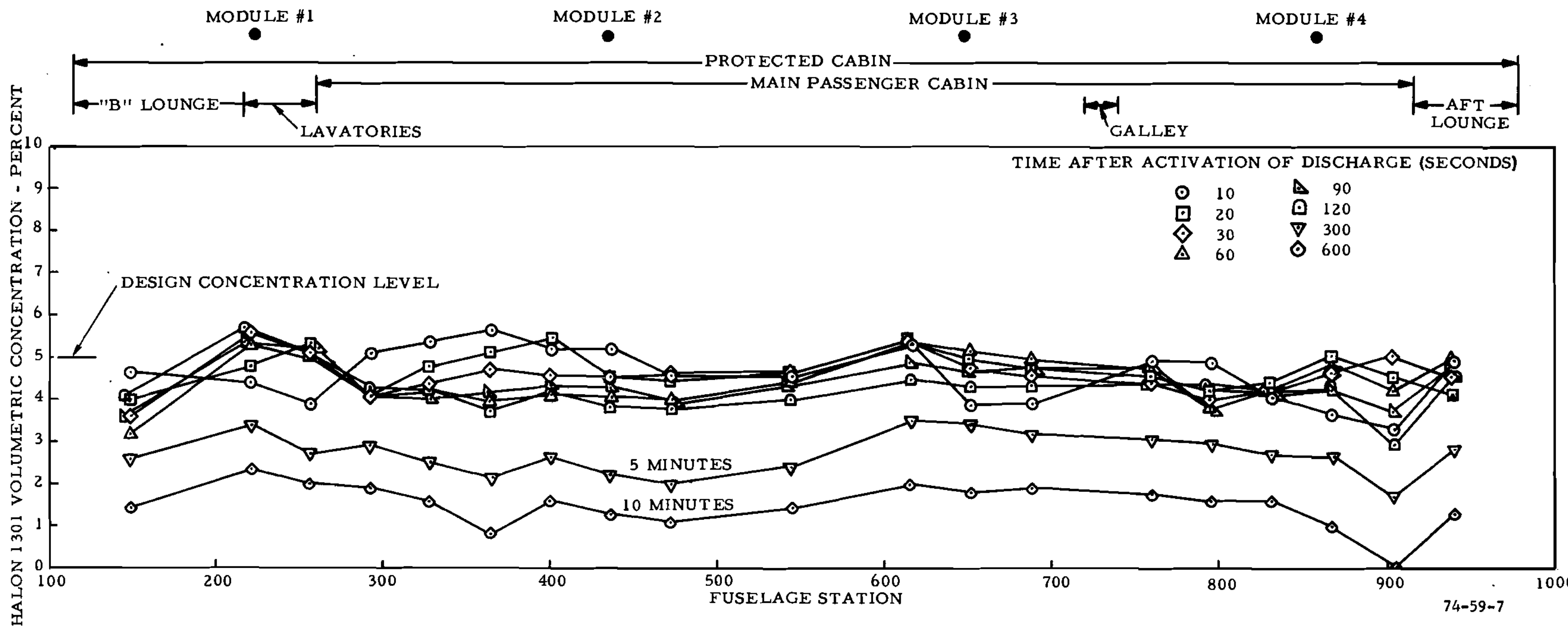

FIGURE 7. CONCENTRATION OF HALON 1301 ALONG THE FUSELAGE SYMMETRY PLANE AT A DISTANCE OF 5 FEET ABOVE THE FLOOR FOR THE MODULAR SUPPRESSION SYSTEM (TEST 1)

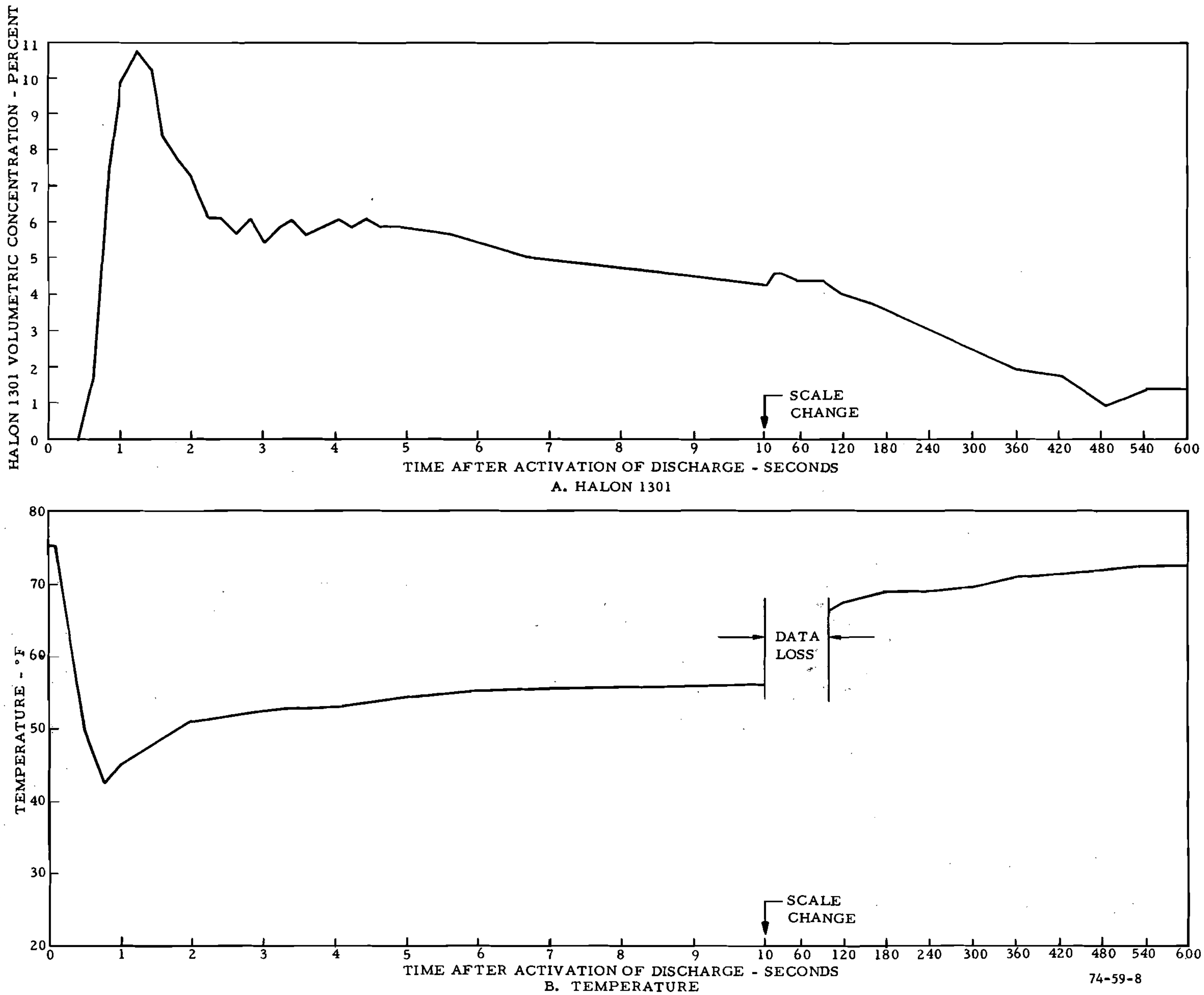

FIGURE 8. HALON 1301 CONCENTRATION AND TEMPERATURE IN THE FUSELAGE SYMMETRY PLANE AT FUSELAGE STATION 545 AT A DISTANCE OF 5 FEET ABOVE THE FLOOR FOR THE MODULAR SUPPRESSION SYSTEM (TEST 1)

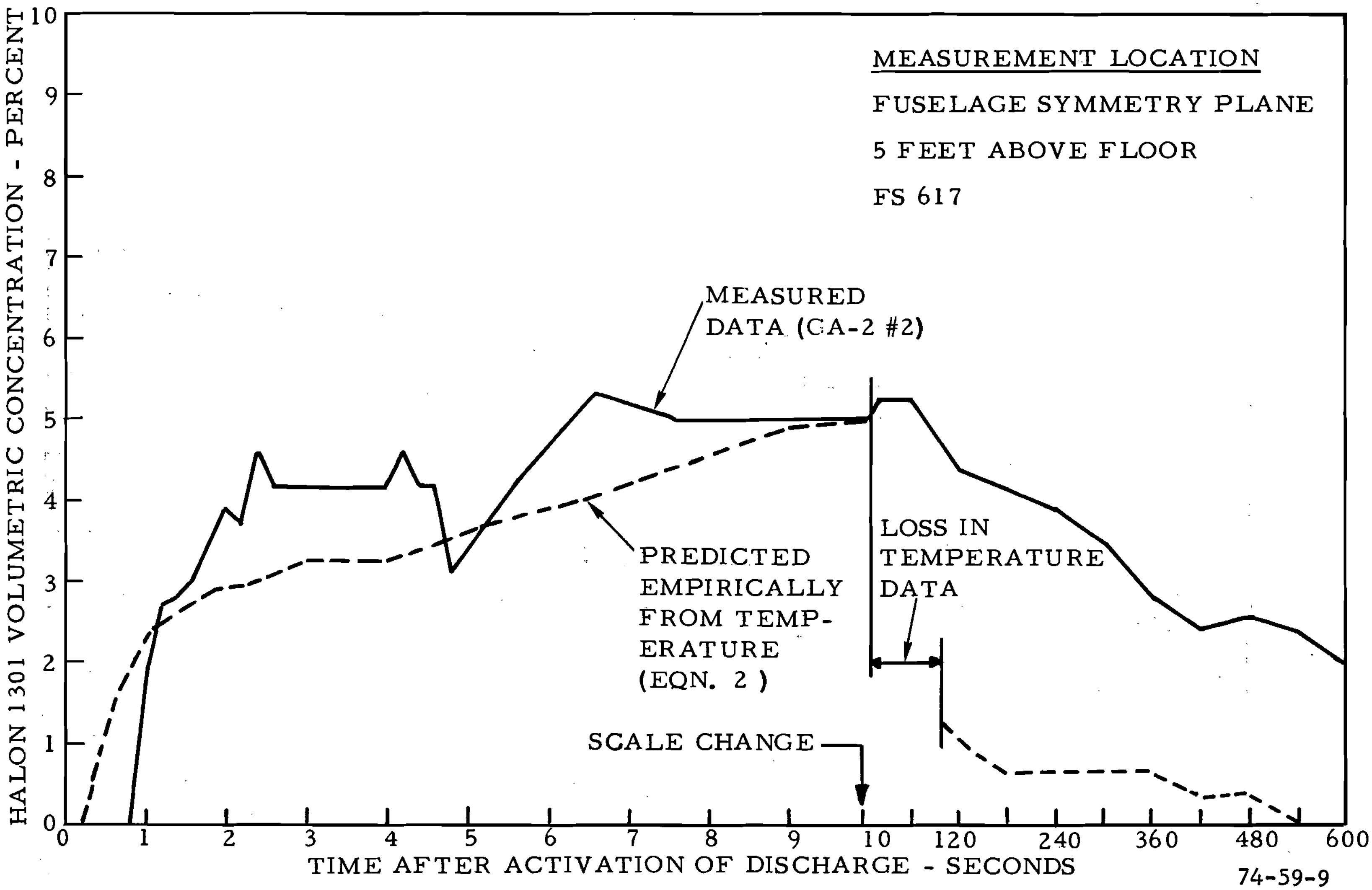

FIGURE 9. A COMPARISON OF HALON 1301 CONCENTRATION MEASURED AND PREDICTED EMPIRICALLY FROM THERMOCOUPLE DATA

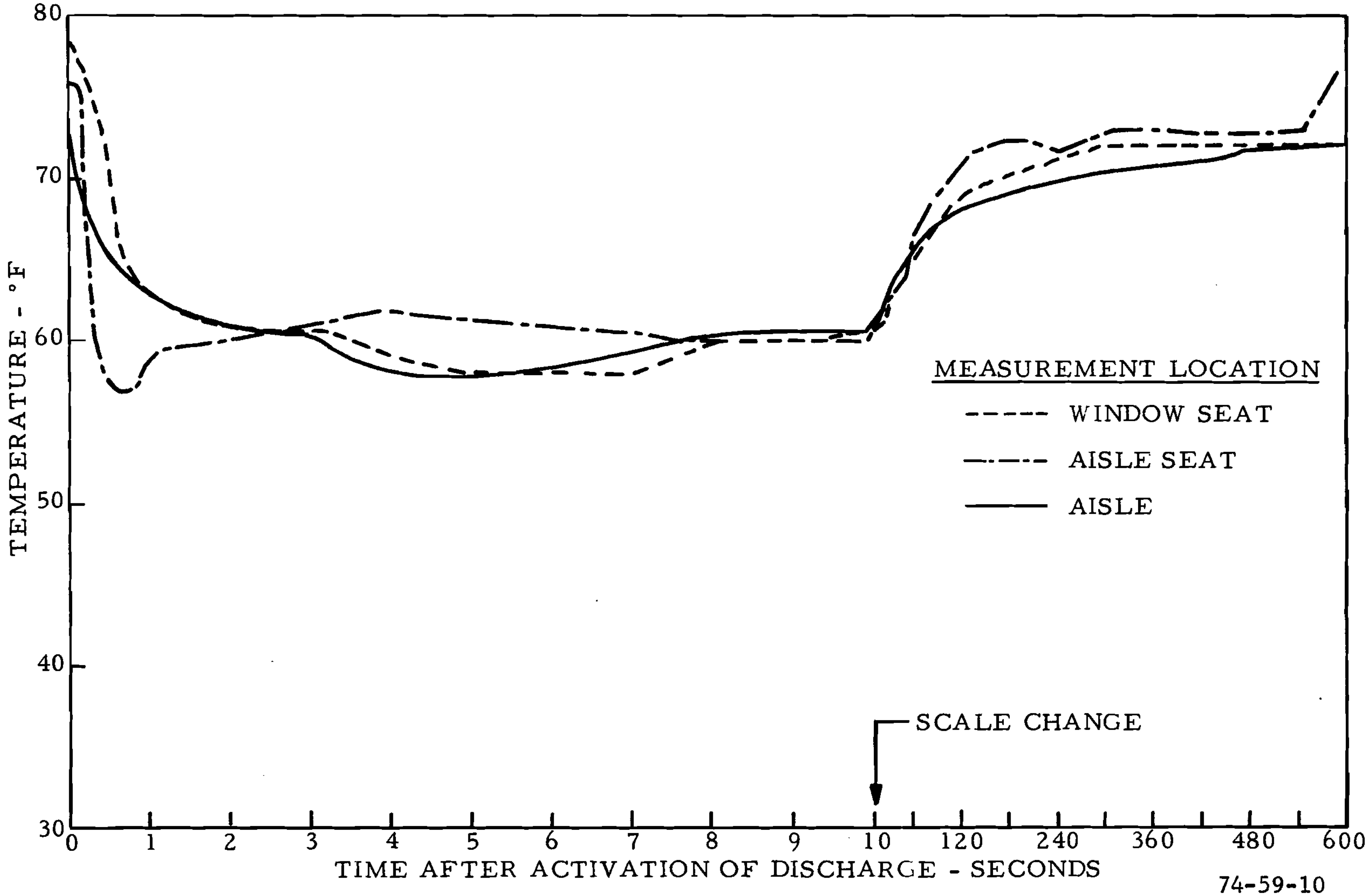

FIGURE 10. SIMILARITY IN THE CABIN TEMPERATURE MEASURED AT THE HEAD LEVEL OF PASSENGERS AT FUSELAGE STATION 652 (TEST 1)

TEST 2.

At the end of the first test (10 minutes), the average Halon 1301 concentration 5 feet above the cabin floor had decreased to about one third its original value. The purpose of the second test was to determine whether this effect was due to a change in the vertical distribution of agent (stratification) or leakage from the cabin. Of additional interest was the repeatability of agent dispersion with the modular system. Stratification was measured at FS 540, near the center of the cabin, from a series of eight sampling probes on a vertical line at the fuselage symmetry plane (figure 11). The remaining sampling probes and the 12 thermocouples were retained at the test 1 locations (figure 12). In addition, cabin pressure was measured at the head level of a seated passenger in the aisle seat at FS 540.

Generally, there was good repeatability between tests 1 and 2 of the Halon 1301 concentration-time profile measured at identical locations. Differences of about 1 percent in agent concentration, however, did exist for prolonged periods of time at several locations, probably as a result of measurement inaccuracy. A typical comparison at FS 473 is shown in figure 13. The repeatability of all thermocouple measurements was excellent.

The vertically placed sampling probes provided an indication of the "effective discharge time" defined as "the time required to complete the desired mixing of agent with air in all spaces in the enclosure." The effective discharge time corresponded to the instant when the vertical profile first became invariant with time. Figure 14 shows a plot of the vertical Halon 1301 concentration profile at selected times immediately following activation of discharge. From the profile at 1 second, it appears as if the rapid discharge, vaporization, and turbulent mixing of Halon 1301 with air distributed Halon 1301 into the cabin in a manner like a curtain dropping from the ceiling. By 2 seconds, the agent has covered the symmetry plane from ceiling to floor and the shape of the profile is established. From 2 to 4 seconds, the concentration decreases slightly as the agent permeates the remaining cabin spaces, but the shape of the profile is unchanged. After 4 seconds, the concentration also becomes invariant, indicating that the "effective discharge time" was 3 to 4 seconds, consistent with this determination in test 1 obtained by examining the convergence of the concentration-time curves from the various sampling locations. Once the cabin is completely flooded with agent and mixing is completed, it is evident that there is stratification with the concentration at the ceiling roughly 2 percent (absolute level) less than that at the floor.

The vertical profiles at various times from the beginning of the test until the end are shown in figure 15. The amount of stratification or difference in concentration between the floor and ceiling appears to increase progressively during the test. Obviously, the agent concentration is decreasing faster at the ceiling than at the floor, and the rate of dropoff is greater at the higher concentrations near the beginning of the test. It is also apparent that the total amount of Halon 1301 in the cabin was diminishing. The formation of an interface with air above and an air/agent mixture below as described in reference 14 for the case of a wall opening was not distinctly apparent, although there was some indication of a tendency toward this behavior, probably because of the very small leakage rates involved.

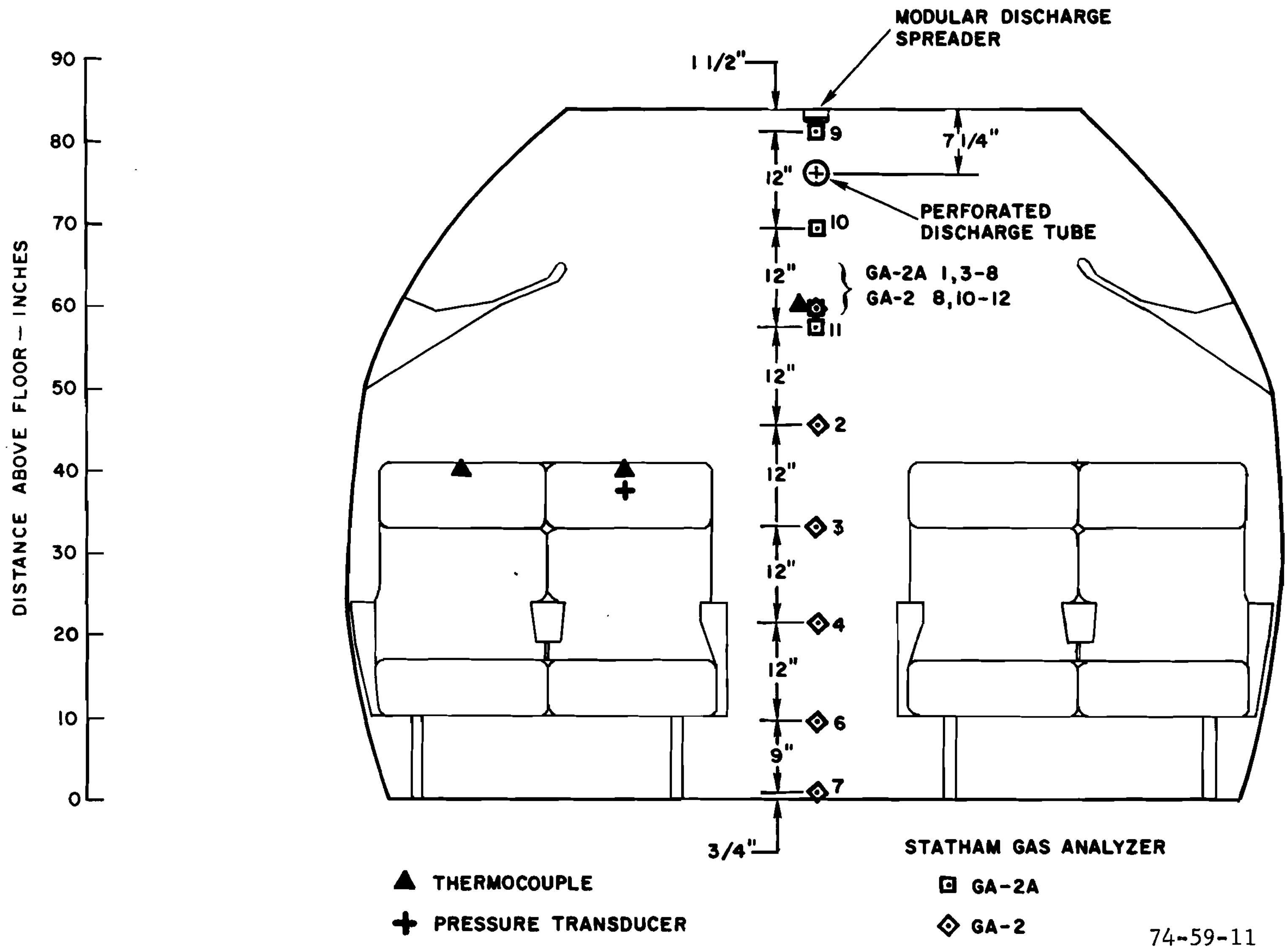

FIGURE 11. CROSS SECTIONAL VIEW OF CABIN SHOWING MEASUREMENT LOCATIONS FOR TESTS 2 TO 5

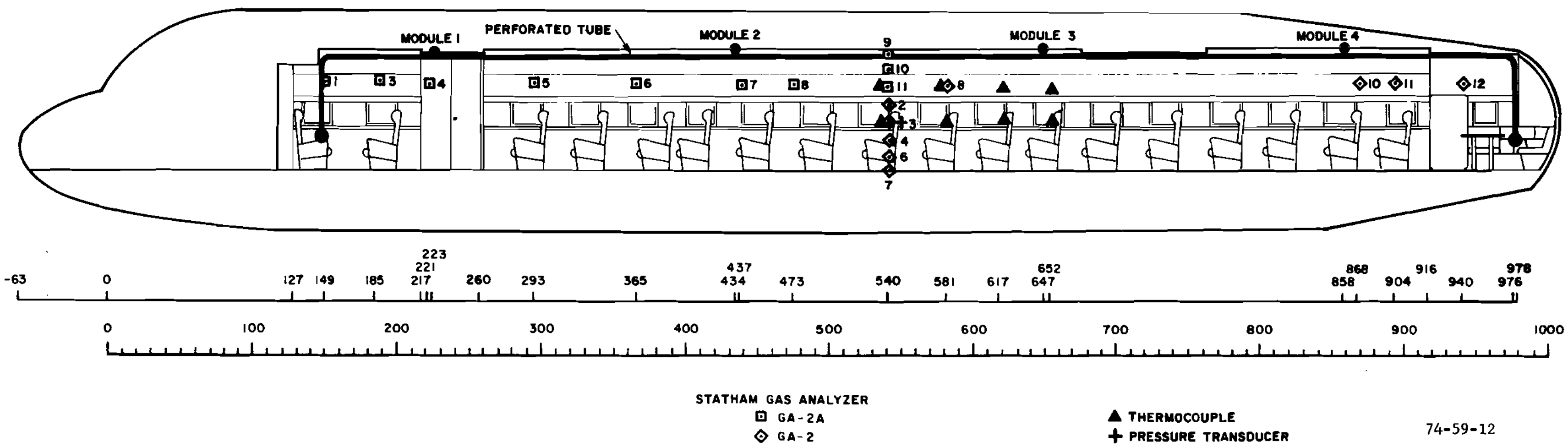

FIGURE 12. SIDE VIEW OF CABIN SHOWING MEASUREMENT LOCATIONS FOR TESTS 2 TO 5

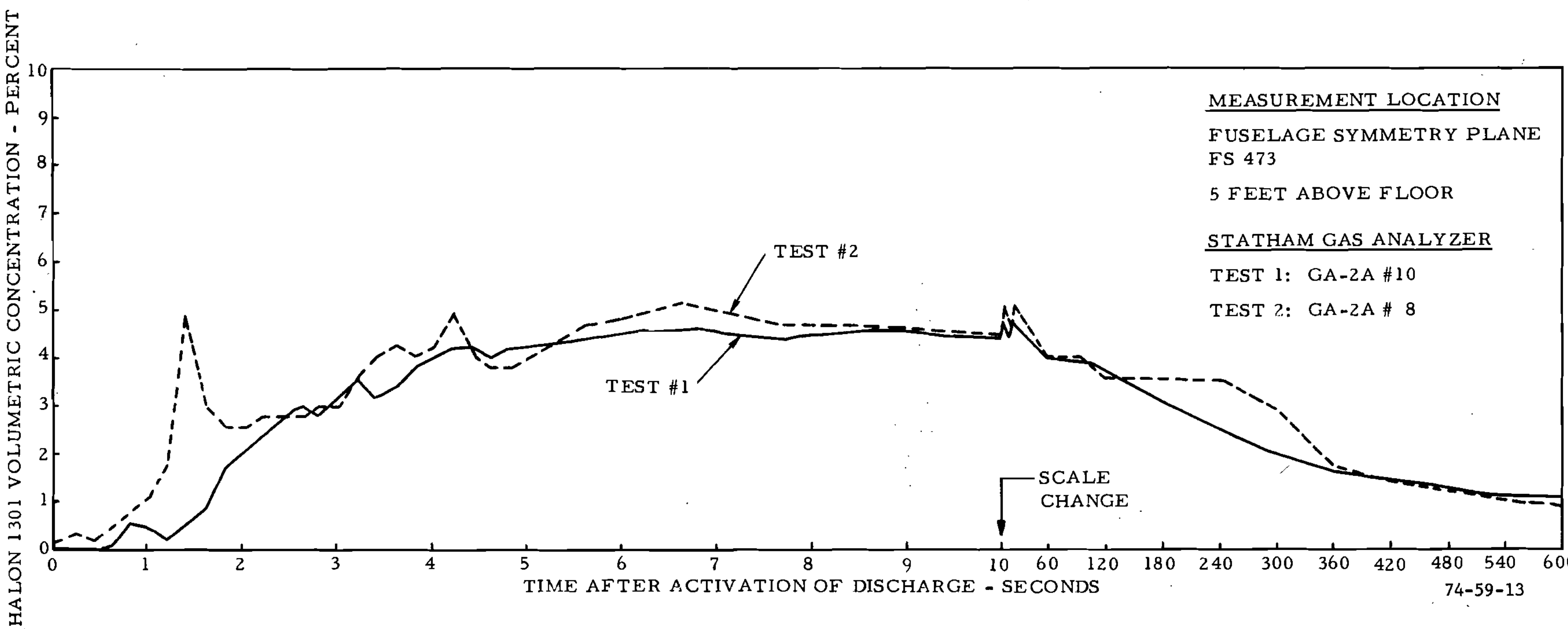

FIGURE 13. REPEATABILITY BETWEEN TESTS OF THE HALON 1301 CONCENTRATION-TIME PROFILE FOR THE MODULAR SUPPRESSION SYSTEM

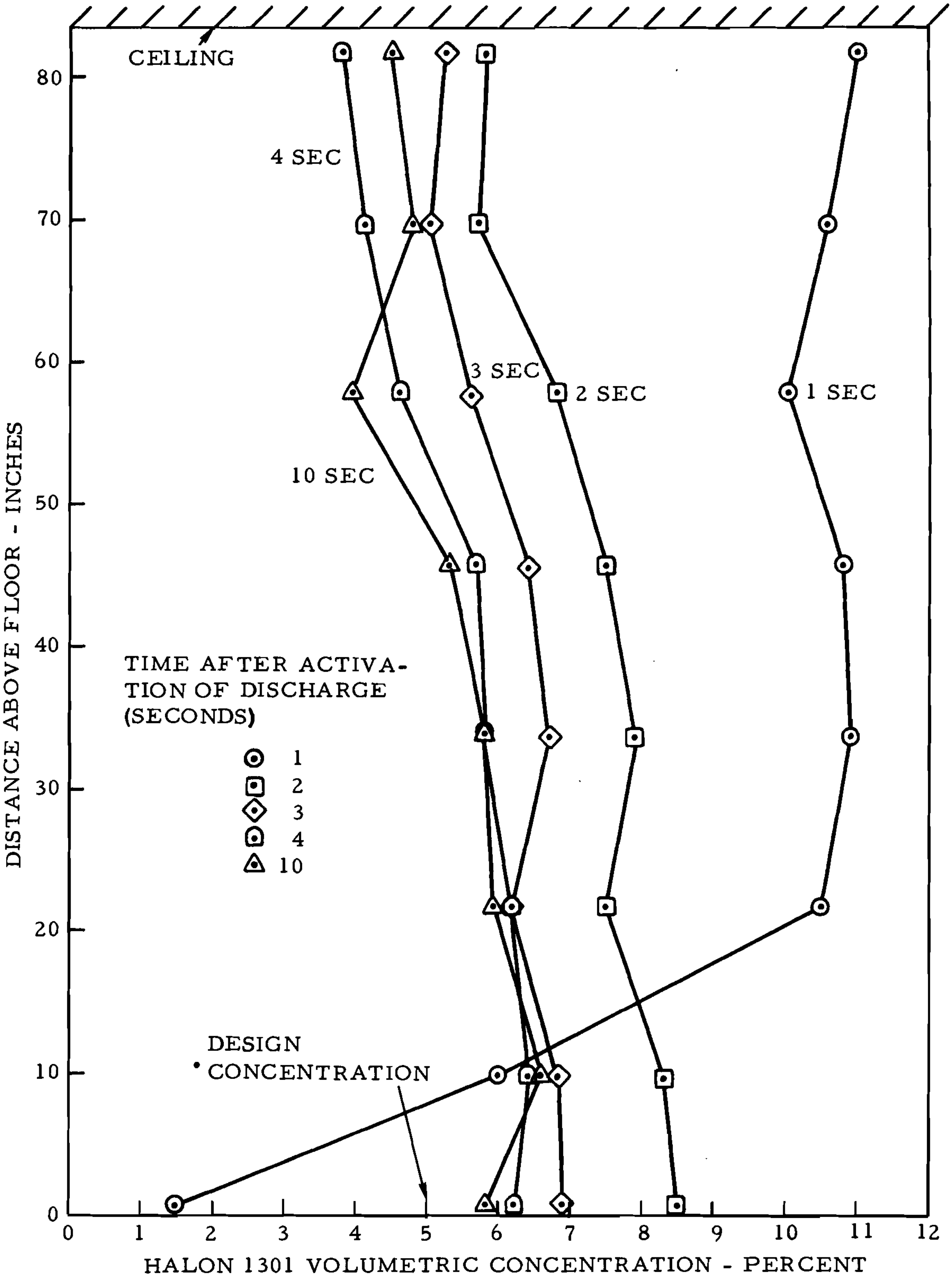

FIGURE 14. VERTICAL DISTRIBUTION OF HALON 1301 AT FUSELAGE STATION 540 IMMEDIATELY AFTER DISCHARGE OF THE MODULAR SUPPRESSION SYSTEM (TEST 2)

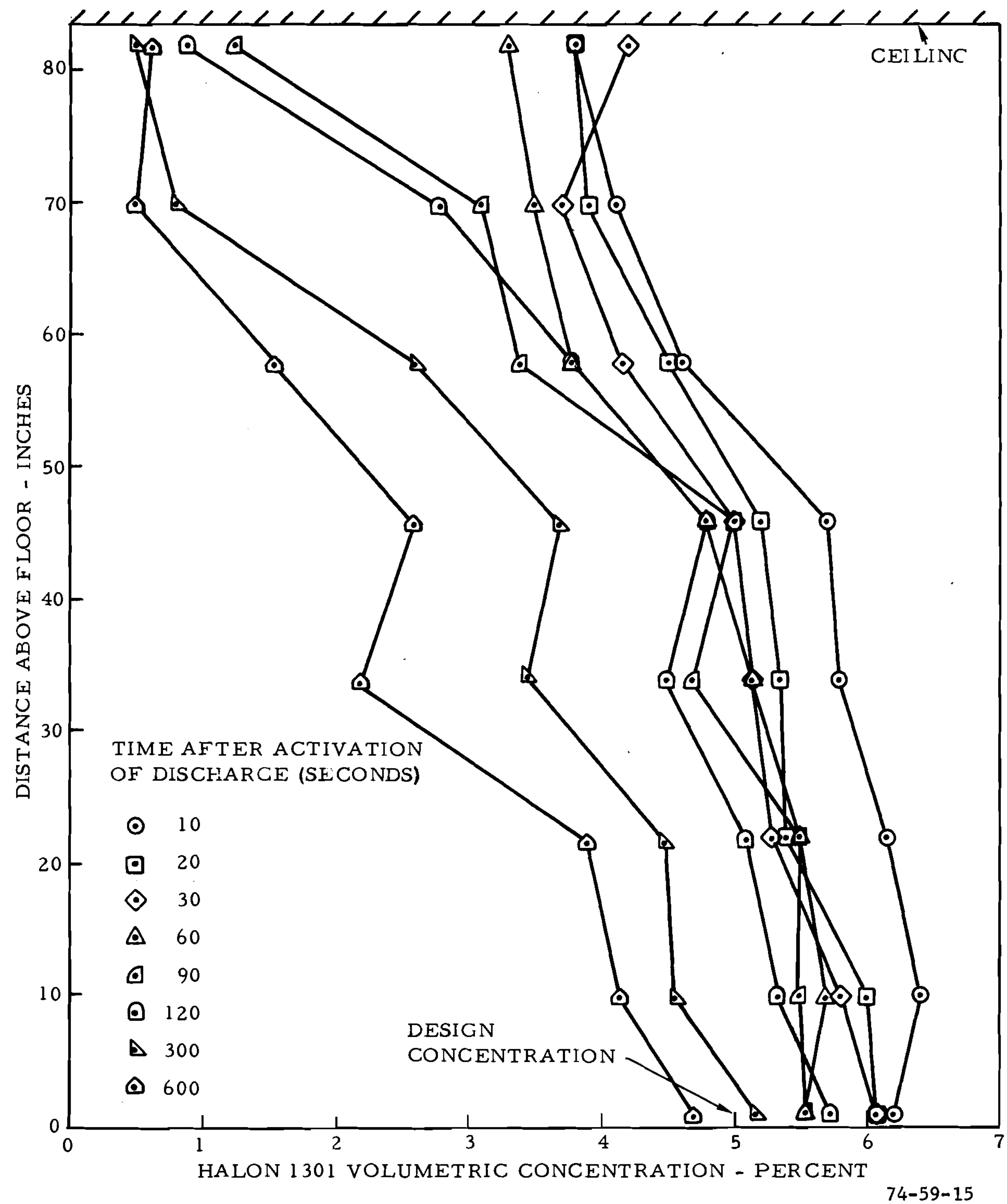

FIGURE 15. VERTICAL DISTRIBUTION OF HALON 1301 AT FUSELAGE STATION 540 FROM 10 SECONDS TO 10 MINUTES AFTER DISCHARGE OF THE MODULAR SUPPRESSION SYSTEM (TEST 2)

Halon 1301 leakage from the cabin was examined by calculating the average concentration between the floor and ceiling over the test duration (figure 16). The average concentration after completion of mixing was about 10 percent higher than the design value. For about 1 minute, the average concentration lingered above 5 percent; thereafter, the concentration decayed logarithmically. By the end of the 10-minute test, approximately 55 percent of the initial quantity of agent leaked out of the protected cabin.

A harmless increase in cabin pressure was measured during agent discharge. Actually, for several tenths of a second, a slight vacuum was formed when the decrease in pressure from abrupt cooling exceeded the increase in pressure expected from mass addition only. A peak pressure of 0.018 psig was recorded at 0.75 seconds. The pressure returned to ambient by 2 seconds.

TEST 3.

After the vertical Halon 1301 profile measured during test 2 demonstrated that about half of the initial agent leaked out of the cabin by the end of the test, it was realized that this loss and possibly the agent stratification might have resulted from the open vents of the inoperable cabin environmental control system. Consequently, all cabin air vents and, as an extra precaution, the seam around the forward slope bulkhead door were taped closed. The modular system was tested again with the same measurement locations as test 2 except for one notable exception--a mantle lantern was hung about even with the hatrack slightly forward of the galley.

It was observed that the mantle lantern light was not extinguished immediately following discharge, although the six kerosene lantern flames were quickly extinguished as in the previous two tests. Instead, the mantle lantern light flickered and produced a thin curl of white smoke throughout the 10-minute test. At the end of the test a mist was evident along the ceiling of the cabin and seemed denser in the aft end. The lantern was then quickly removed from the cabin through the galley door at which time the light immediately intensified to its normal level. It is believed that failure to extinguish the lantern light might be related to either the high Halon 1301 concentration needed to extinguish the lantern fuel (about 6.5 percent if similar to naptha) or to the white-hot surface of the mantle. It was impossible to remain comfortably in the cabin because of the acrid atmosphere that had formed from failure to extinguish the lantern, resulting in continued degradation of the Halon 1301 into toxic by-products. The gas had an irritating effect on the throat and nasal sinuses. This unexpected failure to extinguish a small combustion source over an extremely long period of time reinforced the requirement to investigate Halon 1301 decomposition products in the event of a much larger fire not being quickly extinguished.

Examination of the reduced Halon 1301 concentration recorder data indicated that the two closest sampling lines to the ceiling and the three in the rear cabin all measured zero concentration after 5 to 7 minutes. Since this result was related to the unextinguished mantle lantern and observed mist heaviest at the ceiling and rear cabin, the test was repeated (test 4) without the mantle lantern.

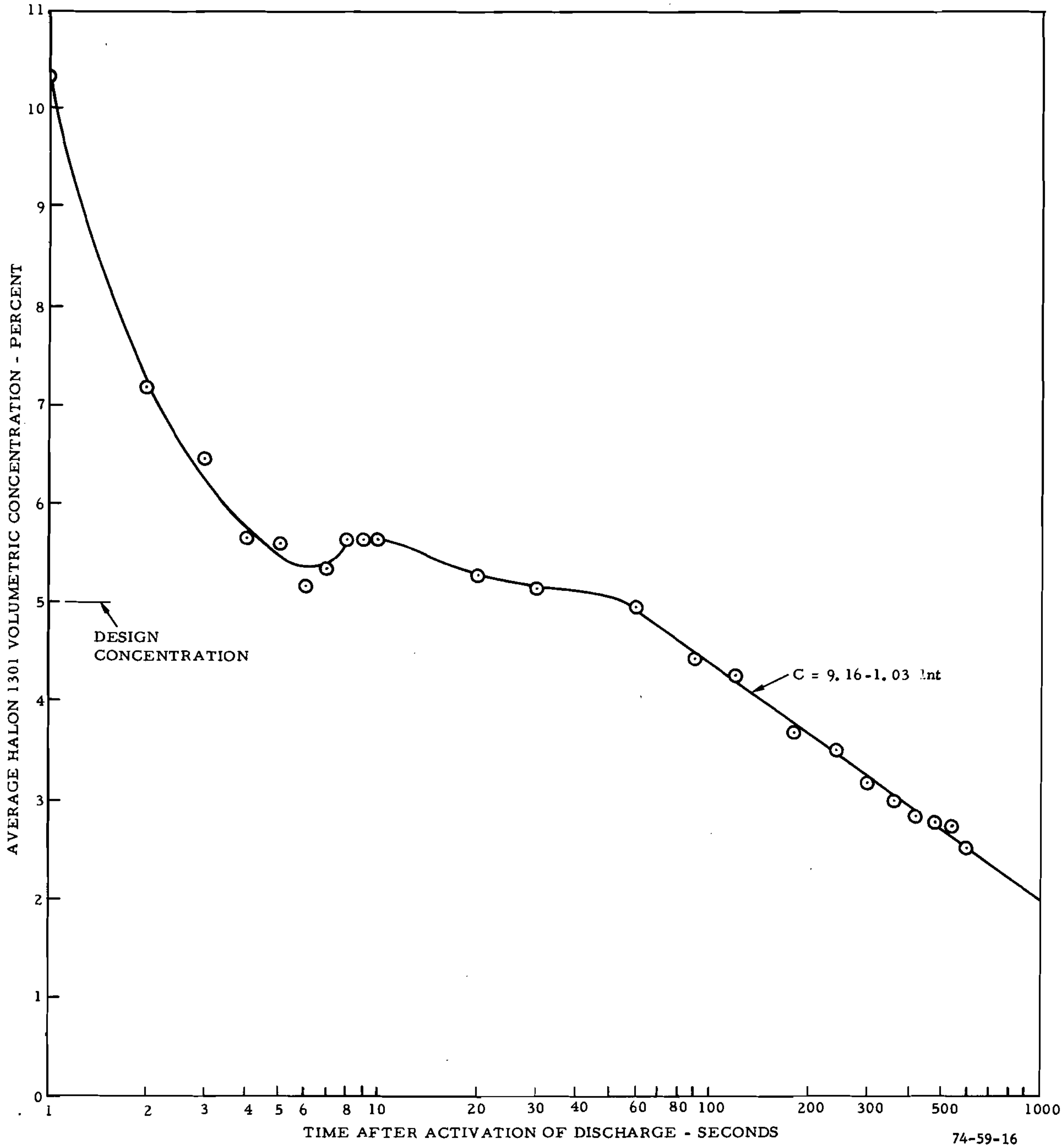

FIGURE 16. AVERAGE HALON 1301 CONCENTRATION BETWEEN THE FLOOR AND CEILING IN THE FUSELAGE SYMMETRY PLANE AT FS 540 OVER THE DURATION OF TEST 2

Examination of the motion picture film showed that the formation of a fog from the rapid reduction in cabin air temperature persisted for less than 1 second and was confined to an area near the ceiling and inside the hatrack. The ambient relative humidity for this test was 28 percent. Generally, no significant obscuration was observed when the relative humidity was about 50 percent or less.

TEST 4.

A photograph of the cabin interior looking aft from FS 365 is shown in figure 17. At the 5-foot-high gas measurement locations, a comparison of the Halon 1301 concentration-time curves between test 2 (open vents) and test 4 (closed vents) provided two important findings with regard to the importance of the air vents on retaining Halon 1301 in the cabin of an actual operating aircraft. First, the curves at corresponding locations were practically identical over the first 10 seconds of the test, indicating that during and immediately following discharge a negligible quantity of agent is lost through the open air vents; secondly, beyond 10 seconds and over the remainder of the 10-minute test, the concentration in test 2 consistently dropped below the test 4 level by as much as 1 percent (absolute), on the average. Therefore, over an adequately long time period, agent can be leaked out of the cabin through the open air vents, although no loss was measured over the small time period during and immediately following discharge overpressure.

The aforementioned trends were most clearly demonstrated by comparing the vertical Halon 1301 concentration profiles for tests 2 and 4 (figure 19). At 30 seconds, the profiles are indistinguishable from one another. By 60 seconds, it is clear that some agent leaked through the vents and was manifested at the three sampling probes closest to the ceiling. Over the next minute, as additional agent leaked through the vents, the loss was only evidenced near the ceiling, while the five probes closest to the floor still indicated an equivalent concentration for both tests. By 5 minutes, a slightly higher concentration in test 4 (closed vents) also existed at the five probe locations closest to the floor, although by far the greatest difference was measured by the second probe, 13 1/2 inches below the ceiling. At this location, the Halon 1301 concentration actually increased for a period of time after 60 seconds, almost as if a stratum of agent had lingered there after settling down from the ceiling.

A calibration check of the Statham gas analyzer channel (GA-2A #10) connected to this sampling location was satisfactory. At the end of the 10-minute tests, the profiles were similar and more uniformly separated. The average vertical Halon 1301 concentration at 10 minutes for tests 4 and 2 was 3.4 and 2.5 percent, respectively. Thus, at 10 minutes, of the 55 percent of the initial quantity of agent that leaked out of the cabin, about 16 percent was through the open air vents, and the remaining 39 percent through small seams in the fuselage structure (especially in the floor as demonstrated in later tests).

Figure 18 demonstrates from another viewpoint the increase in inerting protection provided by closure of the air vents. The vertical Halon 1301 concentration profile at 10 minutes when the air vents were closed (test 4) is

TABLE 2. SUMMARY OF DESCRIPTION OF TESTS AND OBSERVATIONS

	Dispensing System			Initial Cabin Conditions			Measurements						
Test No.	Modular	Foam-Covered Perforated Tube	Perforated Tube	Temperature (°F)	Relative Humidity (Percent)	Exit Configuration	Halon 1301	Temp.	Pressure	Noise	Motion Picture	Halon 1301 Sampling Line Location	Observations
1	X			75	?	All exits closed.	X	X				Equidistant at the fuselage symmetry plane; 5 ft. above the floor.	Aisle kerosene lanterns extinguished in less than 1 sec.; lanterns under hatrack about 5 secs. later. High-rate discharge forces evidenced by paint scraped off ceiling near disperser. Slight odor upon entering fuselage.
2	X			72	43	Same as test 1.	X	X	X			Eight sampling lines to measure FS 540 stratification; remaining lines 5 ft. above floor at symmetry plane.	Same as test 1.
3	X			78	28	All exits closed. All cabin air vents taped to close (retained for remainder of tests).	X	X	X		X	Same as test 2.	Mantle lantern did not extinguish. Flickered during entire 10-minute test. Cabin could not be entered because of acrid atmosphere.
4	X			78	48	Same as test 3.	X	X	X			Same as test 2.	Rotten egg odor not detected in previous tests surmised to be decomposition products from the pyrotechnic discharge actuator.
5		X		76	52	Same as test 3.	X	X	X		X	Same as test 2.	No sound during discharge. Discharge appeared as fog-like waterfall falling straight to the floor. Discharge time and kerosene lantern extinguishment greater than 10 secs. Lanterns extinguish gradually. Circular ice patches on foam.
6		X		70	56	Same as test 3.	X	X	X	X		Peripheral cabin locations at FS 432 and FS 540. Seated passenger head level at FS 432 and FS 540.	Observer inside cabin: liquid drops bouncing on floor, cooling sensation similar to air-conditioned room, sound similar to pressure leakage from auto tire. Frozen areas on foam greatest near center of tube.
7			X	74	54	Same as test 3.	X	X	X	X		Same as test 6.	Propane cigarette lighter flame extinguished by leakage draft from opening in aft pressure bulkhead below the main cabin floor level, indicating substantial Halon 1301 concentrations in the lower compartments.
8	X					Same as test 3. In addition, all potential openings below the main cabin floor taped to close (retained for remainder of tests).	X	X	X	X		Same as test 6.	None recorded.
9			X	78	78	Same as test 8.	X	X			X	Similar to test 2 with the addition of sampling lines in each of the three under-floor compartments.	Complete obscuration of cabin for about 1 minute after discharge. Larger amounts of vapor during discharge and icing after the test noted near the center of the tube. Entire tube moist. Agent in under-floor compartments sufficient to extinguish match.

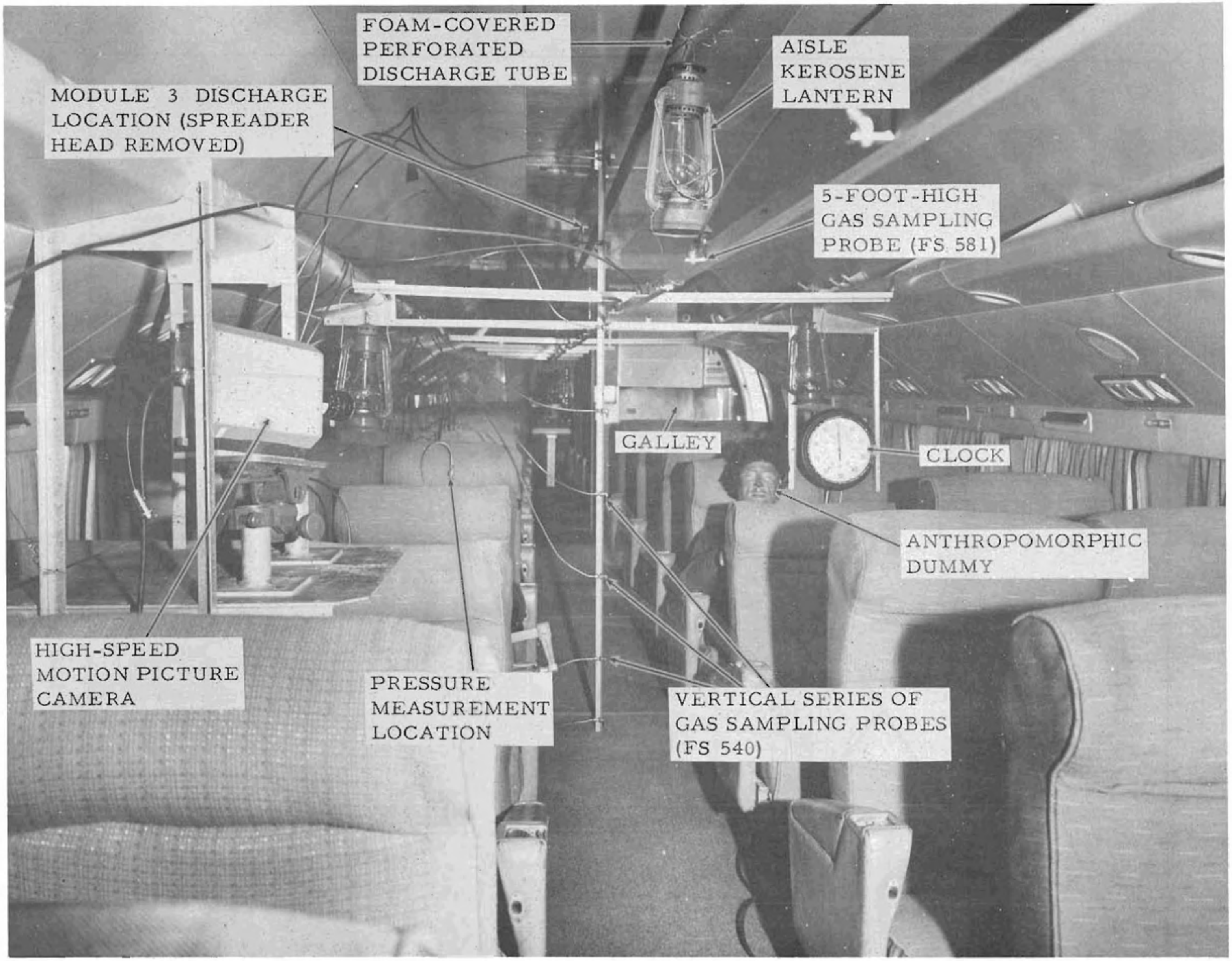

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FIGURE 17. PHOTOGRAPH OF CABIN INTERIOR LOOKING AFT FROM FS 365 BEFORE TEST 4

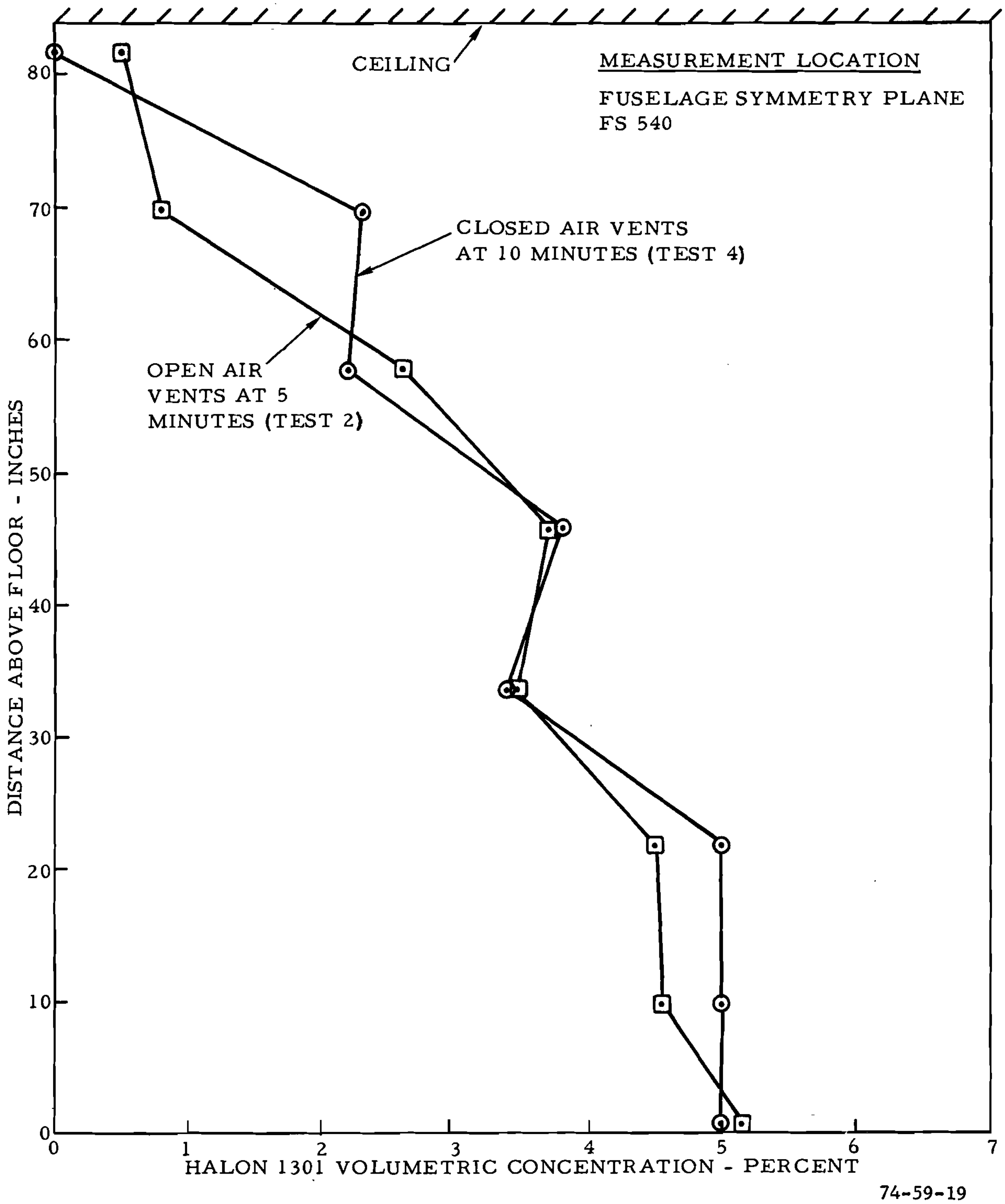

FIGURE 18. AN INDICATION OF THE EXTENSION IN INERTING PROTECTION PROVIDED BY CLOSING THE AIR VENTS

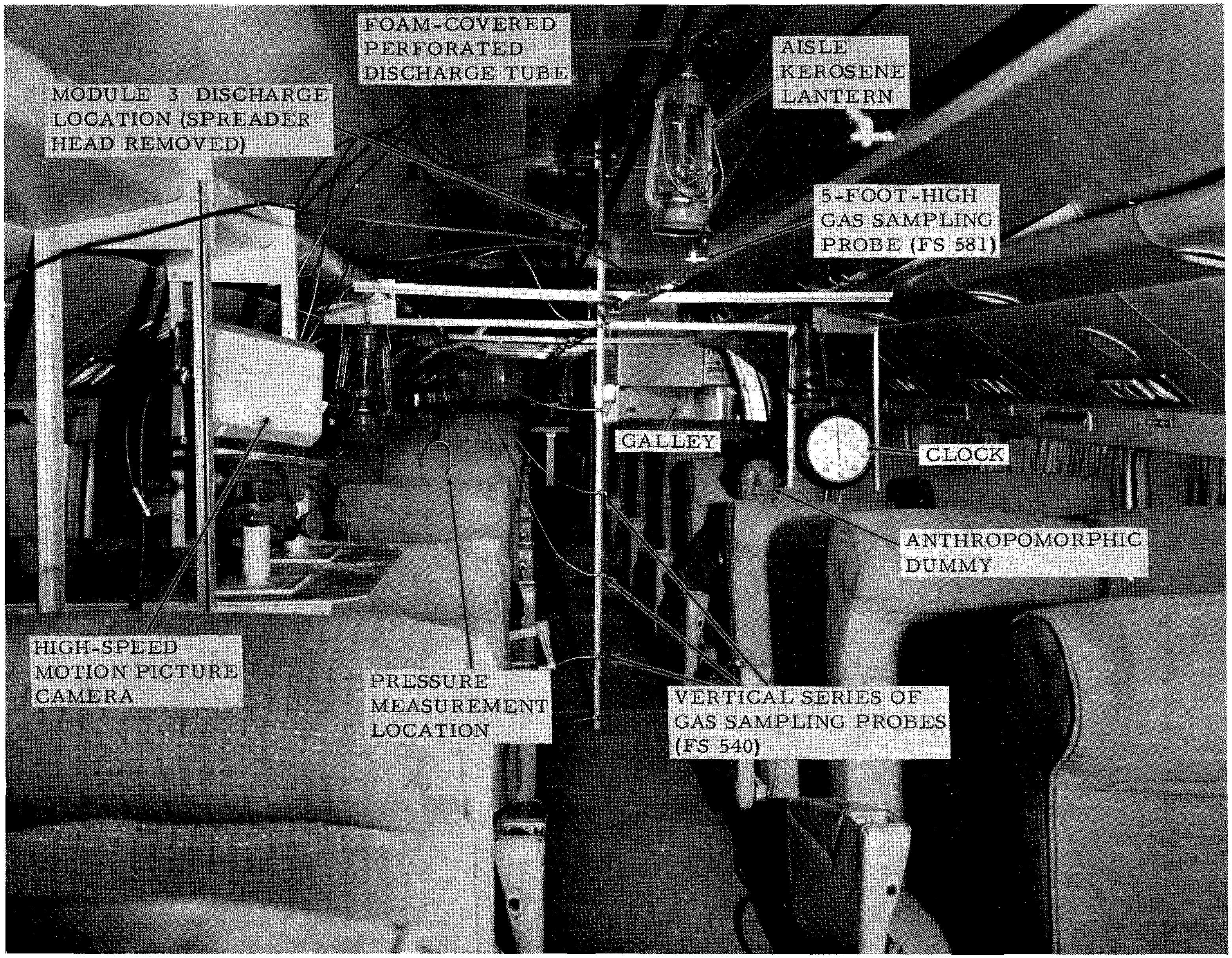

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FIGURE 17. PHOTOGRAPH OF CABIN INTERIOR LOOKING AFT FROM FS 365 BEFORE TEST 4

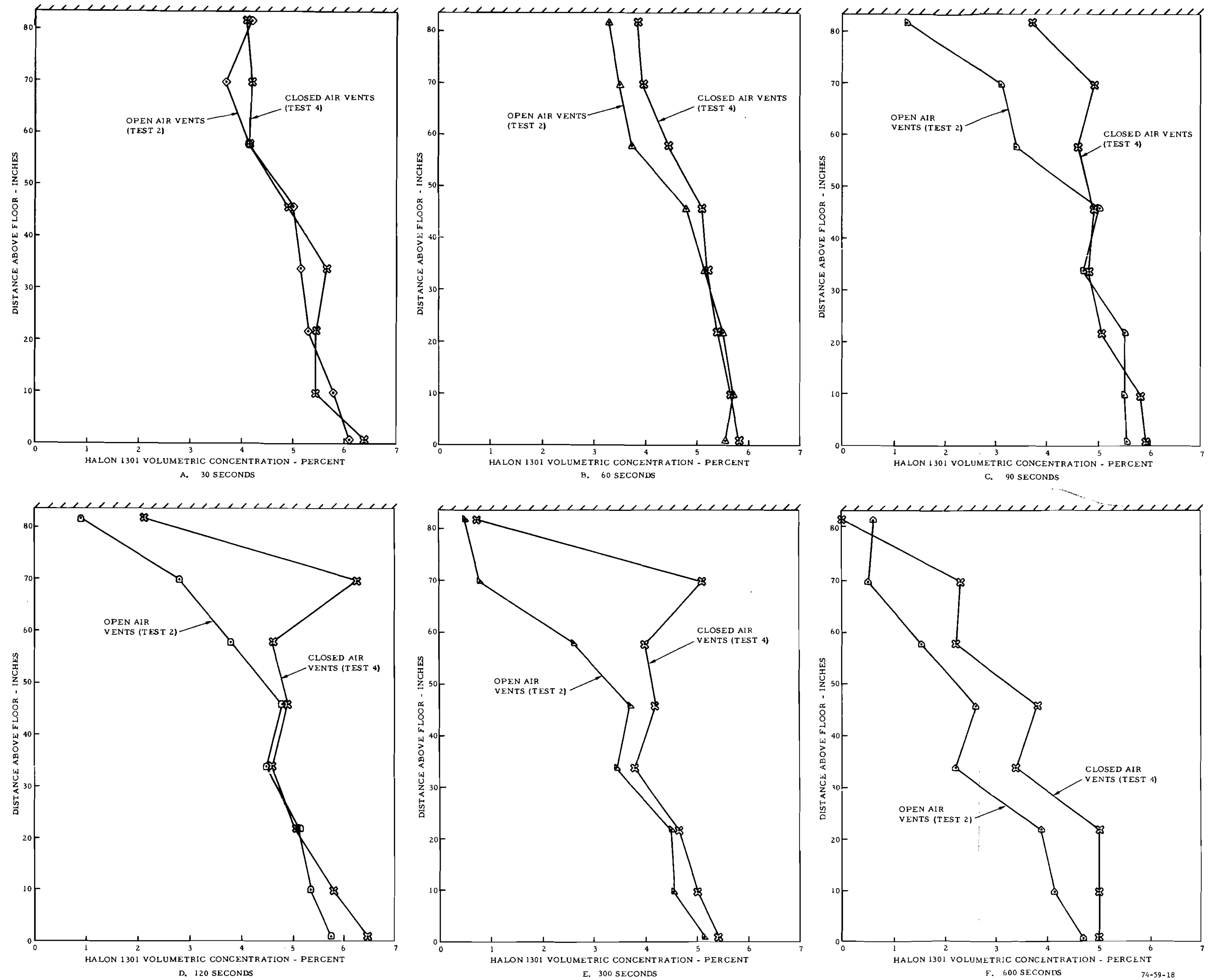

FIGURE 19. EFFECT OF CABIN AIR VENTS ON VERTICAL HALON 1301 CONCENTRATION MEASURED IN THE FUSELAGE SYMMETRY PLANE AT FS 540

practically the same as the profile at 5 minutes with open vents; i.e., the inerting protection was twice as long with the air vents closed than when open.

The pressure data also indicated that sealing the air vents provided for a better "airtight" enclosure. A peak overpressure during discharge of 0.033 psig at 0.85 seconds was measured in test 4, as compared to 0.018 psig at 0.75 seconds when the vents were open (test 2). The overpressure also persisted about 1 second longer when the vents were closed.

The temperature-time profiles for test 4 were similar, but not identical, to the profiles measured during the previous three tests, which were identical to one another at corresponding locations. The temperature did not drop as low as in previous tests (on the average, the minimum temperature was 2° to 3° F higher). It is believed that this difference is related to the higher ambient relative humidity of test 4.

TEST 5.

This test was the first using the foam-covered discharge tube. The gas sampling locations were identical to those in the previous three tests, as shown in figures 11 and 12, since the purpose of the test was to compare the extinguishing and inerting protection from the tubular system with the already tested modular system.

From outside the fuselage, it was noted that a lag of "several seconds" existed between the order to activate the system and the first observed indication of agent discharge. No audible sound accompanied the discharge. Figure 20 shows photographs of individual frames from the motion picture films taken during the test. The circular spots abundantly present at 6.25 seconds in the closeup of the anthropomorphic dummy are either liquid Halon 1301 or ice. Along the length of the foam-covered perforated tube, Halon 1301 discharge gave the appearance of a fog-like waterfall dropping to the floor; there was no visible indication of lateral agent dispersion. The duration of discharge was much longer than that observed for the modular system, as was the elapsed time for extinguishment of lanterns beneath the hatrack. After the 10-minute test, circular frost patches were observed on the surface of the discharge tube foam covering (probably corresponding to each discharge orifice of the outer tube).

Figure 21 shows a comparison of the dropoff in storage container pressure for the modular and foam-covered perforated tube systems. However, the bulk of liquid agent is discharged much earlier than the time it takes for the storage pressure to drop to ambient. For example, assuming an ideal gas relationship for the ullage space in the storage container from the modular system, one can calculate that it takes about 1/2 second for the liquid volume of agent to be expelled. As discussed previously, the duration of discharge from the foam-covered perforated tube is controlled by the choked condition at the 0.0468-inch diameter orifices along the inner tube. The time it takes the agent

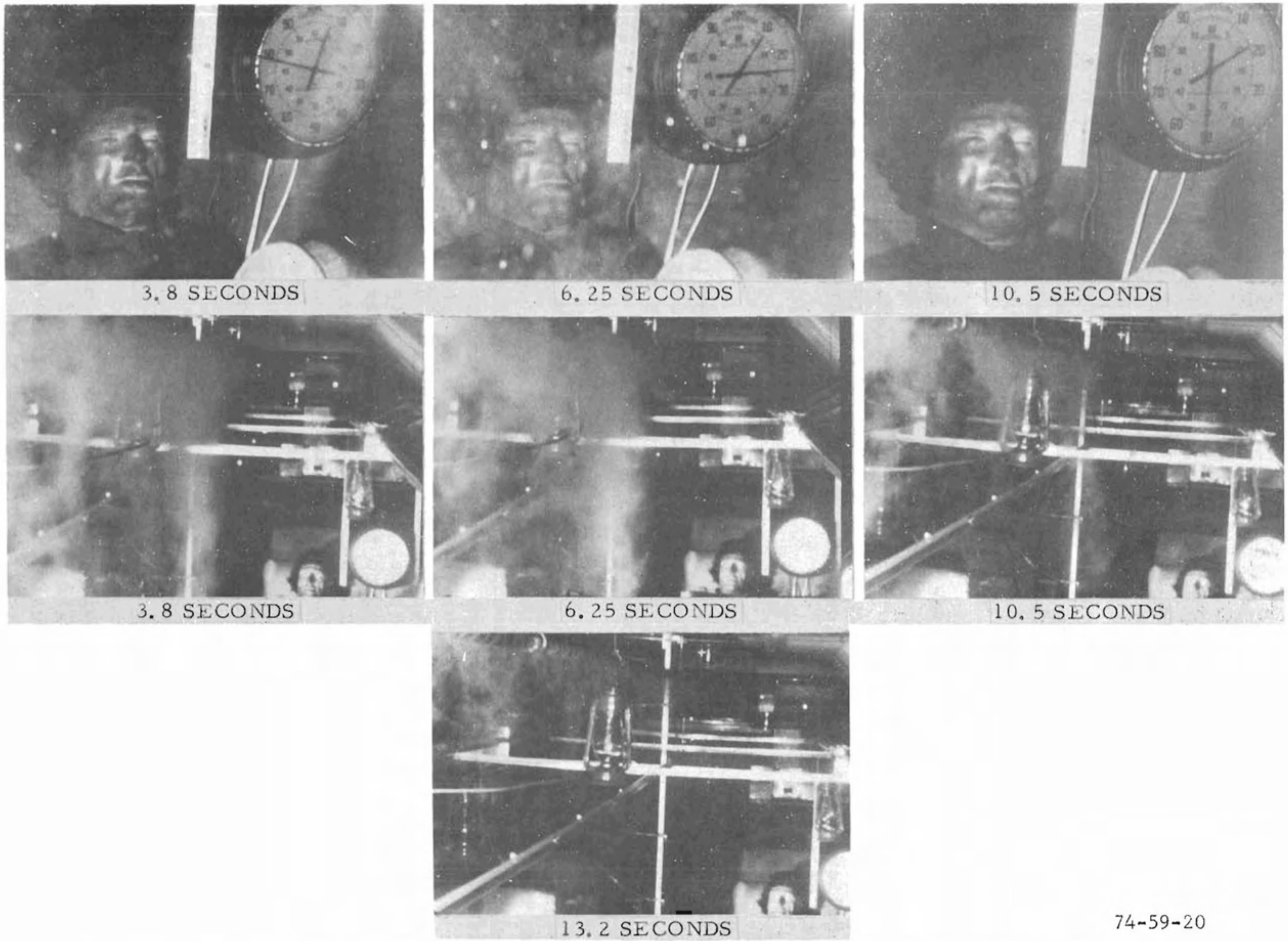

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FIGURE 20. CABIN PHOTOGRAPHS FOLLOWING DISCHARGE ACTIVATION OF THE FOAM-COVERED PERFORATED TUBE SYSTEM (TEST 5)

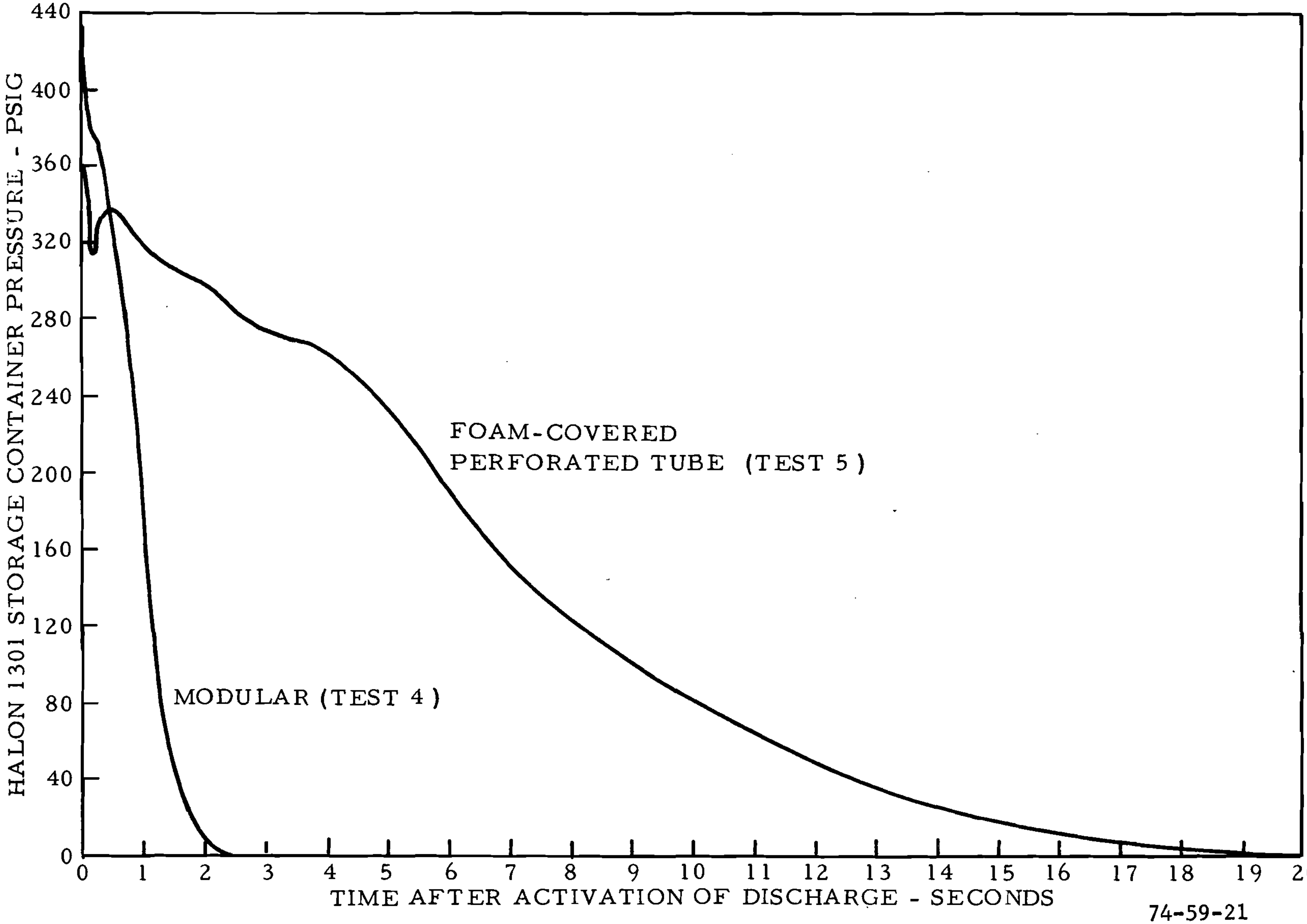


FIGURE 21. DROP-OFF IN HALON 1301 STORAGE CONTAINER PRESSURE AFTER DISCHARGE ACTUATION

(Halon 1301) to fill the inner tube was calculated by Jones and Sarkos (reference 24) to be 1.6 seconds. Using experimental discharge rates at 360 psig from reference 14, the discharge time from the inner tube plenun chamber was calculated to be 2.5 seconds. The total discharge time from activation of discharge is then 4.1 seconds, which is very close to the inflection point in figure 20, indicative of a change of phase (liquid to vapor) in the discharged agent. Thus, the bulk of liquid agent is discharged from the modular and foam-covered perforated tube in about 1/2 and 4 seconds, respectively.

The Halon 1301 concentration traces on the oscillograph recording paper followed an oscillatory pattern for about the first 10 seconds. This behavior is shown in figure 22 at a typical 5-foot-high measurement location, compared with corresponding data for the modular system (test 4). It is apparent that the Halon 1301 concentration "levels off" much earlier for the modular system. It was expected that, possibly, the agent concentration might be low at some locations due to the accumulation of agent at the floor as indicated by the observed characteristics of the foam-covered perforated tube discharge; however, at the 5-foot-high measurement locations for the majority of the test, the concentration was only slightly below the level obtained with the modular system.

This behavior was not representative of locations more proximate to the discharge tube or near the floor, as shown in figure 23. At 5 3/4 inches above the centerline of the discharge tube (1 1/2 inches below the ceiling), except for a "spike" in agent concentration from about 1 to 3 seconds, there was an absence of any sustained inerting protection at this ceiling location. The ceiling must be properly protected since in an enclosure fire it is this location that experiences the highest temperatures and greatest accumulation of combustible gases. The discharge characteristics produced dangerously high localized levels of Halon 1301 immediately below the discharge tube and near the floor. At 2 seconds after discharge activation, the concentration at 6 1/4 inches below the tube (13 1/2 inches below the ceiling) reached 49 percent. An unusually high agent concentration was measured at this location over the total discharge duration and abruptly decreased immediately thereafter. In contrast, the agent concentration at the floor built up later during discharge and remained at a high, although progressively decreasing level for the remainder of the test.

The vertical Halon 1301 concentration profile at six selected times from 10 to 120 seconds after discharge activation is shown in figure 24. Again, the low (zero) ceiling and high floor concentrations are evident. Surprisingly, after the agent filled the remaining cabin spaces, the stratification as measured by the six central probes (excluding ceiling and floor locations) was not overly excessive, although still greater than that measured from the modular system. The profiles demonstrate that lack of turbulent mixing upon discharge will produce agent stratification with excessively low ceiling and high floor concentration levels.

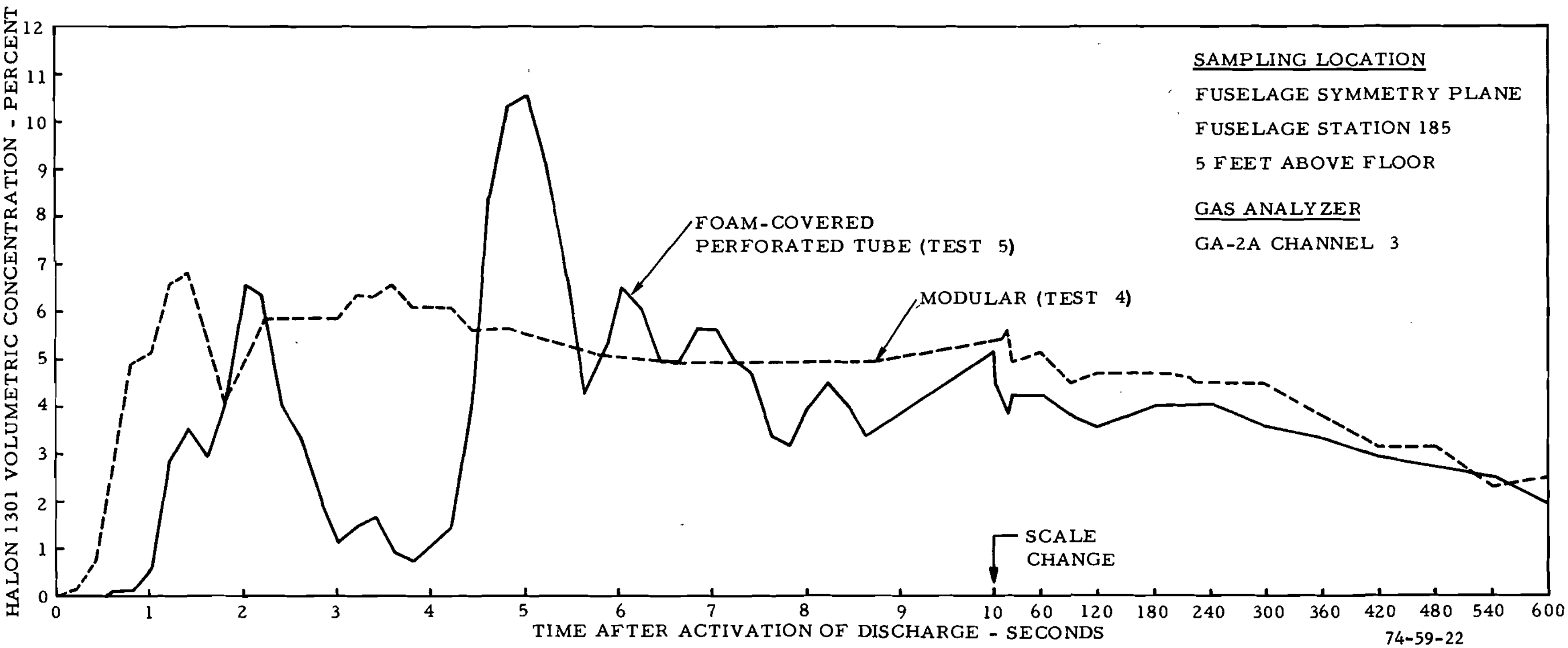


FIGURE 22. HALON 1301 CONCENTRATION IN "B" LOUNGE COMPARED FOR MODULAR (TEST 4) AND FOAM-COVERED PERFORATED TUBE (TEST 5) SUPPRESSION SYSTEMS

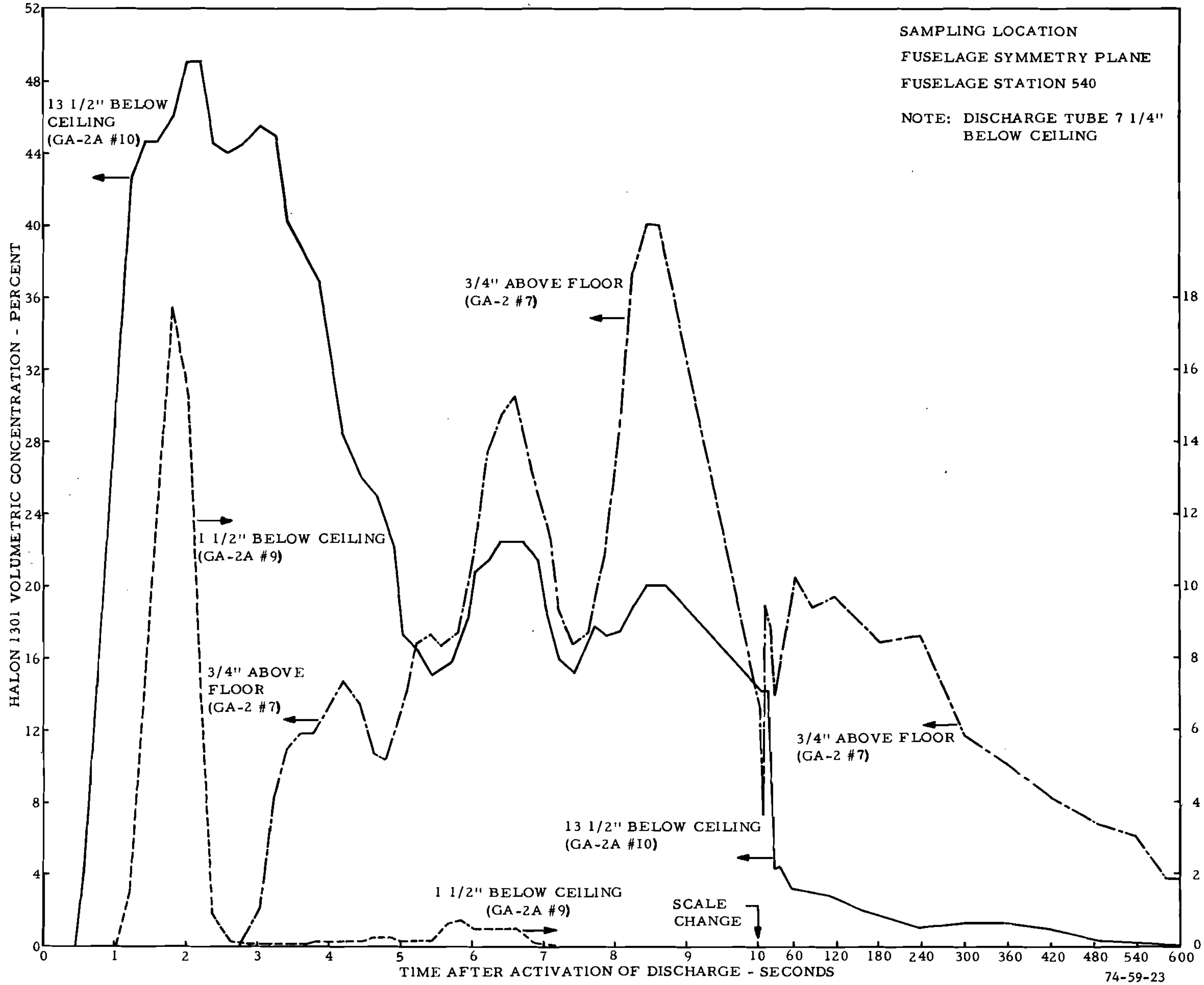


FIGURE 23. HALON 1301 CONCENTRATION ABOVE (GA-2A #9) AND BELOW (GA-2A #10, GA-2 #7) THE FOAM-COVERED PERFORATED DISCHARGE TUBE AT FUSELAGE STATION 540 DURING TEST 5

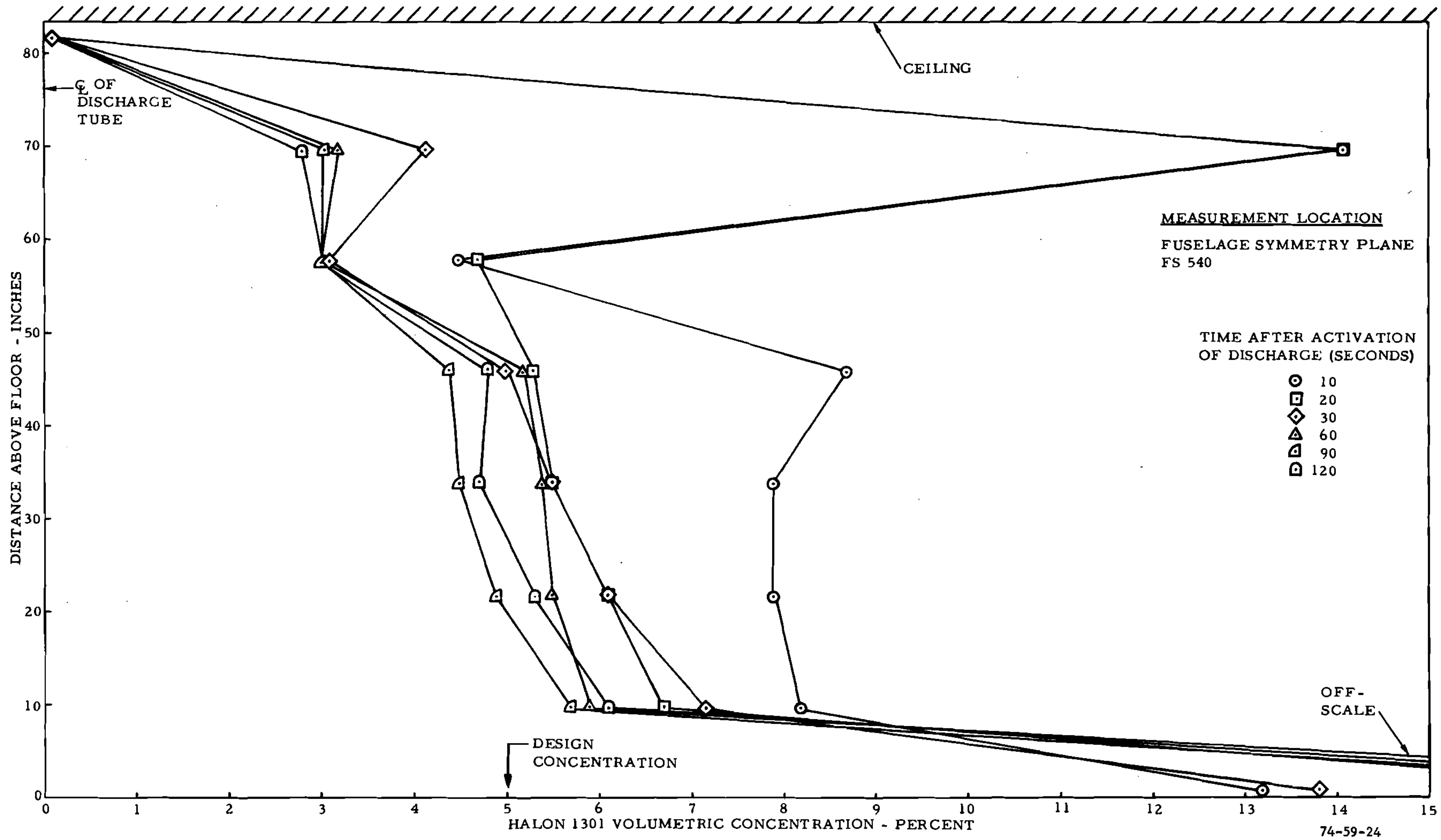


FIGURE 24. VERTICAL DISTRIBUTION OF HALON 1301 AT FUSELAGE STATION 540 FOR THE FOAM-COVERED PERFORATED DISCHARGE TUBE (TEST 5)

At several aisle locations where thermocouples were positioned exactly in the path of the stream of discharged Halon 1301, a rapid, large, and intolerable reduction in cabin air temperature was measured. Figure 25 shows data from one such thermocouple compared with data from another outside the discharge stream. A maximum temperature drop exceeding 80° F was measured in the discharge stream, compared to 10° F at the head level of a seated passenger. The maximum temperature drop measured at the head level of a seated passenger for the foam-covered perforated tube system (test 5) was, on the average, about 1° F higher than that measured for the modular system (test 4), but occurred much later, about 10 to 20 seconds after discharge activation.

The increase in cabin pressure during Halon 1301 discharge from the foam-covered perforated tube was small compared to the modular system. A peak overpressure of 0.0025 psig at about 0.35 seconds was measured in test 5, as compared to 0.033 psig at 0.85 seconds for the modular system (test 4). The cabin overpressure existed for 1.7 seconds.

TEST 6.

The primary objective of this test was to measure the concentration of Halon 1301 at peripheral cabin locations for the foam-covered perforated tube suppression system. Gas sampling lines were routed to the following locations shown in figure 26: center ceiling, ceiling-sidewall juncture, inside hatrack adjacent to sidewall, underneath hatrack adjacent to sidewall, floor-sidewall juncture, center floor, left-hand side (LHS) aisle seat cushion, and LHS aisle seat back top. Gas sampling was accomplished at two fuselage station planes, FS 540 and FS 432, at the approximate center of the cabin (actually midway between modules 2 and 3) and at the module 2 location, respectively. Temperature and pressure were again measured and, for the first time, noise level.

Some insight with regard to the physical mechanism of Halon 1301 dispersion from the foam-covered discharge tube to peripheral cabin locations is provided in figure 27. The sequential order of the initial major agent concentrations (first at the center ceiling, second at the center floor, third at the floor-sidewall juncture, fourth at the underside hatrack-sidewall juncture, and after a substantial delay, last at the inside hatrack-sidewall and ceiling-sidewall junctures) indicates that most of the agent drops in a liquid-vapor sheet to the floor where vaporization occurs and diffusion is predominantly in the upward direction from the floor to the ceiling. Surprisingly, the agent concentrations inside and beneath the hatrack both surpass the extinguishing level (4 to 5 percent) and remain close to one another with negligible decay for most of the test. As determined in test 5, a sustained concentration was not maintained at the ceiling (only a trace was measured at the sidewall juncture) and the floor level was very high, although not excessively so at the sidewall juncture.

In spite of the relatively slow and ineffective vapor-phase diffusive and convective mechanisms for Halon 1301 transport to peripheral cabin locations, the data from symmetrically opposite locations in the cabin were remarkably similar.

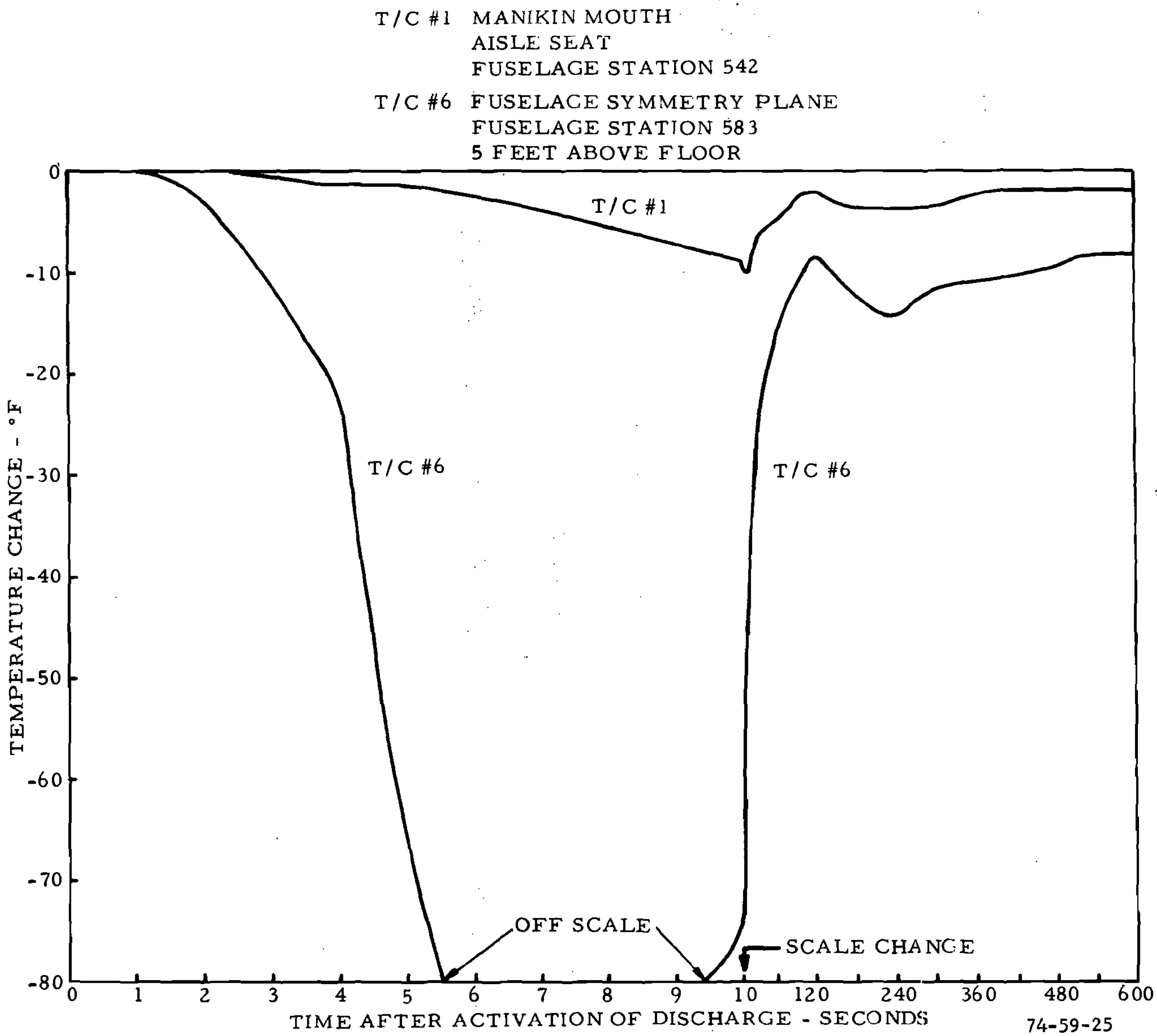


FIGURE 25. CABIN TEMPERATURE CHANGE ASSOCIATED WITH DISCHARGE FROM THE FOAM-COVERED PERFORATED TUBE SYSTEM (TEST 5)

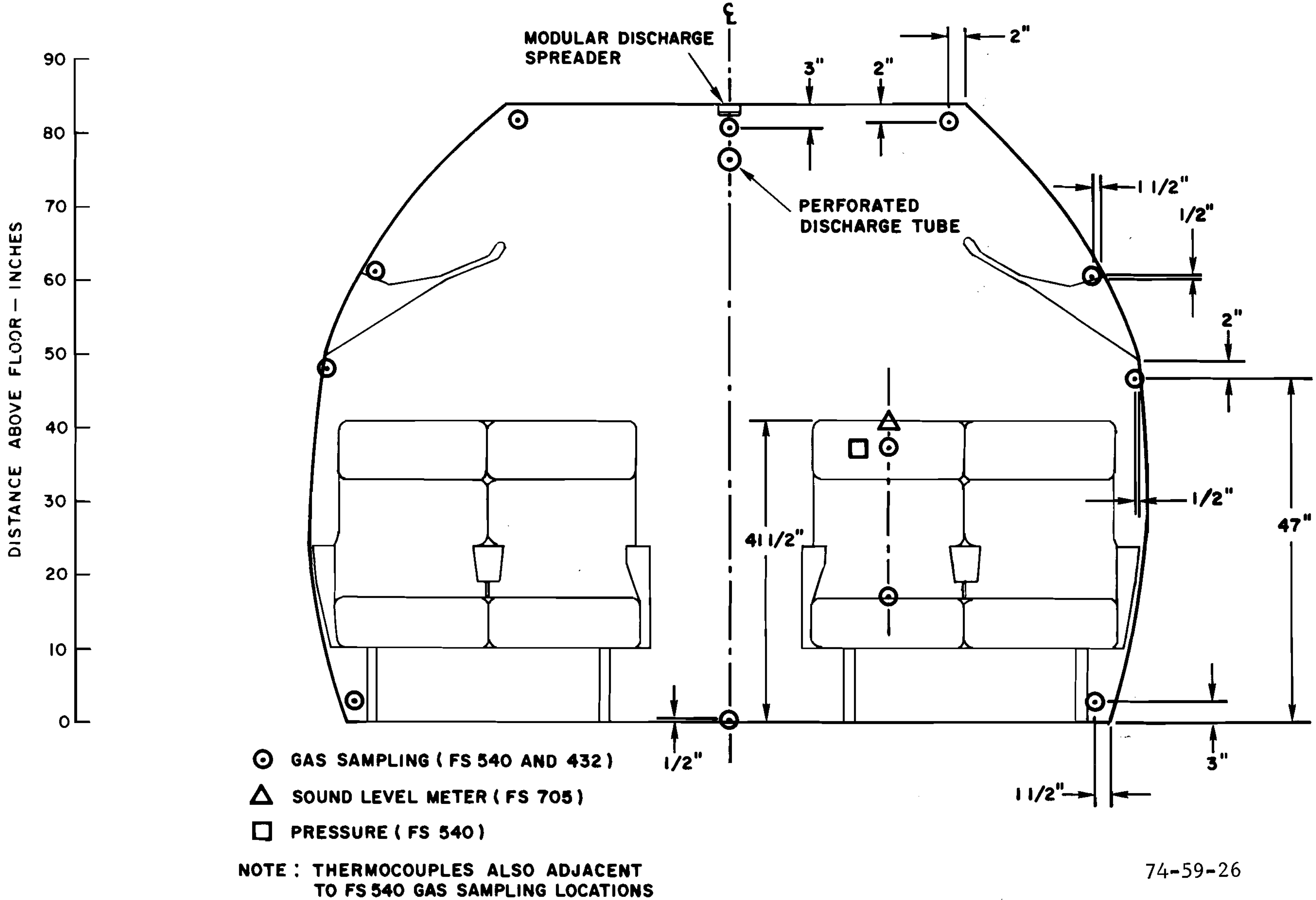


FIGURE 26. CROSS SECTIONAL VIEW OF CABIN SHOWING MEASUREMENT LOCATIONS FOR TESTS 6 TO 8

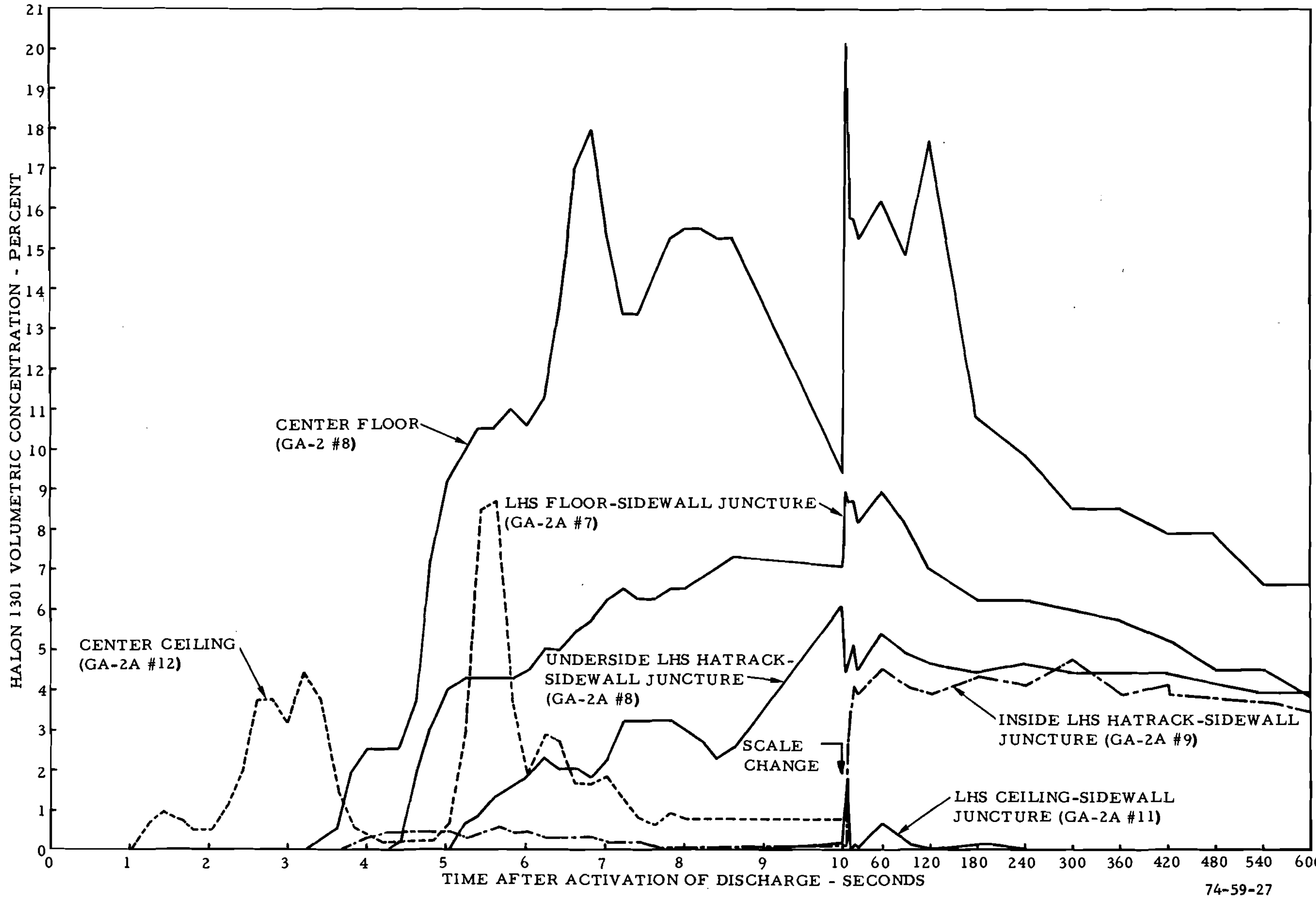


FIGURE 27. HALON 1301 CONCENTRATION AT PERIPHERAL CABIN LOCATIONS AT FUSELAGE STATION 432 FOR THE FOAM-COVERED PERFORATED TUBE SUPPRESSION SYSTEM (TEST 6)

Figure 28 shows a comparison of such data for the floor-sidewall and underside hatrack-sidewall junctures. The concentration-time curves at symmetrically opposite locations are practically identical, even initially during the mixing of Halon 1301.

Once the Halon 1301 is transported throughout the cabin airspace and mixing is completed, it will become stratified to a degree dependent upon the efficiency of the mixing process. The concentration then becomes only a function of height and is independent of cabin longitudinal (fuselage station) or lateral location. Figure 29 is a comparison of the concentration-time profiles at the symmetry plane (test 5) and sidewall (test 6) measured at approximately the same height. Although an extinguishing concentration of 5 percent is attained much earlier in the symmetry plane than at the sidewall (1.8 versus 7.2 seconds, respectively), once mixing is completed at about 20 seconds, the profiles are identical for the remainder of the test and thus independent of lateral location.

Noise was measured with a precision sound-level meter adjacent to the galley (figure 26). The instrument and recorder were operated inside the cabin by a technician wearing ear protection and breathing through a Scott Air Pac. A peak noise level of 92.5 decibels (dB (A)) was measured; however, since the recording pen was stuck for several seconds, the time of peak noise could not be exactly determined for this test. The peak noise level corresponds to that which might exist inside a subway train (reference 24) and is harmless over the short discharge time. The technician likened the sound to "a leaking automobile tire." Additional noteworthy observations were the discharge cooling effect "like walking into an air-conditioned room" and liquid Halon 1301 "bouncing off the floor."

Except at the floor directly beneath the discharge tube, the maximum temperature decrease varied from 5° F to 25° F. The center floor temperature recording again went off scale, dropping over 60° F from 9 to 60 seconds after discharges, although the maximum temperature drop at the floor-sidewall juncture was only 16° F to 17° F. Thus, a severe reduction in cabin air temperature only existed directly beneath the discharge tube. Cabin pressure behaved similarly as in the previous test.

TEST 7.

Analysis of test results from the foam-covered perforated tube system (tests 5 and 6) demonstrated that the 1/4-inch-thick foam cover prevented the efficient and effective dispersion of Halon 1301 by the perforated discharge tube. Consequently, the purpose of this test was to determine the increase in performance of the perforated tube upon removal of the foam and the subsequent change in noise level. Measurement locations were exactly the same as in the previous test (figure 26).

The foam cover affected the dispersion of agent, but not the discharge rate which was controlled by the inner tube orifice size. This was verified by comparing the pressure history inside the storage container with that obtained in the previous test (test 6) when the foam was utilized - the curves were identical.

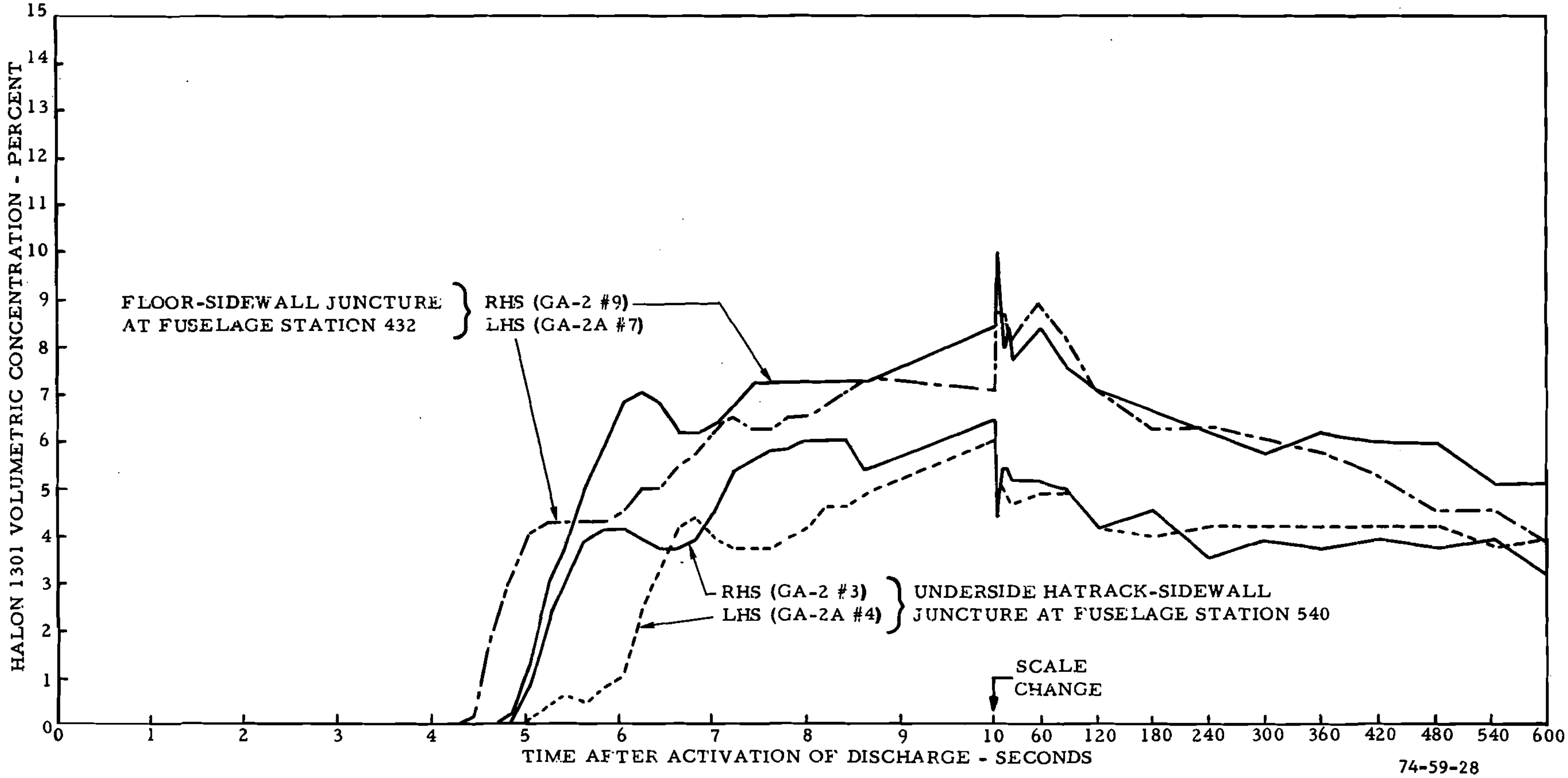


FIGURE 28. LATERAL SYMMETRY OF HALON 1301 CONCENTRATION DISTRIBUTION AT PERIPHERAL CABIN LOCATIONS FOR THE FOAM-COVERED PERFORATED TUBE SUPPRESSION SYSTEM (TEST 6)

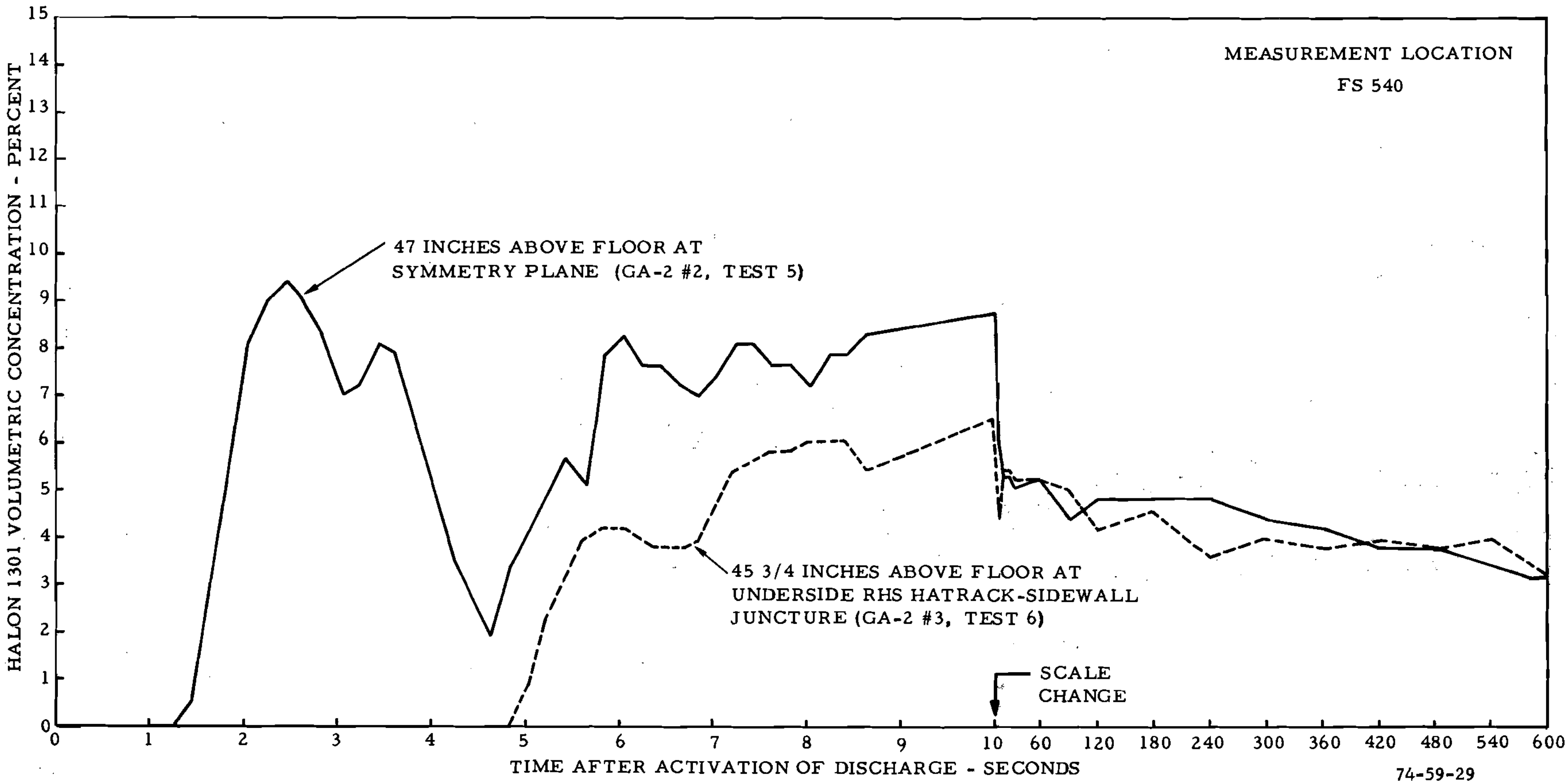


FIGURE 29. COMPARISON OF HALON 1301 CONCENTRATION AT SYMMETRY PLANE AND SIDEWALL LOCATIONS EQUIDISTANT ABOVE THE FLOOR FOR THE FOAM-COVERED PERFORATED TUBE SUPPRESSION SYSTEM

Removal of the foam substantially increased the extinguishing potential of the perforated discharge tube by allowing more effective mixing. This is demonstrated in figure 30 which consists of a comparison of the agent concentration history at representative peripheral cabin locations. For these curves, Halon 1301 was first detected in 1.5 to 4.8 seconds and achieved a 5-percent extinguishing concentration in 3.5 to 6.5 seconds. Cabin locations most influenced by the removal of the foam were those made accessible to agent discharge streamlines directly from the perforated tube; e.g., ceiling-sidewall and inside hatrack-sidewall junctures. Halon 1301 was first detected inside the hatrack in about 2.5 seconds; whereas, with the foam cover (test 6), this did not occur until 10 to 15 seconds. Locations shielded from the discharge streamlines were not overly affected by the foam removal; e.g., underside hatrack-sidewall and floor-sidewall junctures.

At a particular fuselage station, the concentration-time profiles at symmetrically opposite cabin locations were fairly similar; however, the concentration at FS 540 during agent discharge was higher than at FS 432 (figure 31). This behavior probably indicated the creation of a stagnation region in the inner tube at the center of the cabin (near FS 540), resulting from the convergence of Halon 1301 into this area supplied by storage containers located at each end of the cabin.

A good fire protection system must rapidly achieve and maintain for a period of time an extinguishing concentration at all cabin locations. The concentration time profiles measured directly below the drop ceiling are compared for the three Halon 1301 suppression systems (tests 4, 6, and 7) in figure 32. Obviously, the foam-covered perforated tube was inadequate. At this cabin location, the modular system performed better than the perforated tube system, since an earlier (0.3 versus 2.3 seconds) and longer lasting (105 versus 55 seconds) protection (3-percent agent concentration) was provided by the modular disperser.

Removal of the foam produced a negligible 1-dB (A) increase in the noise level. A peak noise level of 93.5 dB (A) was measured at 0.9 seconds, and the noise level exceeded 70 dB (A) for about 14 seconds. Thus, the foam provided very little attenuation of the noise accompanying Halon 1301 discharge, and subsequent tests with the perforated discharge tube were performed without the foam cover.

Analysis of thermocouple data from FS 540 demonstrated that removal of the foam eliminated the intolerable (greater than 60° F) temperature drop at the floor directly beneath the discharge tube, but at the same time, increased the temperature drop at other locations, especially those directly in the path of the discharge streamlines, because of the now unimpeded dispersion of Halon 1301. At the 12 measurement locations, an average maximum temperature decrease of 36.4° F was measured. The minimum temperature was realized in 8 to 10 seconds. In contrast, the average maximum temperature decrease from the foam-covered perforated tube system (excluding the center floor location) in test 6 was only 13.8° F and occurred after 10 seconds. Cabin overpressure during discharge was not affected by removal of the foam.

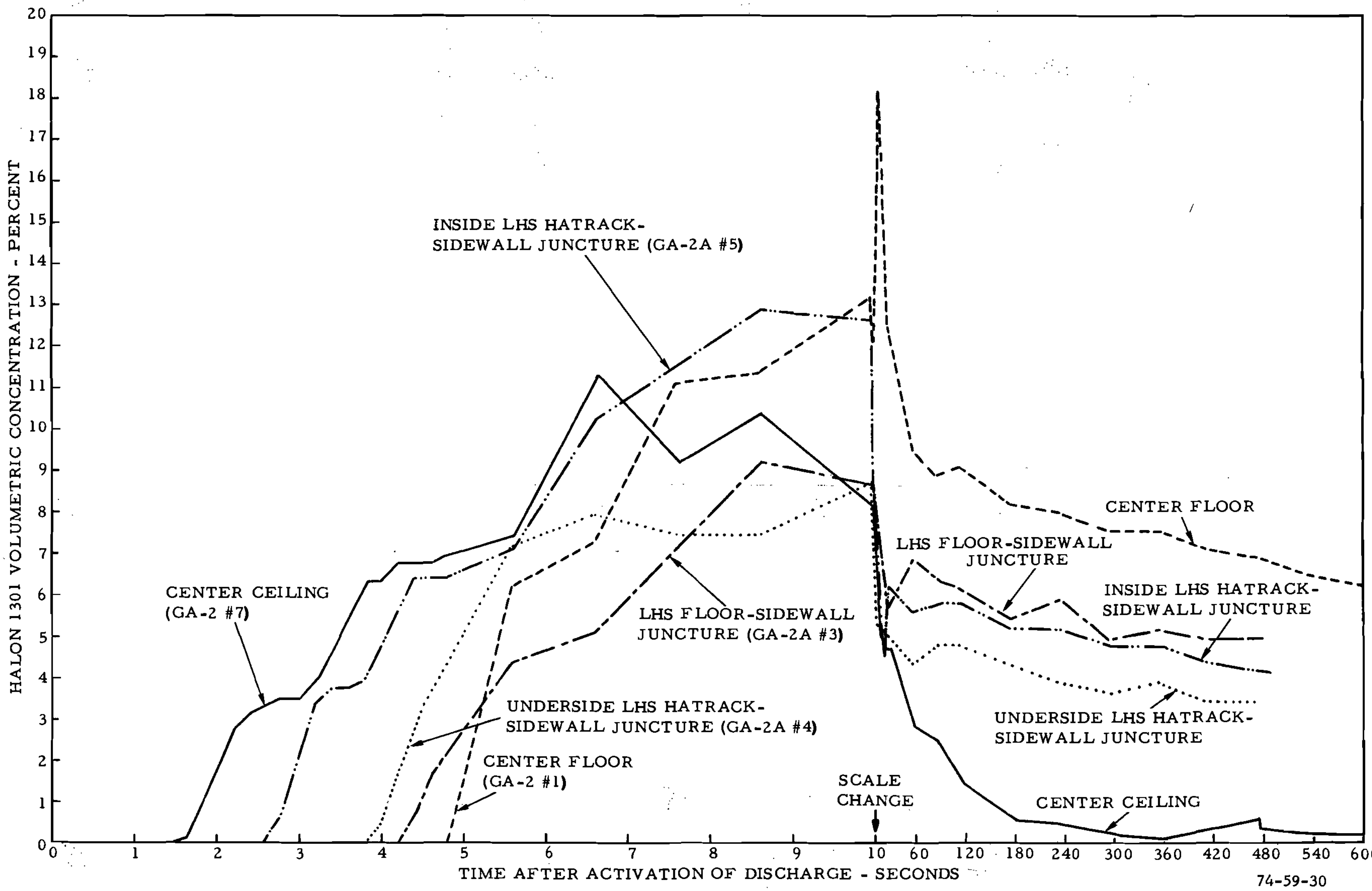


FIGURE 30. HALON 1301 CONCENTRATION AT PERIPHERAL CABIN LOCATIONS AT FUSELAGE STATION 540 FOR THE PERFORATED TUBE SUPPRESSION SYSTEM (TEST 7)

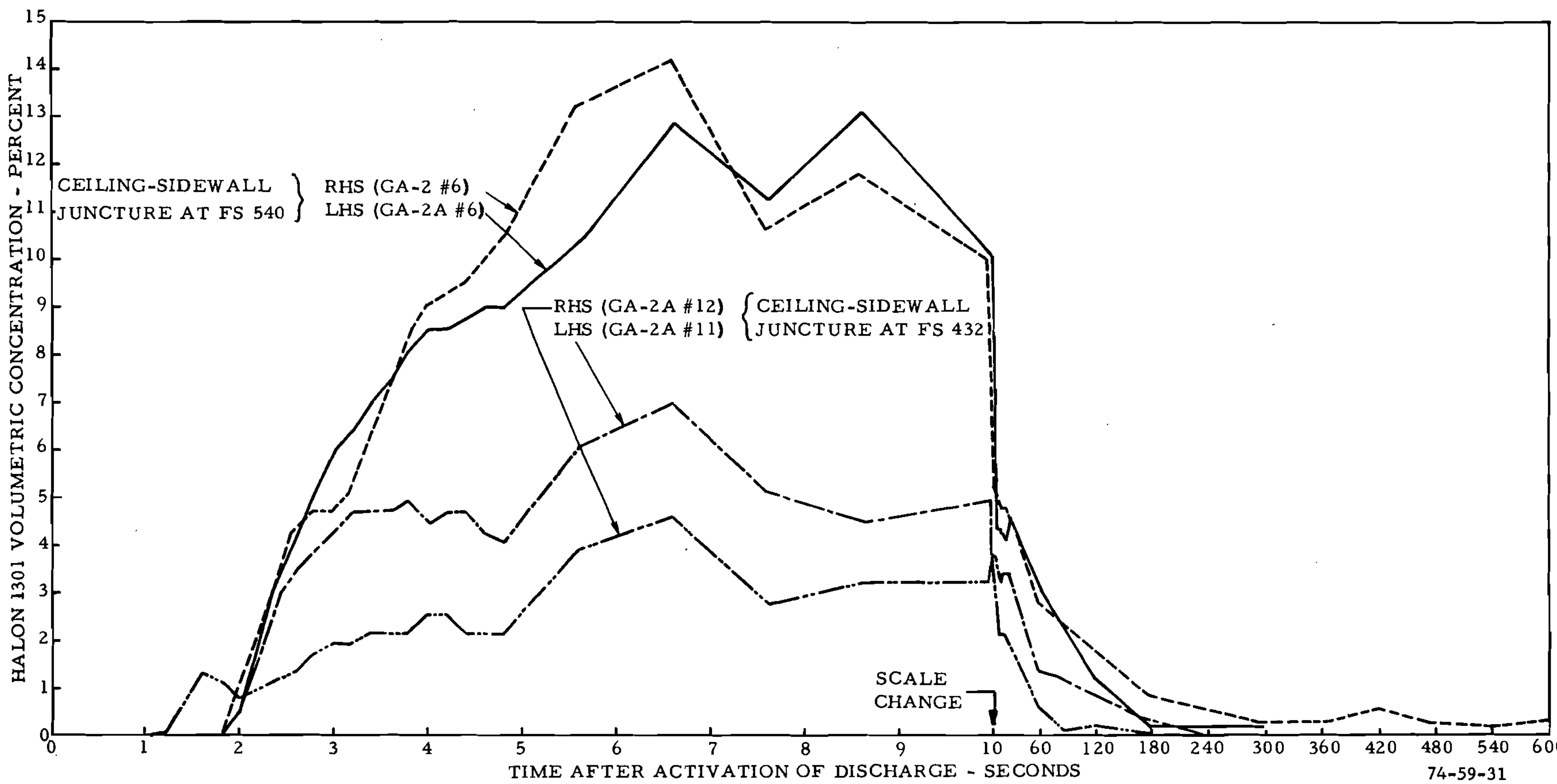


FIGURE 31. SYMMETRY OF HALON 1301 CONCENTRATION HISTORY AT THE CEILING FOR THE PERFORATED TUBE SUPPRESSION SYSTEM (TEST 7)

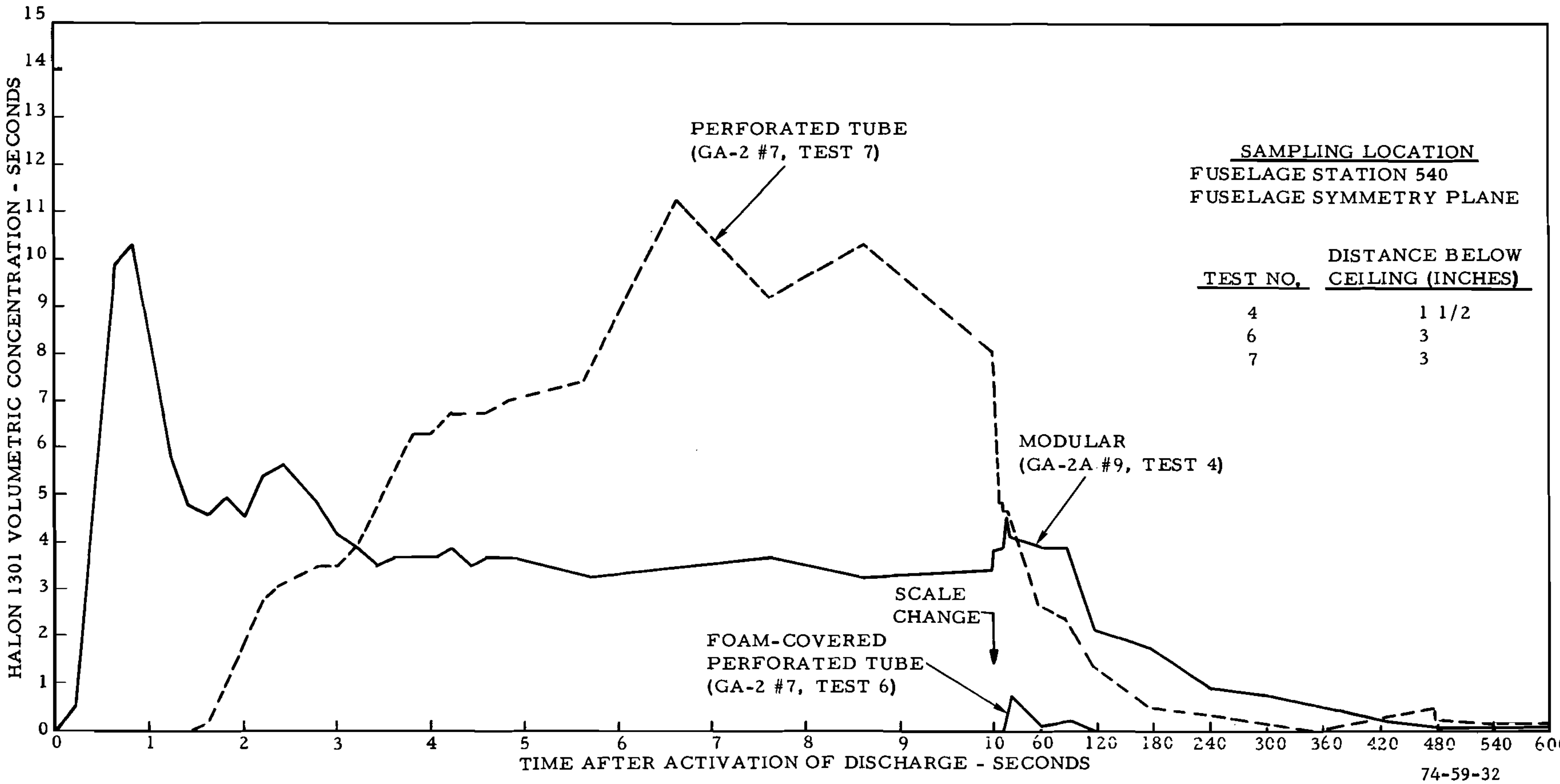


FIGURE 32. CONCENTRATION OF HALON 1301 DIRECTLY BELOW THE CEILING FOR THREE HALON 1301 DISPENSING SYSTEMS

During the course of the test, a pertinent observation was made. A propane cigarette lighter flame was extinguished when placed adjacent to an opening in the aft pressure bulkhead beneath the main cabin floor level. A Halon 1301 concentration of about 2.9 percent is required to extinguish a propane flame (reference 14). It thus became apparent that significant quantities of agent were leaking from the cabin into the lower compartments.

TEST 8.

The purpose of this test was to measure the concentration of Halon 1301 at peripheral cabin locations (figure 26) for the modular suppression system and, at these locations, compare the performance of the modular and perforated tube (test 7) systems. Because of the detected presence of Halon 1301 during test 7 in the aft cargo compartment, all potential leakage points below the cabin floor were taped closed for subsequent tests.

Cabin buildup of Halon 1301 discharged from the modular system was found to strongly depend on the distance of the sampling location from the nearest discharge module(s) if the sampling point was in the direct path of the agent discharge streamlines. Figure 33 shows the Halon 1301 concentration-time profiles at a number of ceiling and floor gas sampling locations at FS 432 and 540, corresponding to lateral planes at module 2 and midway between modules 2 and 3, respectively. The concentrations at the ceiling at FS 432 (module 2) exceeded the full-scale reading (22 percent) during discharge because of the close proximity of these sampling lines to the discharge spreader. A lag in agent buildup was observed at the center ceiling location, where the gas sampling line was attached to the bottom of the spreader head, because of the time required for the agent discharge streamlines to rebound from the hatrack to the symmetry plane. In contrast, the center and sidewall ceiling profiles at FS 540 (midway between modules 2 and 3) are fairly similar during discharge because of their approximately equivalent distance from the discharge points. The concentration-time profiles were fairly similar at all floor measurement locations, demonstrating the invariability of Halon 1301 concentration with respect to fuselage station or lateral position at locations shielded from the streamlines.

A comparison of the Halon 1301 concentration histories from the modular system at representative peripheral cabin locations is shown in figure 34. These curves can be contrasted with figure 30, which is a similar comparison at FS 540 for the perforated tube system (test 7). For the modular system, Halon 1301 was first detected in zero to 0.6 seconds and achieved a 5-percent extinguishing concentration in 0.5 to 1.2 seconds (versus 1.5 to 4.8 and 3.5 to 6.5 seconds, respectively, for the perforated tube system). Even at FS 540, where the maximum discharge rate of agent from the perforated tube was realized, the modular system still dispersed agent and achieved an extinguishing level at peripheral cabin locations more rapidly than did the perforated tube system. Other favorable performance characteristics of the modular system noted by comparing figures 30 and 34 are the more uniform distribution of agent at peripheral cabin locations, evidenced by the close grouping of concentration histories in figure 34, and the less pronounced overshoot in concentration.

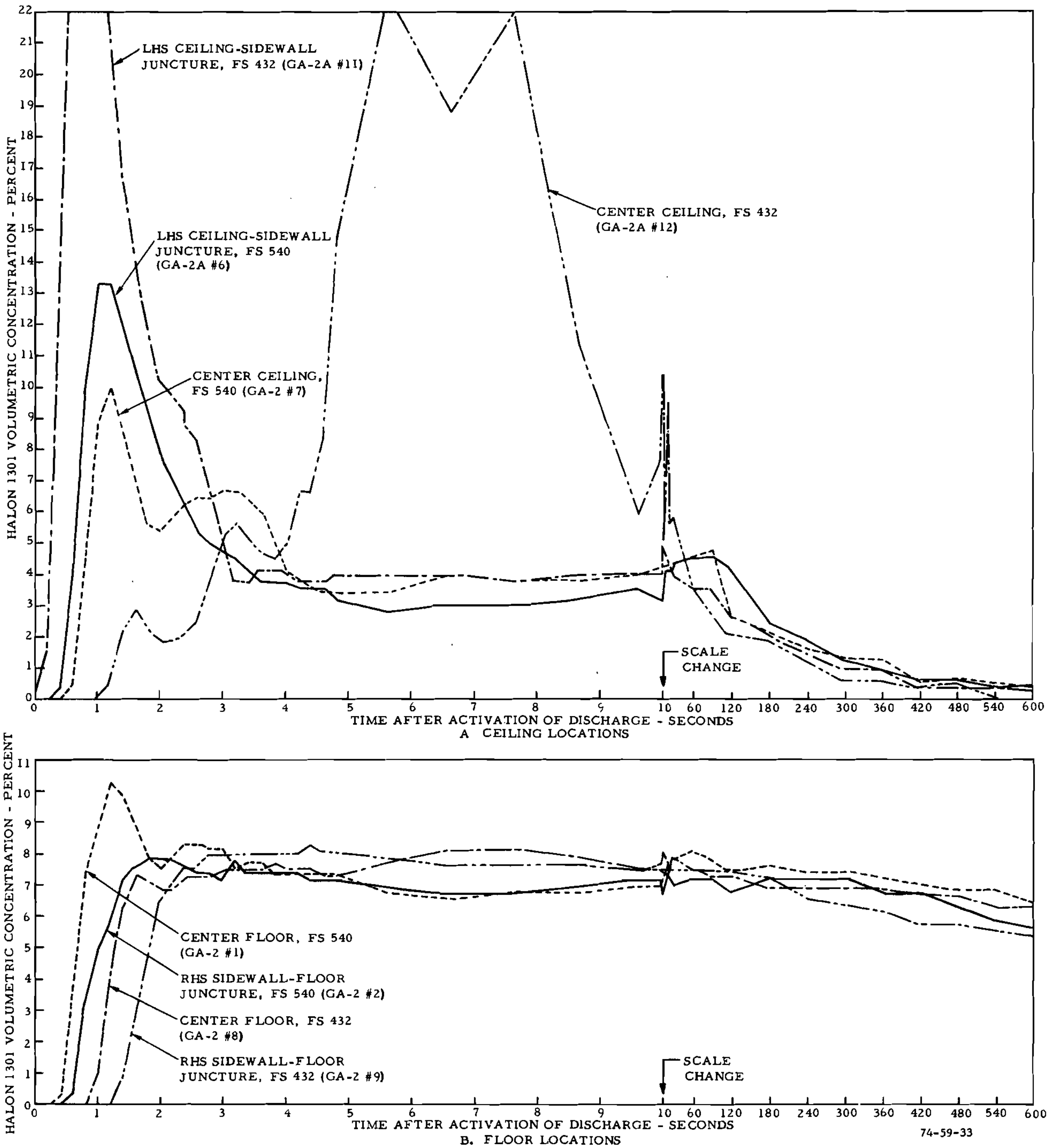


FIGURE 33. BUILDUP OF HALON 1301 CONCENTRATION FOR THE MODULAR SUPPRESSION SYSTEM (TEST 8)

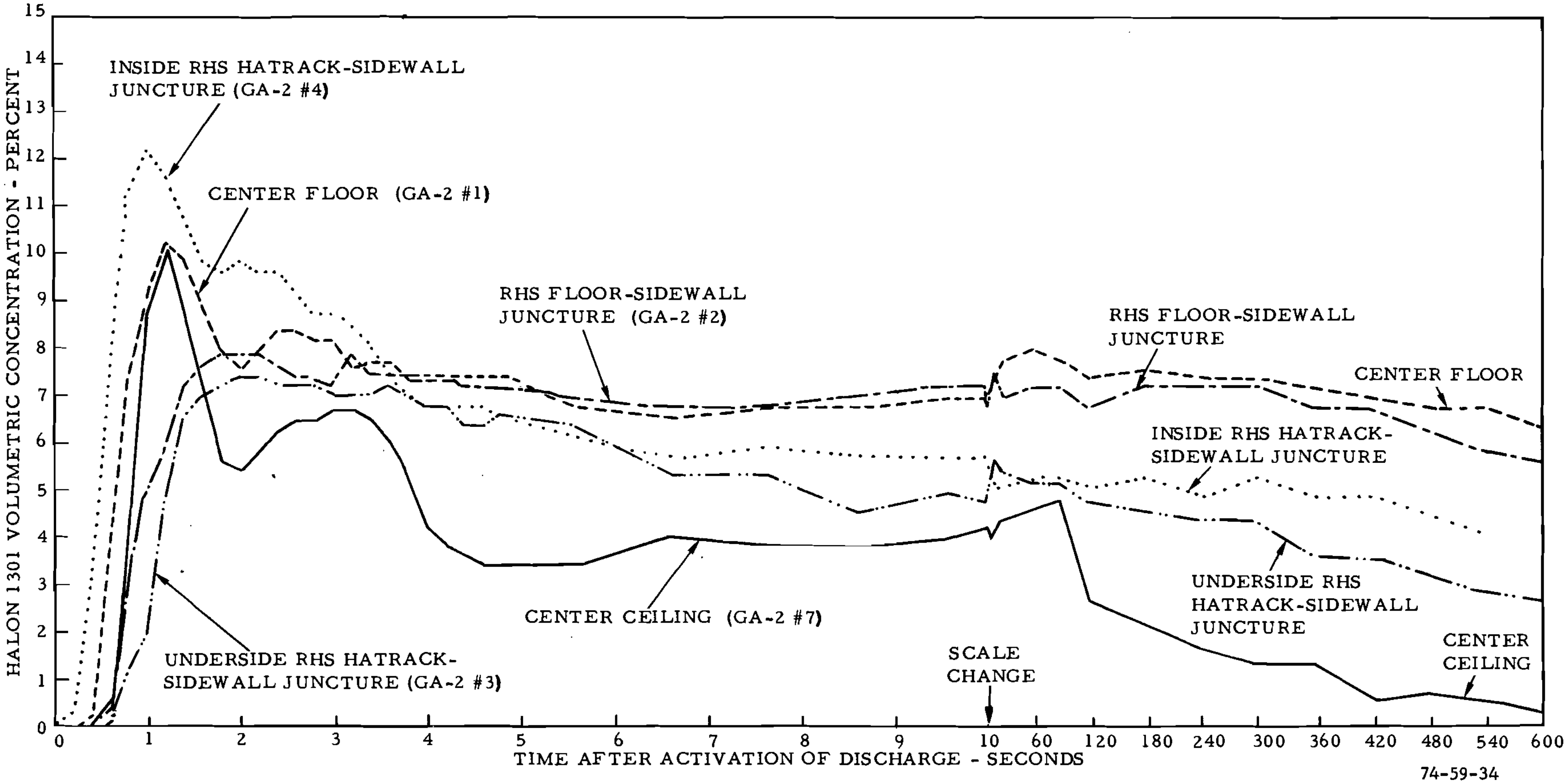


FIGURE 34. HALON 1301 CONCENTRATION AT PERIPHERAL CABIN LOCATIONS AT FUSELAGE STATION 540 FOR THE MODULAR FIRE-SUPPRESSION SYSTEM (TEST 8)

Between the modular and perforated tube systems, the greatest difference in time to build up agent concentration was found to exist at cabin locations shielded from the agent discharge streamlines; e.g., along the sidewall, immediately beneath the hatrack, or near the floor. Figure 35 shows a comparison at these locations of the Halon 1301 concentration histories produced by both systems. A concentration of 5 percent is attained 7.6 and 12.2 seconds sooner for the modular system at sampling locations near the floor (FS 540) and underneath the hatrack (FS 432), respectively. However, once the mixing of agent was completed throughout the cabin in the perforated tube test, the concentration-time curves for the remainder of the test were very similar to those obtained with the modular system.

The Halon 1301 concentration history at the head level of a seated passenger at FS 540 is compared for the modular (test 8) and perforated tube (test 7) systems in figure 36. At this fuselage station, located at the approximate center of the discharge tube and also midway between the second and third agent dispersers of the modular system, the greatest overshoot in agent concentration was experienced by both systems. Because of the inferior mixing of agent with air provided by the perforated tube, the overshoot in agent concentration near seated passengers is higher and lasts longer for this system than for the modular system. In either case, the concentration surpassed the "safe" 7-percent level for an exceedingly short time (figure 36) compared to the allowable 5-minute period, so that the danger from inhalation of agent in concentrations in excess of 7 percent was probably nonexistent for both systems, although surely less for the modular. The more rapid build up of fire extinguishing concentrations obtained with the modular system could, in addition, reduce the level of toxic gases produced by burned interior materials and decomposed Halon 1301.

The noise level associated with the rapid delivery of 80 pounds of Halon 1301 into the protected cabin is compared for both discharge systems in figure 37. Discharge from the modular system, which was much faster than from the perforated tube, produced a peak noise level of 120 dB (A), but the noise only lasted about 2 seconds. In contrast, the discharge noise from the perforated tube was much lower (difference in peak level over 25 dB (A)), but did continue significantly longer. The sound inside the cabin from the discharged perforated tube was likened to a leaking automobile tire, while the 120-dB (A) peak-noise level from the modular system corresponds approximately to the sound from a "loud automobile horn" (reference 25), which might startle an individual, but not affect the hearing threshold (reference 26).

Thermocouple measurements were made primarily to determine if occupants might be exposed to drastic reductions in air temperature associated with the rapid vaporization of agent during discharge. A comparison is made in figure 38 of the air temperatures at the head level of a seated passenger at FS 540 after initiation of discharge for each of the three systems evaluated. Since a minimal temperature change is desirable between the modular (test 8) and

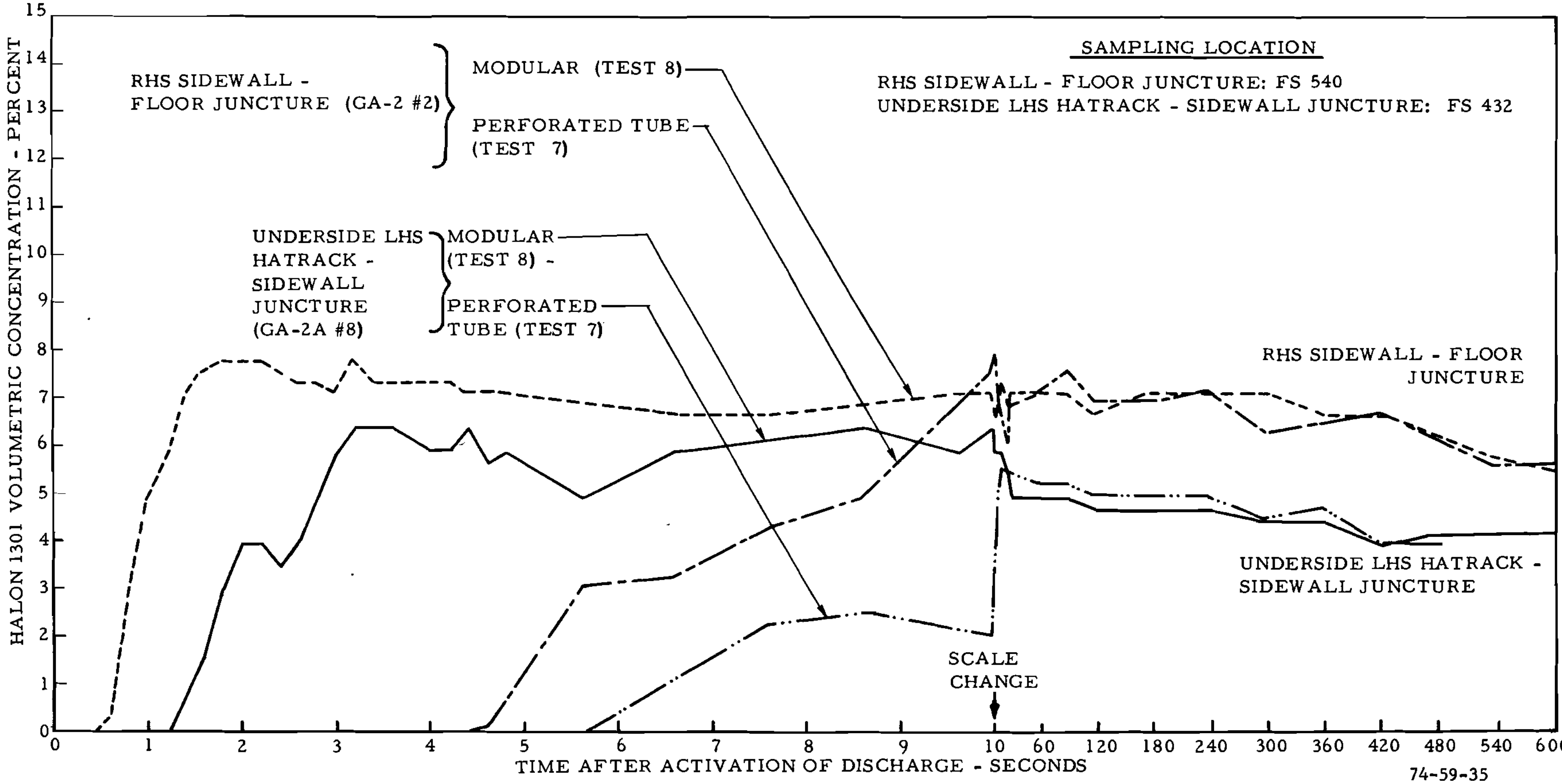


FIGURE 35. HALON 1301 BUILDUP AT CABIN LOCATIONS SHIELDED FROM THE DIRECT DISCHARGE OF THE MODULAR AND PERFORATED SUPPRESSION SYSTEMS

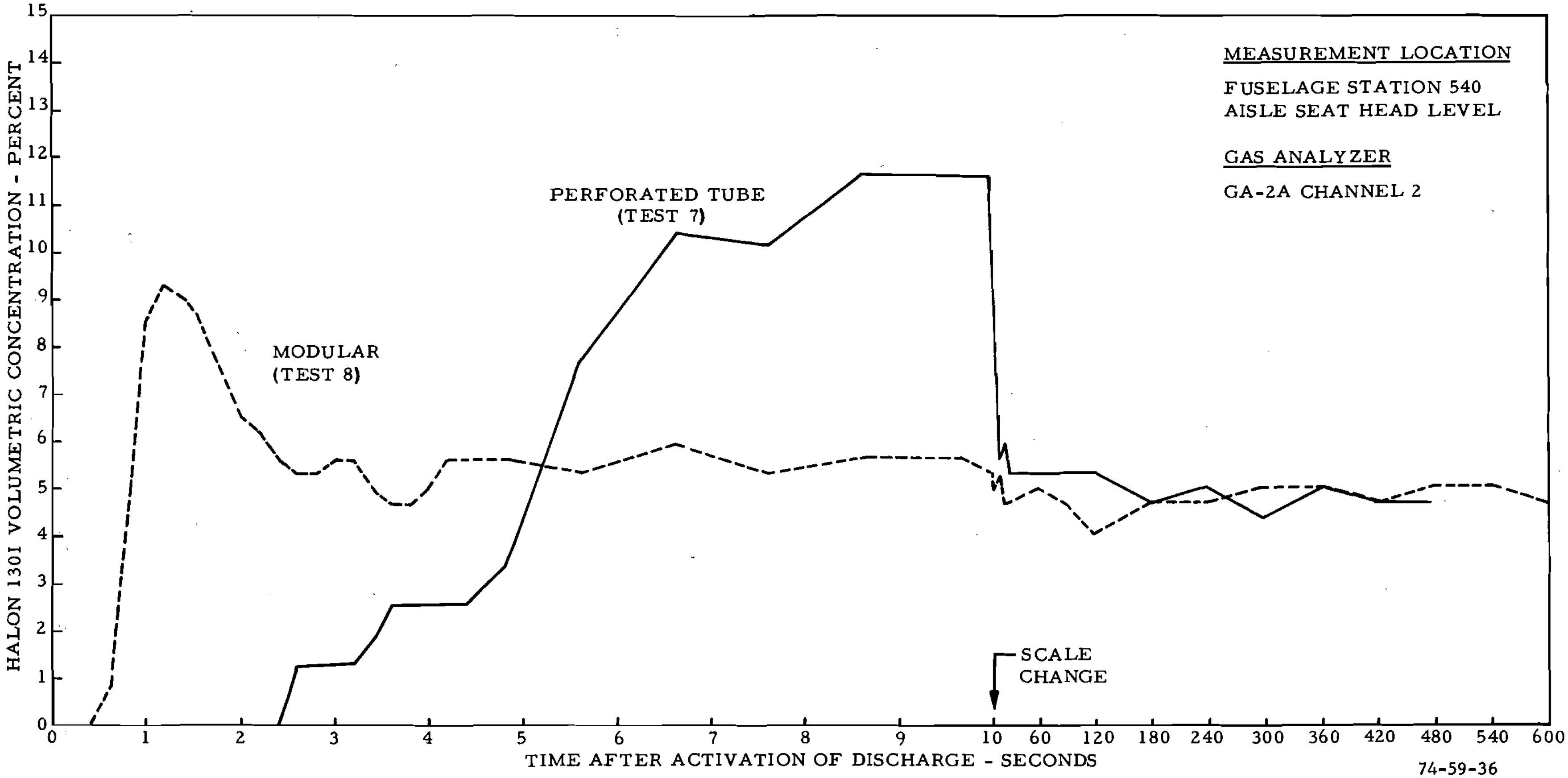


FIGURE 36. HALON 1301 EXPOSURE LEVEL FOR A SEATED PASSENGER COMPARED FOR MODULAR AND PERFORATED TUBE DISPERSERS

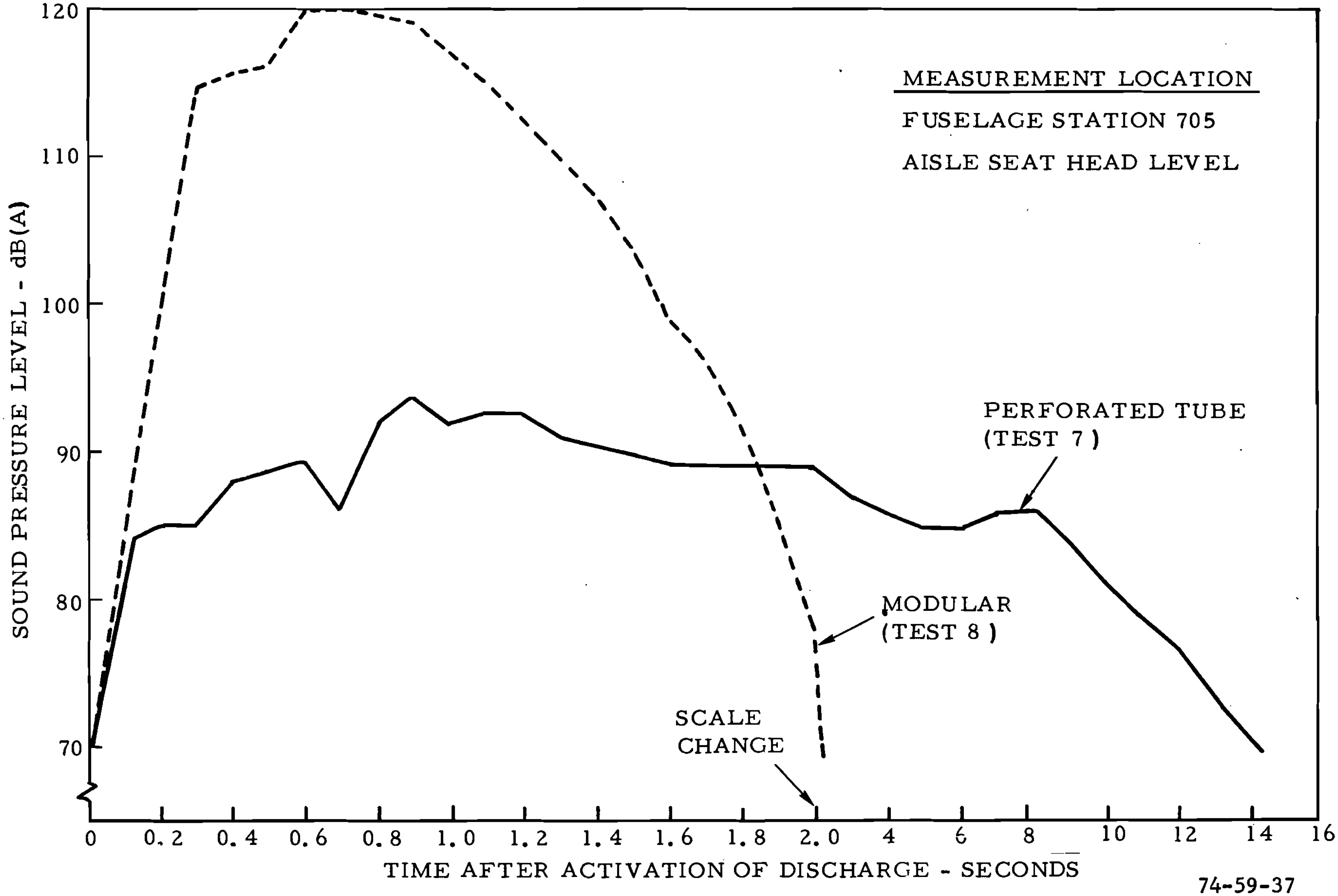


FIGURE 37. CABIN NOISE DURING HALON 1301 DISCHARGE FROM MODULAR AND PERFORATED TUBE DISPERSERS

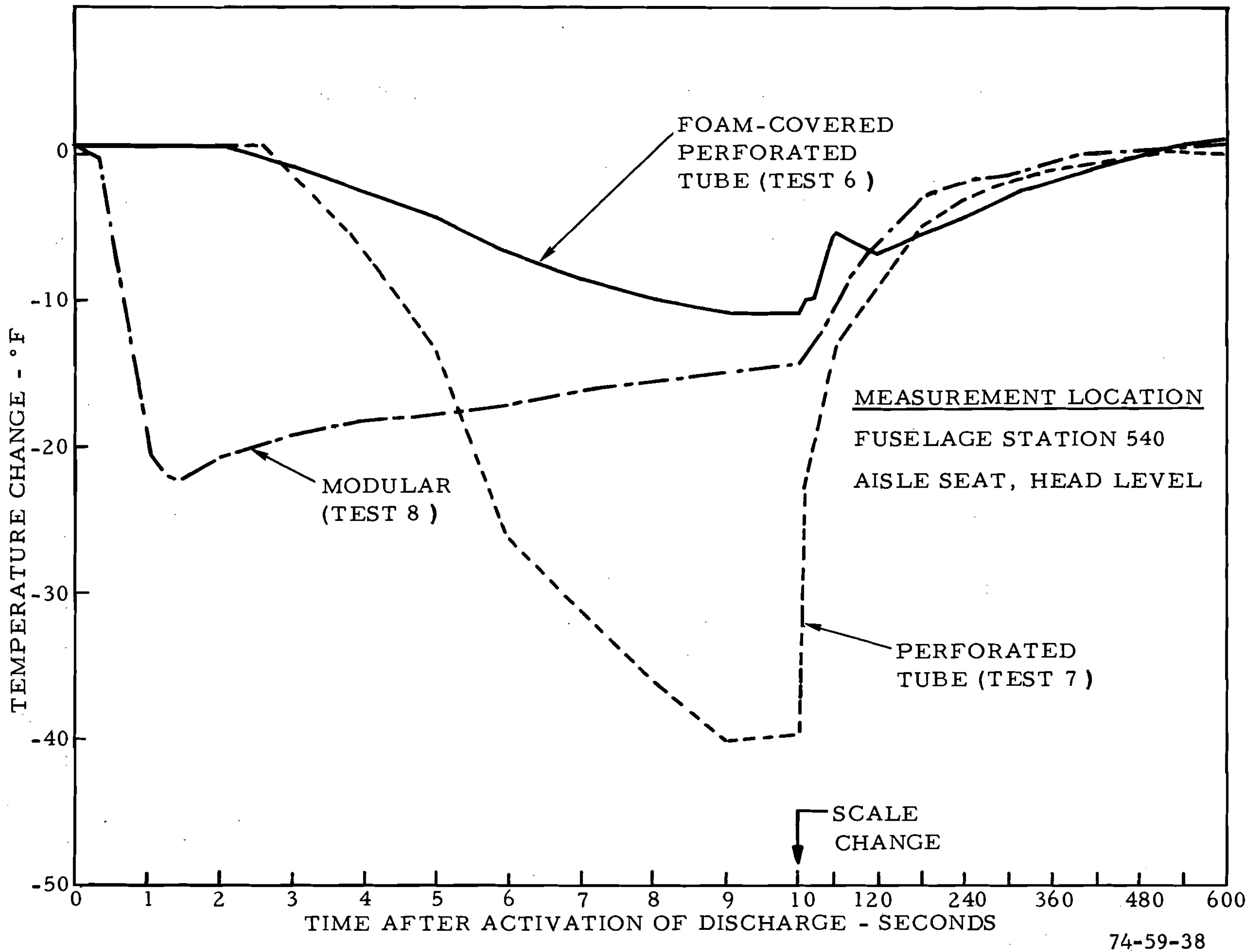


FIGURE 38. AIR TEMPERATURE AT THE FACE OF A SEATED PASSENGER FOR THREE AGENT DISPENSING SYSTEMS

perforated tube (test 7) systems, the modular is clearly more suitable from this respect. The temperature drop from the modular system can be likened to the cooling effect associated with walking into an air-conditioned room on a hot, summer day; whereas, for the perforated tube system, the temperature would be reduced to near or below the freezing point of water. In either case, the temperature change is not very profound, demonstrating that this effect is not an important consideration.

TEST 9.

Utilizing the perforated tube system, this test was undertaken primarily to determine the vertical distribution (stratification) of Halon 1301 within the cabin as measured previously for the modular (test 4) and foam-covered perforated tube (test 5) systems. Thus, the gas sampling lines were returned to the locations shown in figures 11 and 12, with the exception of three lines routed to each of the three underfloor compartments to measure agent buildup at these locations resulting from leakage through the floor.

At the 5-foot-high gas sampling locations along the entire cabin length, three characteristic concentration-time profiles were found to exist (figure 39). These profiles differed only during Halon 1301 discharge and mixing (20 to 25 seconds) and generally coincided for the remainder of the test. At most fuselage stations (e.g., FS 689 as shown in figure 39), the agent concentration built up gradually to the design level, usually in 8 to 10 seconds, without any significant overshoot. However, at two locations--between the lavatories (FS 221) and near the center of the discharge tube (FS 540)--a major overshoot in agent concentration was experienced only during discharge and mixing. The occurrence of high concentrations between the lavatories was also measured for the modular system (figure 6) and is a consequence of the small cross-sectional area at this location compared to the remainder of the cabin. Apparently, as discussed earlier in test 7, a stagnation pressure is created at the center of the inner tube during discharge that increases the agent discharge rate, and this is responsible for the momentarily high Halon 1301 concentrations near (e.g., FS 540) the center of the cabin.

The effective discharge time of the perforated tube system was derived from the vertical Halon 1301 concentration profile. Figure 40 shows the vertical profile at selected 5-second intervals. After 20 seconds, the shape and magnitude of the agent profile becomes invariant, indicating that the effective discharge time was 20 to 25 seconds, compared to 3 to 4 seconds for the modular system (figure 14). Unlike the modular system, the profile appears to "tilt" as the Halon 1301 permeates and mixes into the remaining cabin spaces.

Inherently, Halon 1301 can be discharged much faster from the modular system consisting of multiple units than from a single perforated tube. This capability was just shown to provide for a more rapid dispersion of agent throughout the cabin (i.e., effective discharge time of 3 to 4 and 20 to 25 seconds

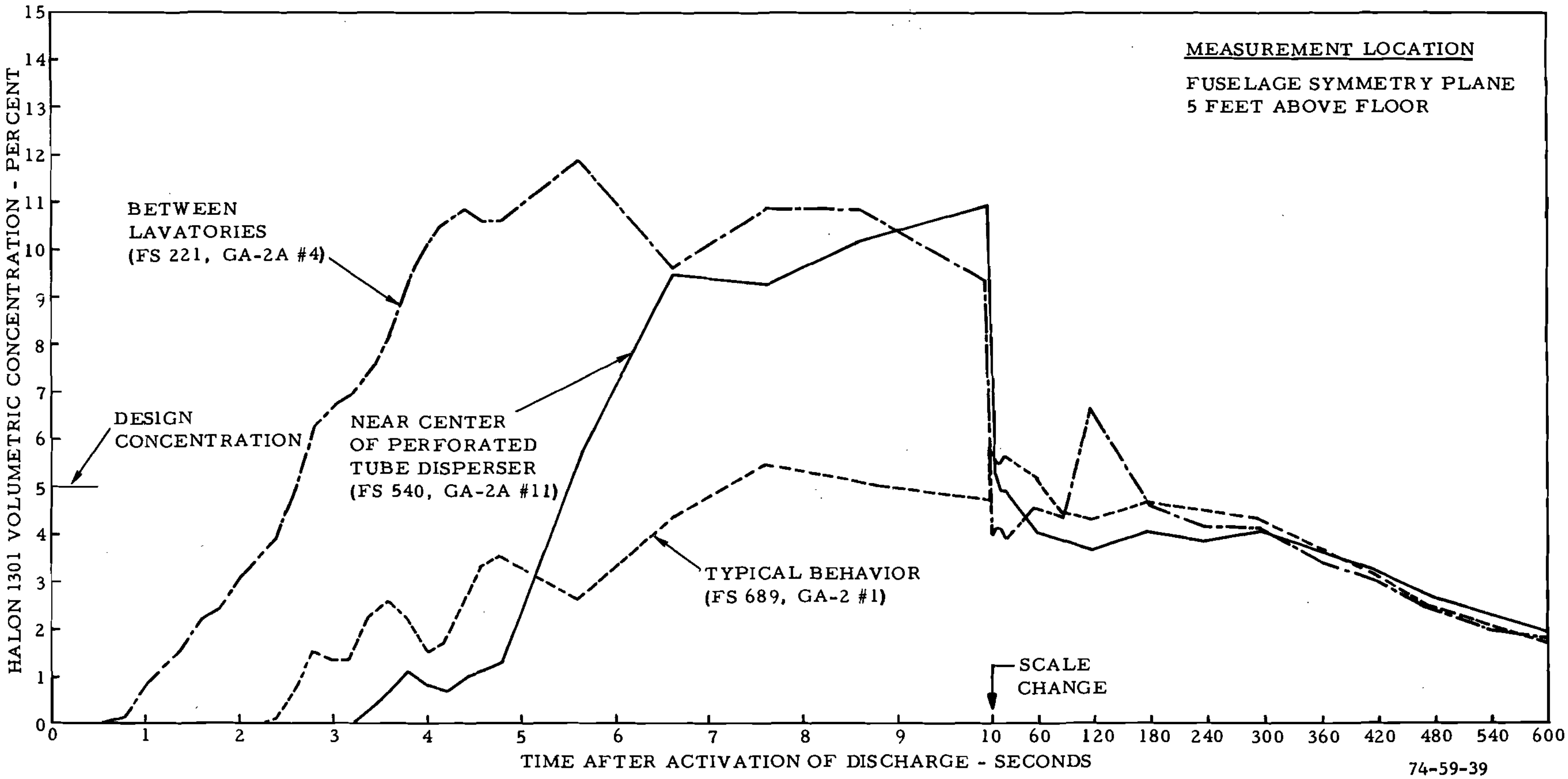


FIGURE 39. HALON 1301 CONCENTRATION-TIME PROFILES AT VARIOUS CABIN LOCATIONS FOR THE PERFORATED TUBE SUPPRESSION SYSTEM (TEST 9)

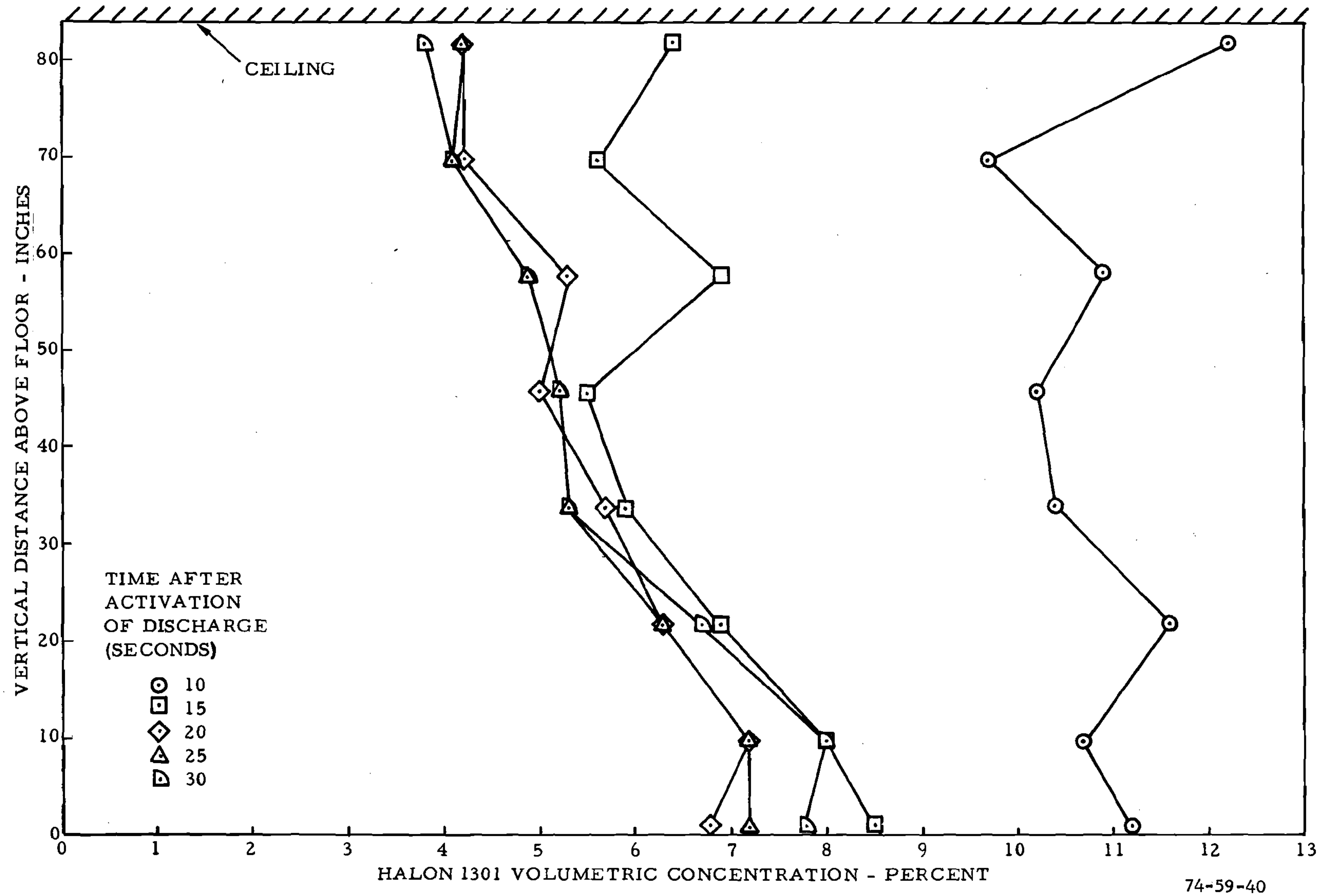


FIGURE 40. VERTICAL HALON 1301 PROFILES AT FUSELAGE STATION 540 SHORTLY AFTER ACTIVATION OF DISCHARGE FROM THE PERFORATED TUBE SUPPRESSION SYSTEM (TEST 9)

for the modular and perforated tube systems, respectively). In addition, the high rate discharge from the modular system distributed the agent more uniformly in the cabin than did the perforated tube. This is demonstrated in figure 41, which consists of a comparison of the vertical Halon 1301 concentration profiles for both systems taken at 90 seconds and 10 minutes. Although the average agent concentration in the cabin produced by both systems was about the same, the modular system provided a higher ceiling concentration and lower floor concentration than did the perforated tube, and this relative behavior prevailed over the entire test. Thus, in addition to the modular system providing more rapid dispersal of agent than the perforated tube system, it also distributes the agent in a more uniform manner.

Figure 42 shows the concentration history measurements taken inside each of the three underfloor compartments. Halon 1301 was first detected in 1 to 2 minutes and increased progressively throughout the test in two of the compartments. Since there were no observed major leakage passages from the cabin into the underfloor compartments, it was surprising that substantial quantities of agent could apparently soak through the floor seams.

Figure 43 shows photographs of individual frames from the motion picture films taken during the test. The ambient relative humidity was 78 percent. Significant visual obscuration occurred several seconds after activation of discharge, and cabin visibility did not improve appreciably until after 1 minute. Generally, substantial obscuration was observed in tests when the ambient relative humidity exceeded 70 percent.

TEST 10.

In this test utilizing the modular system, Halon 1301 concentration was measured in three general areas: (1) inside the lavatories (one lavatory door was open, the other closed), (2) at the head level of seated passengers, and (3) in the galley. The location of the gas sampling line inlets are shown in figures 44 and 45.

The purpose of the lavatory measurements was to determine if fire protection could be provided by a dispensing system external to the lavatory with agent access limited to a small (4.6 inch^2) louvered vent, under two conditions: (1) lavatory door open, and (2) lavatory door closed.

In figure 46, a comparison is made of Halon 1301 concentration measurements in both lavatories taken in the paper towel dispensor (GA-2A #2,5) and adjacent to the electrical receptacle (GA-2A #1,6). The rapid attainment of extinguishing concentrations and sustained inerting protection was provided at both locations inside the open lavatory; however, although traces of agent were detected inside the closed lavatory during discharge, protection equivalent to that obtained inside the open lavatory did not occur adjacent to the

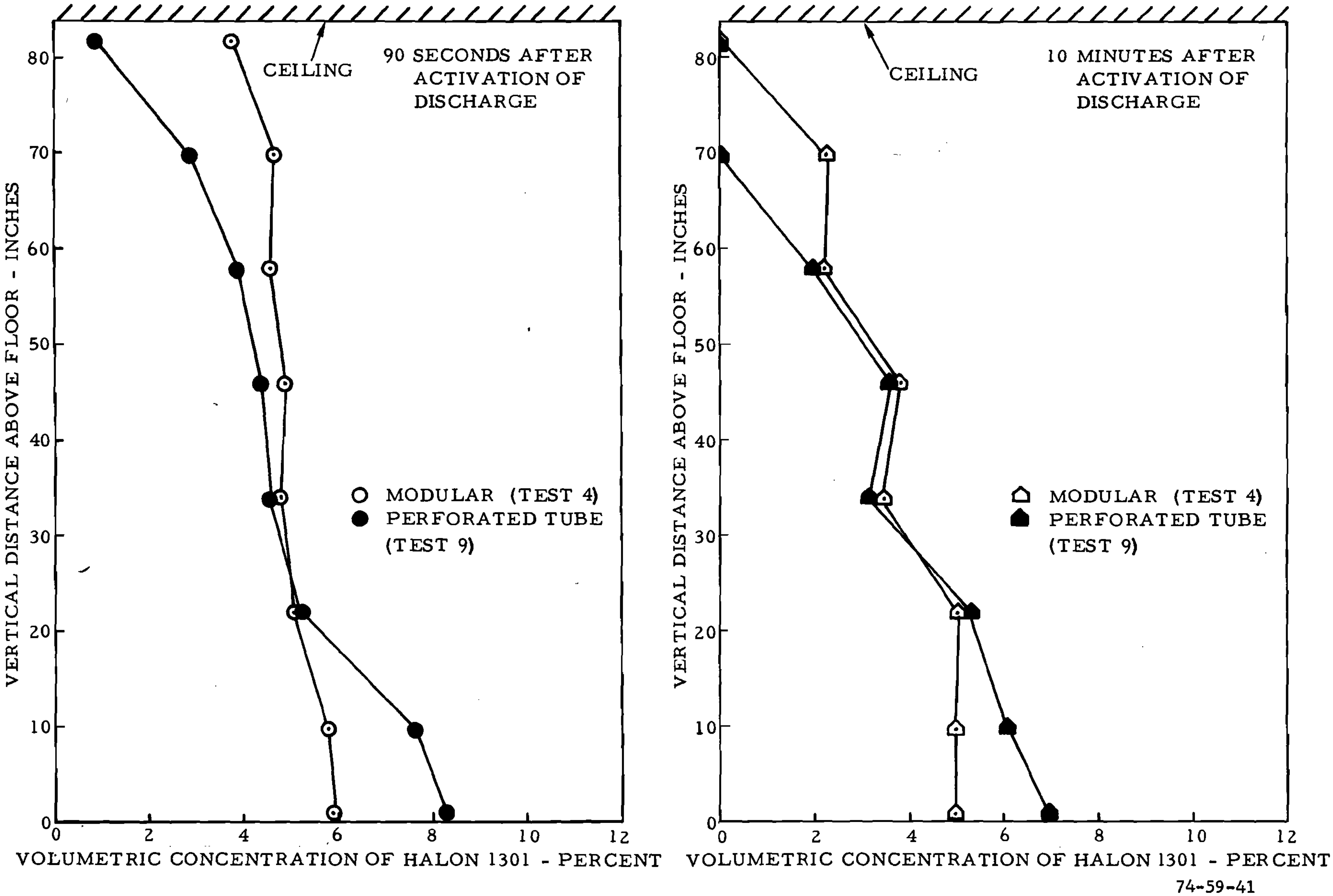


FIGURE 41. COMPARISON OF HALON 1301 STRATIFICATION AT FUSELAGE STATION 540 FOR THE MODULAR AND PERFORATED TUBE SUPPRESSION SYSTEMS

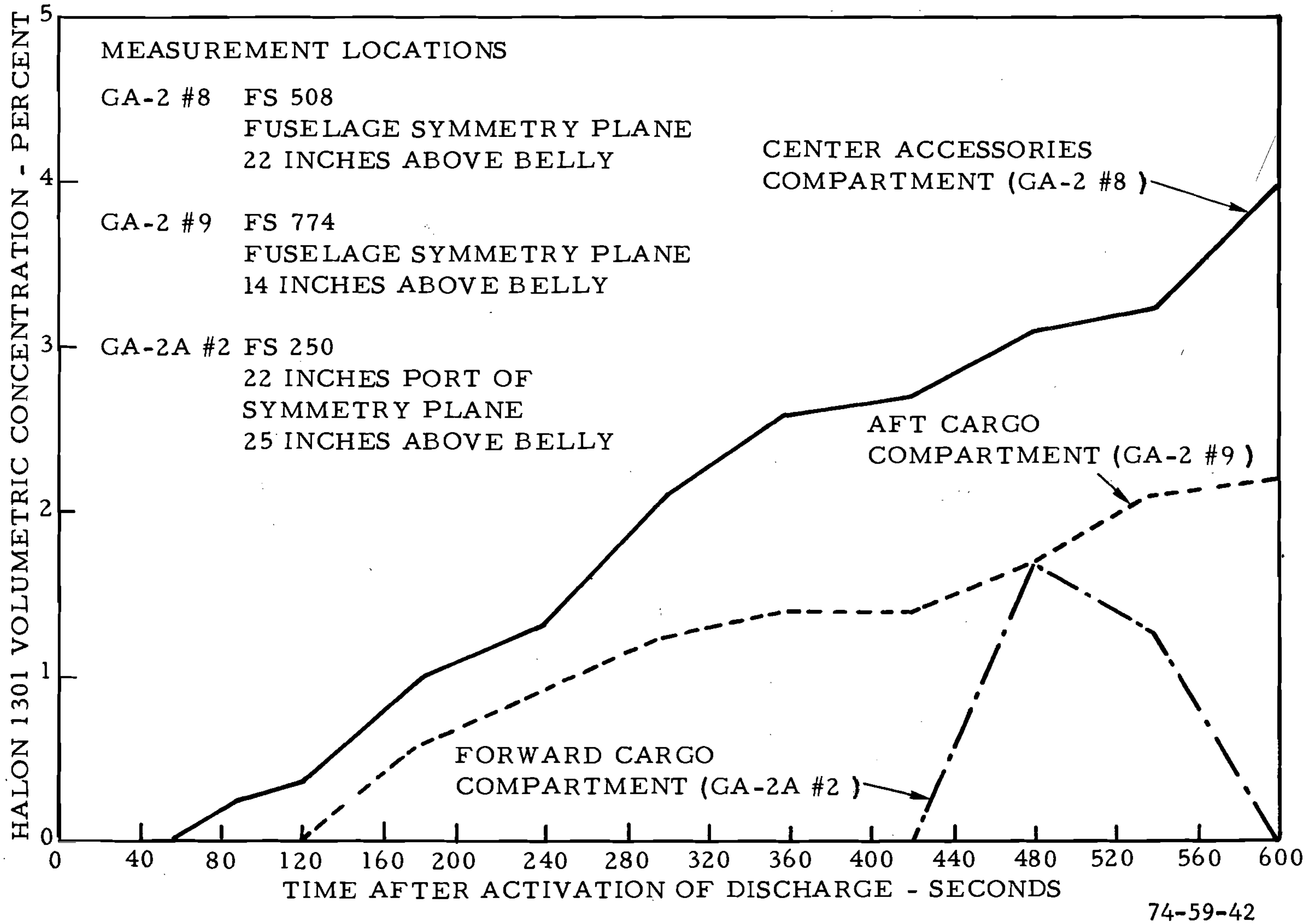
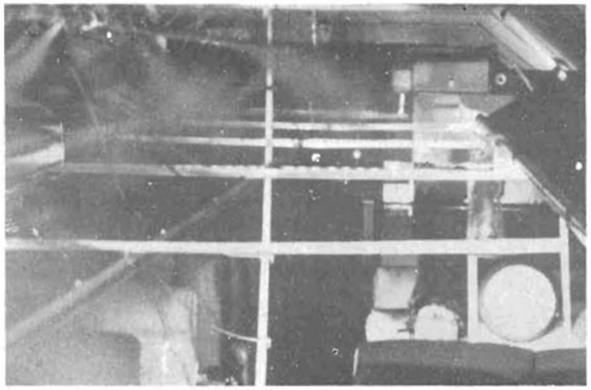
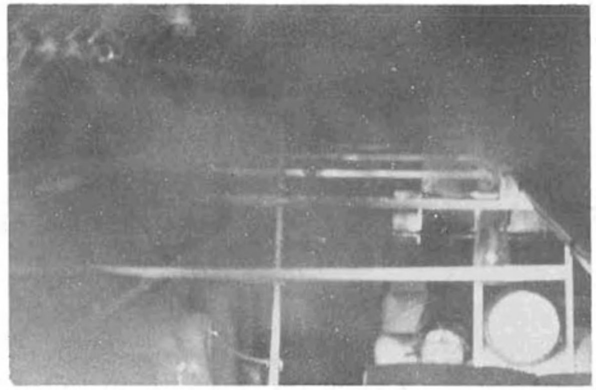


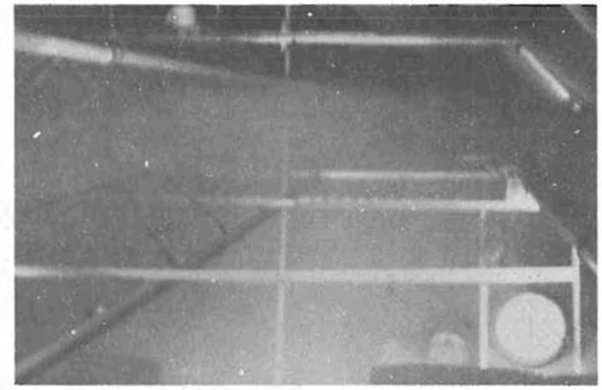
FIGURE 42. AGENT LEAKAGE INTO COMPARTMENTS BELOW MAIN CABIN FLOOR (TEST 9)



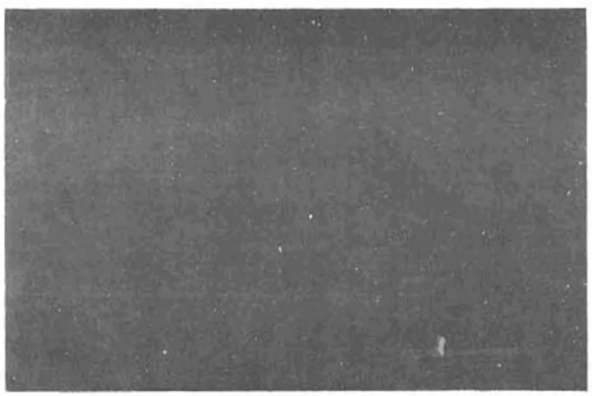
1. 5 SECONDS



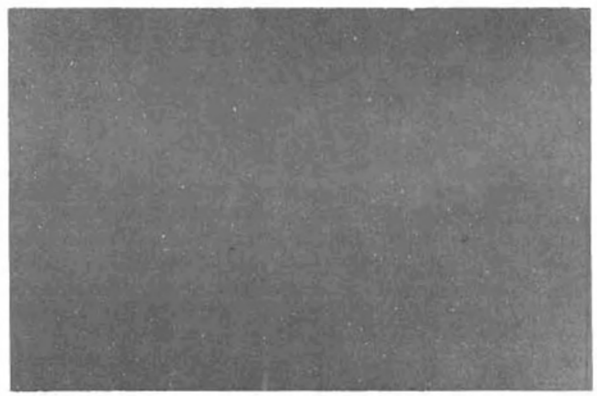
2. 0 SECONDS



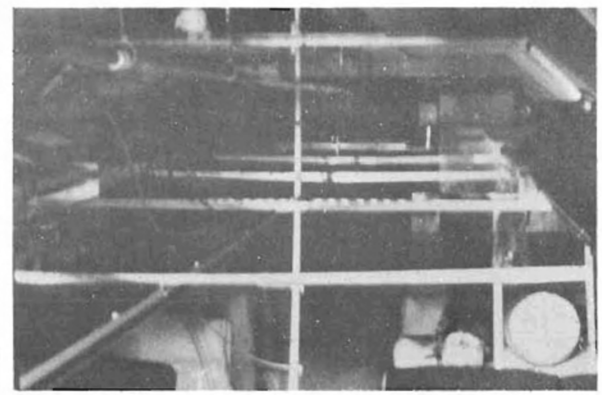
2. 5 SECONDS



3. 8 SECONDS



60 SECONDS



120 SECONDS

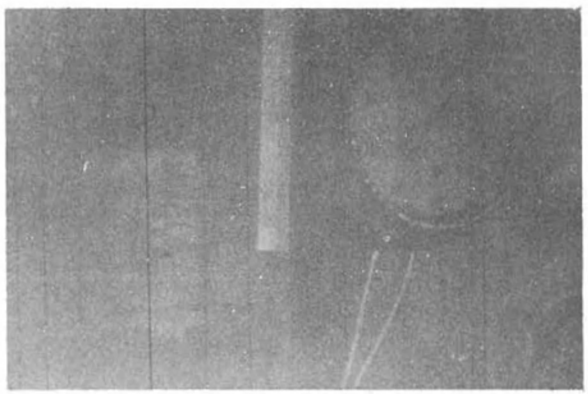
74-59-43b

FIGURE 43. CABIN PHOTOGRAPHS FOLLOWING DISCHARGE ACTIVATION OF THE PERFORATED TUBE SYSTEM (TEST 9) (Sheet 1 of 2)

2.0 SECONDS

2.5 SECONDS

3.0 SECONDS



36 SECONDS

45 SECONDS

74-59-43a

FIGURE 43. CABIN PHOTOGRAPHS FOLLOWING DISCHARGE ACTIVATION OF THE PERFORATED TUBE SYSTEM (TEST 9) (Sheet 2 of 2)

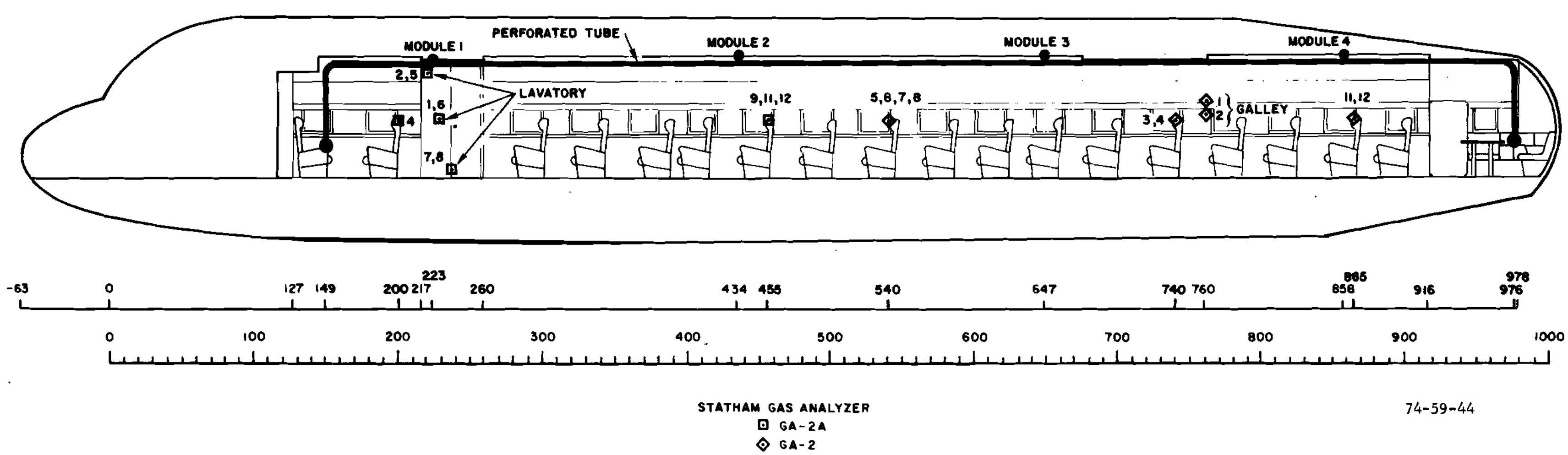


FIGURE 44. SIDE VIEW OF CABIN SHOWING MEASUREMENT LOCATIONS FOR TESTS 10 AND 11

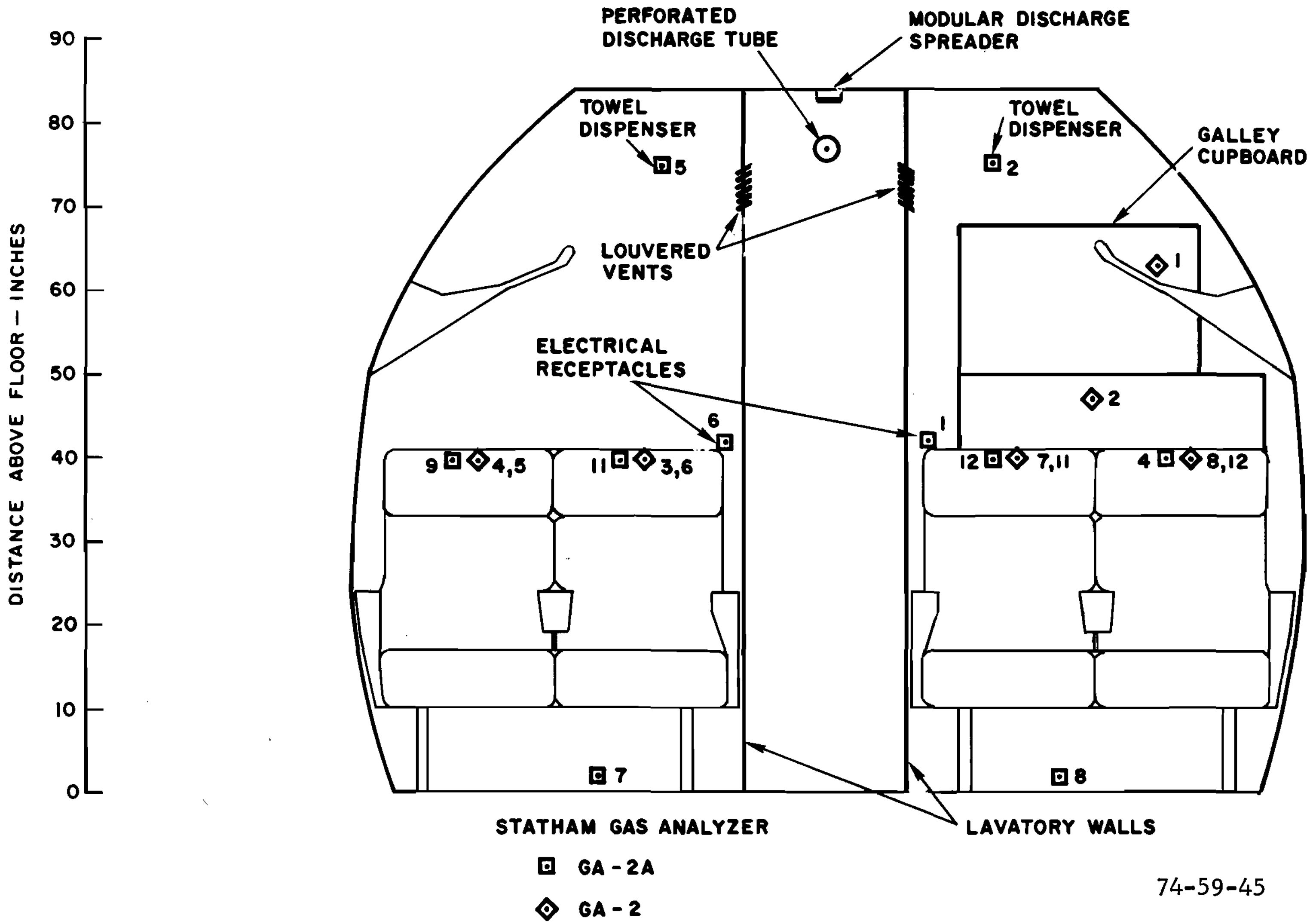


FIGURE 45. CROSS SECTIONAL VIEW OF CABIN SHOWING MEASUREMENT LOCATIONS FOR TESTS 10 AND 11

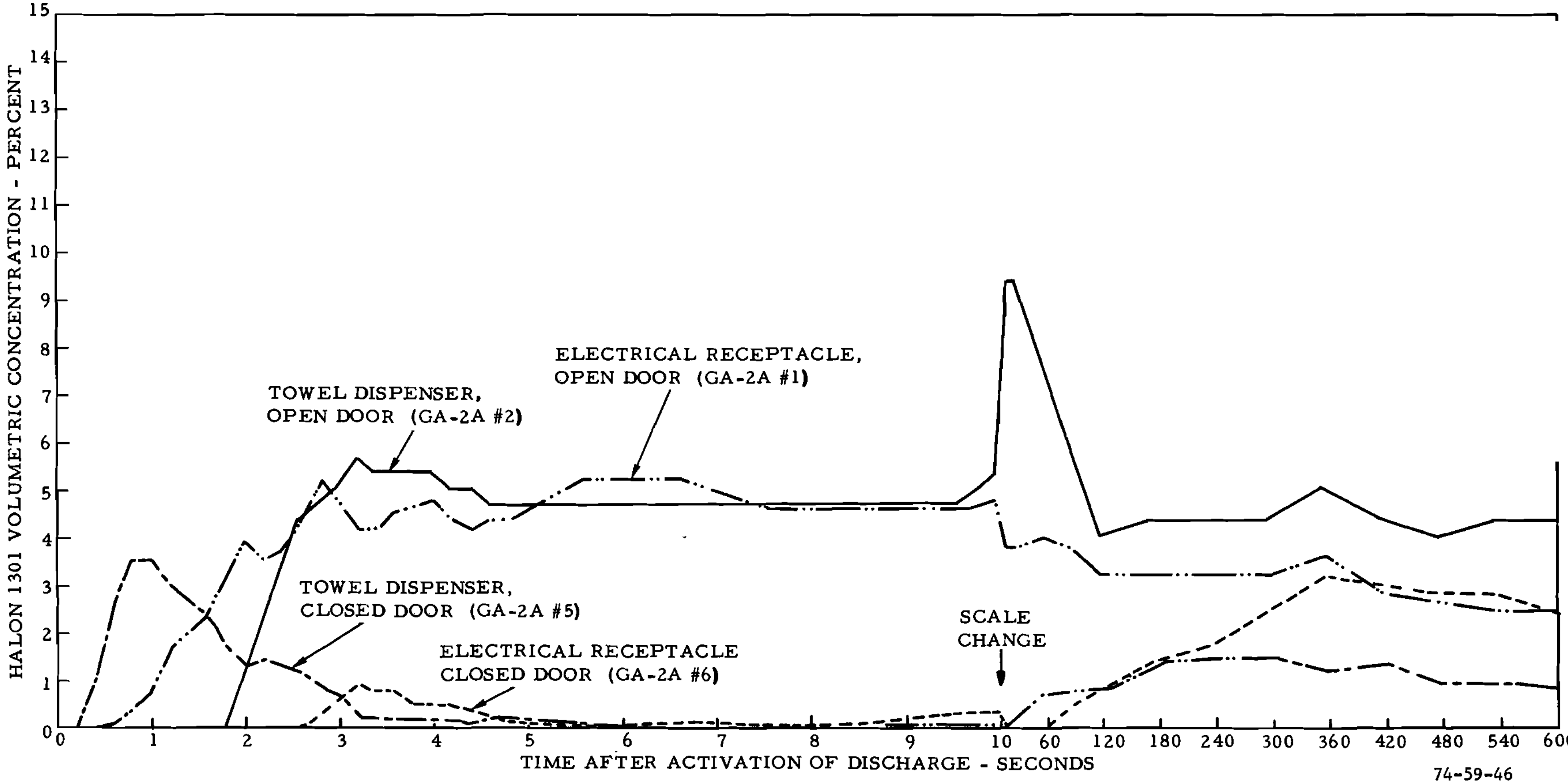


FIGURE 46. COMPARISON OF AGENT BUILDUP IN THE LAVATORY WITH THE DOOR OPEN AND CLOSED FOR THE MODULAR SUPPRESSION SYSTEM (TEST 10)

electrical receptacle until 6 to 7 minutes and was never achieved inside the towel dispenser. Thus, lavatory protection from a Halon 1301 discharge source outside of the lavatory is effective only if the lavatory door is opened, as permitted during ramp servicing and maintenance.

The Halon 1301 concentration-time profiles at the head level of seated passengers in the four seats at FS 540 are shown in figure 47. During discharge, a characteristic "overshoot" in agent concentration was experienced that was slightly more pronounced at the aisle than window seats. Good agreement was obtained for the concentration profiles measured at symmetrically opposite sides of the cabin. The agent concentration ranged from 5 to 7 percent over most of the test, which was slightly higher than measured previously (figure 36), and quite unexpectedly, began increasing gradually over the later part of the test.

This latter trend was found to exist only at measurement locations in the aft half of the cabin. The only possible explanation for this peculiar behavior was that a large building exhaust fan that was operating for most of the test was creating a negative pressure near the back of the cabin and drawing some of the agent to this area (the fan was not used in any other tests). Figure 48 shows a comparison of the Halon 1301 concentration history near a passenger seated at a window seat at three locations throughout the cabin. During discharge, the Halon 1301 profiles are similar at FS 455 and 865, located approximately the same distance from the nearest module (figure 44), but diverge over the remainder of the test because of the buildup of agent in the back of the cabin. At FS 540, located midway between modules 2 and 3, the agent concentration during discharge is higher than either that at FS 455 or 865, but is fairly similar to the profile at FS 865 (rear of cabin) for the remainder of the test. Evidently, the agent concentration in the quiescent environment of an "airtight" enclosure can be influenced in a period of several minutes by small ambient drafts or winds. At higher wind velocities and/or with larger openings, this effect would probably be more pronounced.

About 50 seconds transpired before the Halon 1301 concentration inside a galley "cupboard" (GA-2 #1) built up to the level measured below in an open shelf (GA-2 #2).

An obnoxious odor was detected shortly after the agent was discharged. This odor had been noted previously upon entering the fuselage after some tests utilizing the modular system, where discharge is initiated with a pyrotechnic device. The odor was probably related to the pyrotechnic reaction, although the products are not likely to be harmful for the small weight of the charge.

If necessary, the objectionable odor could be masked by incorporating a fragrant additive into the storage containers. The odor did vary from test to test; however, for this test when it was most intense, it was also detected outside of the cabin, apparently as the result of leakage during discharge overpressure. The suitability of pyrotechnic discharge actuators needs further investigation.

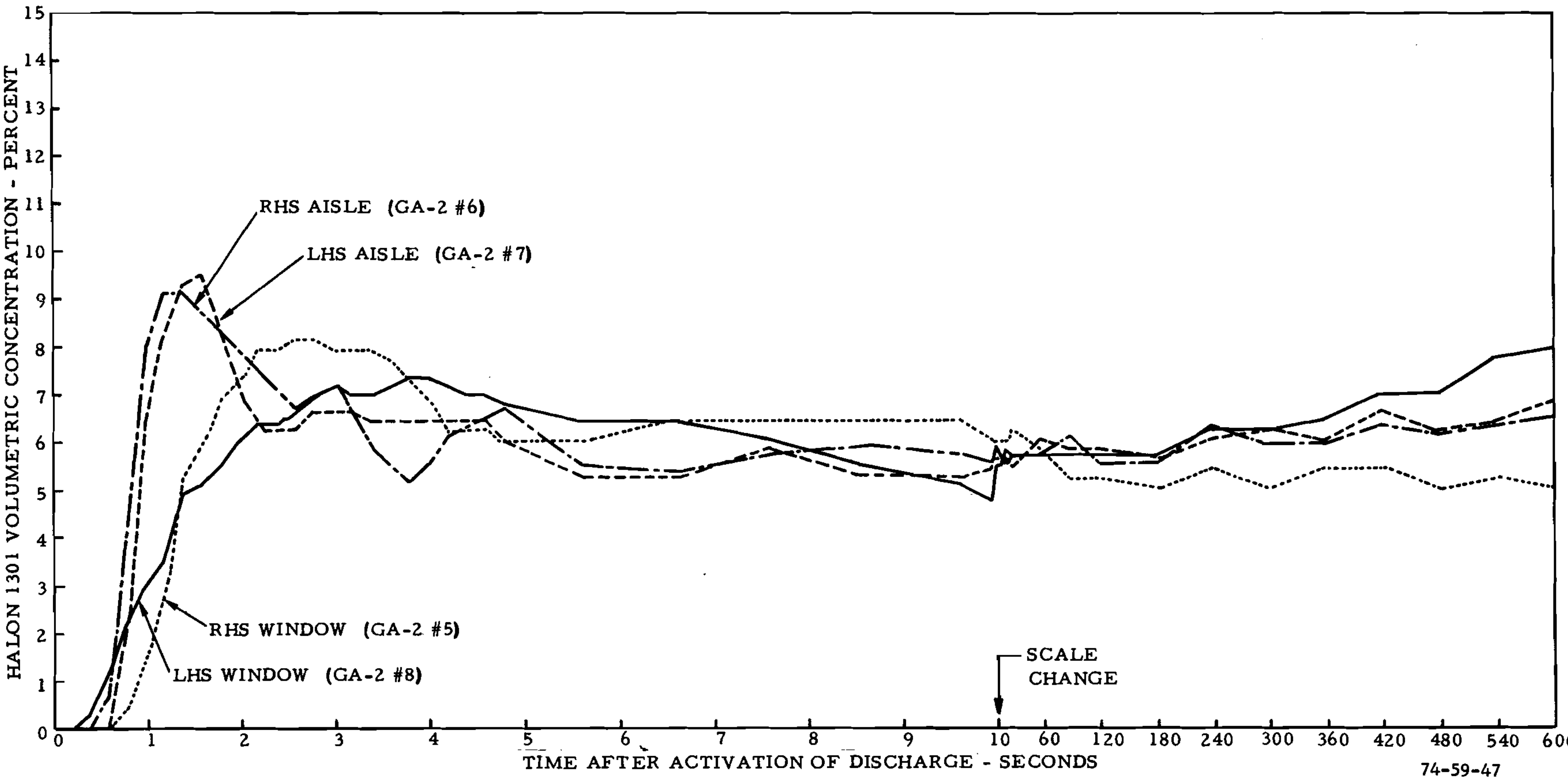


FIGURE 47. HALON 1301 EXPOSURE LEVEL FOR SEATED PASSENGERS AT FUSELAGE STATION 540 FOR THE MODULAR SUPPRESSION SYSTEM (TEST 10)

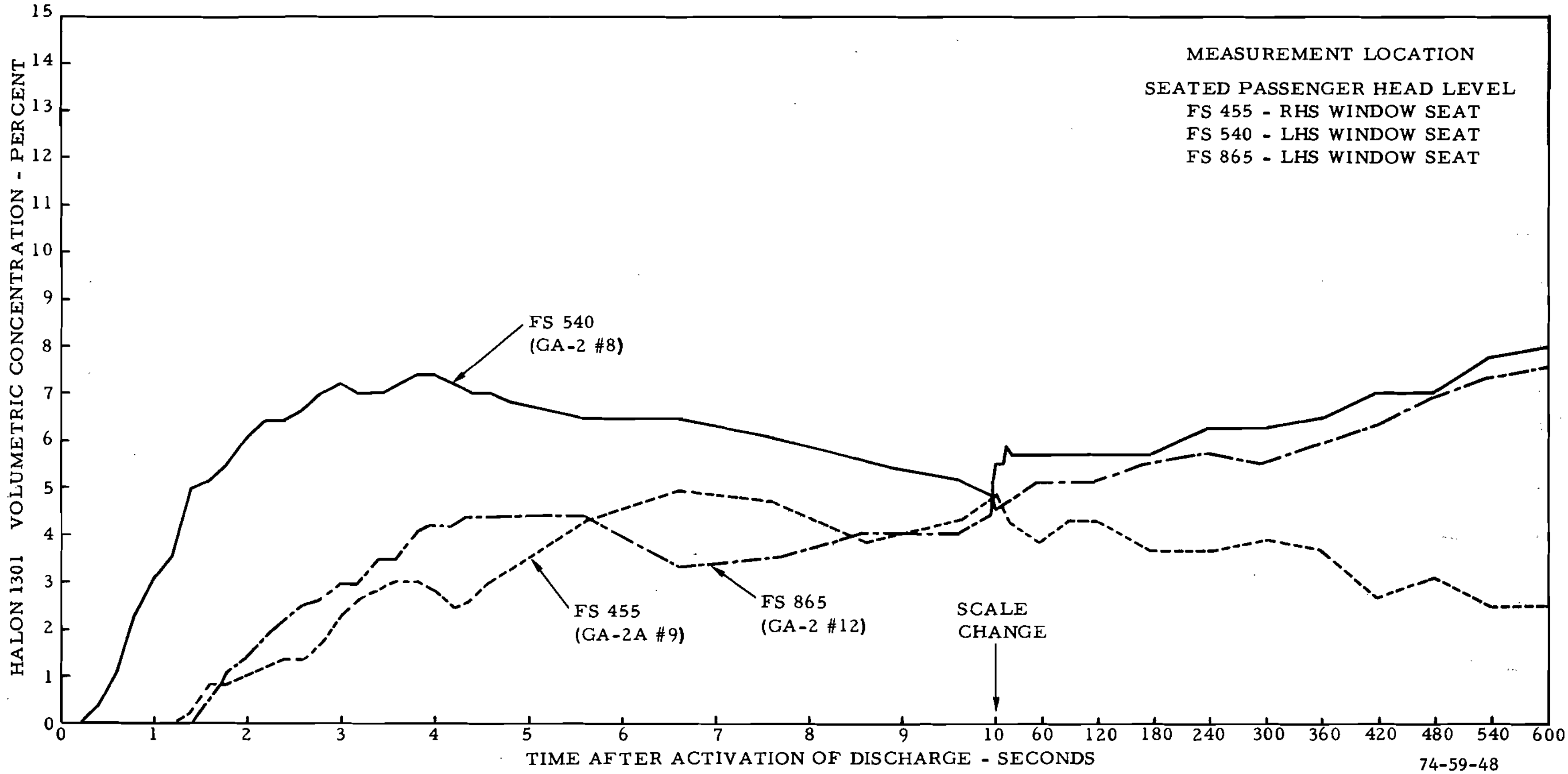


FIGURE 48. HALON 1301 CONCENTRATION-TIME PROFILES NEAR SEATED PASSENGERS DURING TEST 10 (MODULAR SUPPRESSION SYSTEM)

TEST 11.

The perforated tube suppression system was evaluated at the same gas measurement locations used in test 10 (figures 42 and 43) with the modular system.

Inside the open-door lavatory, the most significant difference in agent concentration compared to that exhibited by the modular system (test 10) occurred in the towel dispenser located 75 inches above the floor (figure 49). An extinguishing concentration of 5 percent was never provided by the perforated tube system; whereas, this level was attained in 3 seconds by the modular system. However, at the two remaining measurement locations near the electrical receptacle and center of the floor, a 5-percent concentration was attained only about 5 seconds later than observed from the modular system. As evidenced in test 10, an inadequate agent concentration level was measured inside the closed-door lavatory. In order to provide rapid and sustained lavatory protection, the agent discharge source should be located within the lavatory, since this desired protection is attainable only if the lavatory door is open when the discharge source is outside the lavatory.

The Halon 1301 concentration-time profile measured at the head level of a seated passenger at three fuselage stations is compared in figure 50. Typically, the concentration builds up to the design level in 10 to 20 seconds, except at FS 540 where a slight overshoot occurs a little earlier. Throughout the cabin over the remainder of the test, the concentration remained constant at a level of 5 to 6 percent. The gradual increase in concentration evidenced in test 10 (figures 47 and 48) at the back of the cabin when the building exhaust fan was operating did not occur for this or any other tests.

There was no significant difference between the perforated tube and modular systems for the Halon 1301 concentration measurements taken in the galley. As noted in all tests utilizing the perforated tube system, there was no unusual odor outside the fuselage during the test or inside the cabin after the test. Unlike the modular system where a pyrotechnic device was used, discharge was initiated by an electrically actuated pneumatic valve.

TEST 12.

If a fire should erupt in the cabin of an airplane following a crash landing or when parked at the loading ramp, the natural instinct of the reacting occupants is to escape from the confined danger through the nearest emergency exit. The extinguishing effectiveness and, more important, inerting capability of Halon 1301 when passengers are departing through the available exits will depend upon the agent leakage rate through these same exits. If the system was programmed to actuate the discharge of agent at the first instant the fire penetrated into the cabin, this event could conceivably occur before or after the opening of the emergency exit(s). In this test, the former possibility was studied. The galley door (75 inches by 35 inches) was opened

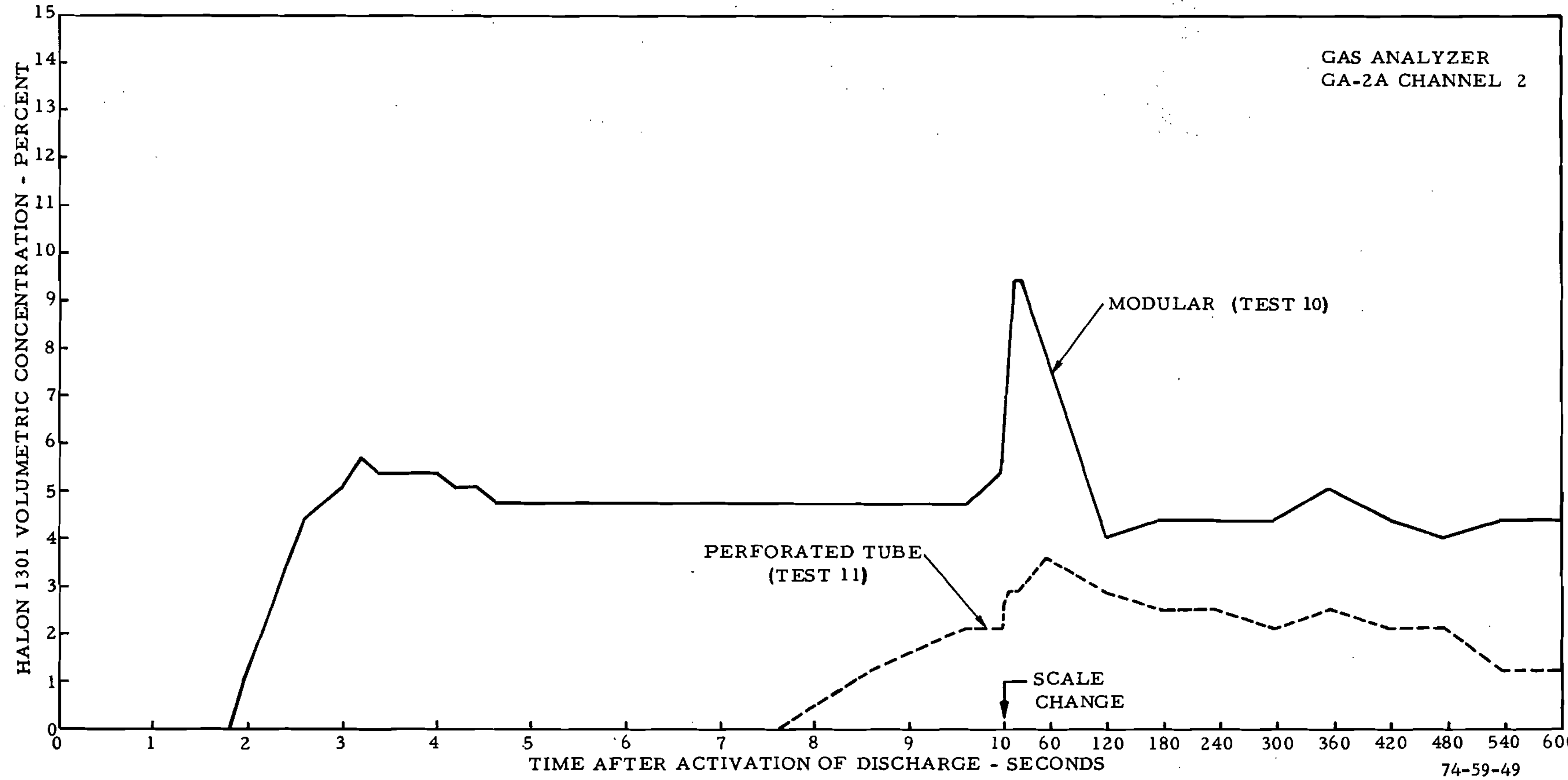


FIGURE 49. COMPARISON OF HALON 1301 BUILDUP IN THE TOWEL DISPENSER OF THE OPEN LAVATORY FOR THE MODULAR AND PERFORATED TUBE SUPPRESSION SYSTEMS

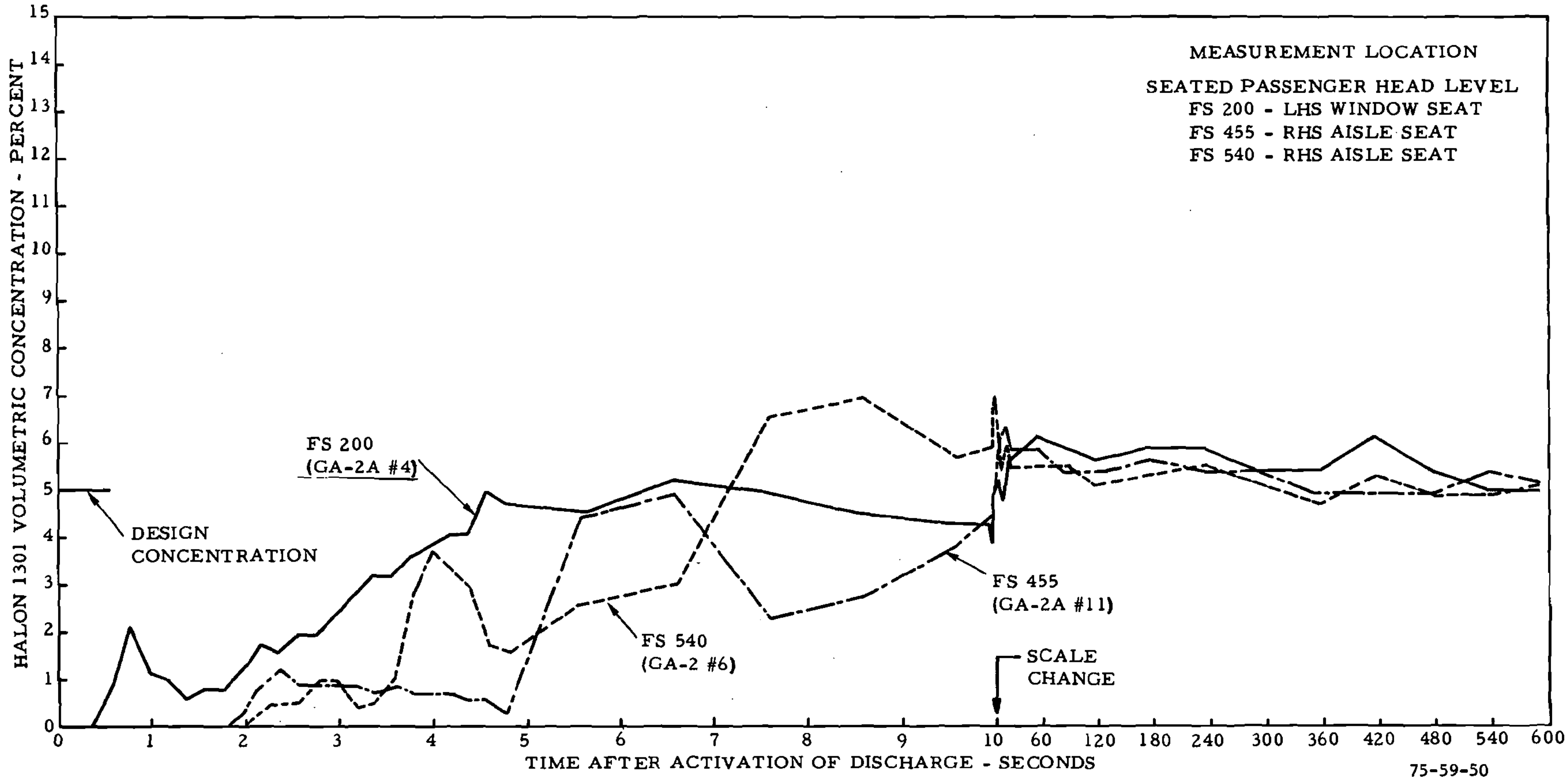


FIGURE 50. HALON 1301 CONCENTRATION-TIME PROFILES NEAR SEATED PASSENGERS DURING TEST 11 (PERFORATED TUBE SUPPRESSION SYSTEM)

at a time 10 seconds after activation of discharge from the modular system when it was known from prior tests that Halon 1301 total dispersion was completed. A number of identical vertical sampling trees were fabricated, each consisting of four sampling lines. The sampling trees were placed throughout the cabin (figure 51), primarily in the fuselage symmetry plane, although one tree was positioned adjacent to the galley door (figure 52).

The depletion of Halon 1301 concentration behaved similarly to that measured previously in the closed cabin, but occurred at a significantly accelerated rate. A major reduction in agent concentration was first measured at the sampling location positioned nearest to the ceiling; similar reductions occurred progressively later in the test the nearer to the floor tham the sampling probe location. This behavior is demonstrated in figure 53 consisting of concentration-time profiles for the four symmetry plane sampling probes at FS 265, which was located 38 feet forward of the 18.3-square-foot galley door opening. At distances of 72, 52, 32, and 12 inches above the floor, a 3-percent agent concentration was maintained for 28, 50, 90, and 193 seconds, respectively.

The vertical Halon 1301 profiles as determined by each sampling tree are compared with one another in figure 54 at 4 points in time during the test. Within measurement accuracy the vertical Halon 1301 profiles at the symmetry plane are identical and thus are independent of relative location to the galley door opening. The Halon 1301 profile adjacent to the galley door opening has a shape similar to, but at a slightly lower concentration level than, the symmetry plane profiles. It appears as if agent dropoff was more abrupt and severe compared to the gradual decrease experienced in previous tests. Apparently, a more distinct interface with air above and Halon 1301/air below is established as the leakage area is increased. The receding movement of the interface is essentially independent of location relative to the leakage opening and is analogous to the top surface of water draining out of a tub.

The invariability of the symmetry plane profiles with regard to fuselage station is more vividly indicated in figure 55. In this figure, the time duration that the Halon 1301 concentration exceeded 3 percent is plotted at each location against the sampling line elevation from the floor, which reduces the scatter in the data resulting from measurement inaccuracies. The apparent scatter for the two sampling heights closest to the floor is a result of increasing the time interval after 90 seconds during data reduction. The agent concentration near the floor exceeded 3 percent for about 2.5 minutes longer than it did at the ceiling. (This "extended protection" at the floor relative to the ceiling may be an asset in cabin protection by retarding fire entry from an external fuel fire burning on the ground.)

TEST 13.

The results from this test were erroneous and discarded because of the presence of a vacuum manifold leak discovered after the data were reduced.

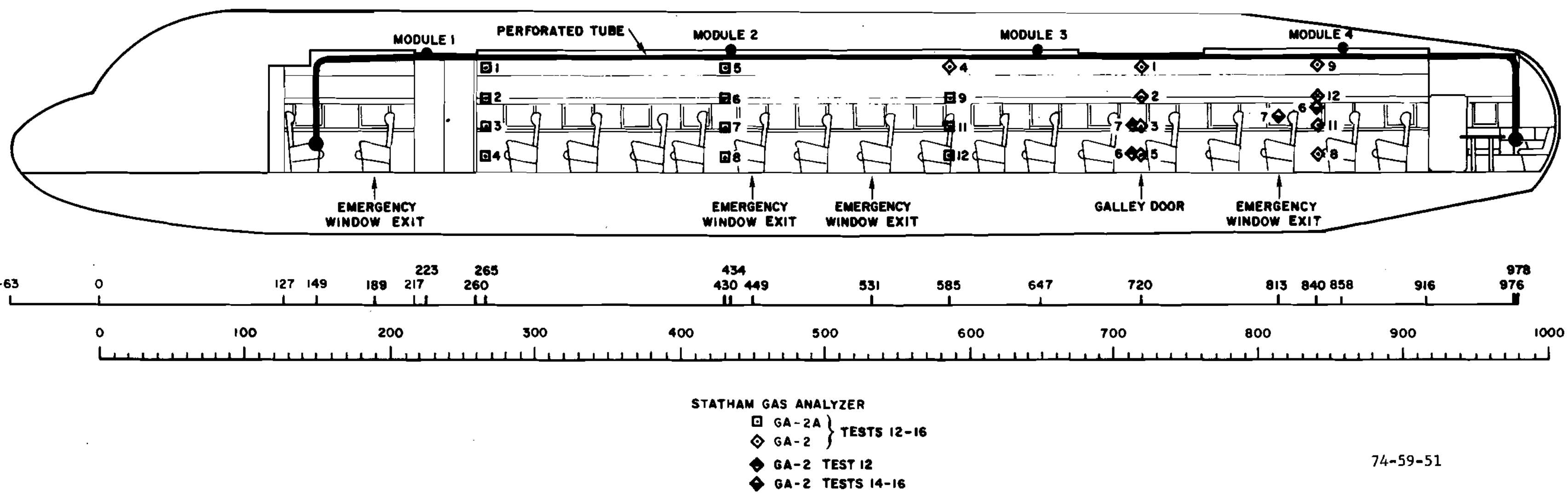


FIGURE 51. SIDE VIEW OF CABIN SHOWING MEASUREMENT LOCATIONS FOR TESTS 12 TO 16

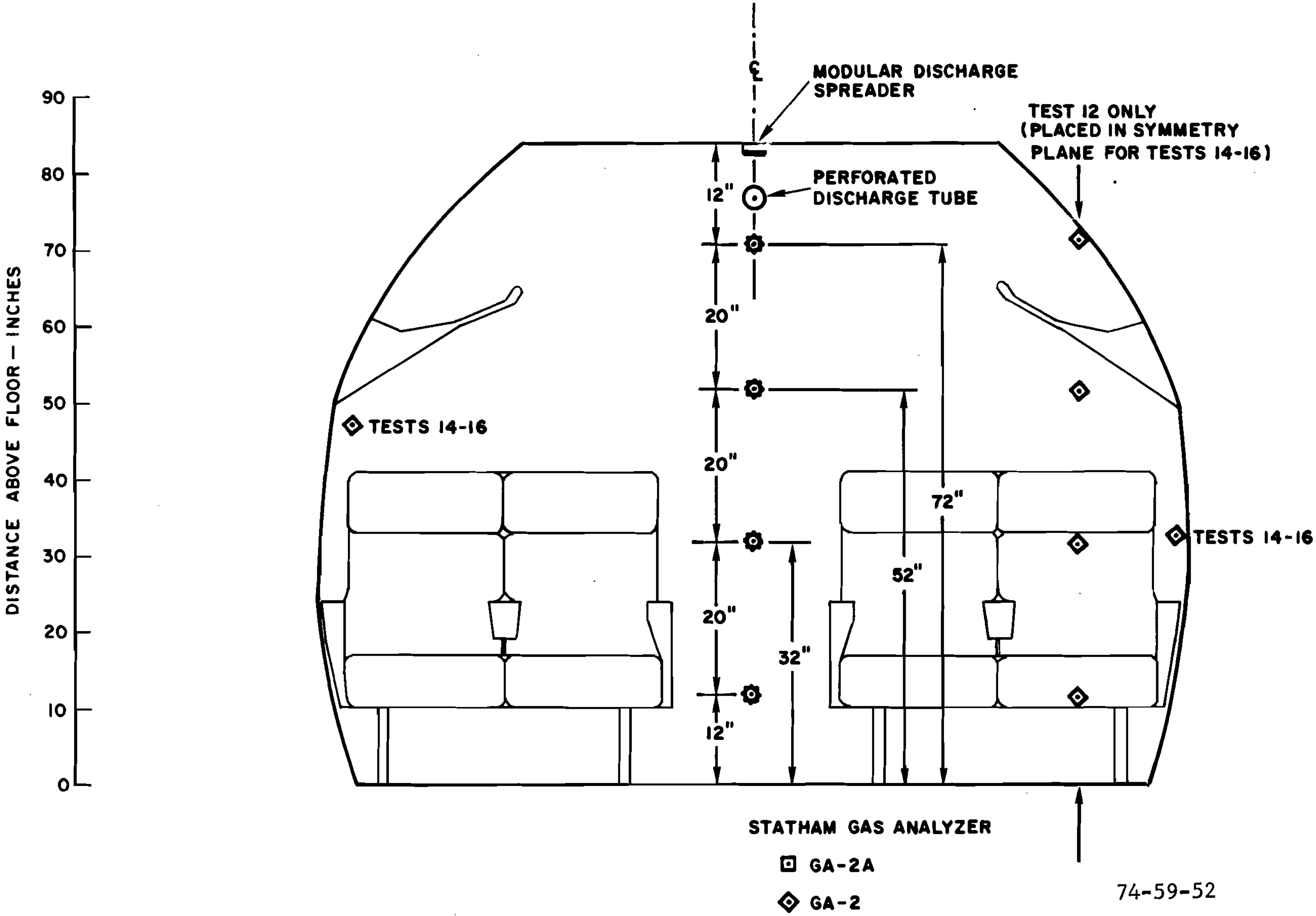


FIGURE 52. CROSS SECTIONAL VIEW OF CABIN SHOWING MEASUREMENT LOCATIONS FOR TESTS 12 TO 16

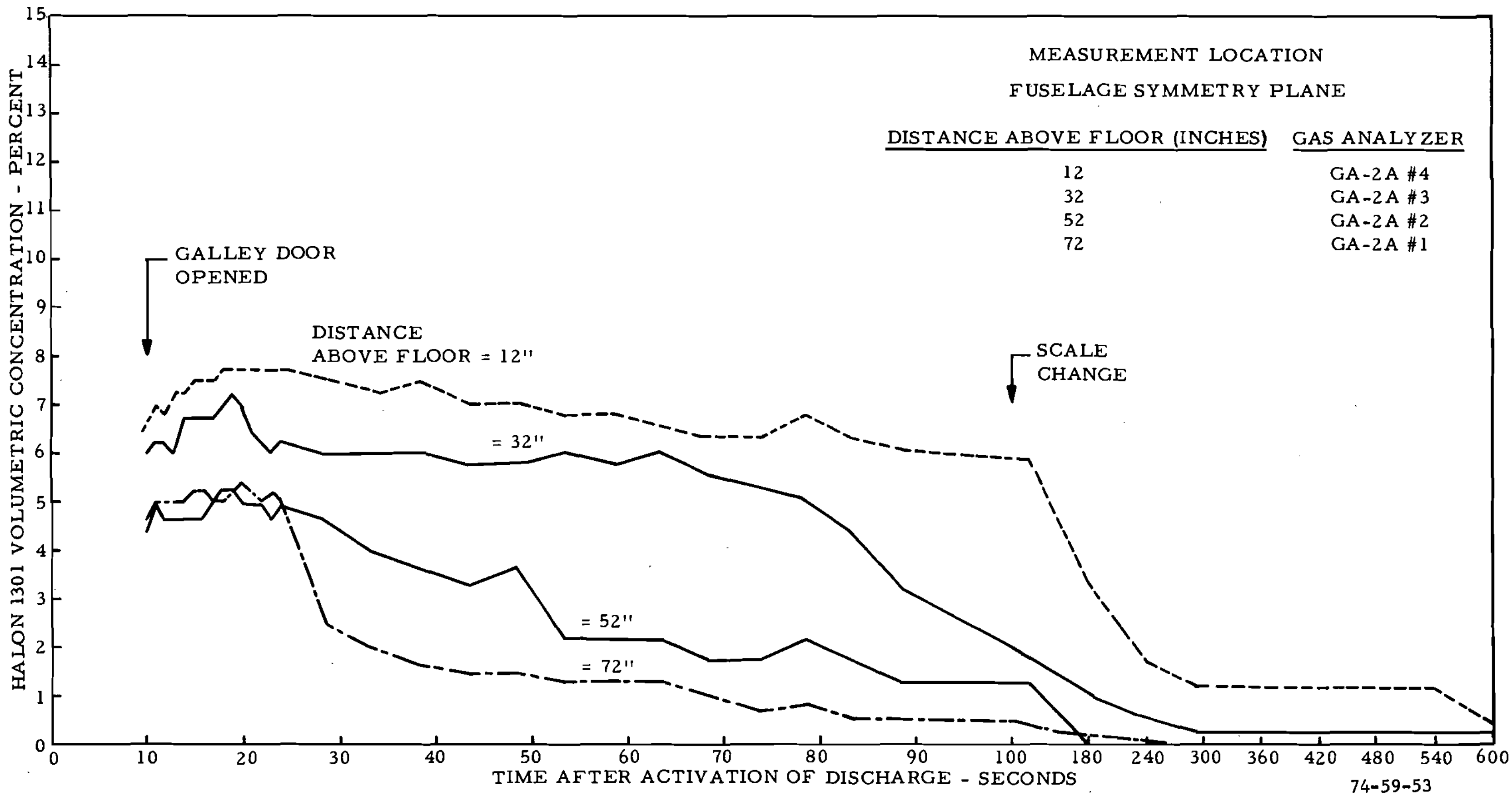


FIGURE 53. LOSS OF HALON 1301 AT FUSELAGE STATION 265 AFTER GALLEY DOOR OPENED 10 SECONDS AFTER ACTIVATION OF DISCHARGE (TEST 12)

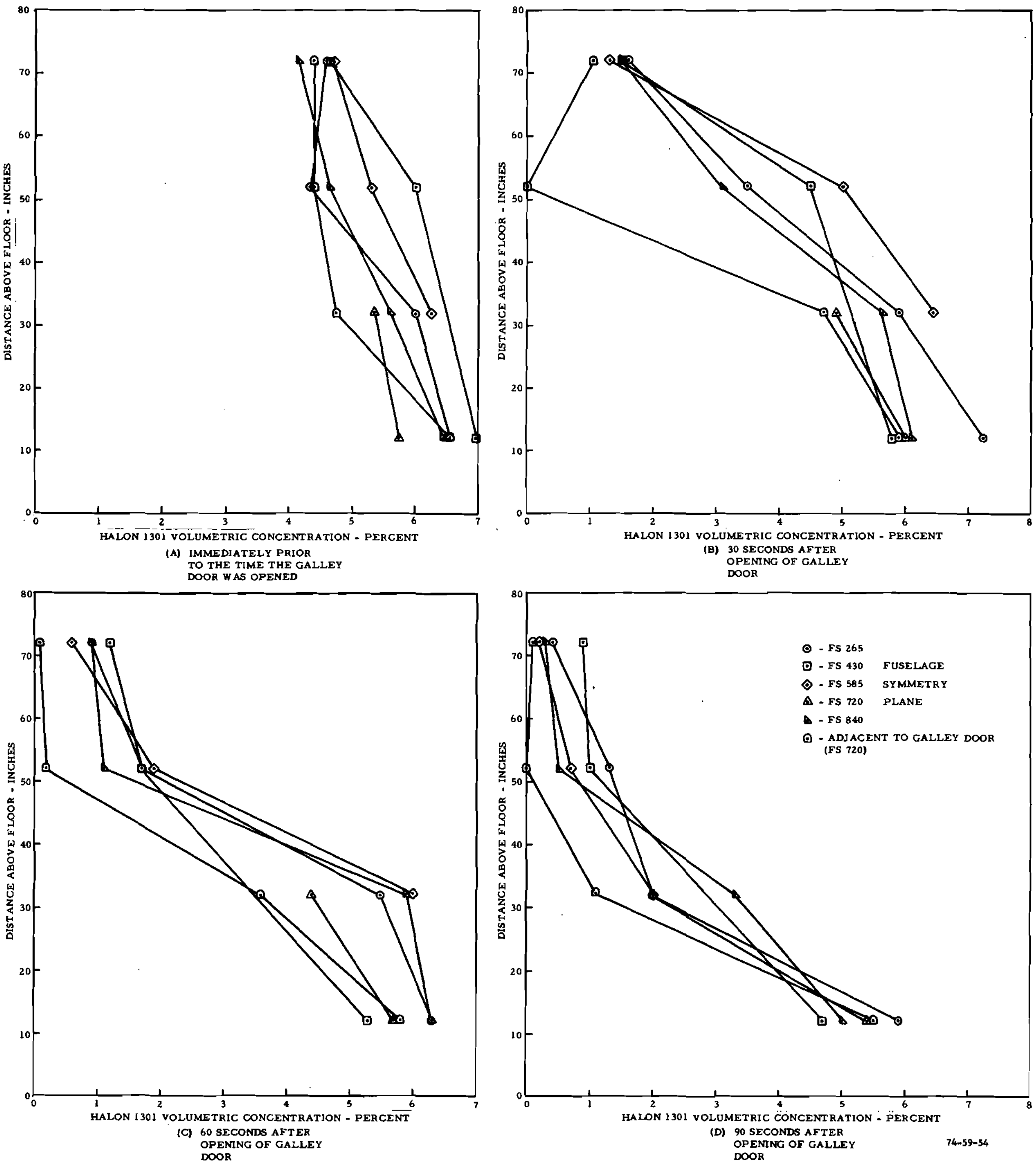


FIGURE 54. VERTICAL HALON 1301 PROFILES AT VARIOUS FUSELAGE STATIONS FOR TEST 12

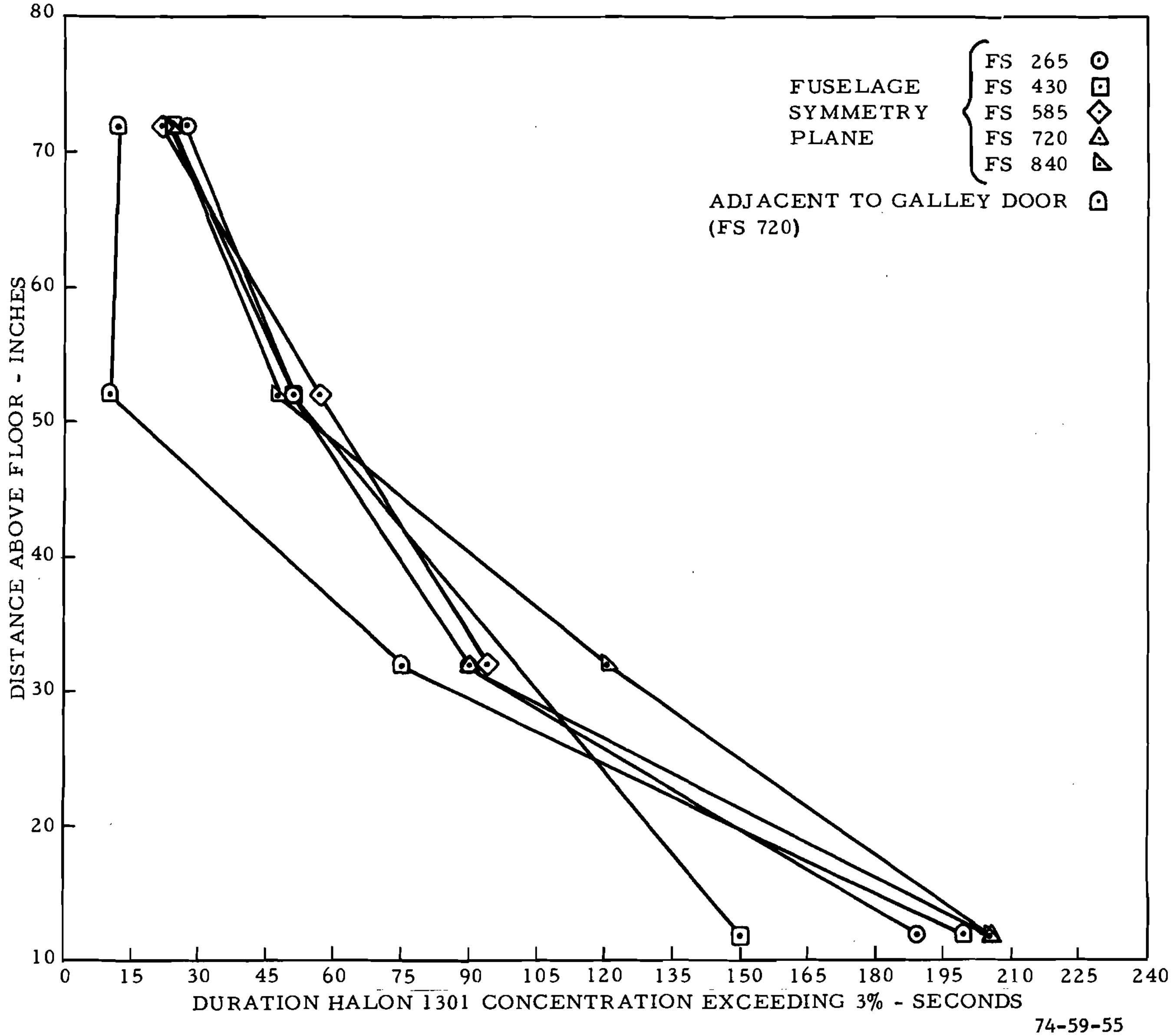


FIGURE 55. LOSS OF HALON 1301 FROM CABIN AFTER GALLEY EXIT DOOR OPENED 10 SECONDS AFTER ACTIVATION OF DISCHARGE (TEST 12)

TEST 14.

The purpose of this test was to determine the loss in inerting protection when, in addition to the galley door (as in test 12), the four LHS emergency windows were opened 10 seconds after activation of the modular system. This configuration included all emergency exits on the LHS of the cabin. For this airplane (DC7), FAA regulations required that the evacuation from a completely occupied cabin be effected within 2 minutes using the exits on one side of the airplane (the current requirement is 90 seconds). For this test and also tests 15 and 16, the gas sampling tree adjacent to the galley door was moved laterally to the symmetry plane, displacing two sampling lines that were moved slightly aft; one line was placed adjacent to an emergency window exit and the other roughly across to the other side of the cabin (figures 51 and 52). The window bottoms were 23 inches above the floor. Each window was 25 inches high and 20.75 inches wide. The opening area of the four windows was 14.4 square feet and, including the galley door opening, the total leakage area was 32.7 square feet.

When Halon 1301 is leaking out of an enclosure through an opening, the concentration adjacent to the opening was found not to be adversely diluted. Figure 56 shows a comparison of the concentration-time profile adjacent to a window opening with that measured at the opposite side of the cabin. Except for a transient, sharp drop in concentration adjacent to the window of from 1 to 2 seconds after the window was opened, the Halon 1301 concentration histories exhibited reasonably good agreement, although the level measured adjacent to the window was slightly lower for most of the test. Thus, Halon 1301 inerting protection will extend throughout an enclosure and will not be compromised by localized dilution near leakage openings.

As observed in test 12, the Halon 1301 concentration in the enclosure at a particular point in time was found to be only a function of height and independent of cabin station. The average vertical Halon 1301 profile was calculated from the five sampling trees to cancel out measurement inaccuracies and compared at 30 and 90 seconds with test 12 (galley door opening only) in figure 57. The loss in inerting protection in test 14 (all LHS exits opened) compared with test 12 did not correspond to the 79-percent increase in leakage area. At 30 seconds, the greatest loss in agent concentration (approximately 1.5 percent) occurred at the probe locations immediately above (52 inches) and across from (32 inches) the window, and there was virtually no change near the ceiling or floor. However, by 90 seconds, the loss in agent concentration became greater the closer the probe was to the floor. The behavior described above is attributable to the fact that the leakage rate of Halon 1301 is dependent upon both the concentration level and height of agent above the opening. In test 14, the additional leakage of Halon 1301 occurred from the cabin space above the window bottom level where the height and concentration of agent is less than below the window. Thus, the overall additional

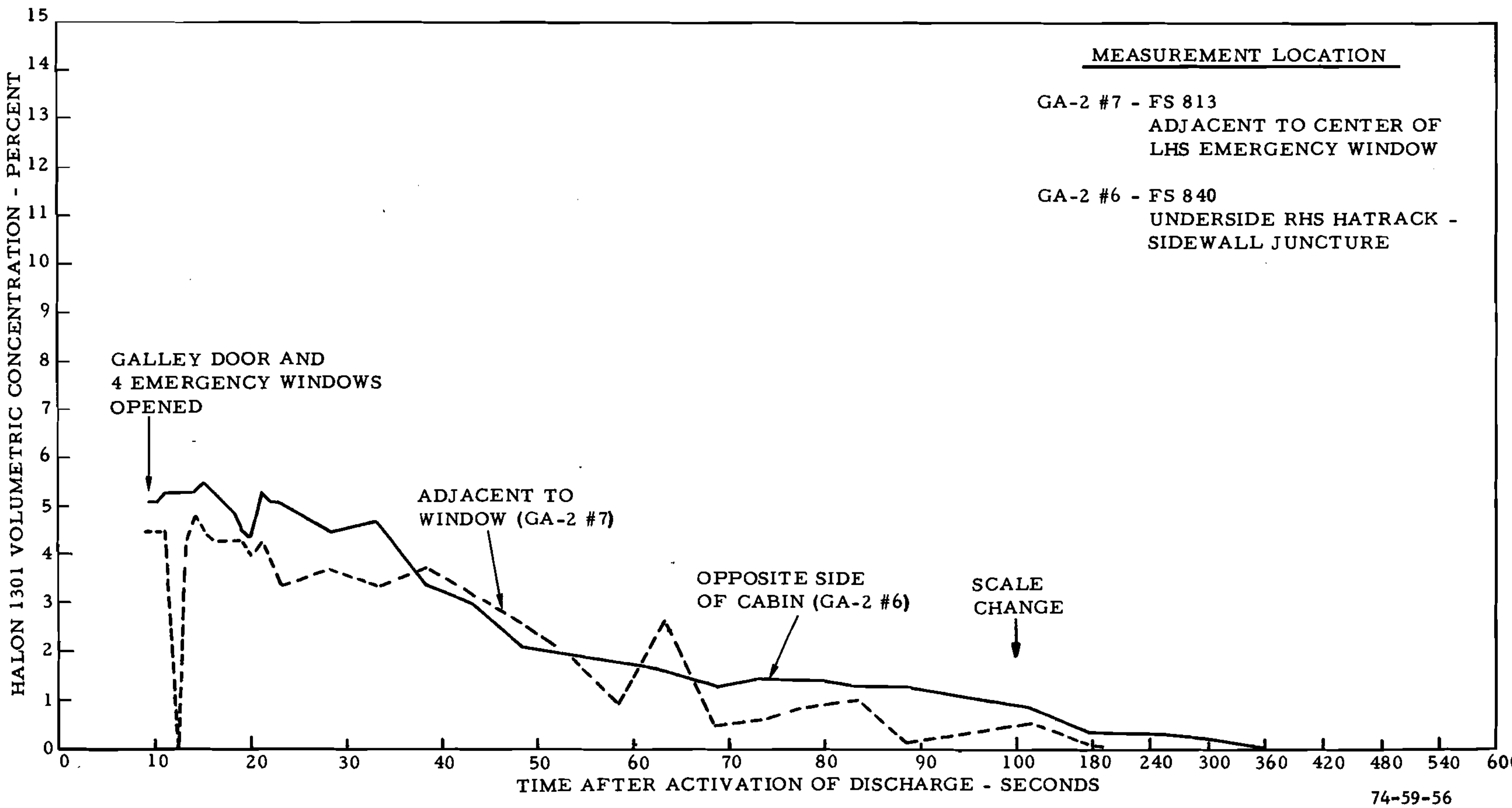


FIGURE 56. COMPARISON OF HALON 1301 CONCENTRATION-TIME PROFILE ADJACENT TO AN OPEN EMERGENCY WINDOW AND ON THE OPPOSITE SIDE OF THE CABIN FOR THE MODULAR SUPPRESSION SYSTEM (TEST 14)

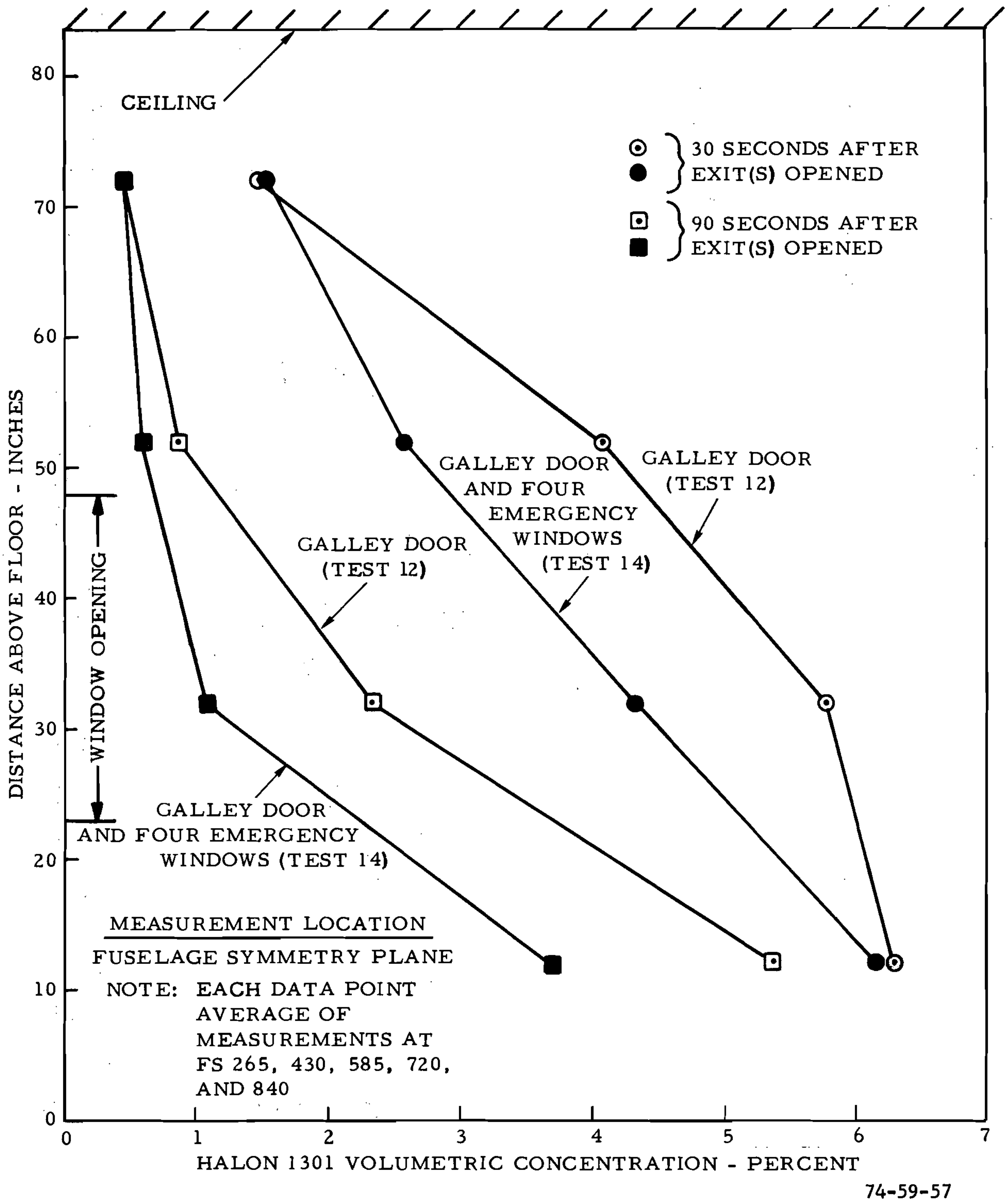


FIGURE 57. EFFECT OF NUMBER OF OPENED EXITS ON THE AVERAGE VERTICAL HALON 1301 PROFILE

loss in Halon 1301 agent through the four windows did not correspond to the increase in leakage area. If, for example, another door with the bottom edge along the floor and identical to the galley door were opened instead of the four windows, the amount of agent leakage would have been twice as great as with the galley door alone.

The time duration that the agent concentration exceeded 3 percent is a relative measure of inerting protection. Such data from tests 12 and 14 is shown in figure 58. The reduction in inerting time due to the additional four-window area (test 14) increased progressively toward the floor where, fortunately, the loss tends to be compensated by longer inerting times in this direction. There was no significant change in inerting time between tests at the measurement location closest to the ceiling. Opening the emergency windows, in addition to the door, only reduced the inerted level of the cabin by about 10 inches.

TEST 15.

Following a crash landing, it is possible that evacuation can be taking place at the instant agent discharge is initiated, perhaps triggered by a sudden outbreak of fire within the cabin. To study this possibility, all LHS exits were already opened when the modular system was discharged. The purpose of the test was to determine if a significant quantity of Halon 1301 would be lost through the exits during discharge over pressure. The measurement locations were the same as those used in the previous test (figures 51 and 52).

Figure 59 compares the agent concentration histories at three fuselage stations at a sampling location (A), 12 inches below the ceiling, and (B), 32 inches above the floor. In test 14, when all the LHS exits were opened 10 seconds after discharge activation, the concentration histories at any given probe height were independent of the fuselage station; however, when the LHS exit doors were already open at discharge (test 15), the agent level at the ceiling dropped off faster adjacent to the galley door (FS 720) than at other fuselage stations (figure 59A). Obviously, the dropoff in ceiling agent near the galley door was never replenished by neighboring areas of the cabin. This effect was only evidenced near the ceiling and did not occur at the lower locations (figure 59B).

The inerting protection was compared for the conditions of all open LHS exits before (test 15) or after (test 14) activation of the modular suppression system. Figure 60 shows a comparison of the inerting profile from these tests at FS 265, which, compared to the other sampling tree locations, was at a greater distance from the nearest exit openings. Apparently, a small quantity of Halon 1301 was lost through the exits that were open during discharge and the loss was manifested near the ceiling and distributed throughout the cabin, although greater adjacent to the opening (figure 59A). For most of the cabin, the loss of inerting time resulting from agent discharged through open exits was minor.

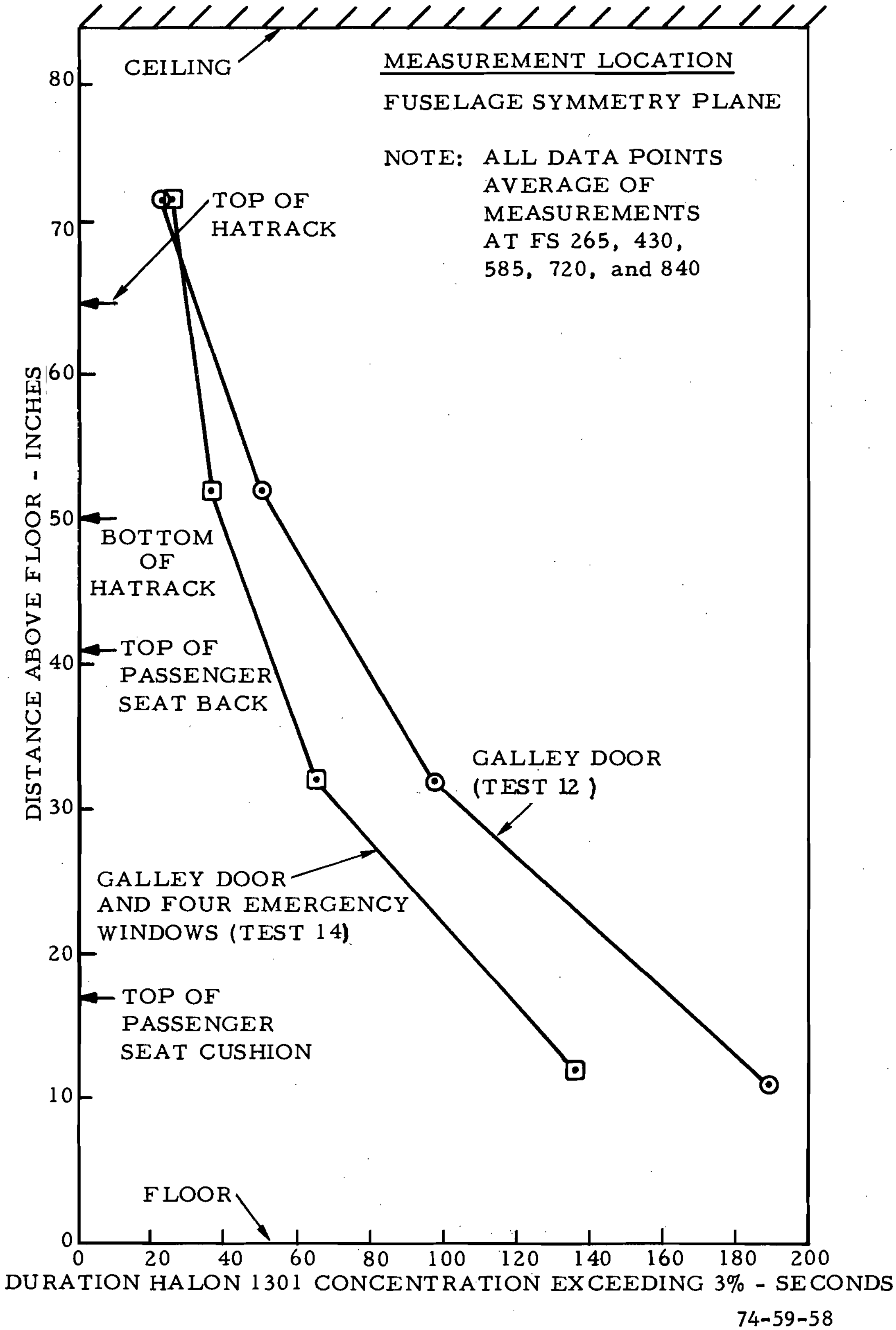


FIGURE 58. AVERAGE LOSS OF HALON 1301 FROM CABIN AFTER EXITS OPENED 10 SECONDS AFTER ACTIVATION OF DISCHARGE

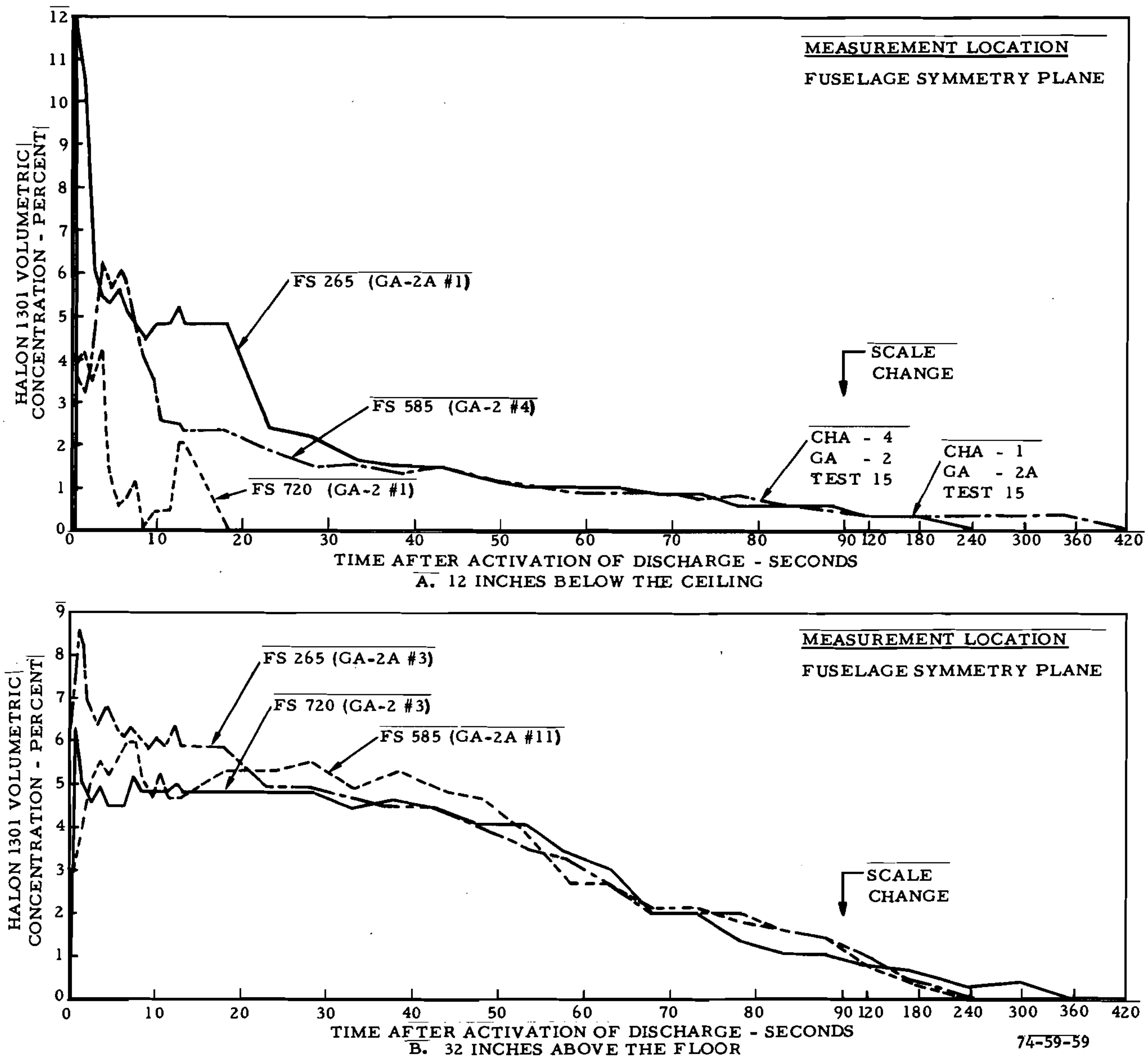


FIGURE 59. COMPARISON OF HALON 1301 CONCENTRATION-TIME PROFILES AT VARIOUS FUSELAGE STATIONS WHEN THE LHS EXITS ARE OPEN AT DISCHARGE ACTIVATION FROM THE MODULAR SYSTEM (TEST 15)

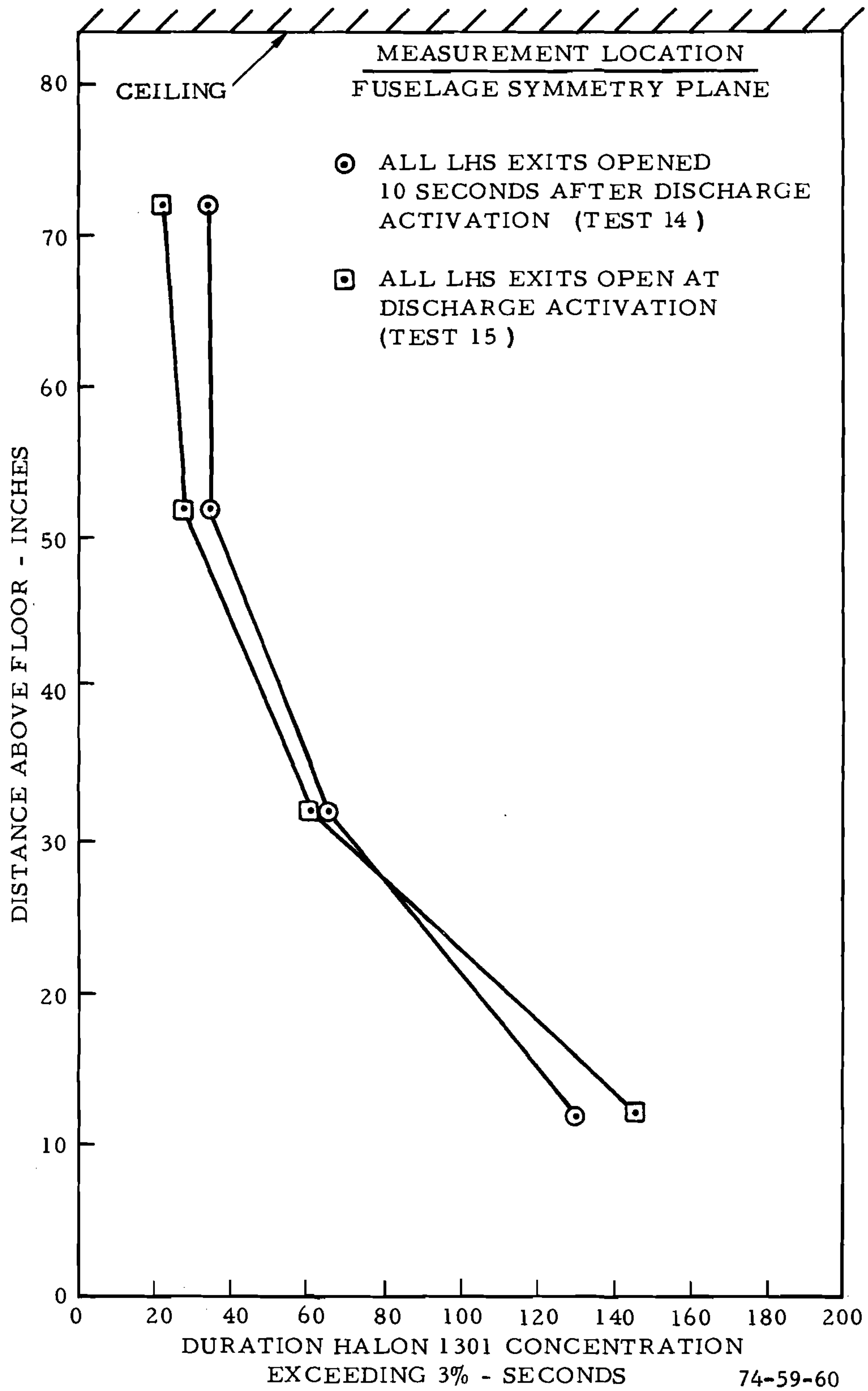


FIGURE 60. COMPARISON OF HALON 1301 PROTECTION AT FS 265 WHEN ALL LHS CABIN EXITS ARE OPENED BEFORE (TEST 15) AND AFTER (TEST 14) ACTIVATION OF THE MODULAR SUPPRESSION SYSTEM

TEST 16.

The purpose of this test was to determine if the small quantity of Halon 1301 discharged through the open exits by the modular system (test 15) could be further minimized by utilization of the perforated tube system, which has a lower discharge rate and, consequentially a smaller cabin discharge overpressure. The measurement locations were the same as those used in tests 14 and 15 (figures 51 and 52).

Figure 61 shows a comparison of the average inerting profiles for the two suppression systems when all the LHS exits were opened before discharge activation. The perforated tube system provided, on the average, a slightly longer inerting time of 8 and 3 seconds at the sampling probes located 12 and 32 inches below the ceiling, respectively. No measurable difference was experienced by the two remaining sampling probes closer to the floor. In spite of this small increase in inerting protection provided by the perforated tube system for the special condition of all open LHS exits before discharge activation, overall, the modular system is still considered superior primarily by virtue of its efficient and effective extinguishing characteristics.

TEST 17.

The final test was conducted to determine the Halon 1301 extinguishing and inerting characteristics at potential ignition and fire areas in a lavatory. For this test, Halon 1301 was discharged from the modular ceiling spreaders located above the cabin aisle, rather than from a separate disperser inside the lavatory. The lavatory door was opened in order to make the lavatory interior as readily accessible to agent discharge as possible, and all fuselage exits were closed. The test results indicated that fire protection in an open lavatory, as might occur in an unattended aircraft, was provided by agent dispersers outside the lavatory; however, for sustained lavatory protection, agent must be strategically dispensed from within the lavatory.

Halon 1301 was continually measured at 15 locations in the LHS lavatory (table 3). All sampling line inlets were located at possible ignition/fire areas and, as such, were concealed from view and shielded from agent discharge streamlines. Each sampling-line access hole to a hidden measurement location was taped over to prevent agent ingress by that route. The only measurement locations impervious to an adequate and sustained concentration of agent were those behind the sidewall liner (GA-2A #1-4), where only a trace of Halon 1301 was detected shortly after discharge activation (table 3). An extinguishing concentration of 5 percent was attained at the remaining locations, except inside the fluorescent light fixture and at the top of the paper towel dispenser where the concentration peaked at slightly over 4 percent. In contrast to the unshielded cabin areas where a peak concentration was usually attained in less than 10 seconds, the peak concentration in the lavatory occurred anywhere from 2 to 458 seconds. After the agent concentration peaked off, a very small decay was experienced for the remainder of the test, and the concentration at 10 minutes was generally 4 to 5 percent, except at the two highest locations where a greater decay was evidenced.

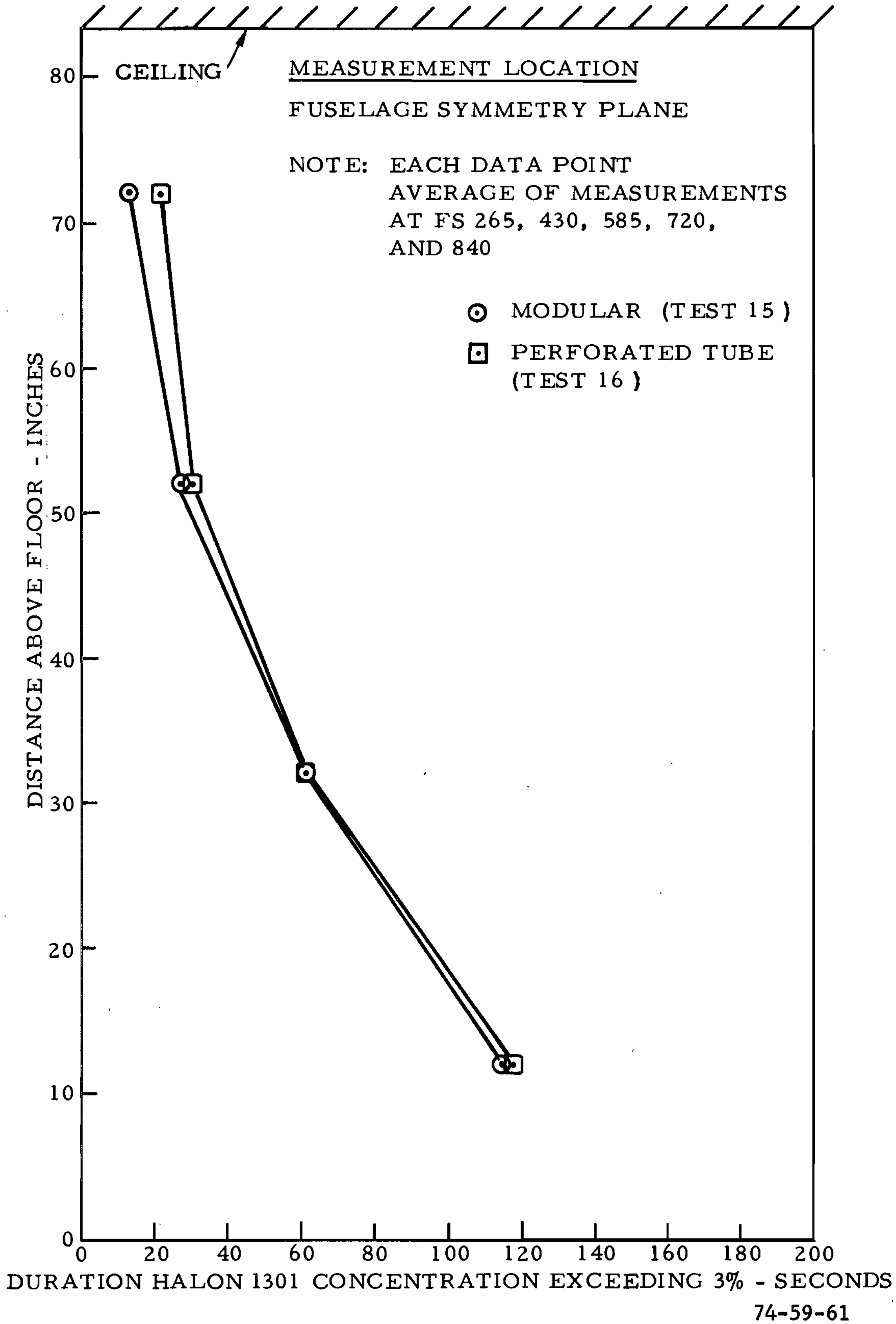


FIGURE 61. COMPARISON OF AVERAGE VERTICAL HALON 1301 PROFILES FOR THE MODULAR (TEST 15) AND PERFORATED TUBE (TEST 16) SYSTEMS WHEN ALL LHS EXITS ARE OPEN AT TIME OF DISCHARGE ACTIVATION

TABLE 3. HALON 1301 PROTECTION AT POTENTIAL IGNITION AND FIRE AREAS IN THE LHS LAVATORY (DOOR OPEN) FOR THE MODULAR SUPPRESSION SYSTEM (TEST 17)

Gas Analyzer	Sampling Location	Distance Above Floor (Inches)	Peak Concentration		Time To Reach 5 Percent Conc. (sec)	Conc. At 10 Minutes (Percent)
			Percent	Time (sec)		
GA-2 #1	Near electrical relay under sink.	24	6.2	118	35	4.8
GA-2 #2	Behind toilet paper roll.	28	5.7	38	30	4.4
GA-2 #3	Inside cabinet adjacent to paper towel disposer.	7	6.4	58	51	4.6
GA-2 #4	Behind tissue dispenser.	34	6.2	178	56	5.0
GA-2 #5	Near flushing motor switch.	6	7.5	38	7	6.0
GA-2 #7	Bottom of paper towel disposer (half filled).	2	5.8	238	129	4.6
GA-2 #8	Top of paper towel disposer (half filled).	12	4.2	458	-	4.2
GA-2 #9	Between towels in paper towel dispenser.	78	6.7	38	17	0.2
GA-2 #11	Behind electric razor outlet.	39	5.3	58	44	3.6
GA-2 #12	Inside fluorescent light fixture.	43	4.1	177	-	3.9
GA-2A #1	Upper location between insulation and fuselage skin.	76	2.0	2	-	0
GA-2A #2	Upper location between insulation batts.	76	1.7	3	-	0
GA-2A #3	Lower location between insulation and fuselage skin.	42	0.5	2	-	0
GA-2A #4	Lower location between insulation batts.	42	4.6	5	-	0
GA-2A #8	Above overhead ceiling.	85	15.1	5	< 1	0

The concentration histories at five locations inside the lavatory are shown in figure 62. The shape of the individual curves is an indication of the penetration of agent to the measurement location. It appears that some Halon 1301 was discharged directly into the area above the lavatory ceiling; also, a reasonably rapid buildup was experienced near the flushing motor switch terminals, behind the electric razor outlet and inside the paper towel dispenser. A more gradual buildup occurred at the bottom of the half-filled paper towel dispenser. The data demonstrates the ability of Halon 1301 to continually seek, penetrate, and inert inaccessible areas of the lavatory; however, in order to provide a more rapid and sustained agent concentration, the agent disperser should be located inside the lavatory.

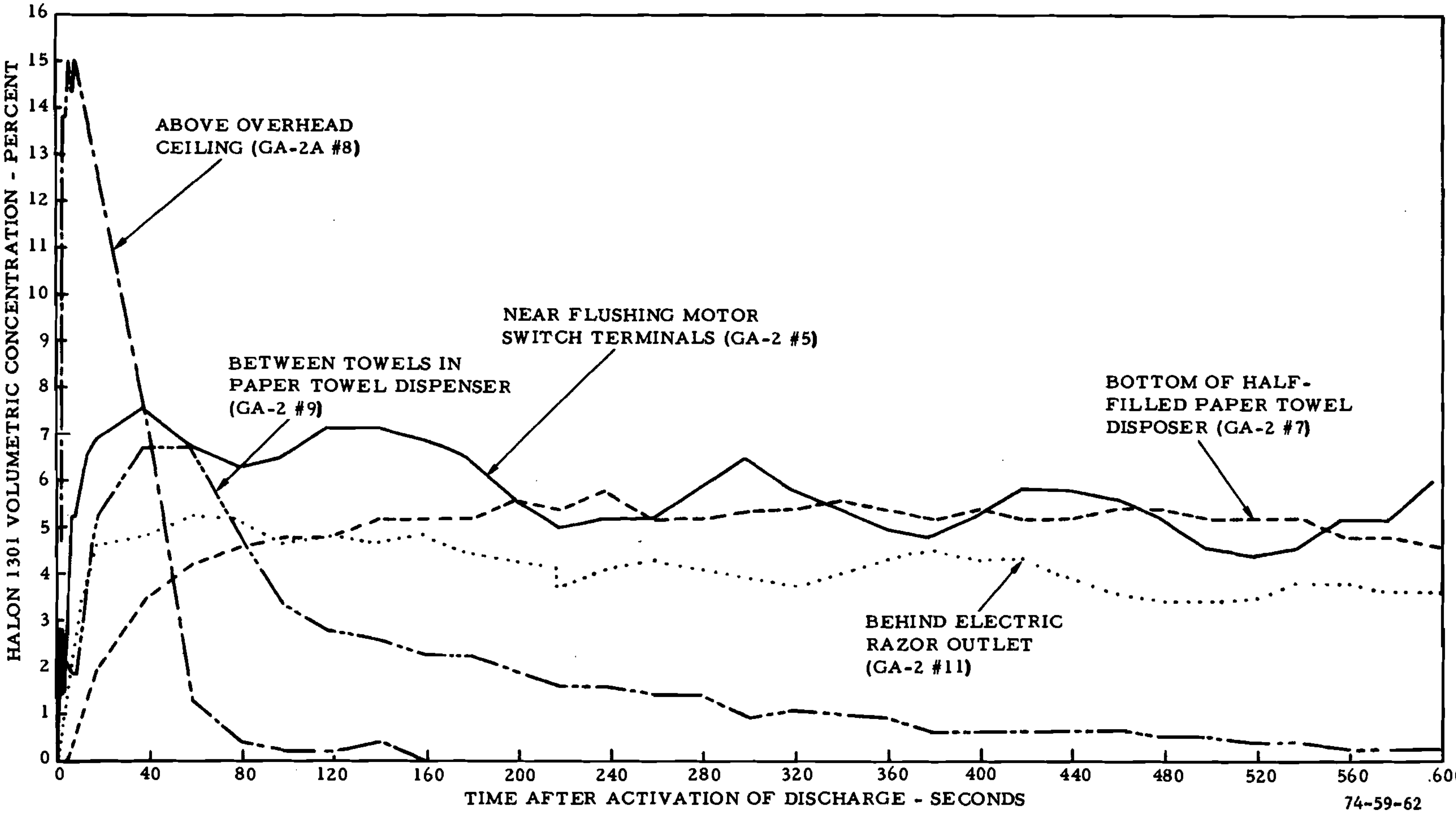


FIGURE 62. HALON 1301 CONCENTRATION-TIME PROFILES AT POTENTIAL IGNITION AND FIRE AREAS IN THE LAVATORY (DOOR OPEN) FOR THE MODULAR SUPPRESSION SYSTEM (TEST 17)

SUMMARY OF RESULTS

The results obtained from Halon 1301 fire-suppression system tests under no-fire conditions in a DC7 passenger cabin are as follows:

WITH DOORS AND EXITS CLOSED.

1. Halon 1301 was dispersed and completely mixed throughout the passenger cabin airspace in a matter of 3 to 4 and 20 to 25 seconds after activation of discharge for the modular and perforated tube systems, respectively.

2. A transient overshoot of Halon 1301 concentration above the 5-percent design value was experienced during discharge at measurement locations proximate to the agent disperser and in the direct path of agent discharge streamlines, or where the cabin cross section became abruptly small (e.g., the hallway between lavatories).

3. The Halon 1301 concentration in a horizontal plane at a particular height above the floor is uniform throughout the cabin following agent dispersion and mixing.

4. The reduction in cabin air temperature associated with the vaporization of Halon 1301 is proportional to the concentration of Halon 1301 for a period of time after discharge until heat transfer from interior surfaces becomes significant.

5. Duplicate tests utilizing the modular system demonstrated that the Halon 1301 concentration histories were virtually identical for both tests at a number of measurement locations.

6. After the agent discharged from the modular spreaders was completely mixed throughout the cabin, a stratified vertical Halon 1301 profile had developed where the concentration at the ceiling was about 2 percent lower than that at the floor. The difference in Halon 1301 concentration between the floor and ceiling increased progressively during the test as agent leaked from the cabin.

7. A peak discharge overpressure of 0.033 and 0.0025 psig was measured for the modular and perforated tube systems, respectively, inside the closed cabin with sealed air vents.

8. Failure to extinguish a mantle lantern over a period of 10 minutes produced an irritating atmosphere within the cabin from the decomposition products of the agent, which prevented entry by test personnel.

9. Leakage of Halon 1301 from the cabin was always first manifested by a reduction in the agent concentration at the ceiling.

10. Fifty-five percent of the initial quantity of Halon 1301 leaked out of the closed cabin over a period of 10 minutes. Seventy-one percent of the leaked Halon 1301 was apparently lost through small seams in the main floor structure, and twenty-nine percent through the air vents.

11. The contents of the Halon 1301 storage containers of the modular and perforated tube systems were expelled in about 2.5 and 19 seconds, respectively. However, for each system, the bulk of the agent in the liquid phase is released much faster than the above respective times.

12. The foam covering around the perforated tube excessively impeded the discharge of Halon 1301, to the extent that rapid cabin mixing was inhibited and intolerably high Halon 1301 concentrations and large reductions in cabin temperature were produced below the tube during discharge.

13. Halon 1301 discharged from the foam-covered perforated tube eventually increased to concentrations sufficient for fire protection at all cabin measurement locations except near the ceiling.

14. For all systems, Halon 1301 concentration histories were essentially the same at locations symmetrically opposite to the fuselage vertical symmetry plane.

15. The peak noise level in the closed cabin measured during discharge from the modular and perforated tube systems was 120 and 94 dB (A), respectively. The attenuation of noise provided by the foam covering was negligible.

16. Removal of the foam from around the perforated tube dispenser substantially increased the extinguishing efficiency of the perforated tube system without affecting the rate of agent discharge or appreciably, the noise level.

17. Fire protection in the closed cabin at the ceiling occurred earlier during agent discharge and was longer lasting with the modular system than with the perforated tube system, and became nonexistent when a foam covering was placed around the discharge tube.

18. Removal of the foam surrounding the perforated tube eliminated the intolerably high Halon 1301 concentration and reduced air temperature beneath the tube experienced when the foam was in place.

19. At peripheral cabin locations, an extinguishing concentration was established more rapidly with the modular system than with the perforated tube system, and the difference in time was more pronounced at sites shielded from the discharge streamlines.

20. At the head level of a seated passenger at cabin stations where the greatest transient overshoot in Halon 1301 concentration was experienced during discharge for each system, the concentration and resulting drop in air temperature was larger with the perforated tube system than with the modular system.

21. A more uniform vertical Halon 1301 profile was established and maintained for the test duration with the modular system than with the perforated tube system.

22. Substantial obscuration was observed inside the cabin for about a 1-minute period when the ambient relative humidity exceeded 70 percent; however, except near the ceiling for several seconds, no obscuration occurred at relative humidities of about 50 percent or less.

23. Inadequate lavatory fire protection was provided by either system when the lavatory door was closed (agent access was via a small louvered vent); however, a significant increase in Halon 1301 buildup occurred to an extinguishing level when the door was open, and the potential fire protection was more complete with the modular system.

24. An objectionable odor was detected during utilization of the modular system that varied in intensity in different tests and was attributed to the products of the pyrotechnic reaction that actuated discharge and accompanied the discharged Halon 1301 into the cabin.

WITH EXITS OPEN.

25. The Halon 1301 concentration at any particular level above the floor when all the left-hand side (LHS) emergency exits were opened was uniform throughout the cabin except adjacent to the galley door where the concentration was slightly lower than elsewhere.

26. The reduction in agent concentration within the cabin resulting from the opening of all LHS exits, beyond the loss obtained with the open galley door alone, was less than that corresponding to the increase in leakage area.

27. With the modular system, a slightly lower Halon 1301 concentration was measured near the ceiling adjacent to exits opened before discharge; this difference was absent in the lower half (approximately) of the cabin.

28. Generally, the loss in inerting protection when the cabin exits were opened before discharge as compared to after discharge was minor.

29. A slight and minor increased duration of inerting was evidenced with the perforated tube system compared to the modular system when all the LHS exits were opened before discharge.

30. An extinguishing concentration of Halon 1301 was achieved with the modular system at a number of potential ignition and fire areas in an open lavatory; however, the time required to attain this concentration at some locations was unacceptably long.

CONCLUSIONS

Based upon the results obtained from this test program, it is concluded that:

1. A Halon 1301 dispensing system (similar to the modular system tested) utilizing air turbulence created by rapid agent discharge to insure effective mixing will provide excellent distribution of agent without exceeding the limits of human tolerance for the agent or for the noise, reduced temperature, or cabin overpressure resulting from agent discharge.

2. As may be expected, open exits result in a more rapid loss of agent. However, under such adverse conditions, a reasonably good degree of inerting protection will still result for a representative evacuation period.

3. A perforated tube type of dispensing system provides a slow discharge and poor distribution of agent in the cabin compared to a modular system.

4. The foam-covered perforated tube system is unsuitable for use in occupied areas because of the potential danger from high agent concentrations and large reductions in air temperature directly below the tube during discharge.

5. Thermocouple data can provide a simple method of estimating the Halon 1301 concentration for a short time interval following discharge when heat transfer effects from cabin surfaces are negligible compared to the reduction in cabin air temperature associated with vaporization of the agent.

6. The application of Halon 1301 from ceiling dispensers above the aisle penetrated and eventually inerted inaccessible areas of an open lavatory; however, in order to provide a more rapid extinguishing concentration and continuously safeguard the lavatory (door closed), a disperser should be located inside the lavatory.

7. A quantity of Halon 1301, corresponding to a 5-percent by volume concentration in air, released inside a cabin or other enclosure will produce substantial visual obscuration lasting about 1 minute when the ambient relative humidity is over 70 percent; however, no obscuration occurs when the relative humidity is about 50 percent or less.

RECOMMENDATIONS

Based upon the experimental evaluation under no-fire conditions of candidate Halon 1301 systems for passenger-cabin fire protection, it is recommended that:

1. Future studies of Halon 1301 fire protection systems for a passenger cabin utilize the modular dispensing concept for the main cabin and include a separate disperser for the lavatory.

2. Further experimental investigations and development of Halon 1301 cabin fire suppression systems be carried out to further define the extent of protection such a system can provide and the potential hazard to occupants from its use under actual fire conditions.

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APPENDIX

CALIBRATION OF AGENT CONCENTRATION RECORDERS FOR THE MEASUREMENT OF HALON 1301

Before initiating the evaluation of the candidate Halon 1301 fire protection systems, a calibration was conducted of the two agent concentration recorders (models GA-2 and GA-2A) used for measuring the concentration of Halon 1301. A detailed description of this gas analysis instrumentation is contained in references 22 and 23.

Basically, the Halon 1301 concentration in air is determined at each of the 24 channels by measuring the differential pressure across a porous plug during constant volumeric flow and constant temperature of the drawn sample. For these conditions, the pressure drop is a function of the porosity of the plug (constant), the viscosity, molecular weight and ratio of specific heats of the gas sample. A sensitive transducer measures the pressure drop and the electrical output is transmitted to an oscillograph recorder. The calibration setup and procedure was similar to that described in reference 27. Figures A-1 and A-2 are photographs of the NAFEC calibration setup.

A sample manifold allowed for simultaneous calibration of all 12 channels from an agent concentration recorder during each calibration test run. The recorders were calibrated using the following Halon 1301 in air volumetric concentration mixtures provided by the DuPont Company: 2.63, 5.24, 9.46, 12.90, and 19.20 percent. The calibration mixture was first passed into a flexible Teflon bag at atmospheric pressure. The calibration mixture in the Teflon bag was then simultaneously sucked through the three gas analyzer units (four channels per unit) by a vacuum pump after first passing through the sample manifold. The procedure utilized for each test is outlined below.

1. Close "Fill" and "Air" valves and open "Gas" valve.

2. Start vacuum pump and operate until the Teflon sampling bag is deflated.

3. Close "Gas" valve and open "Fill" valve to partially fill sampling bag with calibration gas.

4. Close "Fill" valve and open "Gas" valve.

5. Start vacuum pump and operate for 5 minutes. This step is a purging of the sampling bag with the calibration gas mixture to be utilized. Close "Gas" valve and stop vacuum pump.

6. Open "Air" valve.

7. Start oscillograph and run off about 24 inches of recording paper at a speed of 1 inch per second.

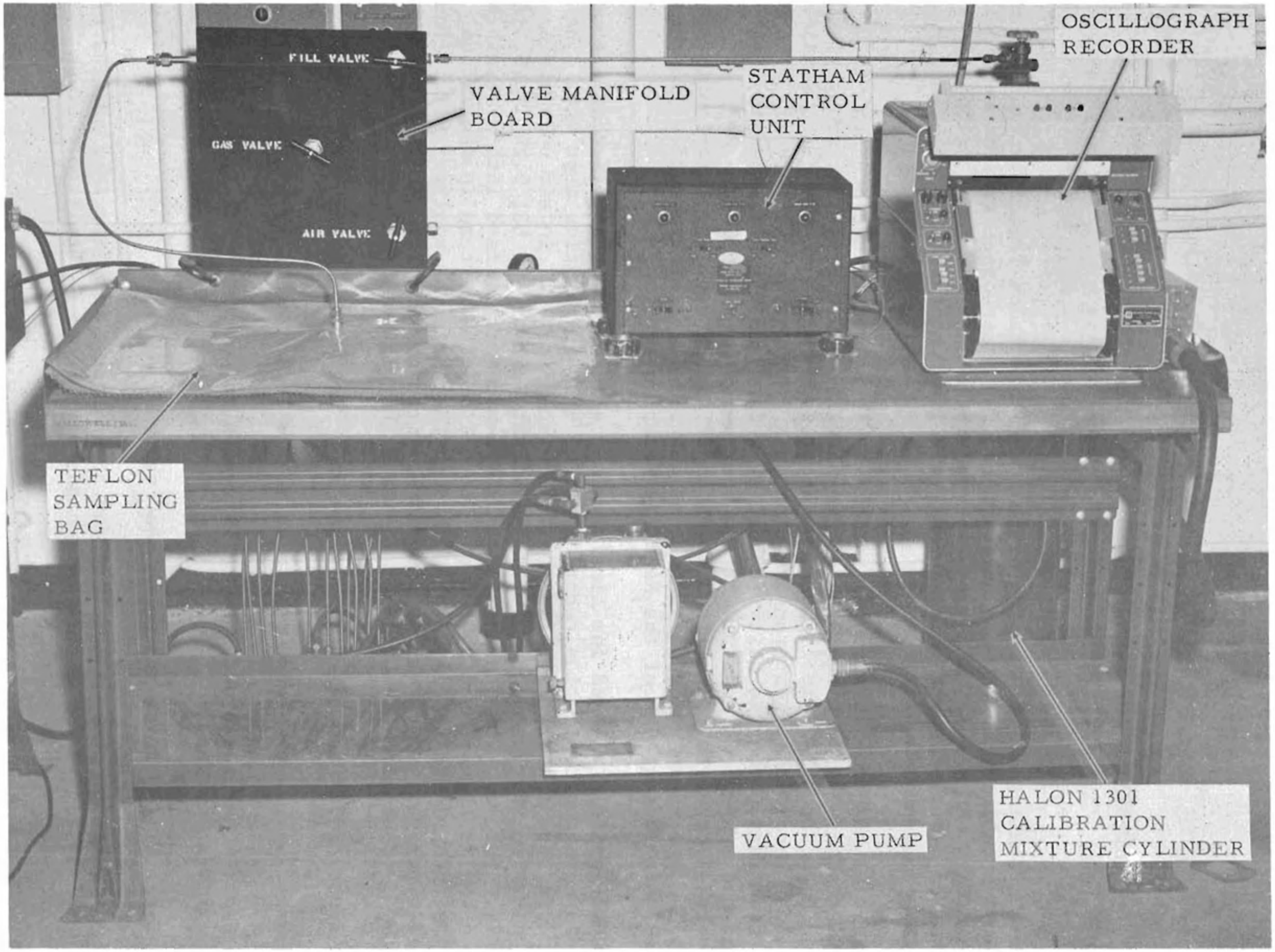

FIGURE A-1. FRONT VIEW OF HALON 1301 CONCENTRATION RECORDER CALIBRATION TEST SETUP

74-59-A-1

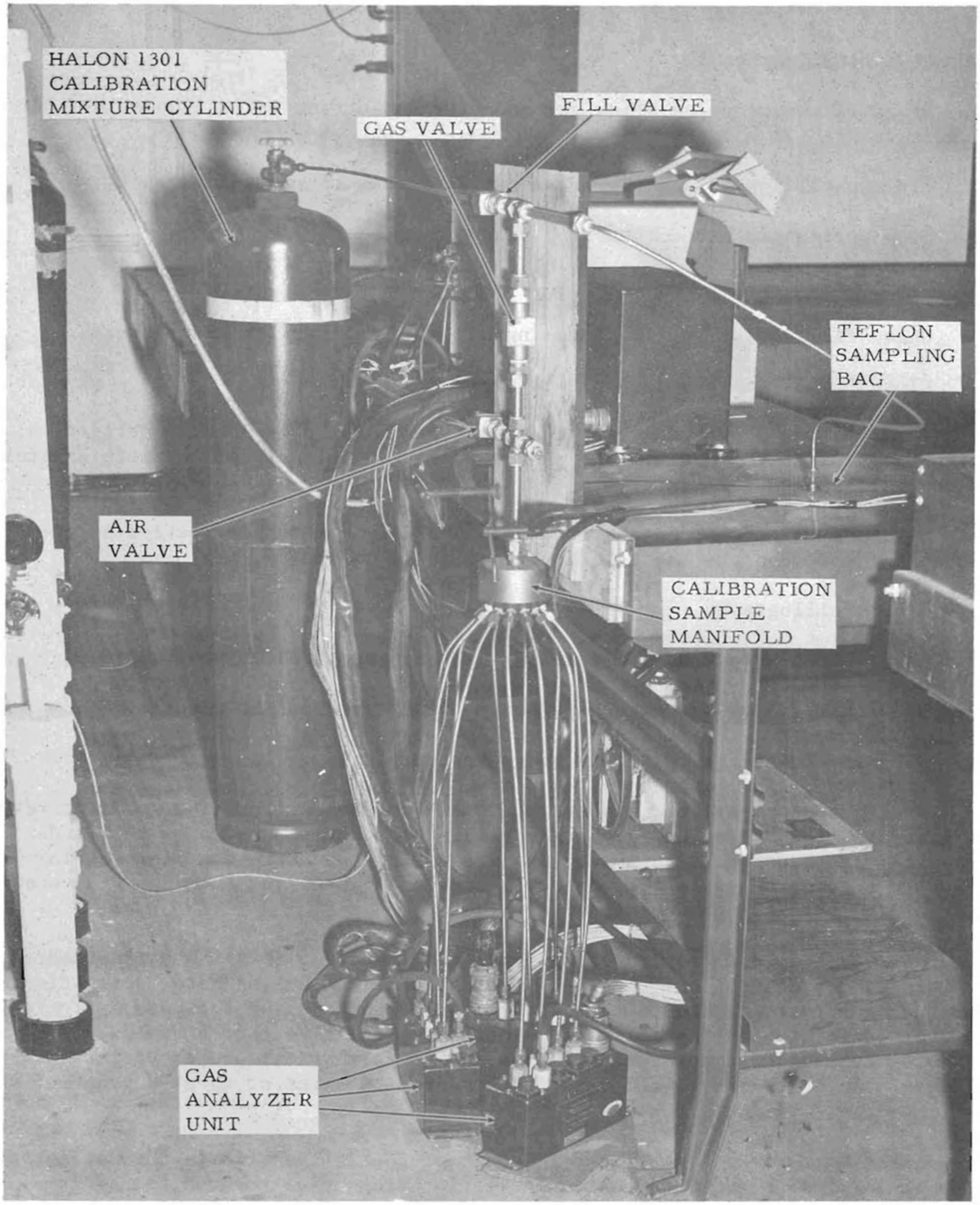

FIGURE A-2. SIDE VIEW OF HALON 1301 CONCENTRATION RECORDER CALIBRATION TEST SETUP

8. Stop oscillograph.

9. Start vacuum pump and allow galvonometer deflection for a 100-percent air mixture to stabilize.

10. Start oscillograph and run off about 24 inches of recording paper.

11. Stop oscillograph and then stop vacuum pump.

12. Close "Air" valve.

13. Open "Fill" valve to fill sampling bag with calibration gas mixture.

14. Close "Fill" valve and open "Gas" valve.

15. Start vacuum pump and await stabilization of the galvonometer deflection, which occurs when the gas mixture passing through the analyzer consists entirely of the calibration gas mixture.

16. Start oscillograph and operate until the galvonometer deflection becomes unstable (near when the bag is almost completely deflated).

17. Stop oscillograph.

18. Stop vacuum pump when the sampling bag becomes completely deflated.

19. Open "Air" valve and allow system to purge for about 10 minutes.

20. Identify the recording paper trace appropriately.

This test procedure was repeated three times for each calibration gas mixture. Purging of the sampling bag with the calibration gas mixture to be utilized (step 5) was found to be necessary when using low concentration mixtures in order to prevent a possible erroneous measurement resulting from the presence of residual gas from the previous test.

Previously, the concentration of an extinguishing agent in air was reported as a "relative concentration," which is the ratio of the galvonometer deflection for the agent/air mixture to that for the pure agent, using the pure-air galvonometer deflection as the reference line. The "relative concentration" is directly related to agent concentration in air, a physical property of the mixture. In this report, all data is presented in terms of agent concentration expressed on a volumetric basis.

A calibration curve was generated for each of the 24 channels in the concentration range of zero to 20 percent. The calibration curve related the agent concentration to the instrument reading, which was expressed in terms of the galvonometer deflection for the mixture (MD) divided by that for pure air (AD), or MD/AD. A least squares power-law curve fit of the triplicate test data for each of the five certified calibration gas mixtures was used. Figure A-3 shows a typical calibration curve.

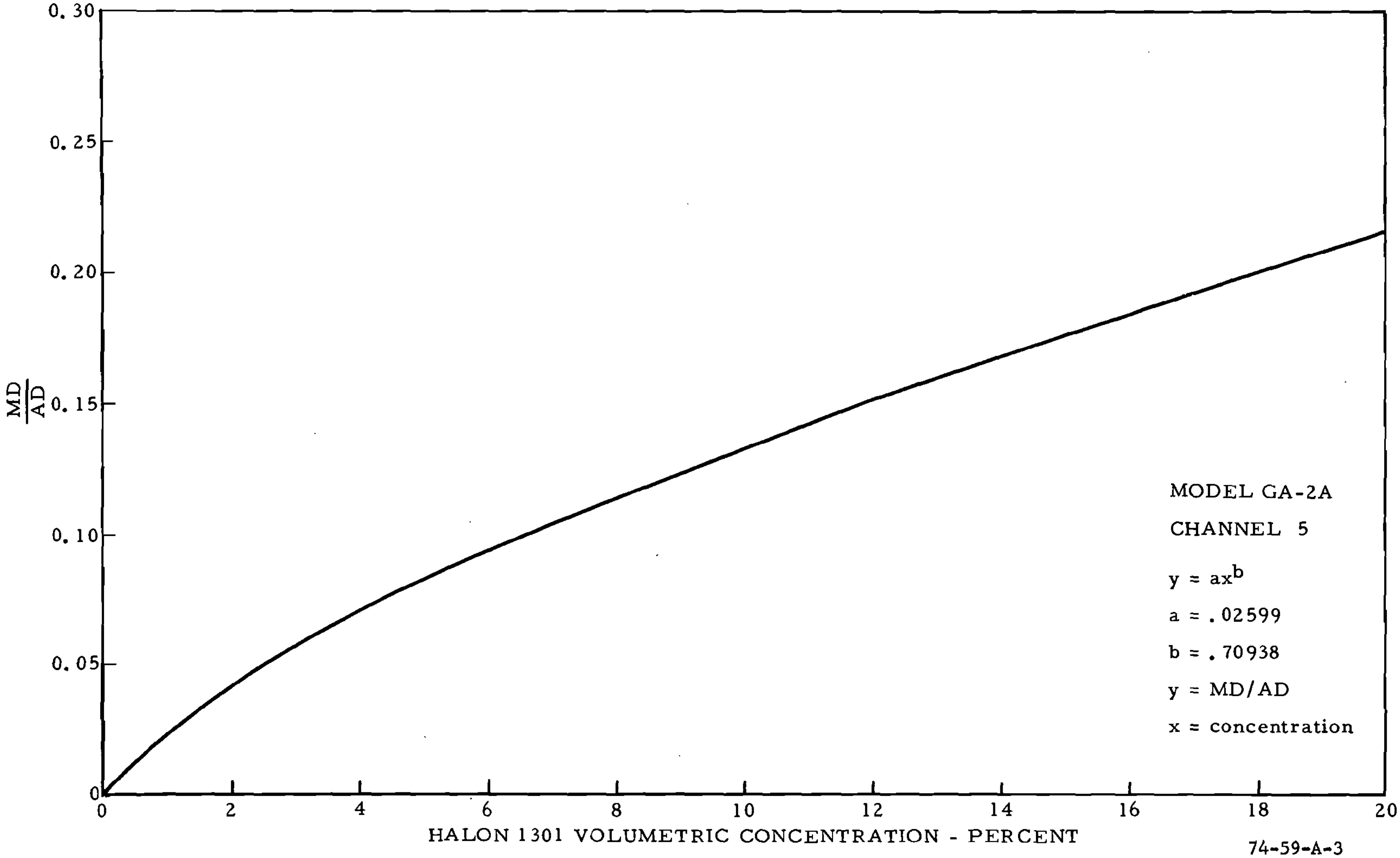

FIGURE A-3. TYPICAL HALON 1301 CALIBRATION CURVE FOR HALON 1301 CONCENTRATION RECORDER