

Richard Hill
SSEL6

EVALUATION OF A HALON 1301 SYSTEM FOR POSTCRASH AIRCRAFT INTERNAL CABIN FIRE PROTECTION

Richard Hill
Paul N. Boris



OCTOBER 1976

FINAL REPORT

Document is available to the public through the
National Technical Information Service
Springfield, Virginia 22151

Prepared for

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research & Development Service
Washington, D.C. 20590

1. Report No. FAA-RD-76-132		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle EVALUATION OF A HALON 1301 SYSTEM FOR POSTCRASH AIRCRAFT INTERNAL CABIN FIRE PROTECTION				5. Report Date October 1976	
				6. Performing Organization Code	
7. Author(s) Richard Hill and Paul N. Boris				8. Performing Organization Report No. FAA-NA-76-21	
				10. Work Unit No. (TRAIS)	
9. Performing Organization Name and Address Federal Aviation Administration National Aviation Facilities Experimental Center Atlantic City, New Jersey 08405				11. Contract or Grant No. 181-521-000	
				13. Type of Report and Period Covered Final May 1975 - December 1975	
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Systems Research and Development Service Washington, D.C. 20591				14. Sponsoring Agency Code	
				15. Supplementary Notes	
16. Abstract <p>The use of a Halon 1301 fire-suppression system was evaluated in regard to increasing escape time during a ground crash situation with an internal cabin fire. Tests were conducted in a DC7 fuselage varying the exit configurations, and fire size at agent discharge. Smoke, temperature, carbon monoxide, oxygen, and Halon 1301 levels were continuously monitored during the tests at various locations throughout the cabin. A sampling system for collecting hydrogen fluoride (HF), Halon 1301's primary decomposition product, was used. Samples at four locations were taken every 30 seconds, for 5 minutes after discharge. The use of a curtain to inhibit the spread of HF was also examined.</p> <p>The results indicated that in order to minimize the HF concentrations, the fire should be extinguished when its size is as small as possible, and prior to the opening of cabin exits. In order to reduce HF concentrations, the cabin exits should be opened as soon as the fire is extinguished. The use of a curtain to partition the cabin greatly reduced the spread of HF from the fire zone to the protected section.</p> <p>Test results also indicated that a system malfunction causing Halon 1301 concentrations less than those needed to extinguish a fire could produce very high HF levels. Conversely, a deep-seated fire produced relatively small HF levels.</p>					
17. Key Words Aircraft Fires, Fire Extinguishers, Aviation Safety, Halon 1301, Gas Analysis, Cabin Fires Fire Management Systems			18. Distribution Statement Document is available to the public through the National Technical Information Service, Springfield, Virginia 22151		
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 35	22. Price

PREFACE

The authors of this report express special recognition and appreciation to Dr. J. Spurgeon and R. Feher, of the Fire Protection Branch at NAFEC, for their effort in developing the hydrogen fluoride (HF) sample recovery and analysis technique, and for demonstrating the applicability of the procedure for full-scale tests.

TABLE OF CONTENTS

	Page
INTRODUCTION	1
Purpose	1
Background	1
Halon 1301 Characteristics and Hazards	1
DESCRIPTION OF TEST EQUIPMENT	3
Test Article	3
Instrumentation	6
TEST DESCRIPTION	7
TEST RESULTS	7
Exits Closed	7
Exits Closed, Opened After Discharge	15
Deep-Seated Fire (Exits Closed)	15
System Malfunction	19
Detection	19
SUMMARY OF RESULTS	21
CONCLUSIONS	22
REFERENCES	23
APPENDIX	

LIST OF ILLUSTRATIONS

Figure		Page
1	Fuselage Configuration	4
2	Curtain Configuration	5
3	Temperature and Smoke Levels with Exits Closed	10
4	Hydrogen Fluoride Levels with Exits Closed	11
5	Temperature and Smoke Levels with Exits Open	13
6	Hydrogen Fluoride Levels with Exits Open	14
7	Smoke Level Comparison: Exits Open, Closed, and Exits Opened after Discharge	16
8	Hydrogen Fluoride Level Comparison: Exits Open, Closed, and Exits Opened after Discharge	17
9	Hydrogen Fluoride Level from Deep-Seated Fire	18
10	Hydrogen Fluoride Level - Normal System Operation vs. System Malfunction	20

LIST OF TABLES

Table		Page
1	Effects of Hydrogen Fluoride on Humans	2
2	Test Matrix	8

INTRODUCTION

PURPOSE.

This program was designed to assess the extended survivability aspects provided by the introduction of Halon 1301 for fire suppression into an aircraft passenger compartment and to determine the levels of hydrogen fluoride (HF) that can be expected from its decomposition. The tests were limited to the extinguishment of an internal fuselage fire.

BACKGROUND.

This report covers the first of a two-phase effort involving Halon 1301 fire suppression/extinguishment in aircraft passenger compartments. The first phase involves internal fires, and the second, external fires.

The cargo compartments of some present-day wide-body airplanes are protected with Halon 1301, and their interiors are protected with portable automatic Halon 1301 systems during assembly. The use of Halon 1301 to protect passenger compartments can have its advantages and disadvantages, as will be discussed later in this report.

Internal aircraft fires can develop in flight, when an airplane is occupied or unoccupied on the ramp, or in a postcrash situation. Data show that most internal in-flight fires in occupied sections are easily detected by occupants at an early stage and usually extinguished without incident. The use of a Halon 1301 dispensing system could prove its merit by limiting damage during ramp fires, which have occurred during servicing or even while the aircraft was left unattended.

The third type, an internal fire as the result of a crash, is of primary concern in this investigation. An uncontrollable internal fire is perhaps a specialized case of the postcrash fire situation, since the general concern is likely to be in keeping the external fire from penetrating the fuselage. However, the internal fire is a real threat, and it has resulted in fatalities in an otherwise survivable crash situation.

HALON 1301 CHARACTERISTICS AND HAZARDS.

Halon 1301 is a colorless, odorless gas, which is easily liquified under pressure. The vapor pressure at 70° F is 200 pounds per square inch gauge (psig), the critical temperature and pressure being 152.6° Fahrenheit (F) and 575 psig, respectively. Chemically, Halon 1301 is bromotrifluoromethane (BrF₃), and has a molecular weight of 148.93 (reference 1).

The National Fire Protection Association (NFPA) guidelines (reference 2) stated that Halon 1301 can be safely used in occupied areas in concentrations up to 7 percent, but further recommends that occupant exposures to Halon 1301 concentrations of 7 percent or less not exceed 5 minutes. The volume of agent in the majority of tests described herein was 5 percent.

At elevated temperatures (approximately 900° F), Halon 1301 breaks down, with the decomposition products including HF, hydrogen bromide (HBr), free bromine, and carbonyl halides. The decomposition products of Halon 1301 pose much more of a threat to human habitation than does the agent itself. The reported approximate lethal concentration (ALC) using white rats for decomposed Halon 1301 ranges from 2,300 parts per million (ppm) (reference 3) to 14,000 ppm (reference 4). From previous data, it was determined that the major decomposition product of Halon 1301 was HF (reference 3) and that the ALC for decomposed Halon 1301 and for HF were close enough to assume that the toxicity of the decomposed Halon was due to the HF concentration (reference 3). Therefore, only HF concentrations were determined from the decomposing Halon 1301.

HF is an irritant in low concentrations, but can lead to serious injury or death in larger amounts. Table 1 (reference 5) shows some of the effects on humans of the acid gas.

TABLE 1. EFFECT OF HYDROGEN FLUORIDE ON HUMANS

<u>Hydrogen Fluoride Concentration (ppm)</u>	<u>SYMPTOMS</u>
3-5	Redness of skin, irritation of nose and eyes after 1 week's exposure
32	Irritation of eyes and nose
60	Itching of skin, irritation of breathing tracks from exposure of 1 minute
120	Conjunctival and respiratory irritation, just tolerable for 1 minute
50-100	Dangerous to life after a few minutes.

DESCRIPTION OF TEST EQUIPMENT

TEST ARTICLE.

All tests were conducted in a furnished DC7 fuselage, modified and instrumented to meet test requirements. The fuselage was located indoors to eliminate weather effects, e.g., wind, rain, etc., which could introduce variables, making comparison of different configurations more difficult.

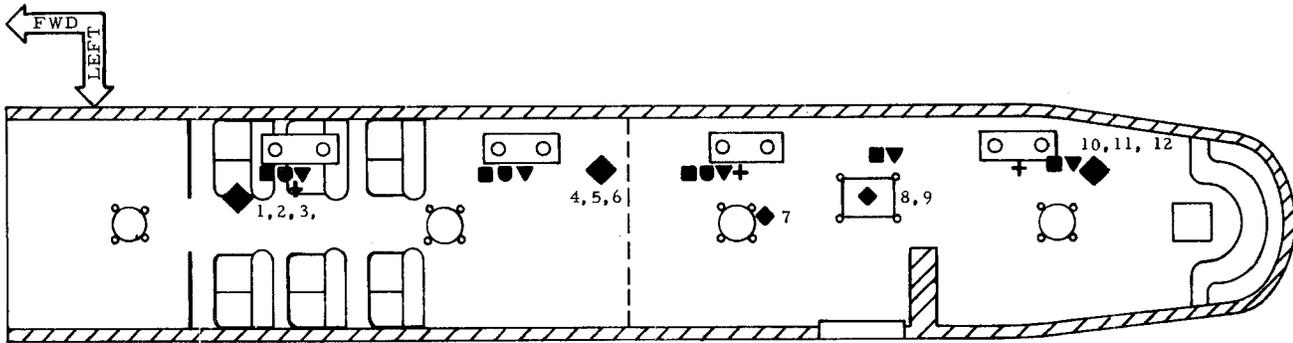
Figure 1 illustrates the test article and the location of the cabin air sampling stations, thermocouples, and fire load. In all cases, except for the deep-seated fire, the fire load consisted of two 3-foot by 3-foot by 4-inch slabs of untreated (i.e. for fire retardation) open-cell urethane seat foam with a density of 1.5 lb/ft³. The foam slabs were positioned horizontally, one atop the other, in a metal frame. Ignition was effected by an electric spark and 4 ounces of aviation gasoline placed under the fire load. The fire load was located just inside the left rear entrance door forward of the galley. In order to preclude the introduction of extraneous factors due to burning cabin materials, and to preserve the test article for the number of tests that were to be conducted, the seats in the immediate vicinity of the fire load were removed. In addition, aluminum sheet metal was placed on the floor in the fire load area and an insulation blanket secured to the ceiling. The latter consisted of ceramic fibers sandwiched between thin sheets of stainless steel.

Figure 1 also shows the location of the four Halon 1301 dispensing modules. (The details of the system are described more completely in reference 6.) The discharge of Halon 1301 was accomplished by the remote activation of a squib, which fractured a frangible disc allowing the module to expel its contents into the fuselage. Usually, each bottle was charged with 20 pounds (lbs) of agent in order to produce a 5-percent concentration within the 4,000-cubic-foot compartment.

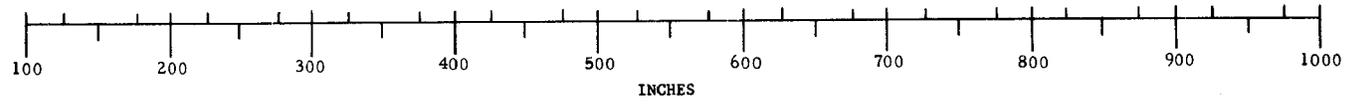
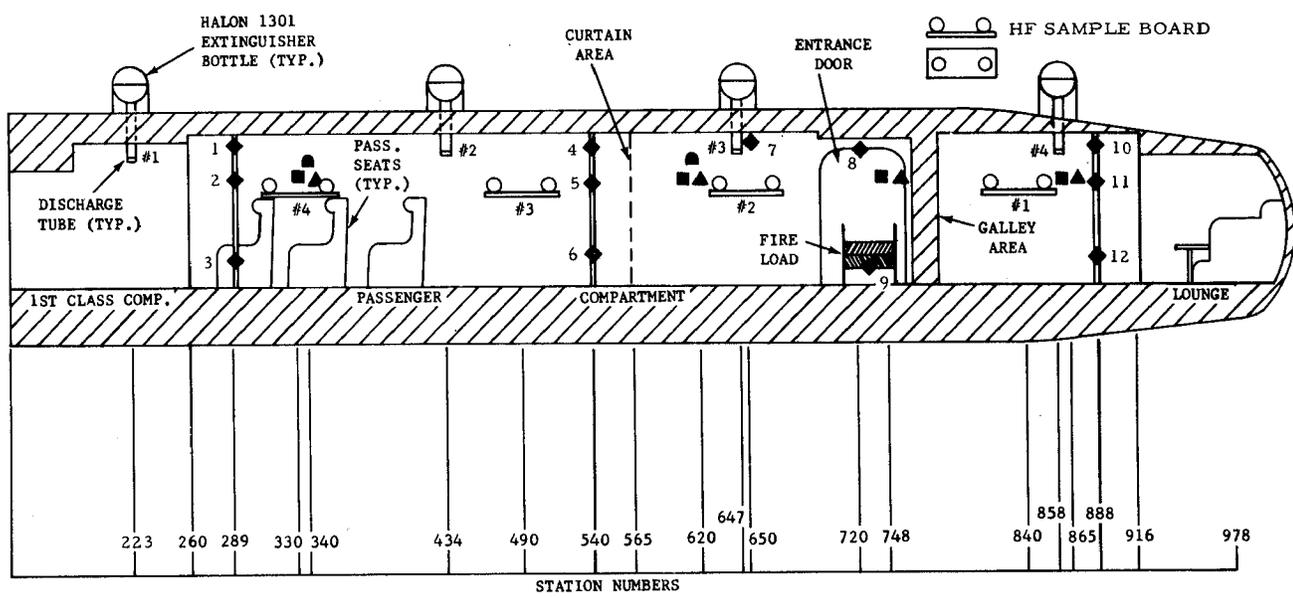
To characterize each test environment, cabin air was continuously sampled for smoke density (light transmission), Halon 1301, oxygen (O₂), and carbon monoxide (CO) at stations described in figure 1. Temperatures at various locations were also recorded. A vacuum line placed on the floor of the fuselage served to evacuate the vacuum bottles used in taking cabin air samples which were later analyzed for HF. Refer to the appendix for further information regarding the HF sampling system and analysis.

A closed circuit video monitor located outside the fuselage at a window near the fire load provided confirmation of ignition, and a visual record from ignition to extinguishment.

For several tests, a Kynol[®] curtain was installed at fuselage station 565 which served as a barrier between the fire and nonfire zones. Figure 2 is a photograph of the curtain installation.

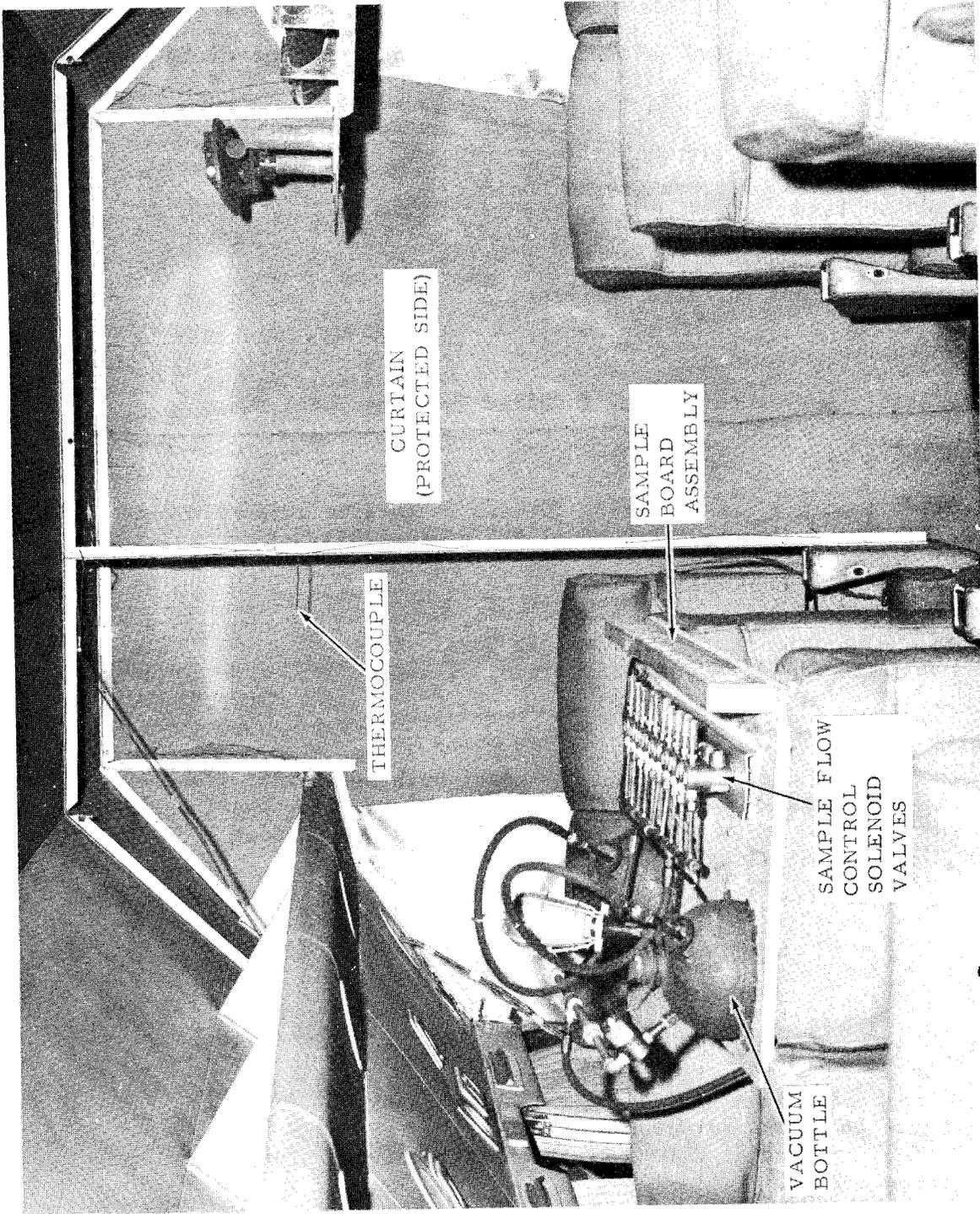


- + - H. F. SAMPLE POINT
- ◆ - THERMOCOUPLES
- - O₂ & CO. SAMPLE POINTS
- ▲ - 1301 SAMPLE POINTS
- - SMOKE SAMPLE POINT
- - HF SAMPLE BOARD



76-21-1

FIGURE 1. FUSELAGE CONFIGURATION



76-21-2

FIGURE 2. CURTAIN CONFIGURATION

INSTRUMENTATION.

The instrumentation utilized in monitoring and recording the various parameters was as follows:

Oxygen:

Beckman Model 715 Process Oxygen Monitor

Carbon Monoxide:

Beckman Model 864 Infrared Analyzer

Halon 1301:

Mine Safety Appliance Company Infrared Analyzer Model 300

Hydrogen Fluoride:

Fluoride specific ion electrode (Orion: range 1 to 10^{-6} moles/liter F ion)
Ion Analyzer (Orion research model 801/digital-pH)

Temperature:

Chromel-Alumel thermocouple wire, 22 gage
Thermo Electric Chromel-Alumel Ceramo, 32 gage

Smoke:

Weston Model 856 photocell and PR3 light bulb monitoring light transmission over a distance of 1 foot. (This smoke meter was located external to the fuselage, with a sample continuously drawn through a 3/4-inch sample line and the meter.)

Video:

Sony Model AV-3400 Videorover®
Sony Model CVM-192U Monitor

Recorders:

Esterline Angus Model D2020 digital chart recorder (for O₂, CO, Halon 1301, and temperature)
Esterline Angus Model L11025 strip chart recorders (for smoke and temperature).

All instrumentation was calibrated prior to each test, and all lag times for the sampling systems were incorporated when reducing the data (lag times for all the sample systems were less than 5 seconds).

TEST DESCRIPTION

The tests conducted under this investigation were divided into two major categories, exits closed and exits open. The only exception was test No. 211, in which the exits were opened after Halon 1301 discharge. This was intended to simulate evacuation following impact. The Halon 1301 system was manually activated at a predetermined temperature indicated by a thermocouple mounted either on the ceiling adjacent to the Halon 1301 discharge nozzle (TC#7) nearest the fire or directly over the fire (TC#8). In most cases, 165° F was used as the agent discharge temperature, since it represented a commonly used temperature in thermal-type detection systems.

Although two major test categories were noted, there were variations within each category. Table 2 lists the tests conducted and the variations thereof. In tests 212 and 215, a Kynol curtain was positioned between the fire and non-fire zone to determine its effectiveness in isolating the protected portion of fuselage from the hazards of the burning fire load and Halon 1301 decomposition products. Test 210 was conducted using a DC7 passenger seat (latex foam) instead of the urethane foam, thus creating a deep-seated fire. Tests 213 and 214 were conducted without Halon 1301 and were intended to establish a baseline, i.e., to determine what environmental conditions would exist without Halon 1301 extinguishment. The fire was allowed to burn until it was obvious (temperatures well over 400° F) that tolerance limits were met or exceeded. At this time, the cabin was flooded with CO₂ to extinguish the fire.

A number of tests not included in the table 2 test matrix were conducted with and without Halon 1301, to determine HF background and sample collection efficiency. Refer to the appendix for further information regarding these tests.

TEST RESULTS

EXITS CLOSED.

Four tests were conducted with the exits closed. Tests 205 and 206, both of which involved Halon 1301 extinguishment, differed in that the fire was allowed to reach a higher intensity (i.e. burn longer) for test 205 before the Halon 1301 was discharged. Test 215 configuration was similar to test 205 except that a Kynol curtain was installed at fuselage station 565, resulting in a compartment cabin. Note also, that the temperature at discharge (see table 2) is higher than that of test 205 and was due largely to the rapid temperature rise due to the curtain. For test 214, the fire load was allowed to burn until it was obvious that human tolerances had been met or exceeded, at which point the cabin was flooded with CO₂. Thus, a baseline was established against which survivability aspects provided by Halon 1301 extinguishment would be assessed.

TABLE 2. TEST MATRIX

<u>Test No.</u>	<u>1301</u>		<u>Temperature¹</u> (°F)	<u>Curtain</u>		<u>Exits</u>		<u>Exits</u> <u>Closed</u>	<u>Remarks</u>
	<u>Yes</u>	<u>No</u>		<u>Yes</u>	<u>No</u>	<u>Open</u>	<u>Closed</u>		
205	X		165	X				X	
206	X		105	X				X	
207	X		165	X			X		
208	X		105	X			X		
209	X		140	X			X		
210	X		70	X				X	Deep-seated fire
211	X		165	X			X		Exits open after 1301 discharge
212	X		165		X		X		
213		X	-		X		X		2 fire load extinguished with CO ₂
214		X	-		X			X	2 fire load extinguished with CO ₂
215	X		220					X	

¹ Temperature at 1301 discharge nozzle: Fuselage Sta. 650.

² CO₂ extinguishment after human tolerances were exceeded.

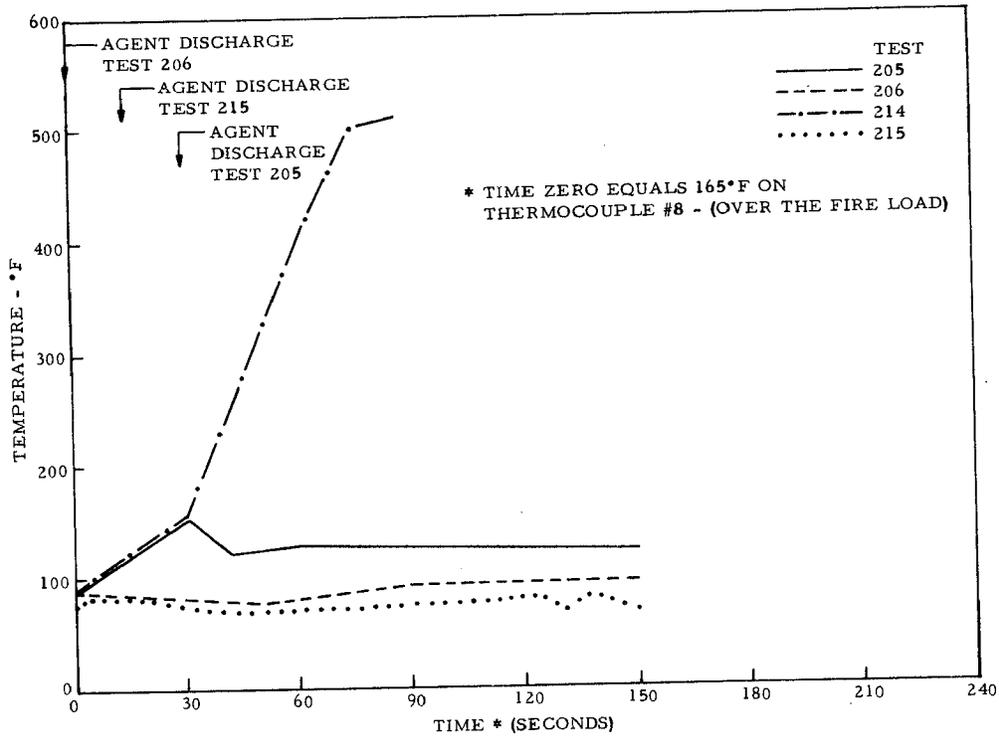
When comparing the forward smoke and temperature levels of the four tests with exits closed, it can be seen that the use of Halon 1301 greatly diminishes the increase in temperature and smoke levels in the cabin, as compared to what would have been there had the agent not been used. Figure 3A shows the temperature in the forward portion of the cabin for the four tests, which are typical of all tests conducted in this program. Subsequent to Halon 1301 extinguishment, the temperatures dropped to near ambient in a short time. When a curtain was used to partition the cabin (test 215), the temperature dropped below ambient on the protected side. When no extinguishment was used, the approximate human tolerance level (390° F) was reached in about 90 seconds (reference 2). It can be seen, by comparing test 214 and test 205, that a very significant amount of thermal protection can be provided even when the fire is allowed to go uncontrolled for a time before discharging the Halon 1301.

The smoke levels in the forward section of the fuselage (figure 3B) show the ability of the curtain to inhibit the spread of smoke from the fire side to the protected side. When no curtain was used, even when the fire was detected early (light transmission was 95 percent at discharge for test 206), the smoke level increased significantly after agent discharge, prior to clearing. This decrease in visibility was due, in part, to the disturbance of the upper smoke level by the force of the agent discharge. In addition, the burning fire load probably contributes to the water vapor already present in the cabin air, and the cooling effect of the discharging Halon 1301 may produce a temporary misting (reference 6). In all cases, the use of Halon 1301 provided protection by decreasing the smoke level, compared to when no agent was used.

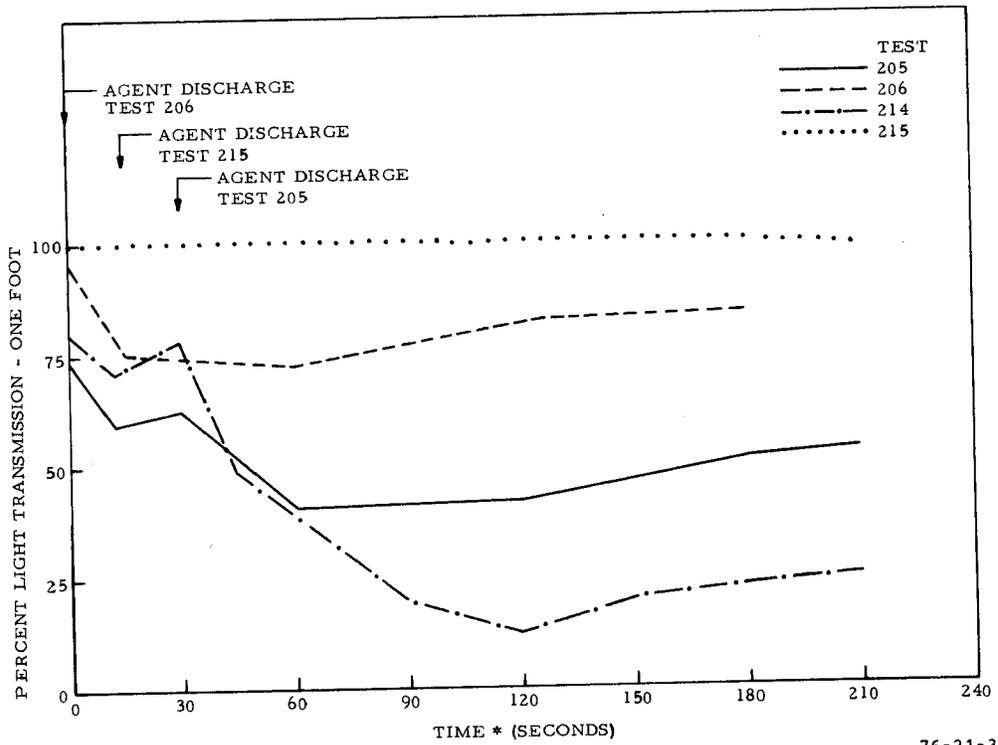
It is apparent from these tests, that early detection and suppression is more important from the standpoint of smoke than heat, since the smoke level is increased for a short time after discharge; whereas, the temperature level immediately drops. This is not to imply that a fire can generally be detected earlier from smoke levels than it can from temperature levels, because proper detection depends on the type of fire.

No noticeable difference in O₂ or CO concentrations was noted because of agent discharge. O₂ remained near 20 percent, and the CO was almost nonexistent. Since in all Halon 1301 tests (except the deep-seated fire) the fire was extinguished, no further reduction in O₂ or increase in CO occurred. Therefore, the amount of protection provided would depend on the type of fire, the amount of O₂ that would have been consumed, and the amount of CO that would have been produced had the Halon 1301 not been used.

Results to this point using Halon 1301 have been favorable; however, decomposition presents the negative aspect of its use. Figure 4A and 4B show the HF levels (the main decomposition product of Halon 1301) at locations near the fire (sample location 2) and forward in the aircraft (sample location 4) for the three Halon 1301 tests with the exits closed. In comparing the two locations, it can be seen that 15 seconds after discharge, the highest concentrations were in the vicinity of the fire, after which the concentration near the fire began to drop and increase forward in the cabin.



A. TEMPERATURE LEVELS (TC #1)



B. SMOKE LEVELS (FORWARD METER)

76-21-3

FIGURE 3. TEMPERATURE AND SMOKE LEVELS WITH EXITS CLOSED

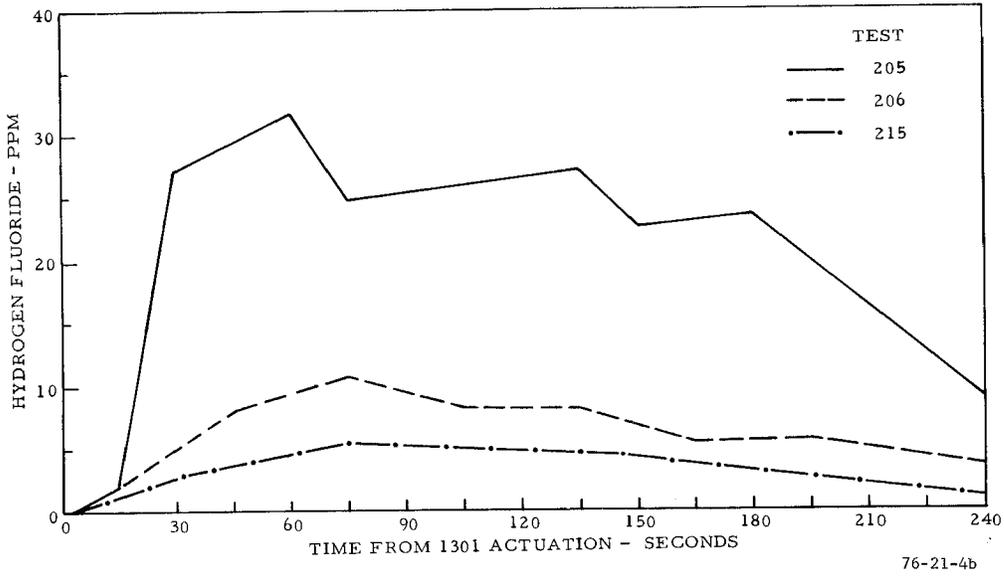
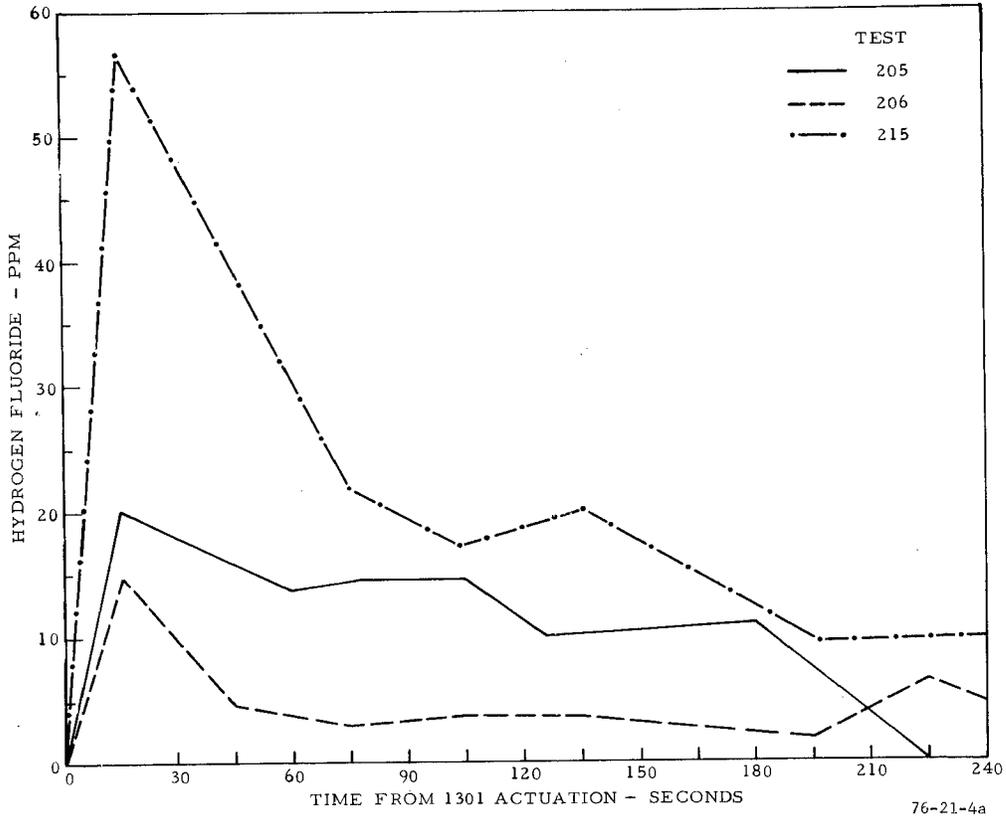


FIGURE 4. HYDROGEN FLUORIDE LEVELS WITH EXITS CLOSED

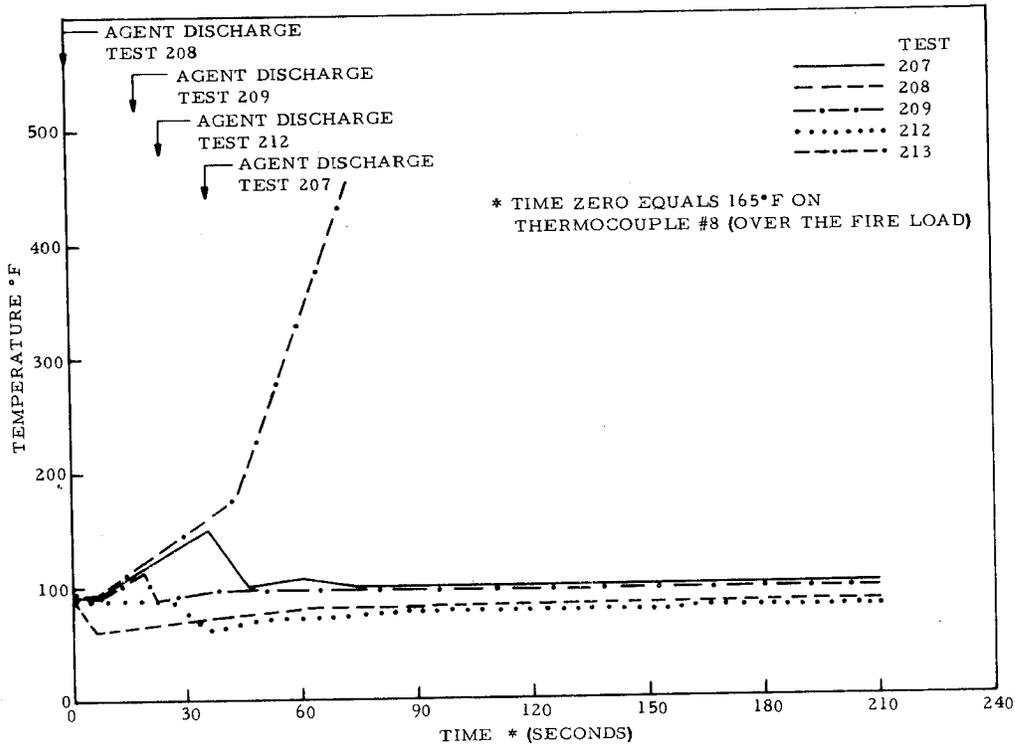
Sixty seconds after discharge, the concentrations for tests 205 and 206 were higher forward in the cabin (sample 4) than near the fire load (sample 2). The peak levels of HF in the forward zone occurred between 60 and 90 seconds after discharge, and the levels remained near the peak concentration for most of the test. Note that approximately three times as much HF was generated when the agent was discharged at the higher environmental temperature (test 205) than at the lower temperature (test 206). An obvious conclusion is that HF output increases with increasing temperature or fire size.

The use of a curtain (test 215) proved very effective in inhibiting the flow of HF from the fire to the nonfire zone. Except for the curtain, the fuselage configuration was essentially the same as for test 205. Sample 2 was on the fire side, and sample 4 was in the protected zone. As shown in figure 4, for test 215, a much higher concentration of HF was measured on the fire side of the curtain than was measured in test 205 (the peak being almost 3 times higher) and the HF concentrations were much lower than those measured in test 205 in the forward section of the fuselage (about one-fifth that of test 205, and about half that of test 206). It should be noted that there was no forced ventilation during these tests.

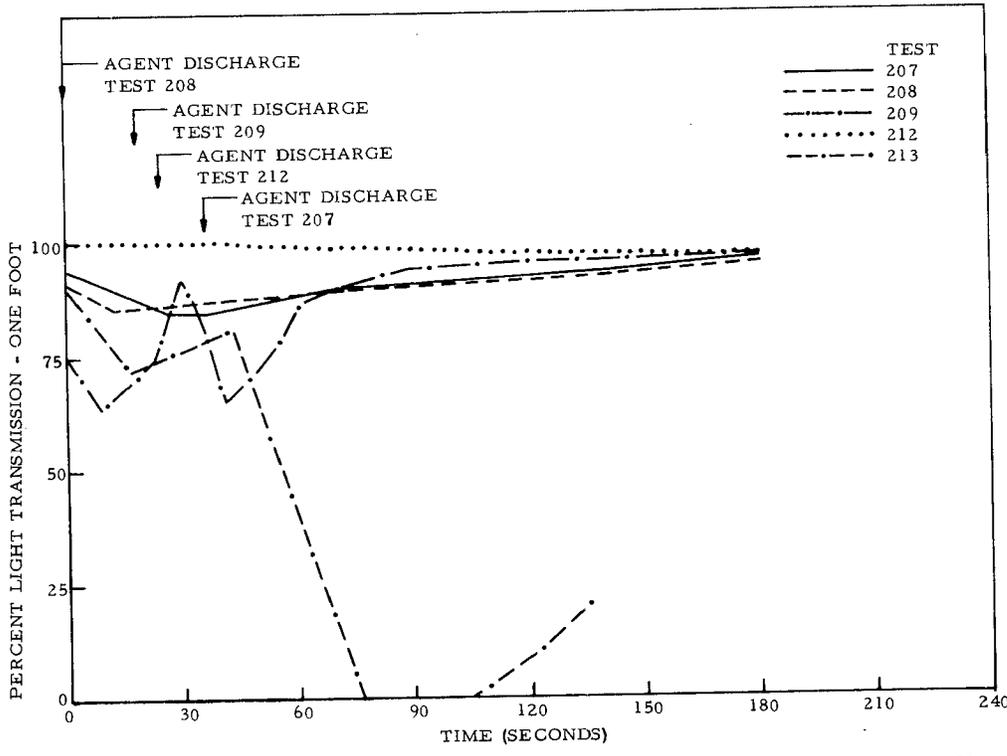
EXITS OPEN. To determine the effects of agent discharge during evacuation conditions, five tests were conducted with the four over-wing exits and rear-entrance door open. Four of the tests were similar to those conducted with the exits closed, with the fifth test (209) being that of an intermediate size fire (temperature reaching 165° F at a point between thermocouple Nos. 7 and 8). Immediately after discharge, the momentary turbulence caused the smoke levels to act erratically, but eventually the general trend was toward increased visibility. In test 207, the agent was discharged when the temperature at the discharge nozzle reached 165° F, test 208's discharge temperature was 165° F over the fire load, and there was no agent discharge during test 213. A curtain was installed for test 212 (same curtain configuration as shown in figure 2), with agent discharge being when a 165° F temperature was reached at the discharge nozzle (refer to table 1).

Figures 5A and 5B show the forward temperature and smoke levels for the exits open condition. The temperature levels and behavior follow very similar patterns as the temperature did with the exits closed. The discharge of the Halon 1301 prevented any further temperature rise. The smoke levels with the exits open varied slightly from that with the exits closed, in that the reduction in visibility was not as pronounced as when the exits were closed. The levels of smoke were less with the exits open than with the exits closed. In all tests with exits open, smoke protection was provided by the discharge of Halon 1301. Furthermore, the use of a curtain to partition the cabin (test 212) increased the effectiveness of the agent in providing smoke protection.

With regard to the decomposition of the Halon 1301 with the exits open, figures 6A and 6B show the levels at sample locations 2 and 4. The peak HF levels were much higher for these tests than with the exits closed (in some



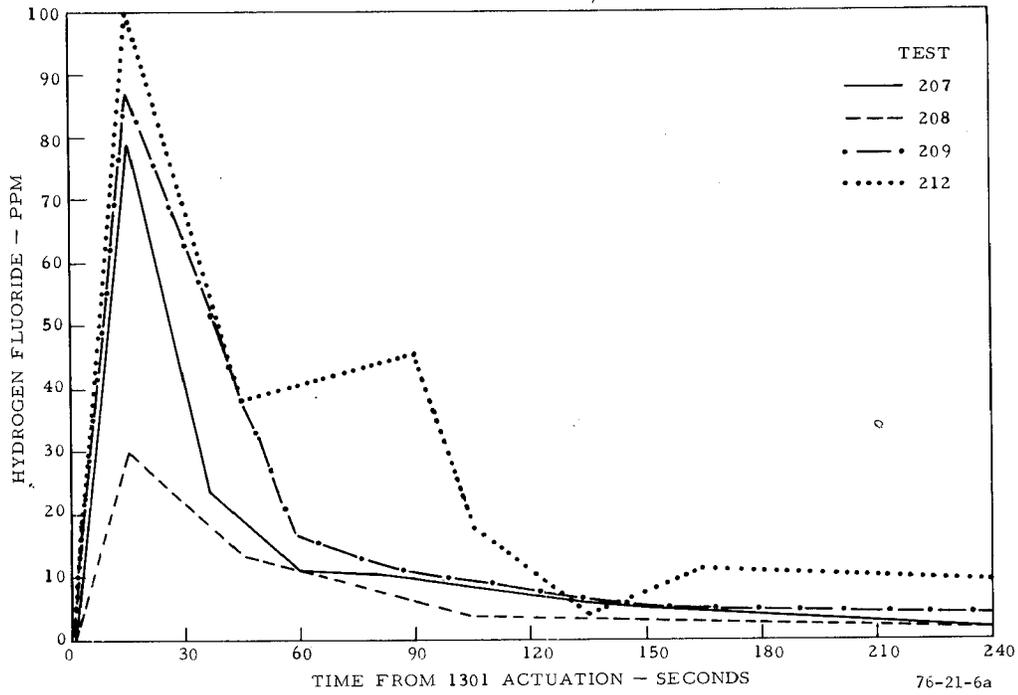
A. TEMPERATURE LEVELS (TC #1)



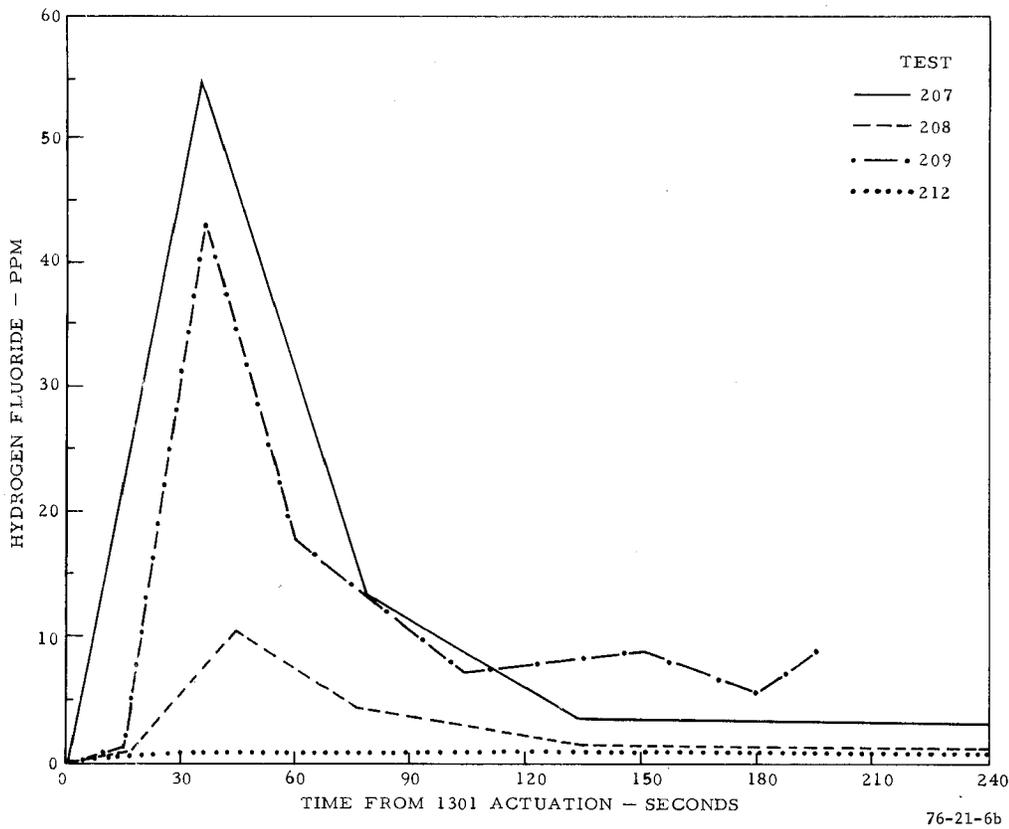
B. SMOKE LEVELS (FORWARD METER)

76-21-5

FIGURE 5. TEMPERATURE AND SMOKE LEVELS WITH EXITS OPEN



A. SAMPLE NO. 2



B. SAMPLE NO. 4

FIGURE 6. HYDROGEN FLUORIDE LEVELS WITH EXITS OPEN

cases twice as great). Although peak concentrations were higher, the concentrations dropped off much quicker than with the exits closed. After 60 to 90 seconds, the HF concentrations were lower with the exits open than with the exits closed. The difference in HF levels, depending on fire intensity, were greater with the exits open than with the exits closed, with a difference of almost six times (at location 4) between agent discharge at 165° F over the fire load and discharge at 165° F at the discharge nozzle. When a curtain was used to partition the cabin, the spread of HF was effectly curtailed with very little HF measured in the protected section. Also, with the curtain installed, the concentration of HF remained higher longer in the fire zone than when no curtain was used.

The probable cause in the high HF level for the exits open was the loss of some of the agent through the exists, thus causing a long extinguishing time. It should also be noted that a fire in an open area is harder to detect with smoke or thermal detectors than in a confined area, since some smoke and heat is lost to the outside atmosphere. Therefore, the intensity of the fire at agent discharge (165° F) could have been greater when the exits were open. (Film and video coverage seemed to indicate that the fire intensities were about equal for exits open or closed configuration.)

EXITS CLOSED, OPENED AFTER DISCHARGE.

From the preceding tests it was shown that in order to reduce peak HF concentrations the exits should be closed, and in order to quickly reduce the HF levels, the exits should be open. Therefore, test 211 was conducted with the exits initially closed, and opened after agent discharge to determine whether the advantages of both test conditions could be combined into one.

Temperature levels followed the trends of previous tests, with a drop noted at agent discharge. The smoke increased after agent discharge (as in previous tests with exits closed), but cleared quicker when the exits were opened (figure 7). The HF levels, as seen in figures 8A and 8B, show that the minimum levels, as a function of time, can be obtained by discharging the agent prior to opening the exits, then immediately opening the exits after discharge. At both station 2 (near the fire load) and station 4 (forward in the cabin), the peak HF concentrations for test 211 were similar to those for test 205. The drop-off in HF concentration resembled that of test 207, and because of the low initial peak concentration, the overall levels for the remainder of the test were considerably lower than in test 207.

DEEP-SEATED FIRE (EXITS CLOSED).

For this test, an original double passenger seat from the DC7 test article was used as the fire load. The Halon 1301 concentration was the same as in previous tests, i.e., 5 percent; all exits were closed. Figure 9 shows the HF levels recorded throughout the cabin during test 210. Although the fire continued to smolder after agent discharge and subsequently throughout the test,

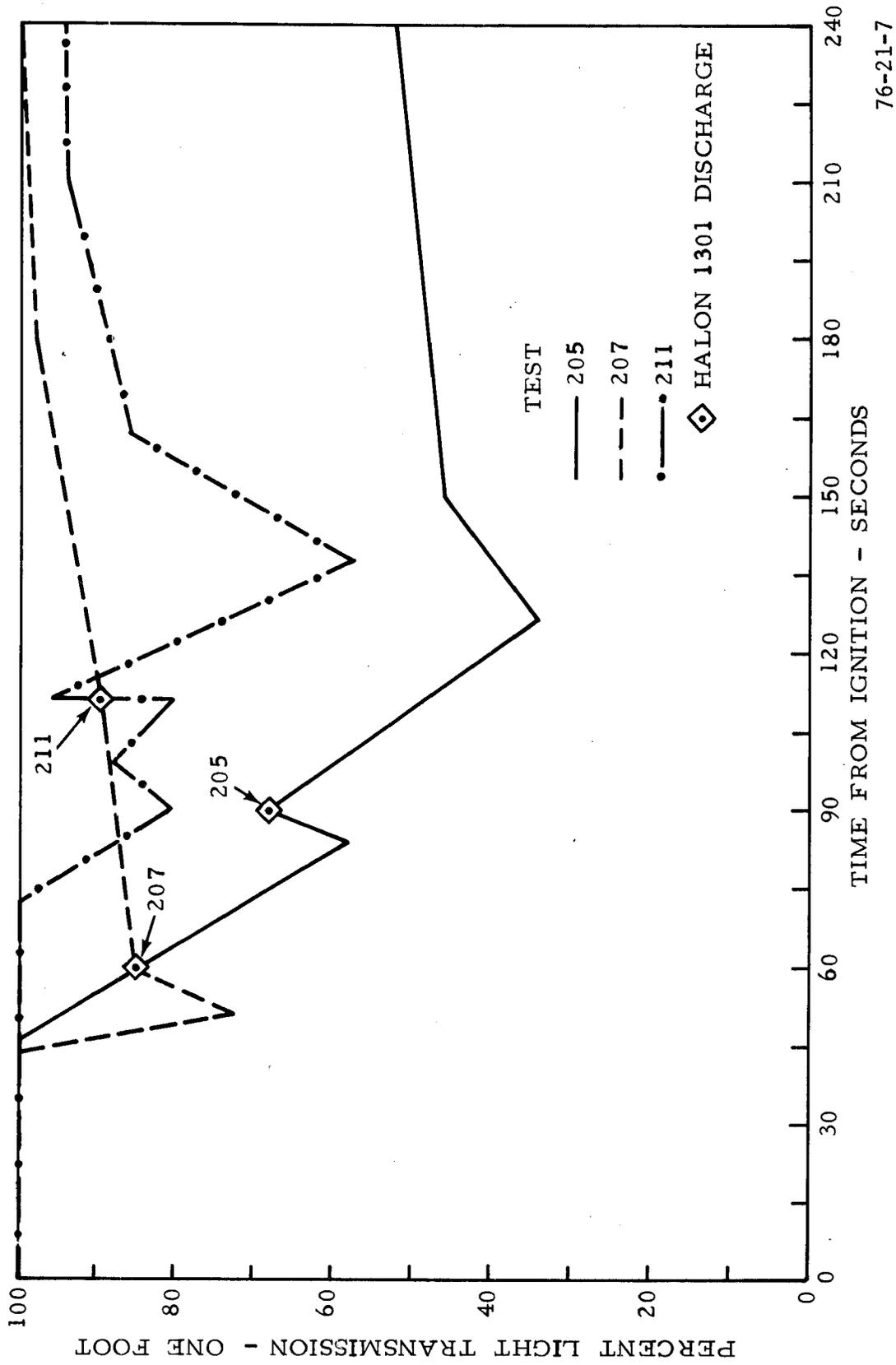
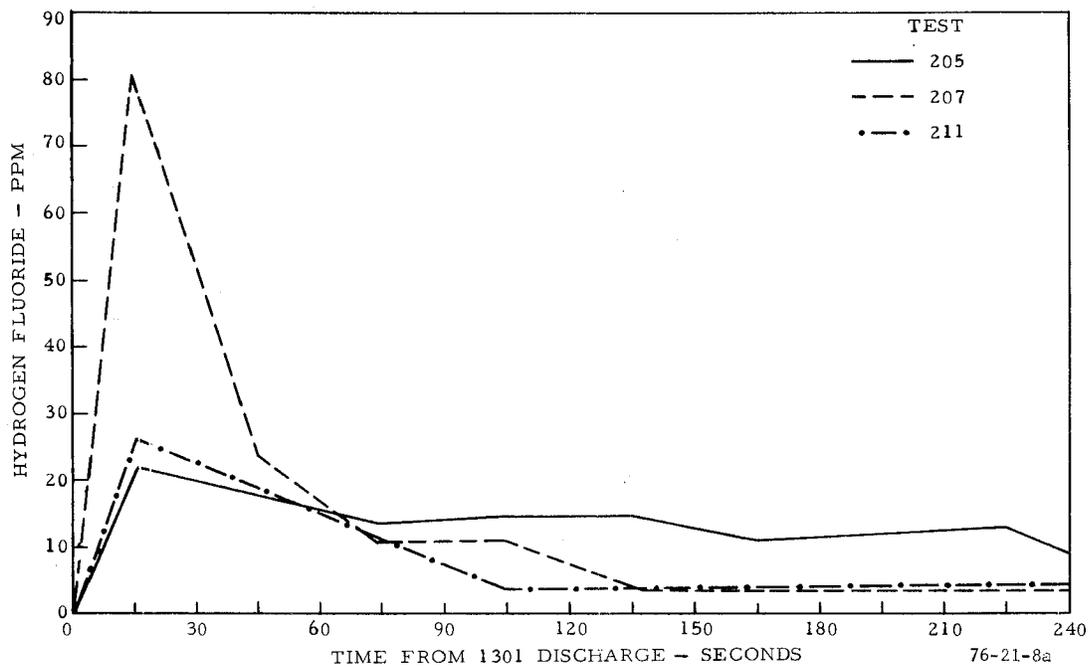
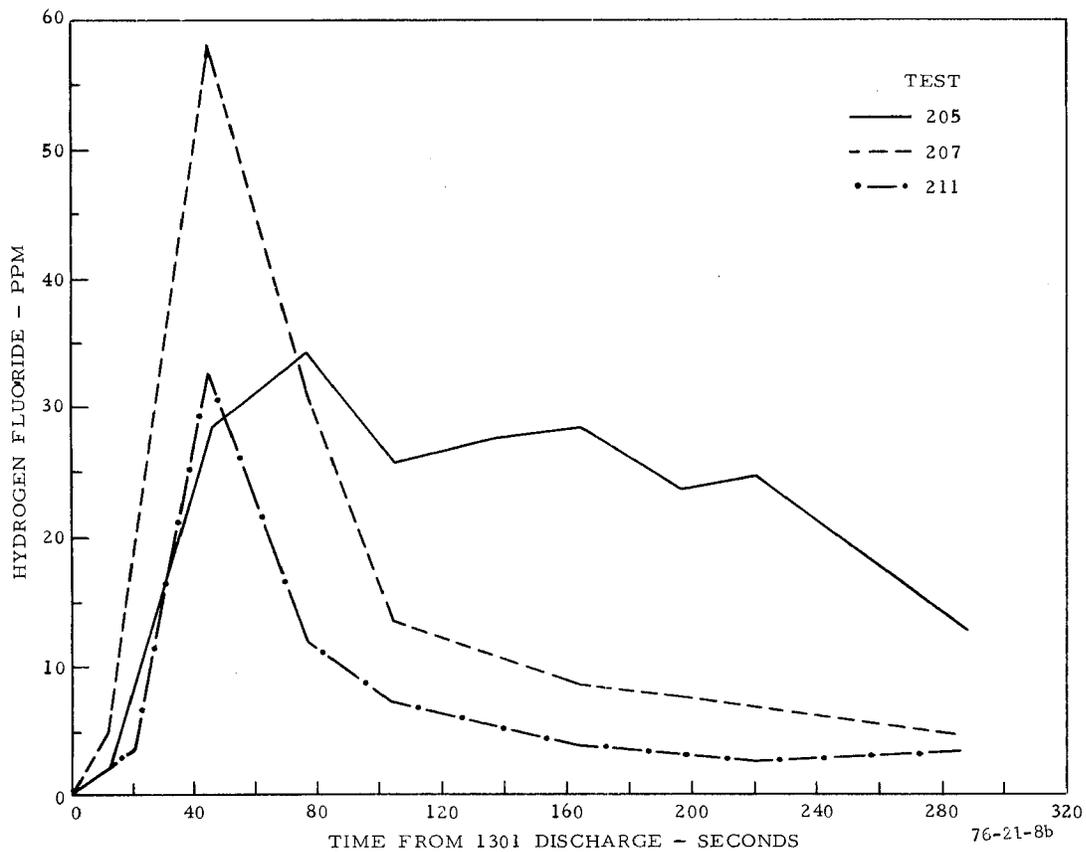


FIGURE 7. SMOKE LEVEL COMPARISON: EXITS OPEN, CLOSED AND EXITS OPENED AFTER DISCHARGE

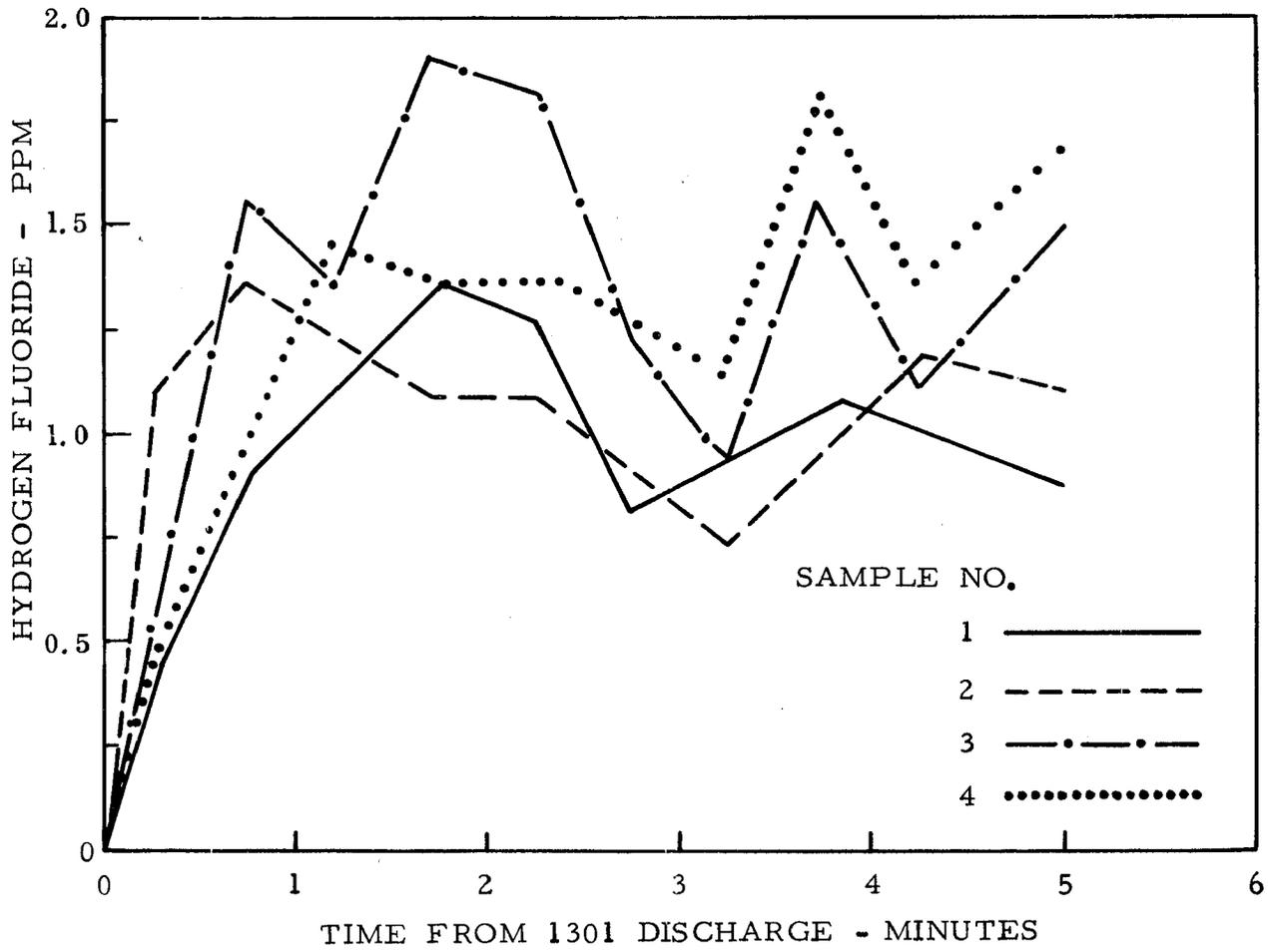


A. SAMPLE STATION NO. 2



B. SAMPLE STATION NO. 4

FIGURE 8. HYDROGEN FLUORIDE LEVEL COMPARISON: EXITS OPEN, CLOSED, AND EXITS OPENED AFTER DISCHARGE



76-21-10

FIGURE 9. HYDROGEN FLUORIDE LEVEL FROM DEEP-SEATED FIRE

very little HF was produced. The temperature of the smoldering material was apparently not sufficient to produce significant decomposition of the agent. Most, if not all, of the HF produced probably resulted from the extinguishment of the small amount of open flaming at the time of agent discharge.

SYSTEM MALFUNCTION.

Since the Halon 1301 system is to be used during a ground crash situation, the possibility of a system malfunction exists. During preliminary testing, a test was conducted using only one of the four Halon 1301 bottles with 20 lbs of agent (1.25 percent Halon 1301 concentration for the cabin). Figure 10 illustrates the comparison of the HF concentration of two comparable test situations except for agent concentration. That column identified as "normal operation" is that HF level at sample location No. 2 of test 205, 60 seconds after discharge. That column identified as "system malfunction" is the HF level taken at the same location in the fuselage, 60 seconds after agent discharge. In both cases, the exits were closed. As can be seen from the results, high levels of HF are generated when the concentration of agent was not sufficient to extinguish the flames. The lower Halon 1301 concentration greatly hindered the fire, but complete extinguishment did not occur. The HF levels increased ten-fold with the simulated system malfunction test, and based on the information in table 1, it could have been a major deterrent for passenger survival.

DETECTION.

The decomposition of Halon 1301 is a function of fire size and temperature, agent concentration, and duration of agent/fire contact. Since the amount of agent and discharge time is fixed by the system, the only variable is the fire size. The type of detection system needed to trigger an extinguishing system before the fire size becomes large enough to produce high levels of HF would depend on the fire load and its burning characteristics. Slow-burning materials could be easily detected by a smoke detector before the fire size became very large, but a fire caused by fuel spray would have to be detected optically or the cabin inerted prior to ignition in order to keep the fire size to a minimum.

From the results of the tests, it can be seen that in order to keep the HF concentrations to a minimum, the fire should be extinguished prior to opening the exits. Therefore, agent discharge should take place at or just after impact, possibly activated by an inertia switch. An inertia switch used in combination with an optical detector could minimize accidental discharge or preclude discharge when no fire is present. In the latter case, an unnecessary discharge of agent could reduce visibility by the condensation of moisture in the air. This type of system could detect and discharge agent, in most cases, before the fire intensity reached the level that produced ceiling temperatures of 165° F over the fire load.

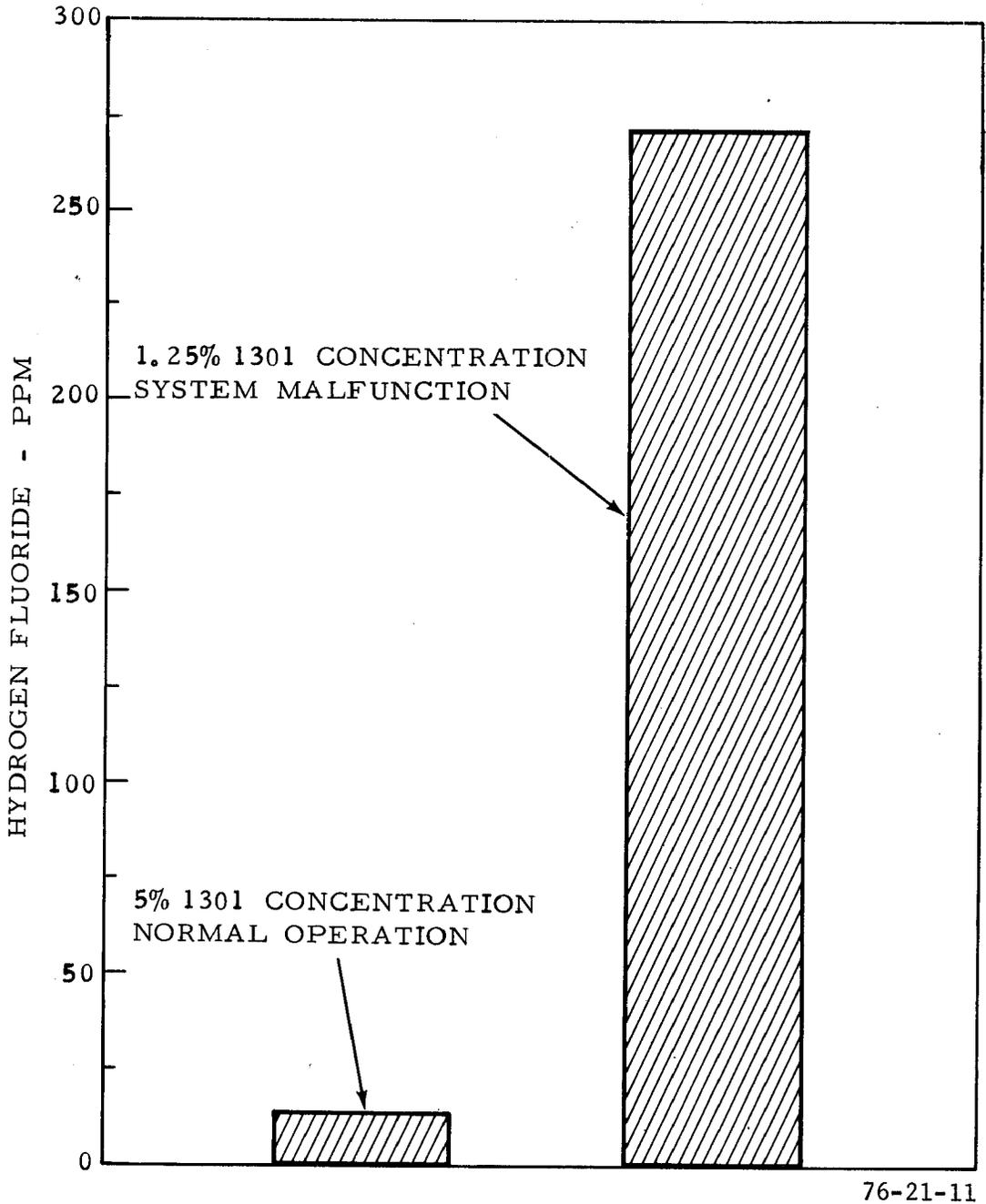


FIGURE 10. HYDROGEN FLUORIDE LEVEL - NORMAL SYSTEM OPERATION VS. SYSTEM MALFUNCTION

SUMMARY OF RESULTS

1. Vaporization of Halon 1301 causes a brief cooling effect within the cabin.
2. Discharging the Halon 1301 causes a momentary turbulence with a subsequent fluctuation in smoke levels. Shortly thereafter, smoke levels begin to diminish.
3. The level of HF increases with increasing fire size.
4. HF tends to move away from the fire area, and except for the peak concentrations nearest the fire just after agent discharge, the highest concentration recorded was at the sample station most distant from the fire.
5. HF remained at near peak levels with the exits closed for the test duration.
6. HF concentrations reached higher levels with the exits open than with exits closed, but diminished more rapidly with exits open.
7. With the exits opened after Halon 1301 discharge, the HF levels were comparable with that of exits closed, and diminished in a pattern similar to the exits-open condition.
8. Peak HF concentrations of less than 2.5 ppm were recorded during the deep-seated fire test.
9. Under a simulated system malfunction (1.25-percent Halon 1301 concentration), the HF level was 10 times higher than under comparable conditions using a 5-percent Halon 1301 concentration.
10. Compartmentizing the cabin with a curtain inhibits the spread of HF into the protected area.

CONCLUSIONS

1. Detection and extinguishment using Halon 1301 must occur as soon after the start of a postcrash aircraft internal cabin fire as possible in order to keep HF concentrations to a minimum, since the amount of HF from the decomposition of agent increases with the size of the fire.
2. In order to minimize the HF concentration, the Halon 1301 should be discharged prior to opening of the exits, with the exits being opened as soon as the fire is extinguished.
3. Without forced ventilation, the use of a curtain to partition the cabin can provide a great deal of protection from the spread of HF, as well as smoke and heat, thus making a joint compartmentation/extinguishing system the most promising.
4. A deep-seated-type fire (other than surface burning) will produce very little decomposition of the agent.
5. A system discharge malfunction or only partial operation resulting in insufficient Halon 1301 concentration to extinguish the fire will produce high HF levels.

REFERENCES

1. Technical Bulletin FE-2A, Handling and Transferring Dupont Halon 1301 Fire Extinguishant, E. I. Dupont De Nemours and Co., Inc.
2. National Fire Protection Association, Standard on Halogenated Fire Extinguishing Agent Systems - Halon 1301, NFPA, No. 12A, 1972.
3. Haun, C. C., Vernet, E. H., MacEwen, J. D., Geiger, D. L, McNerney, J. M., and Geckler, R. P., Inhalation Toxicity of Pyrolysis Products of Monobromochloromethane (CB) and Monobromotrifluoromethane (BrF₃), Report No. AMRL-TR-66-240, March 1967.
4. Chambers, W. H., and Krackow, E. H., An Investigation of the Toxicity of Proposed Fire Extinguishing Fluids, Part I, Medical Division Research Report No. 23, U.S. Army Chemical Center, October 1950.
5. Kimmerle, George Dr. Med., Aspects and Methodology for the Evaluation of Toxicological Parameters During Fire Exposure, JFK/Combustion Toxicology, Vol. I, pp 4-51, February 1974.
6. Sarkos, C. P., Characteristics of Halon 1301 Dispensing Systems for Aircraft Cabin Fire Protection, Federal Aviation Administration, Report No. FAA-RD-75-105, September 1975.

APPENDIX A

AIRCRAFT CABIN ATMOSPHERE SAMPLING SYSTEM AND ANALYSIS

APPENDIX

LIST OF ILLUSTRATIONS

Figure		Page
A-1	Aircraft Cabin Atmosphere Sampling Board Assembly	A-2
A-2	Hydrogen Fluoride Sample Tube	A-5
A-3	Hydrogen Fluoride Comparison for Two Similar Tests at Four Locations	A-6
A-4	Hydrogen Fluoride Comparison for Two Similar Tests at Four Times	A-7

APPENDIX

AIRCRAFT CABIN ATMOSPHERE SAMPLING SYSTEM AND ANALYSIS

SAMPLING SYSTEM DESCRIPTION.

Figure A-1 of the appendix is a graphical illustration of one of the four aircraft cabin air-sampling assemblies used in tests described herein. Their locations were shown in figure 1 in the body of this report. Ten 115-V a.c., normally closed, solenoid valves were mounted on a 3-foot x 2-foot x 3/4-inch plywood panel, as were two steel spheres which served as vacuum bottles. On each panel, the 10 valves were divided into two groups of five with each group manifolded to a common vacuum bottle. Not shown on figure A-1 is a solenoid valve on the vacuum side of each bottle which allows the bottle to be evacuated upon command. In a typical operation sequence, one valve from a set of five is activated allowing a cabin air sample to be drawn through the sample tube, while the bottle servicing the second set of five is being evacuated. After the sample is drawn, a valve from the second set of five is activated concurrently opening the valve to the other vacuum bottle allowing it to be evacuated. The procedure is repeated until all 10 samples are drawn. The four air-sampling assemblies function simultaneously. The system has the capability of drawing approximately a 3.5-liter sample per sample tube.

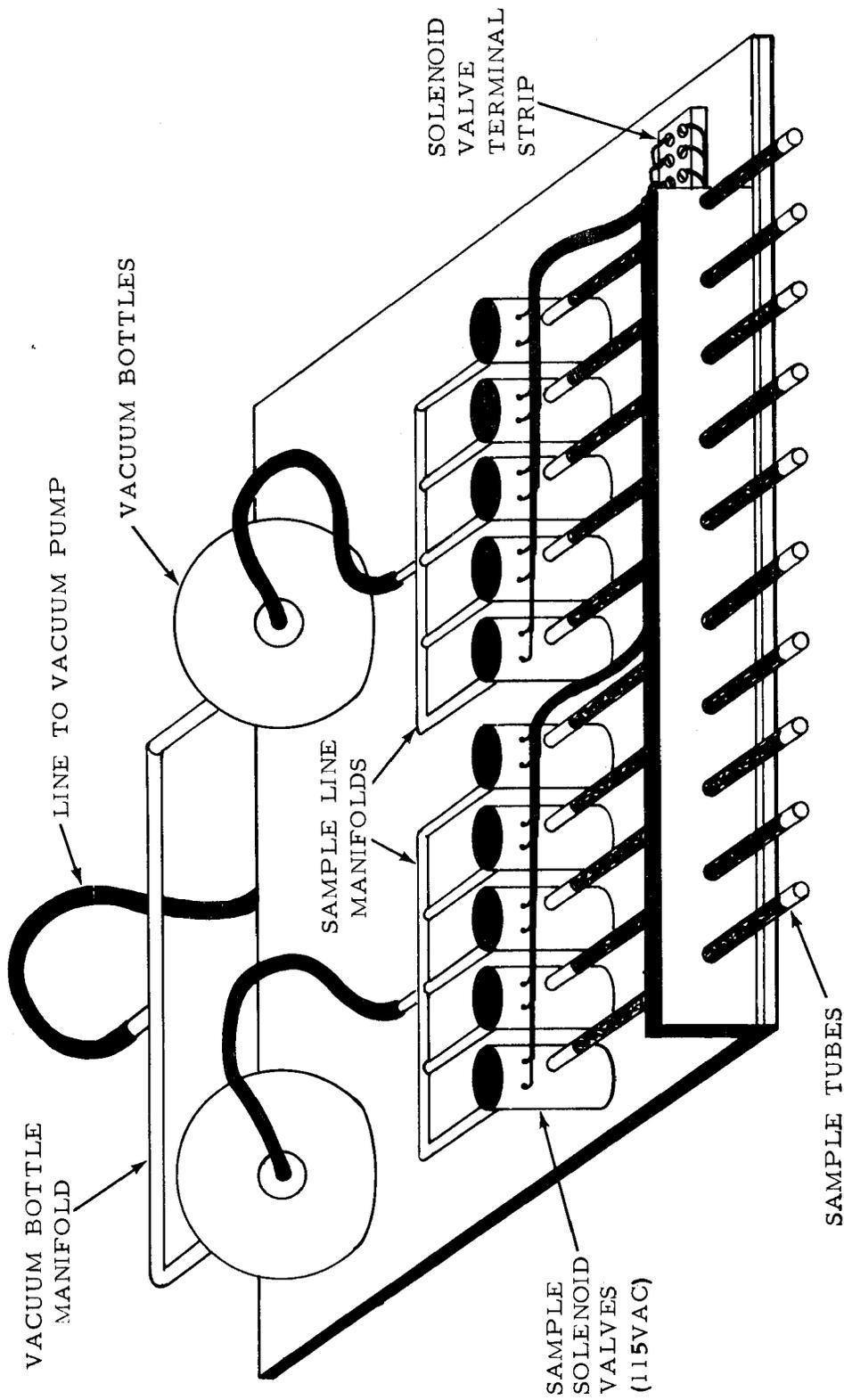
A typical sample tube, shown in figure A-2, was fabricated using 10-millimeter (mm) outside diameter (o.d.), 8-mm inside diameter (i.d.), glass tubing cut into 6-inch lengths. The tube was filled with 3-mm glass beads, and a 1-inch long (2-mm i.d.) glass capillary tube was secured on each end with shrink sleeving. It required approximately 30 seconds to draw a 3.5-liter air sample.

SAMPLE COLLECTION, RECOVERY AND ANALYSIS.

Prior to installing the sample tubes into the sampling assemblies, a 1-molar solution of sodium hydroxide was washed through the tube, taking care that all interior surfaces were wetted, including the inside of the capillary tubes, the entire surface of the glass beads, and the interior wall of the glass tube. Thus, there was reasonable assurance that maximum collection efficiency of acid gases could be realized.

The sample tubes were positioned in the sampling board assembly prior to testing, and the valves were activated during the test as previously discussed. Upon completion, the tubes were gathered and identified for laboratory analysis.

The sample was recovered by washing through the tube 10 ml of a 0.05-molar sodium hydroxide (NaOH) solution. The solution was recycled through the tube several times to assure a thorough mixing and that all interior surfaces were washed. Then, 0.5 ml of this sample solution was mixed with 5 ml of a sodium acetate/acetic acid buffer (pH-5). The fluoride concentration was then determined utilizing a fluoride specific ion electrode (Orion: range 1-1 to 10⁻⁶ moles/liter fluoride ion) and an ion analyzer (Orion research model 801/digital ph). The fluoride concentration in ppm (parts per million) was determined as follows:



76-21-A-1

FIGURE A-1. AIRCRAFT CABIN ATMOSPHERE SAMPLING BOARD ASSEMBLY

where: X mole/l	Fluoride concentration in mole/l as determined from calibration curve
20 gm/mole	atomic weight (in grams) of HF per mole
5.5×10^{-3} l	volume of electrolyte (i.e., 0.5 ml of sample solution +5 ml of buffer)
10 ml	volume of 0.05 NaOH solution used to wash out sample tube
0.5 ml	volume of sample solution
3.46 l	volume of cabin air sample.

Using these values, the fluoride concentration in ppm is determined as follows:

$$\frac{\text{X moles F}^-}{\text{l meas Soln}} \times \frac{5.5 \times 10^{-3} \text{ l meas Soln}}{3.46 \text{ l of Air}} \times \frac{10 \text{ ml sample Soln}}{0.5 \text{ ml Meas Soln}} \times \frac{24.8 \text{ l F}^-}{\text{Mole F}^-} \times 10^6$$

$$p/m = 7.884 \times 10^5$$

where: 24.8 l/mole - liters per mole of HF
20 gm/mole - atomic weight of HF (in grams) per mole

The value of HF concentration in the drawn cabin air sample was then directly determined by substituting for X in the above equation the value of HF in mole/l, as determined from the calibration curve.

COLLECTION EFFICIENCY RATIONALE.

A number of controlled small-scale tests were conducted in order to establish a level of confidence in the proposed sample collection technique. The method was further verified using the same test facilities, procedures, and techniques, that would be employed during the actual full-scale test phase.

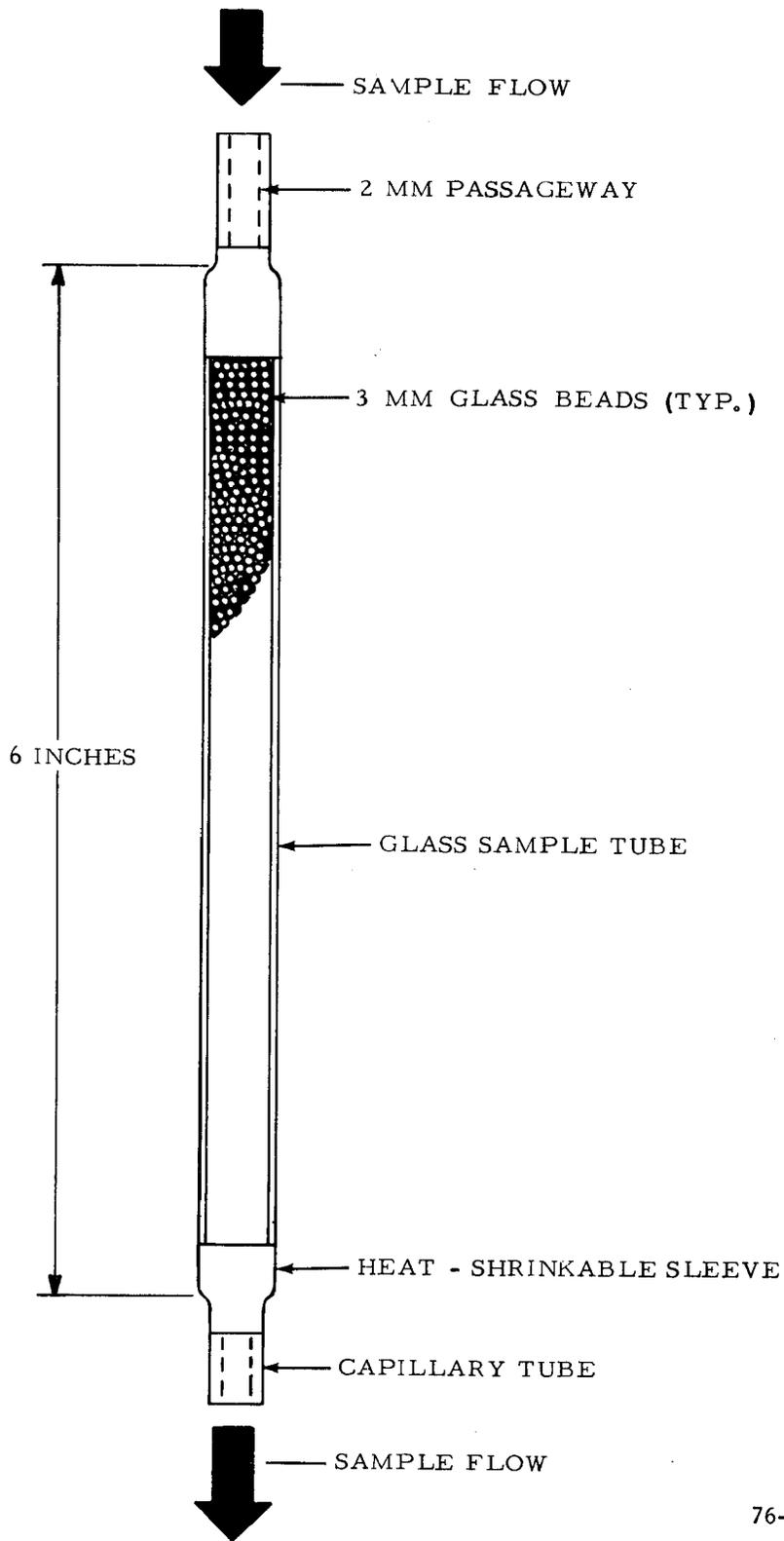
The small-scale tests were conducted using the National Bureau of Standards (NBS) smoke chamber (reference 1). The details of these tests are contained in NAFEC Data Report No. 121 (reference 2). In general, however, tests consisted of subjecting small urethane foam samples to an electrical radiant heat source in the smoke chamber into which Halon 1301 was discharged. Additionally, tests were conducted using the heat source and Halon 1301 only; and the heat source and foam only. Two sample tubes, identical to that previously described, were sealed end to end, and a 3.5-liter sample of the chamber atmosphere was drawn through this sample tube assembly. Concurrently, samples were drawn using a fritted bubbler containing 0.05 molar NaOH. These tests were designed to determine the collection efficiency and ascertain if there were any airborne products of combustion that could result in an erroneous indication of fluoride during analysis.

Tests using the full-scale facility involved extinguishing the foam fire with CO₂ and Halon 1301 in separate tests. Subsequently, the piggyback sample tubes were separated and analyzed individually. Likewise, these tests were designed to provide assurance that there were no airborne products of combustion that could interfere with or result in a false indication of fluoride during analysis; and to determine collection efficiency.

The first tube collected between 85 and 90 percent of the HF, and there was no indication of fluoride when foam was extinguished with CO₂. As the fluoride concentration increases, the first tube collects a greater percentage of the acid gas. Per reference 2, collection efficiency is on the order of 95 percent when HF concentration exceeds 1,000 ppm. HF levels generated during the feasibility tests using the full-scale facility were generally below 1,000 ppm.

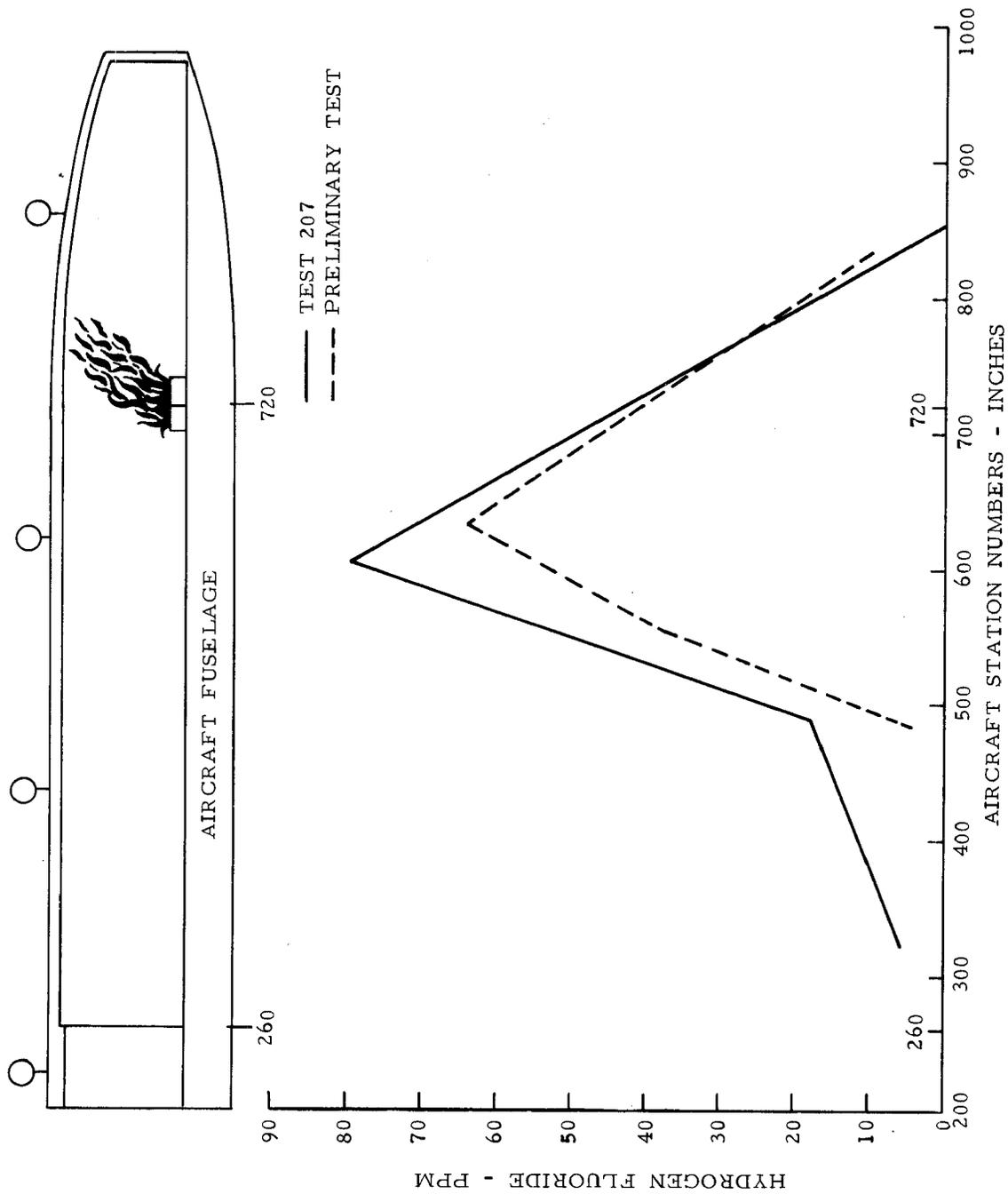
Figures A-2 and A-3 are presented to illustrate the similarity of data between comparable preliminary and critical tests runs. Although it is difficult to maintain all factors constant in a large-scale fire, it demonstrates the level of repeatability that can be expected from the HF sampling system. Figure A-4 indicates that equivalent HF background in a test fire without the use of Halon 1301 is virtually zero.

The aforementioned tests thus established that the fluoride analysis technique could be used under the test conditions described herein, without interference from a foreign species, that the burning urethane foam provided no equivalent HF background to contaminate results, and that the collection efficiency is on the order of 90 percent. It is important to note that collection efficiency was not applied to test results.



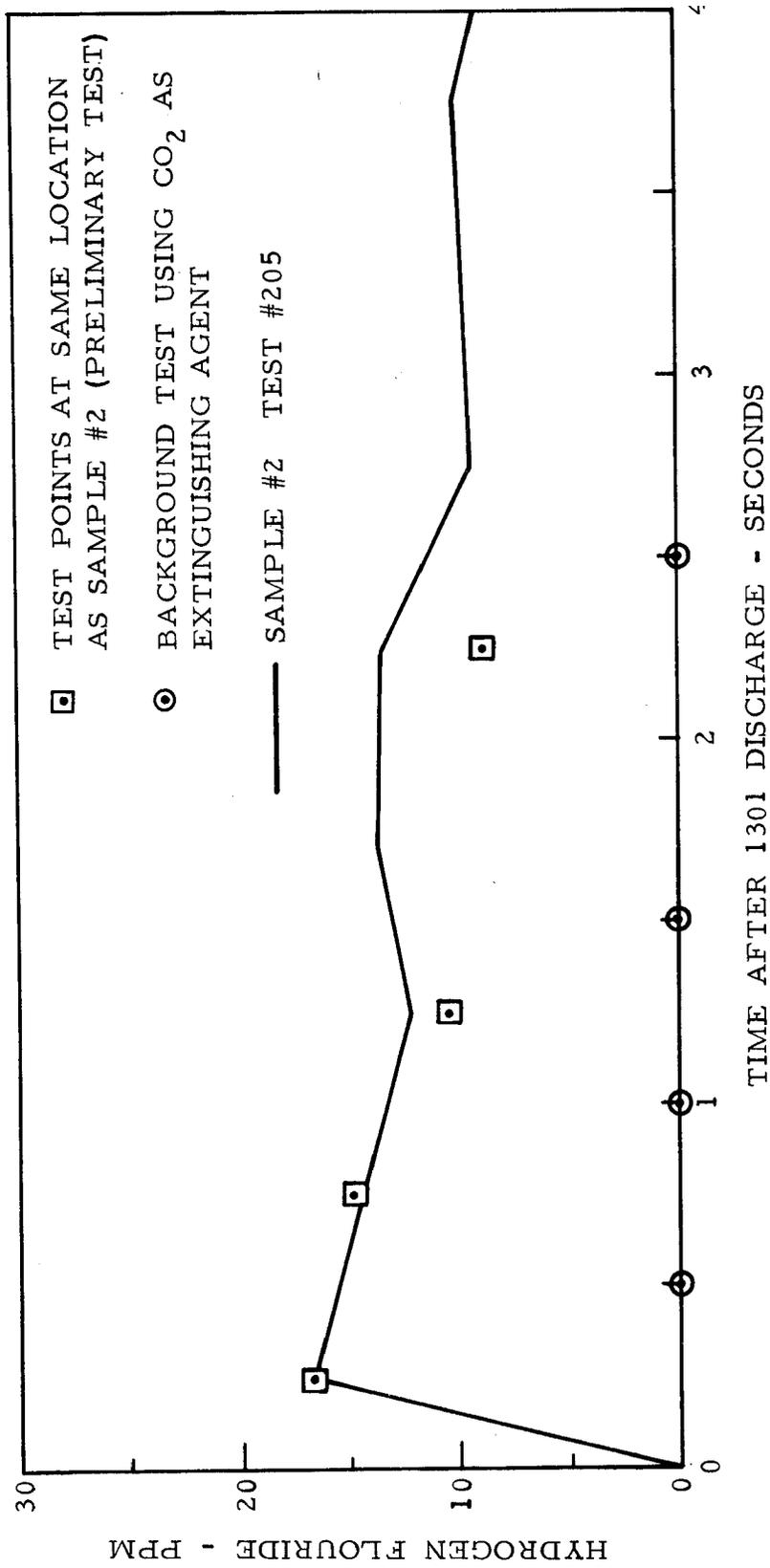
76-21-A-2

FIGURE A-2. HYDROGEN FLUORIDE (HF) SAMPLE TUBE



76-21-A-3

FIGURE A-3. HYDROGEN FLUORIDE (HF) COMPARISON FOR TWO SIMILAR TESTS AT FOUR LOCATIONS



76-21-A-

FIGURE A-4. HYDROGEN FLUORIDE (HF) COMPARISON FOR TWO SIMILAR TESTS AT FOUR TIMES

REFERENCES

1. Interlaboratory Evaluation of Smoke Density Chamber, NBS Tech. Note 708, December 1971.
2. Spurgeon, J. and Feher, R., A Procedure for Determining Hydrogen Fluoride Concentration as a Function of Time in a Combustion Atmosphere, NAFEC Data Report NO. 121, April 1976.