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ADVANCED FIRE EXTINGUISHERS FOR AIRCRAFT HABITABLE COMPARTMENTS

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A four-phase test program was conducted using Halons 1011 (CB), 1211, 1301, and Halon Foam to determine which of the latter three would be a suitable replacement for 1011. The four phases consisted of determining agent concentration in fixed volumes under quiescent and ventilated conditions; agent decomposition products analysis under these same conditions, but with a four pound cotton fire load; agent throw range; and agent effective range against class A and B fires. Within the constraints of this program, 1211 was the most effective agent during effective range testing and 1011 the least effective.

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FOREWORD

This final technical report was prepared by the Federal Aviation Administration (FAA), National Aviation Facilities Experimental Center (NAFEC), Atlantic City, New Jersey. The effort was sponsored by the Air Force Aero Propulsion Laboratory, Wright-Patterson Air Force Base, Ohio under Contract Number F33615-75-M-6251 for the period May 1977 to June 1978. The work, herein, was accomplished under Project 3048, Task 304807, Work Unit Number 30480757, with G. T. Beery, AFAPL/SFH, as Program Monitor and Mr. R. E. Cretcher, AFAPL/SFH, as Project Engineer. Other NAFEC personnel were: G. Chamberlain, Program Manager; P. Boris, Project Manager; R. Young, Project Engineer; R. Filipczak, Chemist.

The authors wish to thank NAFEC aerospace technicians Anthony Spezio and Charles Cole who so ably conducted the bulk of test operations and whose contributions greatly aided in the completion of this project.

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INTRODUCTION

1.1 Purpose

The purpose of this test program was to assess the relative effectiveness of Halon Foam, bromochlorodifluoromethane (Halon 1211), and bromotrifluoromethane (Halon 1301) fire extinguishants and compare this effectiveness to bromochloromethane (Halon 1011) when used in portable units for emergency first aid fire situations. Effectiveness comparison includes firefighting potential and the combustion product environment, which includes oxygen depletion and levels of carbon monoxide, carbon dioxide, and agent pyrolysis products.

1.2 Background

The United States Air Force (USAF) is considering the replacement of Halon 1011, which is presently the standard fire extinguishing agent used in aircraft first aid, portable fire extinguishers. The overall program to provide a more effective and less toxic, all-purpose extinguisher for aircraft habitable areas came as a result of a Strategic Air Command Required Operating Capability (SAC-ROC) which was endorsed by the other USAF operating commands. This program has been designed to fill the remaining data gaps and allow a final choice of agent to be made.

The method used to compare the three candidates (Halon Foam, 1211, and 1301) with Halon 1011 involves four test phases. These phases are described under paragraph 1.3, Method of Approach.

1.3 Method of Approach

1.3.1 Phase I—Agent Concentration. This phase involved the determination of neat agent concentration in known volumes under both quiescent and ventilated conditions. These tests were conducted without fires. Light obscuration effects and compartment temperatures were monitored throughout the duration of each test; relative humidity in the compartment was recorded prior to each test. The schedule of tests is shown in Table 1. The description of the procedure followed in this and the other phases is delineated in the Discussion section of this report.

1.3.2 Phase II—Combustion Products. This phase of the test program involved defining a controlled-fire situation with and without an extinguishment

TABLE 1. PHASE I—AGENT CONCENTRATION TEST SCHEDULE

	QUIESCENT TEST VOLUME				
	261 ft^3		814 ft^3		
AGENT	1 qt	1 gal	1 qt	1 gal	2 gal
1011	X	X	X	X	X
Halon Foam	X	X	X	X	X
1211	X	X	X	X	
1301	X	X	X	X	

	VENTILATED (1 ACPM)* TEST VOLUME				
	261 ft^3		814 ft^3		
AGENT	1 qt	1 gal	1 qt	1 gal	2 gal
1011	X	X	X	X	X
Halon Foam	X	X	X	X	X
1211	X	X	X	X	
1301	X	X	X	X	

*ACPM—Air change per minute

attempt. Thus, the results of the fire/agent interaction could be compared with that in which no agent was used. These tests involved Class A fires only

Initially, the fire environment was defined in terms of visibility, compartment temperature, oxygen depletion, and levels of carbon monoxide and carbon dioxide.

Subsequent tests were similar except that an extinguishing agent was directed at the fire. In addition to those measured parameters previously noted, analysis was also performed to determine the generated level of hydrogen fluoride, hydrogen chloride, and hydrogen bromide. The schedule of tests is shown in Table 2.

TABLE 2. PHASE II--COMBUSTION PRODUCTS TEST SCHEDULE

TEST VOLUME 814 ft^3

	VENTILATION	
AGENT	Quiescent	1 ACPM*
None	X	X
1011	X	X
Halon Foam	X	X
1211	X	X
1301	X	X

*ACPM--Air change per minute

1.3.3 Phase III—Throw Range. The series of tests conducted under Phase III were designed to ascertain throw range only. These did not involve fires and in no way should the results be interpreted as indicative of the effective range. These tests were conducted with 1-quart and 1-gallon units.

1.3.4 Phase IV--Effective Range. This series of tests involved the use of 1-gallon extinguishers only, and their effectiveness against Class A and B fires. Extinguishment attempts were made at fixed distances with the nozzle hand held. No attempt was made to optimize the fire extinguishing technique.

1.4 Test Equipment Description

1.4.1 Extinguishers. Pertinent extinguisher information is given in Table 3. The 1-quart 1011, 1211, and 1301 units were stock items as were the 1-gallon

TABLE 3. EXTINGUISHER UNIT DESCRIPTION

SIZE	AGENT	MFR. AND/OR MOD. NO.	NOM. AGENT WGT (lb) (1)	LOADED PRESSURE (psi)
1 qt	1011	Air Force Type A-20	4	175
1 gal	1011	Air Force Type D-1	16	175
2 gal	1011	A.D. Little, Inc. (2)	32	175
1 qt	1211	Graviner/3-10	3.5	125
1 gal	1211	Graviner/16-10	16	175
1 qt	1301	W. Kidde and General Fire (3)	3.0	(5)
1 gal	1301	Mod. Air Force Type D-1 (4)	16	(5)
1 qt	Foam	A.D. Little, Inc.	3.3	175
1 gal	Foam	Mod. Air Force Type D-1 (4)	10.5	175
2 gal	Foam	A.D. Little Inc.	21	175

Notes:

(1) Actual loaded weights varied slightly from test to test.
(2) Modified for 1011 (see Test Equipment Description).
(3) W. Kidde Bottle was used for Phases I, III, IV; General Fire was used in Phase II and purchased per MIL-E-520138.
(4) Same modified unit used for both agents (see Test Equipment Description).
(5) Vapor pressure of 1301 at ambient temperature (approximately 200 psig).

1011 and 1211 units. The 1-quart and 2-gallon Halon Foam extinguishers provided to the National Aviation Facilities Experimental Center (NAFEC) by the Air Force for this test program were developed by A.D. Little, Inc., under USAF contract F33615-71-C-1756 (Figures 1 through 7).

It was necessary to make modifications to existing available hardware to meet the test requirements for 2-gallon 1011, 1-gallon 1301, and foam extinguishers. The modified 1011 unit consisted of the 2-gallon foam bottle and dip tube mated with the 1-gallon 1011 spray head.

Modifying a 1-gallon unit for use with 1301 and Halon Foam was somewhat similar. The valve and dip tube assembly was removed from a previously expended 1-gallon 1011 extinguisher; likewise, the valve and dip tube assembly was removed from a discharged 2-gallon foam unit. The dip tube from the latter was replaced with one fabricated from stainless steel tubing of precisely the same inside diameter (i.d.), but whose length matched that from the 1-gallon 1011 unit. This modified assembly was used in place of that removed from the 1-gallon 1011 unit and utilized for all tests requiring 1-gallon foam or 1301 agents.

All extinguishers were recharged by test personnel at NAFEC except the 1211 and the 1-quart 1301 General Fire Bottles. The former was recharged by the supplier, Graviner. The latter was purchased as a complete unit per MIL-E-52013B and was presumed to have met paragraph 3.1 which stated that the unit is to be pressurized with nitrogen to 380 pounds per square inch gauge (psig). The Kidde extinguisher was filled with 1301 only, and at ambient temperature its vapor pressure is about 200 psig. The Halon Foam was loaded as specified in Appendix I of report AFAPL-TR-72-62. Some extinguishant characteristics are shown in Table 4.

1.4.2 Test Article. The test article used for Phase I and II was a surplus Air National Guard (ANG) bus whose interior was modified to suit test purposes (Figures 8 and 9). All seats were removed and the entire interior was covered with 2-inch-thick, aluminum-faced fiberglass insulation. One-half-inch-thick plywood sheeting was installed and rigidly supported 2 inches from the original floor which covered the aluminized insulation. The plywood was then covered with an overlay of aluminum sheet. Provisions were made for a moveable aluminized bulkhead to provide for a variable volume test article. Thus, the completed test article had a completely aluminized interior which facilitated cleanup and provided for a nonporous surface to preclude agent absorption. Absorptive surfaces could have resulted in succeeding test samples being contaminated with agents from previous tests. The insulation minimized temperature fluctuation during Phase I testing.

The scope of Phase I was limited to two fixed volumes, 261 and 814 cubic feet (ft^3) with the smaller being approximately one-third of the full compartment. When the full-size compartment was required, the bulkhead defining the 261 ft^3 test volume was simply removed. This as well as the fixed bulkhead defining the full volume had viewing ports to accommodate observation by personnel, video, and motion picture cameras.

FIGURE 1. ONE QUART HALON 1301 EXTINGUISHER (KIDDE COMMERCIAL 2 3/4 lb UNIT)

FIGURE 2. ONE QUART HALON 1011 EXTINGUISHER (AIR FORCE TYPE A-20)

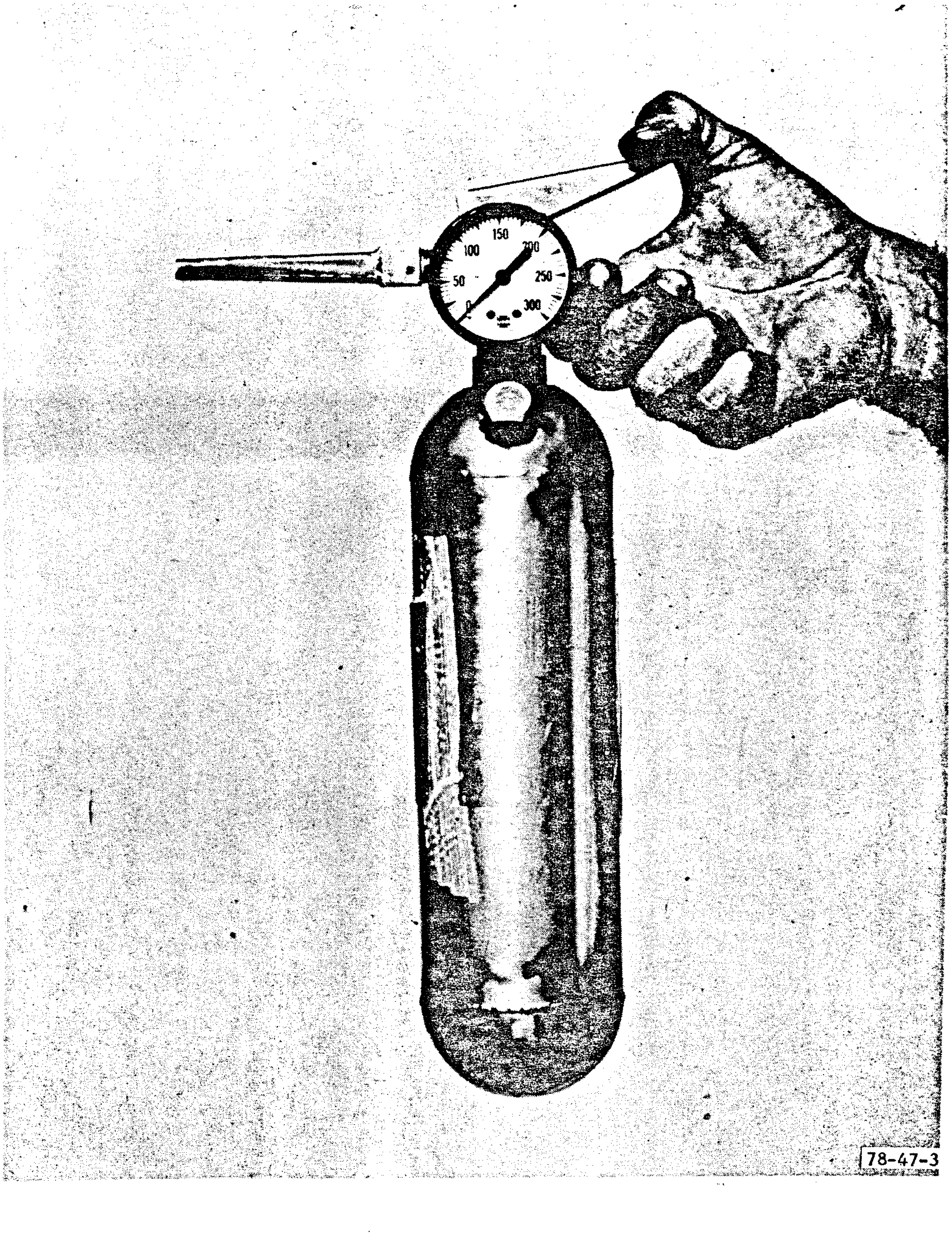

FIGURE 3. ONE QUART HALON FOAM EXTINGUISHER (ARTHUR D. LITTLE PROTOTYPE)

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FIGURE 4. ONE QUART HALON 1211 EXTINGUISHER (GRAVINER COMMERCIAL UNIT)

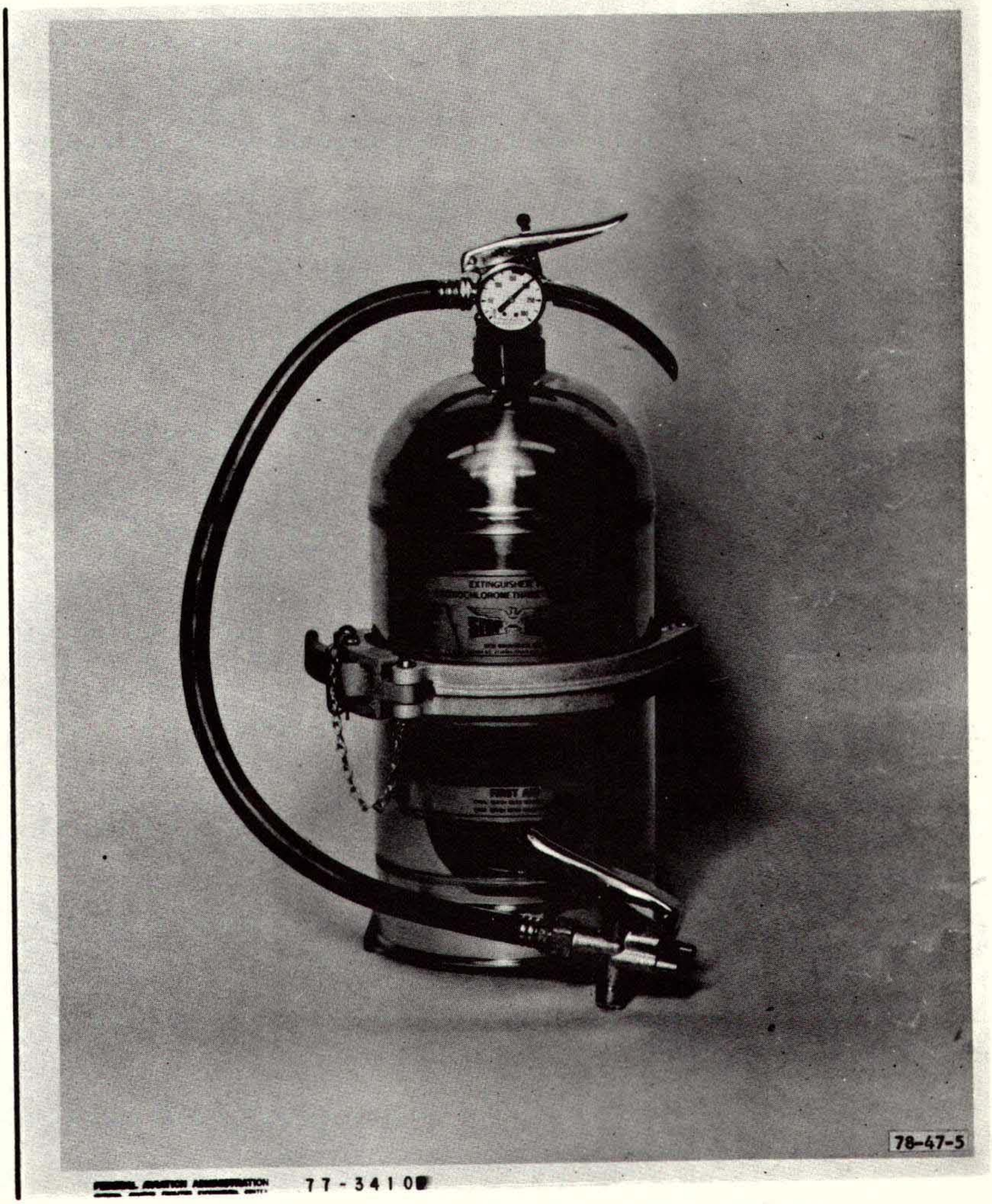

FIGURE 5. ONE GALLON HALON 1011 EXTINGUISHER (AIR FORCE TYPE D-1)

FIGURE 6. ONE GALLON HALON 1211 EXTINGUISHER (GRAVINER COMMERCIAL UNIT)

FIGURE 7. TWO GALLON HALON FOAM EXTINGUISHER
(AF TYPE D-2 MODIFIED BY A.D. LITTLE)

TABLE 4. EXTINGUISHANT CHARACTERISTICS

HALON NO.	CHEMICAL NAME	CHEMICAL FORMULA	TYPE	BOILING POINT (°F)	FREEZING POINT (°F)	SPECIFIC GRAVITY(1)
1011	Bromochloromethane (CB)	CH_2ClBr	Liquid	151	-124	1.93
1211	Bromochlorodifluoromethane	$CBrClF_2$	Liquified Gas	25	-257	1.83
1301	Bromotrifluoromethane	$CBrF_3$	Liquified Gas	-72	-270	1.57
--	Halon Foam(2)					

(1) Specific gravity of liquid at 68°F

(2) Constituents by weight:

1211	60/62%
1301	30/30.5%
Fumed Silica	1/1.4%
Anhydrous Methanol	0.4%
Surfactant	6.5/7%
Nitrogen	0.4%

80% FIG 8

FIGURE 8. TEST FACILITY FOR AGENT CONCENTRATION AND DECOMPOSITION STUDIES

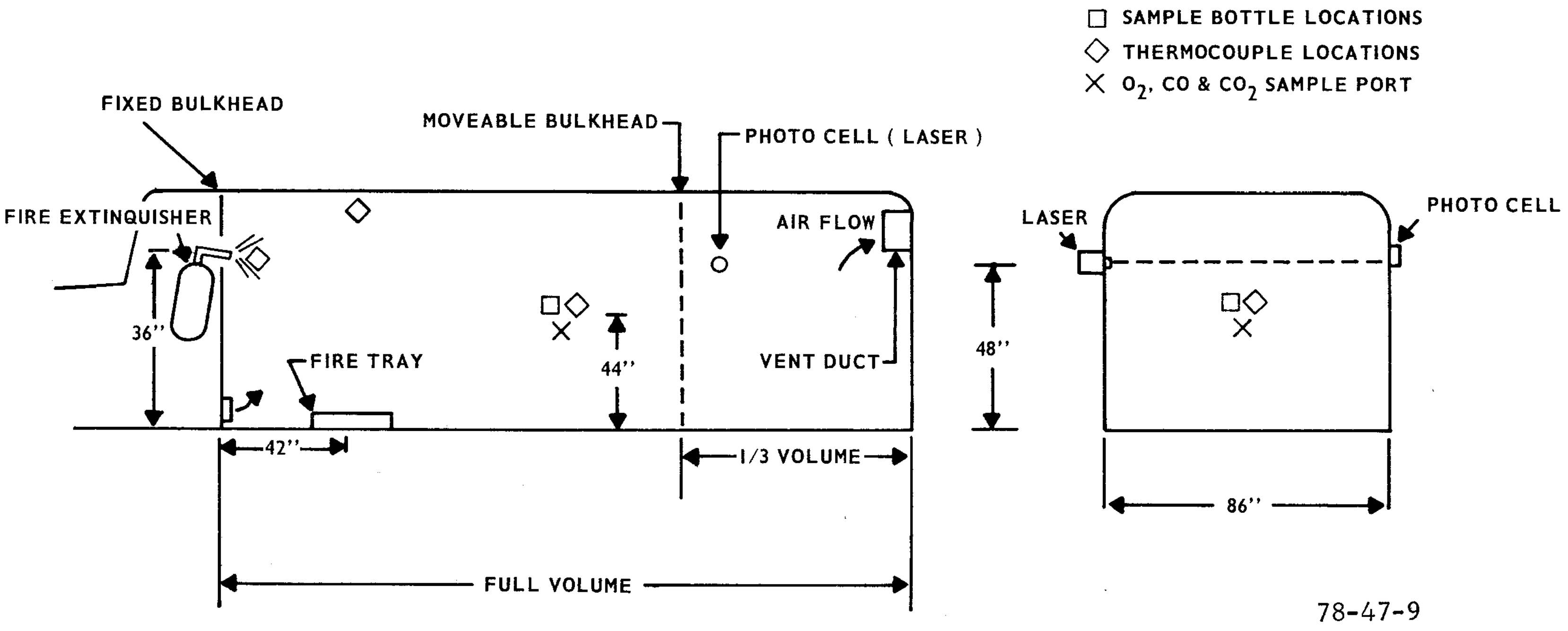

FIGURE 9. TEST ARTICLE SCHEMATIC SHOWING EQUIPMENT LOCATION

The test article was fitted with two exhaust fans of approximately 600 cubic feet per minute (cfm) capacity each, which were mounted in a plenum chamber located outside the rear of the test article. One 12-inch diameter duct was placed between this plenum chamber and the ceiling at the rear of the test compartment. At the bottom of both the moveable and fixed bulkheads, two 8-inch diameter holes were cut, one near each side wall. Thus, during a test with ventilation, air entered the test compartment at the forward end near the floor and exited at the rear near the ceiling.

In order to preclude damage to the test article during the fire tests of Phase II, an auxilliary means of effecting extinguishment was incorporated. This consisted of the placement of a water nozzle directly over the fire tray which was actuated by a remotely-operated solenoid valve. In anticipation of the fire not being extinguished by the 1-quart agent bottle being tested, the water would be used at the termination of the test.

1.4.3 Instrumentation. The neat agent concentration during Phase I was determined by the analysis of compartment air samples drawn into 150 cubic centimeter (cm^3) evacuated cylinders. The details of this analysis is described in Appendix B. Ten electrically operated solenoid valves and a sequencer were mounted on a stand which was located in the test compartment. The sequencer was programmed to activate the valves sequentially at 30-second intervals. A 150 cm^3 stainless steel sample cylinder, which had been previously evacuated, was secured to each valve (Figure 10).

A similar arrangement was used during Phase II, except that every other 150 cm^3 cylinder was replaced with a 1000 cm^3 sample cylinder. The larger sample was required to accommodate the analysis for agent decomposition products. Within the scope of this test program, the analysis was limited to determining the levels of hydrogen fluoride, hydrogen bromide, and hydrogen chloride. The test compartment sample was drawn through a specially prepared sample collection tube into the 1000 cm^3 cylinder. The tube was designed to collect the acid gases for subsequent analysis. For the details of this analysis refer to Appendix B. The contents of both the large and small stainless steel sample cylinders were analyzed for neat agent.

For Phase II studies, a continuous record of oxygen levels were recorded using a Beckman model 7003 Process Oxygen Monitor. Carbon dioxide and carbon monoxide levels were recorded using Beckman model 864 Process Infrared Analyzers. The output from these instruments were recorded on Esterline Angus model L11025 Speed Servo II strip-chart recorders. This continuous sample was drawn from a point near the stand on which the sample bottles and collection tubes were mounted.

In order to determine the light obscuration effects during Phase I and II testing, a 0.5 milliwatt helium-neon laser was mounted externally with the beam directed across the width of the test compartment. The beam fell upon a Weston selenium photovotaic cell model 856YR mounted on the opposite wall. The location of this equipment is shown in Figure 9. The output of the

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FIGURE 10. TEST COMPARTMENT AND INTERIOR SHOWING AGENT SAMPLING SYSTEM

photocell was continuously recorded and the data presented as percent light transmission. For several tests, a 60-watt incandescent light bulb was placed adjacent to the laser source and viewed using a closed-circuit video camera located at a viewing port at the opposite wall. This was used to give the reader an approximate relationship between light transmission and visibility provided by a standard 60-watt light bulb.

Compartment temperature was monitored continuously using copper-constantan thermocouples mounted to the sample bottle stand. A copper-constantan thermocouple was also placed at the port through which the agent was discharged. This method was used to determine discharge time since the agents, especially the gaseous compounds, have a pronounced cooling effect upon discharge.

Relative humidity within the test compartment was recorded prior to each test. This factor can have a pronounced effect on light obscuration as will be discussed later in this report.

During all phases of testing, a closed-circuit video recording system was used for remote viewing and to provide an immediate replay capability. In addition, 16 millimeter (mm) motion pictures were taken during Phases II, III, and IV. The film and video data were used to corroborate onsite measurements of both throw and effective range.

A 24-ft by 8-ft backdrop with a 2-ft by 2-ft grid was used during Phases III and IV. This provided a more positive indication of throw and effective range when reviewing the film and video tapes.

SECTION II

DISCUSSION

2.1 Agent Concentration Tests

Agent concentration tests were conducted using all the agents within the scope of this program (1211, 1301, 1011, and Halon Foam) in 1-quart and 1-gallon sizes. Additionally, 2-gallon sizes of 1011 and foam were tested. Agent concentration levels were determined with and without ventilation in two compartment sizes: 261 and 814 ft^3. The exception was that the 2-gallon bottles were tested in the larger test volume only.

The procedure followed for each test under this phase was the same. The agent was discharged through a port into the test compartment. A thermocouple was located at the bulkhead port in the path of the discharging agent which provided an indication of expulsion time. The use of a stopwatch and a closed-circuit video system provided corroborative data for this parameter. Thirty seconds after the agent was expended, the first compartment air sample was drawn, followed by subsequent samples each 30 seconds, thereafter, for 5 minutes. Compartment temperature and light obscuration were continuously recorded. For a number of tests a 60-watt incandescent light bulb was placed within the view of the video camera. The distance between the bulb and the camera was approximately the same as that between the laser and the photoelectric cell. The intention was to make an attempt to relate light obscuration which is presented as percent light transmission and the ability to see the light bulb under conditions of low visibility.

The agent concentration data are shown in Figures A-1 through A-6. (Time zero on these graphs is the time that agent discharge was complete.) The readily obvious and logical aspect of the data is that concentrations diminished more rapidly with time under ventilated conditions. It is important to note that ventilation was occuring throughout the test. This implies, of course, that the agent was being diluted with fresh incoming air as it was being discharged. This accounts for peak concentrations being greater in the absence of ventilation. As noted, the general trend was for concentration to trail off more rapidly during ventilated tests and less under quiescent conditions. For that matter, some data indicates nearly constant concentrations with time. The exceptions to this general trend were the 1301 and 1211 concentrations which dropped off rapidly as shown in Figure A-2. Note that these data represent what occurred during the discharge of a relatively large quantity of agent (1 gallon) into a relatively small test compartment (261 ft^3). The resultant temperature drop under this condition was the greatest. It is conceivable that the colder, heavier agent settled gradually below the point where compartment air samples were drawn. Although there are no supportive data, it is believed that these two curves do not present a true picture, but that higher concentrations do exist at levels below the sample point station. This condition probably existed in all nonventilated tests, but to a lesser degree. Peak concentrations under ventilated conditions will also depend on the discharge time of the agent. Discharge time for the 1-quart 1301 extinguisher was longer than for 1211 or Halon Foam. Discharge time for the 1301 extinguisher manufactured by General Fire was 16 seconds and 45 to 70 seconds for the W. Kidde unit. The General Fire extinguisher was charged with nitrogen at 380 PSI while the W. Kidde extinguisher depended on the vapor pressure of the 1301 alone for expulsion pressure.

In addition to the agent concentration curves, a data summary is shown in Table 5. The reader has a convienient reference for pertinent information for each test including the precise discharge weight and time.

Of all the agents tested, only 1011 can be considered to be a liquid at ordinary temperatures and pressures. The other agents immediately gasify upon discharge, including the Halon Foam. It is for this reason that the gaseous agents yield higher vapor concentrations. The combined concentrations of 1211 and 1301 resultant from the discharge of 1-gallon foam bottles is comparatively lower than the concentration of either 1211 or 1301 when discharged from the same size bottle as pure agents. This condition was due to the lower agent charge of the 1-gallon foam bottle which was approximately 10 lbs versus about 16 lbs for 1211 and 1301, respectively. All 1-quart extinguishers had about the same discharge weight.

Table 5 presents a calculated maximum concentration for the gaseous agents for nonventilated conditions only. The calculations were based on complete vaporization of all the agents (including the Halon Foam) which appears to be a reasonable assumption. The concentration data obtained provide no substantial indication that the Halon Foam results in a lingering effect. The expectation was that this extinguishant would tend to encapsulate the agent and provide a somewhat controlled release. If this was the case, one would expect 1301 and 1211 concentrations to increase with time to some degree. However, this was not the case as all curves generally followed the same trend. The foam does, however, adhere to irregular and vertical surfaces. When discharged onto a surface at close range, there was an initial bubbling effect which was short lived. This, most likely, was the 1211 boiling off. This foam does not have the appearance of soap suds, but rather blistered paint, which soon flattens out resulting in a slippery surface. This material does require cleanup with large amounts of water, while 1301 and 1211 do not.

The maximum concentration per 100 ft^3 per pound of agent in the nonventilated tests was calculated for the three gaseous agents and averaged. The value for Halon Foam is the sum of the concentrations of 1211 and 1301. The values are: 2.1 percent for 1211, 2.3 percent for 1301, and 1.9 percent for Halon Foam. This value shows the expected agent concentration without the variation due to compartment size and agent weight.

TABLE 5. DATA SUMMARY--PHASE I

AGENT	VOLUME (ft^3)	AGENT DISCH. WGT. (lb)	DISCH. TIME (min:s)	DISCH. RATE (lb/s)	Ventilation[1]	MAX. CONC. (VOL.%)[6]	CALC. MAX. (VOL.%)[6]	AIR TEMP. (°F)[2]	RH (%)[3]	MAX. ΔT (°F)[4]	LIGHT TRANSMISSION[5]
Halon Foam	261	3.28	:21	0.15	None	1.67/1.08	1.76/0.97	70	62	10.5	100
	261	3.19	:24	0.13	1 ACPM	1.07/0.46	--	67	62	5	100
	261	10.34	:09	1.15	None	3.98/2.61	5.53/3.07	66	74	11	100
	261	10.25	:08	1.28	1 ACPM	2.33/1.50	--	66	74	8	90
	814	3.31	:26	0.12	None	0.51/0.24	0.54/0.30	43	74	2	100
	814	3.21	:25	0.12	1 ACPM	0.21/0.12	--	43	80	2	94
	814	10.31	:07	1.47	None	1.26/0.94	1.72/0.96	53	100	9	66
	814	10.68	:08	1.33	1 ACPM	0.75/9.40	--	53	100	8	100
	814	21.06	:17	1.23	None	3.18/1.79	3.6/2.0	65	94	13	52
	814	20.68	:19	1.08	1 ACPM	1.38/0.86	--	70	96	8	70
1011	261	3.95	:23	0.17	None	0.49	--	75	53	0	100
	261	3.88	:18	0.19	1 ACPM	0.60	--	61	88	2	100
	261	16.17	:19	0.85	None	1.74	--	61	85	6	100
	261	16.17	:19	0.85	1 ACPM	1.05	--	64	56	4	100
	814	3.12	:14	0.22	None	0.18	--	75	48	0	100
	814	3.17	:15	0.21	1 ACPM	0.09	--	56	64	0	100
	814	16.38	:21	0.78	None	0.21	--	63	56	0	100
	814	16.06	:20	0.80	1 ACPM	0.28	--	60	64	0	100
	814	32.53	:41	0.79	None	0.31	--	70	57	0	100
	814	32.17	:42	0.77	1 ACPM	0.35	--	64	54	0	100

Legend:

1 1 ACPM (one air change per minute)
2 Air temperature prior to test
3 Relative humidity
4 Temperature drop in test compartment
5 Light transmission 30 s after discharge
6 First value refers to 1211; second to 1301
– Not applicable

TABLE 5. DATA SUMMARY--PHASE I (CONTINUED)

AGENT	VOLUME (ft^3)	AGENT DISCH. WGT. (lb)	DISCH. TIME (min:s)	DISCH. RATE (lb/s)	VENTILATION[1]	MAX. CONC. (VOL.%)[6]	CALC. MAX. (VOL.%)[6]	AIR TEMP. (°F)[2]	RH (%)[3]	MAX. ΔT (°F)[4]	LIGHT TRANSMISSION[5]
1211	261	3.18	:14	0.22	None	2.26	2.60	74	96	8	4
	261	3.50	:12	0.29	1 ACPM	1.65	—	55	85	8	82
	261	16.05	:07	2.20	None	13.52	14.10	62	81	33	8
	261	16.2	:07	2.31	1 ACPM	8.11	—	70	80	28	10
	814	3.56	:12	0.30	None	0.86	0.99	60	95	3	32
	814	3.44	:10	0.33	1 ACPM	0.37	—	75	100	4	70
	814	14.19	:07	2.03	None	4.14	4.05	68	90	17	2
	814	15.81	:09	1.76	1 ACPM	1.63	—	55	95	32	28
1301	261	2.75	1:10	0.04	None	2.65	2.74	70	95	4	20
	261	3.10	:56	0.06	1 ACPM	2.07	—	67	58	5	100
	261	15.50	:09	1.72	None	12.0	15.5	74	87	23.5	0
	261	15.63	:09	1.73	1 ACPM	12.69	—	73	85	20	0
	814	2.80	:48	0.06	None	0.78	0.87	58	64	1	100
	814	3.19	:44	0.07	1 ACPM	0.25	—	84	75	2	100
	814	16.19	:10	1.62	None	4.81	5.18	72	86	12	0
	814	15.75	:10	1.58	1 ACPM	2.02	—	85	80	10.5	72

Legend:

1	1 ACPM (one air change per minute)
2	Air temperature prior to test
3	Relative humidity
4	Temperature drop in test compartment
5	Light transmission 30 s after discharge
6	First value refers to 1211; second to 1301
-	Not applicable

Using information in Report AMRL-TR-74-143 and the volumetric agent concentration per pound per 100 ft^3 noted previously, approximately 0.6 lb of 1211 and 3 lb of 1301 could be discharged per 100 ft^3 with little or no effect on humans for a 3- to 5-minute exposure. As noted in the AMRL report, those concentration levels are 1.2 and 7 percent for 1211 and 1301, respectively. As contained in the Fire Protection Handbook, 1301 and 1211 are nearly identical in flame extinguishing characteristics on a percent by volume of agent basis. With the exception of methanol fires, the highest concentration noted is 7 percent of 1211. Using this as a basis, about 3.3 lb of 1211 and 3 lb of 1301 would be required to inert a 100 ft^3 volume.

Light obscuration data were recorded continuously during each test. In order to preclude misleading the reader, all of these data are not included in this report. Since Phase I did not involve fires, any obscuration of vision was caused by the agent itself. Furthermore, obscuration was not the result of the opacity of the agent vapor, but rather was due to the condensation of water vapor caused by the temperature drop in the compartment. To further complicate the situation, this misting effect was dependent upon relative humidity and ambient temperatures. The temperature drop in the compartment was mainly a function of the type of agent, amount of agent, discharge rate, compartment size and ventilation. Although the ambient temperatures may be representative of an aircraft compartment in flight, the relative humidities in many instances are not (Table 5). Light transmission of less than 20 percent occurred when both temperature and relative humidity were high, (generally greater than 70 degrees Fahrenheit (°F) and 80 percent), respectively. The temperature dropped below the dew point in a number of tests, but there were not a sufficient number of tests conducted to establish a relationship between light transmission, temperature, and relative humidity. It appears, however, that a trend could be established between the change in specific humidity (the amount of water in the air) and visibility. An examination of the data in Table 5 and simple specific humidity calculations indicate, generally, that visibility was less as more moisture was condensed from the air. Based on the limited amount of data in this regard, a qualified statement can be made. In the absence of fire, these agents will not present an adverse visibility situation unless the relative humidity and ambient temperature are such that misting will occur due to the temperature drop caused by the discharging agent. The interpretation of the video tapes of a number of tests is shown in Table 6. It should be noted that this was not a personal observation of the test as it occurred, but as the video camera recorded it. Since the tapes were viewed several times, the observer knew where to look for the 60-watt bulb which was placed within the view of the camera. Between 0- and 1-percent light transmission, the bulb was barely visible appearing as a light through a fog, while between 5 and 10 percent the complete outline of the bulb was obvious. As the visibility began to improve, walls and objects became visible between 10 and 20 percent. Note that all observations were made at a distance of 8 ft, the approximate distance between the laser source and the photoelectric cell. At greater than 25-percent light transmission, all objects were plainly visible. These observations were made during a limited number of tests and are presented merely to give the reader a better feel for the curves shown in Figures A-7 through A-9. As noted previously, all these data are not presented since the obscuration effects are not typical. When temperature and humidity were relatively low, no misting occurred and hence there was no light obscuration.

The cooling effect caused by the discharge into the test compartment is shown in Figures A-10 through A-14. The degree of cooling is primarily a function of the amount of agent discharged and the compartment size with some effect due to discharge and ventilation rates. As shown in Figures A-10 and A-11, the temperature drop can be considerable. In the 261 ft^3 compartment the temperature drop using 1-gallon of 1211 was 33° F which was 26° below the dew point. As shown in Table 5, not only was misting considerable, but the entire interior of the test compartment was covered with droplets of water.

TABLE 6. APPROXIMATE VISIBILITY INTERPRETATION

LIGHT TRANSMISSION (%)	DISTANCE (ft)	VISIBILITY
0-1	8	60-W bulb just visible
5-10	8	60-W bulb outline visible
10-25	8	Objects just visible
>25	8	Objects visible

2.2 Combustion Products and Agent Decomposition Tests

The tests were conducted under this phase utilizing 1211, 1301, 1011, and Halon Foam agents in 1-quart nominal sizes only. Additionally, the tests were conducted in the 814 ft^3 compartment under quiescent and ventilated conditions. The tests performed under Phase II were conducted similarly to those of Phase I. The difference lies in the fact that during this phase, fires were involved (See Figure 11).

The fire load, consisting of 4 lbs of absorbent cotton batting, was allowed to burn for a few seconds beyond the peak temperature as indicated by a thermocouple located at the ceiling above the fire tray before the agent was discharged. This peak temperature varied somewhat above and below 300° F during nonventilated tests and 230° F during ventilated tests. The burning cotton flared up momentarily due to the loose outer layer being consumed by fire first, causing this rather rapid temperature rise. The fire then abated to more of a smoldering type with low flaming, approaching that of a deep seated fire. This approach was taken to allow the fire to become well established. It was felt that to discharge the agent at the peak temperature was premature since the fire had not yet become fully established. Further, to discharge somewhat after this point provided more assurance that discharge would be accomplished at a more consistent temperature from test to test.

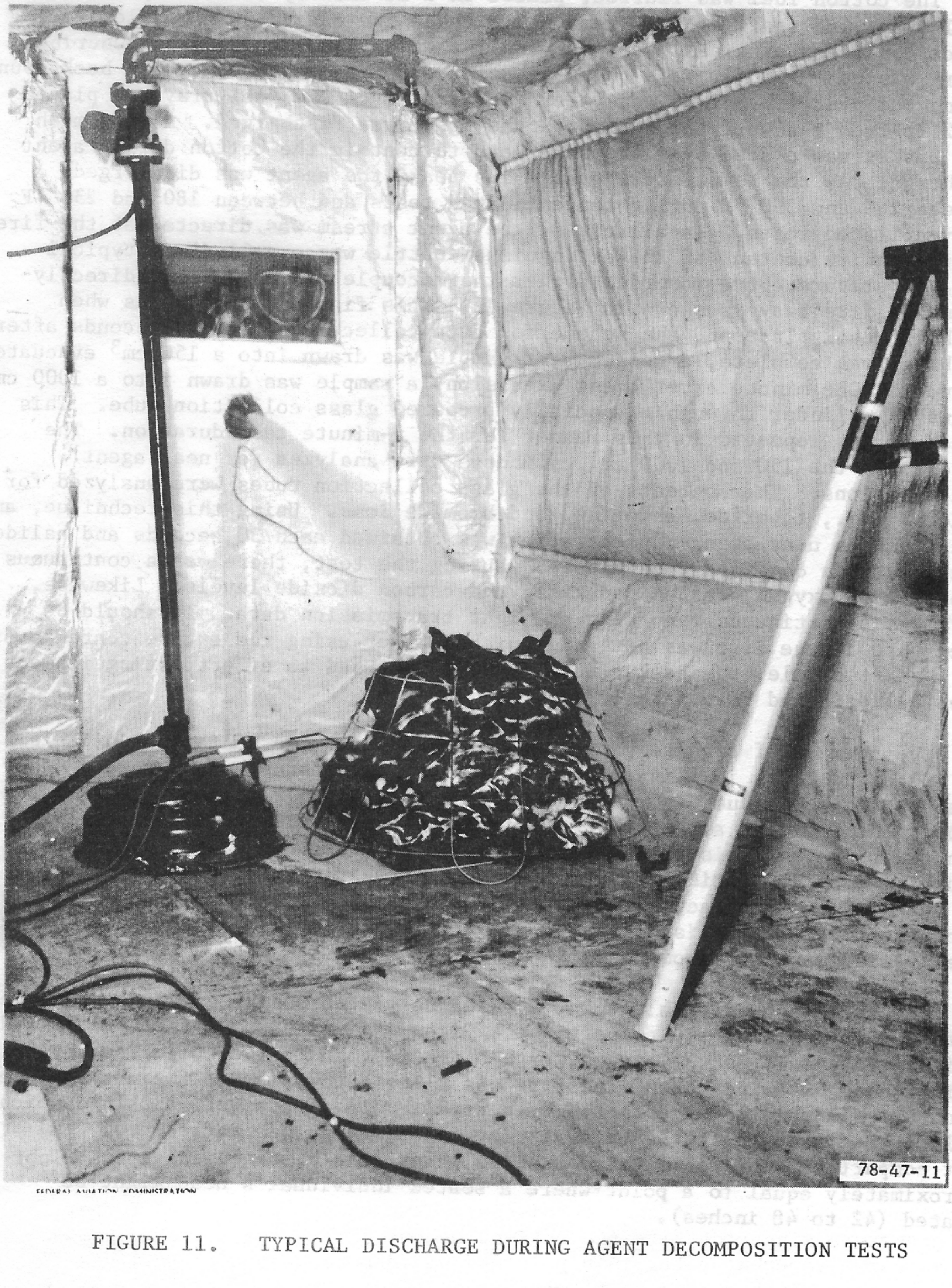

FIGURE 11. TYPICAL DISCHARGE DURING AGENT DECOMPOSITION TESTS

The cotton fuel was fluffed, placed in a 18-inch by 18-inch by 2-inch steel tray, and spark ignited remotely without the use of a flammable liquid. The cotton waste originally used during the effective range tests (described later) was not used for this phase since it provided an undesireable background during the hydrogen halide analyses. The center of the fuel tray was placed 3 1/2 ft from the wall through which the agent was discharged. A wide mesh wire basket was placed over the fire load to contain the cotton during agent discharge. As the temperature passed its peak, the agent was discharged between 260 and 290° F during nonventilated tests and between 180 and 230° F for ventilated tests. In all cases, the agent stream was directed at the fire and the entire content of the extinguisher bottle was expelled. A typical time/temperature curve recorded with a thermocouple at the ceiling directly above the fire tray is shown in Figure 12. This figure also denotes when discharge took place and the scheme for data collection. Thirty seconds after discharge was complete, a compartment sample was drawn into a 150 cm^3 evacuated cylinder. One minute after agent expulsion, a sample was drawn into a 1000 cm^3 evacuated cylinder through a specially prepared glass collection tube. This procedure was repeated in this manner for the 5-minute test duration. The contents of the 150 and 1000 cm^3 cylinders were analyzed for neat agent concentrations. The contents of the glass collection tubes were analyzed for halides; i.e., fluoride, chloride, and bromide ions. Using this technique, an instantaneous neat agent concentration was obtained each 30 seconds and halide concentrations obtained each minute. During the test, there was a continuous recording of oxygen, carbon monoxide, and carbon dioxide levels. Likewise, there was a continuous recording of light transmission data. It should be noted that if the fire was not extinguished after using the entire contents of the 1-quart bottle, the backup water system was used to effect extinguishment after all data had been taken.

The summary of results of this phase of testing are contained in Table 7. The discharge times in this table are less reliable than those recorded under Phase I. This was due, in part, to reduced visibility caused by smoke in the compartment from the attempted extinguishment of the fire, which interfered with the video analysis of the discharge. Also, due to nozzle movement occurring when attempting to extinguish the fire, the agent discharged was not in continuous contact with the fixed thermocouple positioned to record discharge time. There is no reason to believe, however, that agent discharge times varied markedly from those in Phase I.

Prior to testing with agents, a baseline was established. This baseline consisted of defining the compartment environment in terms of temperature and visibility as well as the oxygen, carbon dioxide, and carbon monoxide levels. During these baseline tests, the fire was allowed to burn for 5 minutes, after which extinguishment was effected with water. Thus, data were obtained which could be compared to that when an extinguishing agent was introduced. All test compartment environmental data were taken at a distance above the floor approximately equal to a point where a seated individual's head might be located (42 to 48 inches).

CHARACTERISTICS OF EXTINGUISHING AGENTS

AGENT	SYMBOL	CHEMICAL FORMULA	FREON NUMBER	HALON NUMBER	MOLECULAR WEIGHT	SPECIFIC GRAVITY	SPECIFIC WEIGHT, lb/in³	BOILING POINT, °F.	FREEZING POINT, °F.	HEAT OF VAPORIZATION Btu/lb.	APPROXIMATE LETHAL CONC. PPM *	VAPOR PRESSURE (psia)		
												-65°F	70°F	160°F
Bromochloromethane	CB	CH_2BrCl		1011	129.4	1.94	.069/.070	149	-110	99.8	29000 4000		2.7	17.0
Bromotrifluoromethane	BT	$CBrF_3$	13B1		148.9	1.57	0.057	-72	-270.4	47.7	800,000 14000		212	550
Carbon Dioxide	CO_2	CO_2			44	1.02 (0°F)	0.0368	-110		112.5	658000 658000		750	
Carbon Tetrachloride		CCl_4		104	153.8	1.63	0.059	170		83.5	28000 300		1.9	12.5
Dibromochlorotri-fluoroethane		$C_2Br_2ClF_3$	113B2		276.5	2.25	0.081	200						
Dibromodifluoromethane	DB	CBr_2F_2	12B2	1202	209.8	2.28	0.0822	76	-223	52.4	54000 1850		13	58
Methyl BROMIDE	MB	CH_3Br			95.0	1.73	0.0625	39	-139	108.2	5900 9600		27	120
Monobromomonochloro-difluoromethane		$CBrClF_2$	12B1		165.4	1.83	0.0663	25	-257	57.6	324000 7650		35	135
Dibromotetrafluoro-ethane		$CBrF_2-CBrF_2$	114B2		259.9	2.16	0.078	117.5	-166.8	45.0	126000 1600		5.6	31
EARTH-MINERAL-SALTS SOLUTION														
10% Lithium Chloride 20% Calcium Chloride		$LiCl+CaCl_2$					0.044	221	-80					
24% Lithium Chloride		$LiCl$					0.057	237	-87					
47% Zinc Chloride		$ZnCl_2$					0.041	230	-69					

* NOTE: 15 MINUTE EXPOSURE TO RATS - 1ST NUMBER, UNHEATED AGENT

\- 2ND NUMBER, AGENT HEATED TO 800°C.

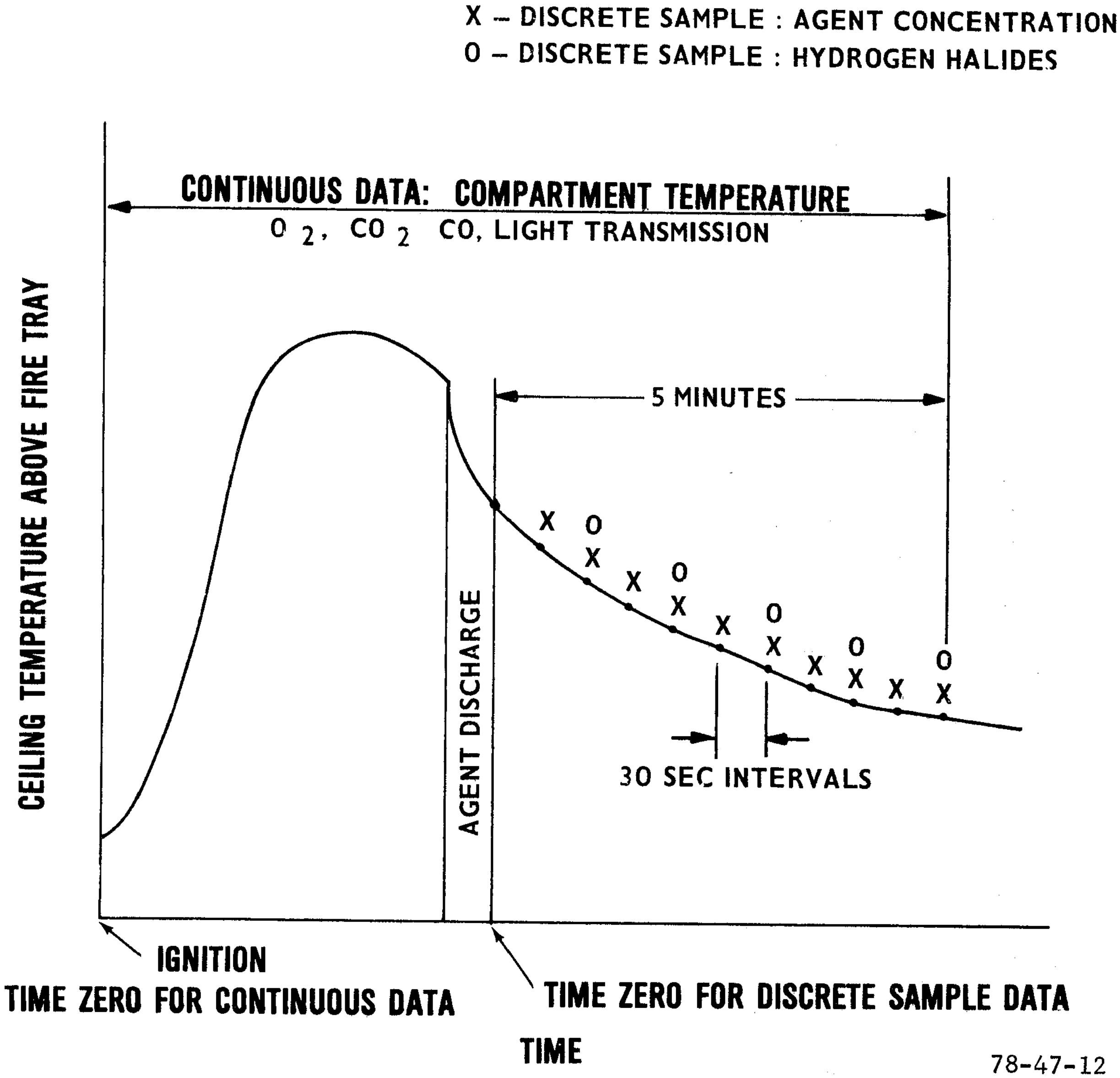

FIGURE 12. TYPICAL CEILING TEMPERATURE CURVE SHOWING DATA COLLECTION TECHNIQUE FOR PHASE II

TABLE 7. DATA SUMMARY--PHASE II

TEST VOLUME--814 ft^3

AGENT	AGENT DISCH. WGT. (lb)	DISCH. TIME (s)	DISCH. RATE (lb/s)	MAX. AGENT CONC. (VOL.%)	MAX. COMPARTMENT TEMP. (°F)	MIN. LIGHT TRANSMISSION (%)	MAX. CO_2 CONC. (VOL.%)	MAX. CO CONC. (VOL.%)	MIN. O_2 CONC. (VOL.%)	MAX. HF CONC. (PPM)	MAX. HBr. CONC. (PPM)	VENTILATION
None	--	--	--	--	210	2	2.20	0.17	19.2	--	--	None
None	--	--	--	--	315	2	3.00	0.21	18.8	--	--	None
None	--	--	--	--	205	34	1.00	0.06	20.3	--	--	1 ACPM
None	--	--	--	--	240	41	1.25	0.06	20.4	--	--	1 ACPM
1211[1]	3.48	15	0.23	0.37	190	69	1.40	0.025	20.3	12.2	10.8	None
1211	3.35	15	0.22	0.47	135	17	0.70	0.020	20.25	4.4	2.6	1 ACPM
1301[1]	2.92	17	0.17	0.10	187	92	1.60	0.020	20.25	5.3	0	None
1301	2.80	16	0.18	0.27	165	22	0.95	0.038	20.25	7.5	4.1	1 ACPM
Foam	3.26	20	0.16	0.8/0.3*	187	2	1.60	0.100	19.9	39.9	28.6	None
Foam	3.23	20	0.16	0.3/0.12*	143	25	0.70	0.023	20.3	1.1	0	1 ACPM
1011[2]	3.06	16	0.19	0.176	213	25	1.90	0.056	19.8	--	8.5	None
1011	3.27	18	0.18	0.182	207	34	1.25	0.065	20.5	--	87.3	1 ACPM

1 Stratification of smoke at the floor--below sampling point
2 Flame visible throughout test period
- Not applicable
* 1211/1301 concentration

2.2.1 Baseline Tests. Two baseline tests were conducted with ventilation and two without ventilation. Test conditions were identical at the onset.

There was no significant depletion of oxygen in either the ventilated or nonventilated tests. These results are shown in Figure A-15. As one might expect, there was a lesser effect on oxygen levels under ventilated conditions. With no ventilation, oxygen levels remained nearly constant (at approximately the 19 percent level). With ventilation, oxygen concentration was very nearly normal. Additionally, there was no wide variation between the two tests under each condition.

The carbon dioxide levels are shown in Figure A-16. With one air-change per minute, carbon dioxide levels peaked at about 1 percent at 1 minute followed by a gradual decrease. At 5 minutes, the level was about 0.3 percent. When ventilation was absent, carbon dioxide levels increased to slightly above 2 percent during one test and 3 percent for the other. In anything other than strictly controlled laboratory conditions, it is virtually impossible to maintain fire uniformity from test to test. When attempting to simulate an actual aircraft compartment fire environment, variations are unavoidable. Every attempt was made to maintain uniformity in all aspects including having the same individual prepare the fire load for all tests. A loosely packed cotton bundle would, of course, burn more rapidly than one that was more dense. It is surmised, therefore, that the most influential factor contributing to variations in the measured parameters was fire dynamics. Those tests identified as "B" and "BV" in Figures A-15 through A-19 displayed the greatest oxygen depletion, and the highest carbon dioxide, and carbon monoxide levels. Note, however, that these tests also resulted in the highest compartment temperatures, which is generally synonymous with a higher combustion rate.

Carbon monoxide levels are shown in Figure A-17. Under ventilated conditions, the level peaked at about 0.05 percent between 4 and 5 minutes and remained relatively constant. During the nonventilated tests, the level continued to increase at the termination of the test reaching a level of 0.15 percent between 5 and 6 minutes. As previously noted, test "B" displayed a consistantly higher level of carbon monoxide.

Light transmission continued to decrease through both the ventilated and nonventilated tests with the latter being the lower of the two. Using the information presented in Table 7, an individual could not perceive objects or dim lights during the nonventilated test at the end of 5 minutes, whereas, this was not the case during the ventilated tests. Light transmission data is presented in Figure A-18.

The compartment temperatures for the baseline tests are shown in Figure A-19. For the unventilated condition, the difference in peak temperature was about 105° F between the two baseline tests. Again, this can be attributed to varying fire dynamics with the most probable cause being fire load density. Test B peaked higher and sooner than did test A. Under the ventilated condition, the differences in peaks between the two tests was about 35° F with test B having the higher temperatures.

2.2.2 Agent Discharge Fire Tests. The oxygen levels recorded during the tests where extinguishants were introduced are shown in Figures A-20 and A-21. For the tests with ventilation and considering all four agents as a group, there was no significant difference as compared to the oxygen levels of the baseline tests. Similarly, as evidenced in Figure A-21, there was no significant difference in oxygen levels among all agents.

With the absence of ventilation, there were some differences in oxygen depletion, but not markedly so. In comparing the agents as a group (Figure A-20) with the baseline nonventilated tests A and B, oxygen levels were about 1 percent higher when an agent was introduced. In comparing one agent to another, the least oxygen depletion occurred with the use of 1211. Again, the difference is not considered significant.

The levels of carbon dioxide are shown in Figures A-22 and A-23. Peak levels for all agents were below that recorded during the baseline tests for both ventilated and nonventilated conditions. In comparing carbon dioxide, oxygen, or carbon monoxide levels, the factor that introduces a measure of caution is fire dynamics. As stated earlier, this aspect is surmised to have been a causative factor in the variations in measured parameters obtained during the A and B baseline tests. It also makes it difficult to compare the various agents with regard to oxygen, carbon dioxide, and carbon monoxide levels. Since the temperature above the fire tray was used as a guide in discharging agents, and since relative burning rates affect this temperature, there was a time difference between ignition and initiation of agent discharge among the various tests. The greater the burn time and temperature at discharge, generally, the more combustion gases will be produced with lesser levels of oxygen. Figure A-22 shows that by using 1211 a lower carbon dioxide level resulted. However, note that the fire did not burn as long nor was it as hot as those where the other agents were used. This had a favorable effect on, not only, the carbon dioxide, but the carbon monoxide and oxygen levels as well. Comparing carbon dioxide concentrations at and following discharge, all reacted in substantially the same manner. The levels dropped somewhat and remained nearly constant throughout the tests for nonventilated conditions and approached zero for the ventilated tests.

Carbon monoxide levels are shown in Figures A-24 and A-25. These followed the same trend as the carbon dioxide levels, but to a lesser degree; i.e., the levels tended to be higher with higher temperatures and longer preburn times. For the ventilated tests, the compartment temperature at discharge in decreasing order was with agents 1011, 1301, Halon Foam, and 1211. Peak carbon monoxide and carbon dioxide levels were in the same order; i.e., 1011 producing the highest levels and 1211 the lowest. This trend varied somewhat for nonventilated tests, but one aspect must be considered in these and all tests in this phase. Due to the high levels of smoke, it was difficult to determine whether the fire had been extinguished completely or whether reignition occurred after initial extinguishment. It should be noted that in all cases, however, the fire load continued to smolder throughout the test duration. (No agent was effective in completely extinguishing a really deep-seated fire under the test conditions described herein.) The highest level of carbon monoxide was generated with the use of Halon Foam and the least amount with agents 1211 and 1301. In the ventilated 1011 test, the cotton continued to flame throughout the test period.

Light obscuration data are shown in Figures A-26 and A-27. Since light transmission was recorded in only one position, that data shown for nonventilated tests may be misleading. Agents 1011 and Halon Foam show the greatest obscuration to vision with the latter being the lowest. One interesting aspect of 1301 and 1211 is that there was a pronounced stratification of smoke with little abatement of this condition although some mixing did occur gradually. This smoke strata was below the gas sample station and also the point where light transmission was measured, which might lead the reader to believe that less smoke was generated. As gradual mixing occurred, light transmission reduced. This stratification condition lends credence to the supposition regarding 1211 and 1301 concentrations when Figure A-2 was discussed in paragraph 2.1. Stratification with 1011 or Halon Foam was virutally nonexistant but the smoke appeared to be uniformly dispersed throughout the compartment. This stratification did not exist under ventilated conditions. There was an immediate generation of smoke upon discharge of all agents followed by a gradual clearing. The only agent that deviated somewhat was Halon Foam. After initially following the same general trend as the other agents, light transmission began to decrease again, 3 minutes into the test. The reason for this is not immediately obvious from other data for this same test or visual observations. Sudden dips in visibility as that shown for 1301 at about 6 minutes can be attributed to a puff of smoke passing through the laser beam.

The stratification effects of 1301 and 1211 present an aspect which, thus far, has not been discussed. In an actual fire situation, one is always instructed to keep near the floor where there is generally less heat and smoke. The high density and cooling effect of discharging either 1301 or 1211 undoubtedly is a prime factor in the smoke strata lingering near the floor. This pronounced layer was about 2 to 3 feet deep. Visibility, as indicated by the video monitor which was submerged in this smoke layer was zero. Since the sampling station was above this layer, the nature of the smoke is not known. One can make suppositions, however, which will bring forth pro and con arguments. Visible smoke is generally composed of solid particles suspended in air. However, during Phase I it was seen that in the absence of fire, there could be light obscuration due to mist formation because of high humidity and a large temperature drop. With the fire adding additional moisture to already humid air, it is possible that this smoke layer could be a combination of solid particles and water mist. The latter is not too likely, but nevertheless possible. Since there is an initial mixing in the compartment due to the discharging agent, it is further possible that intimate contact of decomposition products, other noxious substances, smoke particles, and mist could result in the toxic substance being absorbed or condensed onto the solid particles or disolved in mist droplets. This could present a respiratory problem to an individual near the floor. Ventilation is generally a normal condition in a habitable aircraft compartment or cargo area and thus the possibility of stratification is minimumized. Nevertheless, poorly ventilated, stagnant or nonventilated areas provide a suitable condition for stratification of smoke.

A data summary of Phase II appears in Tables 7 and 8. A comparison of selected parameters between the baseline and extinguishment tests is shown in Table 9. Because of the nature of the test procedure; i.e., discharging the agent within prescribed temperature limits, it is difficult to establish a common basis of comparison. Neither selecting a specific time after fire load ignition or after agent discharge for comparison of data present a common basis. In the interest of simplification, Table 9 shows data of selected measured parameters 5 minutes after ignition of the cotton batting along with the preburn time. The only test that is markedly different from the others is that using 1011 under nonventilated conditions. Its preburn was slightly over 2 minutes, whereas, the others were slightly over 1 minute. In all cases, the introduction of an agent resulted in an environment less severe than the baseline for the parameters noted. The only exception was the carbon monoxide levels for the queiscent condition. This can probably be attributed to a higher level of incomplete combustion brought about by the introduction of extinguishing agent. All agents except Halon Foam had the effect of increasing the levels of carbon monoxide. For the five parameters listed, 1211 generally fared most favorably among the Halons tested in reducing the severity of the baseline environment condition. For the ventilated condition, 1211 was equal to or better than 1011, 1301, and Halon Foam. A similar statement can be made for the quiescent condition with the exception of carbon monoxide levels and measured visibility. With regard to the carbon monoxide, Halon Foam resulted in the lowest level recorded. Although the measured visibility with 1211 was ranked second at 75 percent, there was negligible obscuration to actual vision.

Figures A-28 and A-29 show compartment temperatures during the agent discharge fire tests. For the unventilated condition (Figure A-30), the 1301 and 1211 concentrations resulting from the discharge of either of the neat agents were lower than 1301 and 1211 concentrations resulting when discharged as constituent parts of the Halon Foam. The reverse was expected since the amount of Halon discharged as the sole agent was greater than the amount of either 1301 or 1211 in the Halon Foam. They were also lower than the corresponding Phase I tests. It is theorized that this was due to the stratification evident in the Phase II tests.

The agent concentrations in the ventilated condition (Figure A-31) were comparable to the Phase I tests. The higher 1011 concentration in Phase II test (about double) can be attributed to more rapid volatilization due to the higher compartment temperatures.

The highest levels of decompostion products occurred with 1011 under ventilated conditions and with Halon Foam under nonventilated conditions (Table 8). The Halon 1011, being a liquid, allows for more directional control and does not gassify upon discharge as do the other halons. Consequently, the cotton fuel will absorb the agent and as long as the fuel load continues to flame or smolder, the agent will continue to pyrolyze. It can be surmised that air circulation kept the fuel load burning (or smoldering) at a greater rate than under quiescent conditions. This resulted in a higher level of decomposition products since the liquid agent was either absorbed by the

TABLE 8. DATA SUMMARY--PHASE II: PYROLYSIS DATA

TEST VOLUME - 814 ft^3

CLASS A FIRE

QUIESCENT

AGENT	PYROLYSIS PRODUCT	CONCENTRATION (ppm)				
		1 min	2 min	3 min	4 min	5 min
1211	Hydrogen Fluoride	6.4	12.2	5.5	8.6	4.5
1301	Hydrogen Fluoride	4.1	2.1	2.1	5.3	3.2
1011	Hydrogen Fluoride	--	--	--	--	--
Foam	Hydrogen Fluoride	32.2	24.3	18.4	10.5	39.9
1211	Hydrogen Bromide	8.1	10.8	1.0	4.9	3.4
1301	Hydrogen Bromide	0	0	0	0	0
1011	Hydrogen Bromide	3.3	7.9	8.5	6.7	6.2
Foam	Hydrogen Bromide	28.6	26.6	20.4	8.1	18.7

VENTILATION (ONE ACPM)

1211	Hydrogen Fluoride	4.4	0.8	0.9	1.9	0.2
1301	Hydrogen Fluoride	7.5	2.7	2.6	0.6	1.4
1011	Hydrogen Fluoride	--	--	--	--	--
Foam	Hydrogen Fluoride	0.6	1.1	1.1	1.0	0.7
1211	Hydrogen Bromide	2.6	T	T	T	0
1301	Hydrogen Bromide	4.1	1.5	1.7	0	1.0
1011	Hydrogen Bromide	87.3	21.4	9.2	9.9	12.4
Foam	Hydrogen Bromide	T	T	0	0	0

Legend:

T Trace
-- No analysis performed

TABLE 9. COMPARISON OF BASELINE AND EXTINGUISHMENT TESTS

CLASS A FIRE

NONVENTILATED: 5 MINUTES AFTER IGNITION

TESTS	COMPARTMENT TEMP. (°F)	O_2 (VOL.%)	CO_2 (VOL.%)	CO (VOL.%)	VISIBILITY(%)	PREBURN (s)
Baseline (Test A)	188	19.5	2.1	0.13	5	--
1011	151	19.9	1.6	0.53	41	133
1211	125	20.3	0.9	0.18	75	66
1301	125	20.2	1.4	0.17	100	74
Halon Foam	125	19.8	1.17	0.08	2	80

VENTILATED: 5 MINUTES AFTER IGNITION

TESTS	COMPARTMENT TEMP. (°F)	O_2 (VOL.%)	CO_2 (VOL.%)	CO (VOL.%)	VISIBILITY(%)	PREBURN (s)
Baseline (Test AV)	141	20.6	0.3	0.05	47	--
1011	77	20.8	0.03	0.02	55	78
1211	72	20.8	<0.01	0.004	81	70
1301	82	20.9	<0.01	0.017	71	62
Halon Foam	82	20.8	<0.01	0.01	63	63

cotton fuel or contained in the tray, thus preventing the vapors from being vented overboard. During this test, the fire was not immediately extinguished. In viewing the test films, the flame continued to burn throughout the entire 5-minute test period.

The Halon Foam generated the highest levels of pyrolysis products under quiescent conditions (Table 8). This phenomenon cannot be fully explained, but visual observations could lend itself to a possible cause. After the discharge of agent, the test with Halon Foam did not show significant signs of smoke stratification as did 1211 and 1301. It is, therefore, possible that there was a more uniform distribution of decomposition products. The decomposition products from both the 1301 and 1211 tests were lower than with Halon Foam, possibly due to this same stratification phenomenon. It is intimated that higher concentrations of decomposition products could exist below the sample point station during the 1301 and 1211 tests. Another factor which could contribute to the higher levels of decomposition products obtained with Halon Foam, however tenuous it might be, could be due to the extinguishants heavier constituents; namely, the surfactant and fumed silica. These materials, which are intended to encapsulate the halons, could allow the agent to be in contact with the fire longer before dissipating than would pure agents. This does not imply that Halon Foam has any significant lingering or time release tendencies different from pure agents. This fact was established during agent concentration tests discussed previously. As will be shown further in this report, the foam constituents did not contribute to firefighting effectiveness, nor did the Halon Foam provide better extinguishment capabilities than either the 1301 or 1211 in the agent decomposition tests, which were not specifically designed to assess firefighting effectiveness. The data in Table 8 are shown graphically in Figures A-32 through A-35 in Appendix A.

It should be noted that Table 8 does not contain any hydrogen chloride data. With the analysis techniques used, the presence of chlorides could be detected but not quantified in the presence of bromides. In none of the agents tested was there chlorine in the chemical formulation without bromine. Refer to Appendix B for further discussion. Except for Halon Foam, the levels of chloride were estimated to be approximately equal to the levels of bromide.

In Figure A-31, two samples of the 1211 component of the Halon Foam fall out of the general data scheme of Phase I and Phase II for ventilated tests; i.e., a generally decreasing agent concentration and the curve paralleling the 1301 concentration. There was some difficulty with these particular samples, and these data points may be inaccurate. No explanation will be proposed, but if the reader chooses to disregard these two data points, the curve will follow the general trend.

2.3 Throw Range Tests

Two throw range tests were conducted with each type of extinguisher except the 2-gallon sizes. Prior to and following each test, the extinguisher was weighed to assure reasonable consistancy of loaded weights. Nominal agent weight appears in Table 3. Actual discharged weight does not have the same significance in Phases III and IV as it does in Phases I and II where there is a direct relationship between discharged weight and agent concentration in a fixed volume.

The agent was discharged 3 feet in front of and parallel to the 24-ft by 8-ft backdrop (Figure 13). The agent was initially discharged horizontally with the nozzle approximately 4 feet from the floor and then elevated to 45° above the horizontal (Figure 14). In all instances, the extinguisher was hand held. Visual observations were reinforced with 16 mm color motion pictures filmed at 64 frames per second (fps) and black and white video recordings. Minimum range was that obtained when the agent was discharged horizontally and maximum range was obtained when the spray nozzle was elevated 45°. Note that in all cases, the 1011 was discharged as a straight stream. The results are shown in Table 10.

Determining maximum and minimum range for the liquid agent (1011) was straightforward. By measuring the wetted area on the floor and its distance from the point of discharge the distance could be determined. Since all these tests were conducted with the extinguisher nozzle hand held, there was an initial reaction upon discharge. The 18-foot minimum range for 1011 shown in test 2 of Table 10 is somewhat below what the actual minimum range should be, since upon initial discharge the stream wavered above and below the horizontal. Determining maximum and minimum range for the gaseous agents, which includes Halon Foam, was more arbitrary. As the agent exited the nozzle, a mist was formed which began to dissipate shortly thereafter. The distance beyond the end of the nozzle that the mist began to breakup and dissipate was that distance recorded as minimum range. This generally corresponded to the point where the mist contacted the ground. As shown in Table 10, no data are listed for maximum range for gaseous agents. When the agents were discharged at a 45° angle, the mist dissipated and never contacted the ground. To record a figure that would be representative of maximum range, therefore, would be meaningless.

As noted previously, Phase III did not involve fires and was essentially a prelude to Phase IV which involved extinguisment of Class A and B fires. It is for this reason that the data shown in Table 10 should not be construed as indicative of effective range.

2.4 Effective Range Tests

Effective range tests were conducted with 1-gallon extinguishers only. As in Phase III, each extinguisher was weighed prior to and after each test. Discharge time and the time to extinguishment were recorded. The results of the extinguishment tests are shown in Table 11.

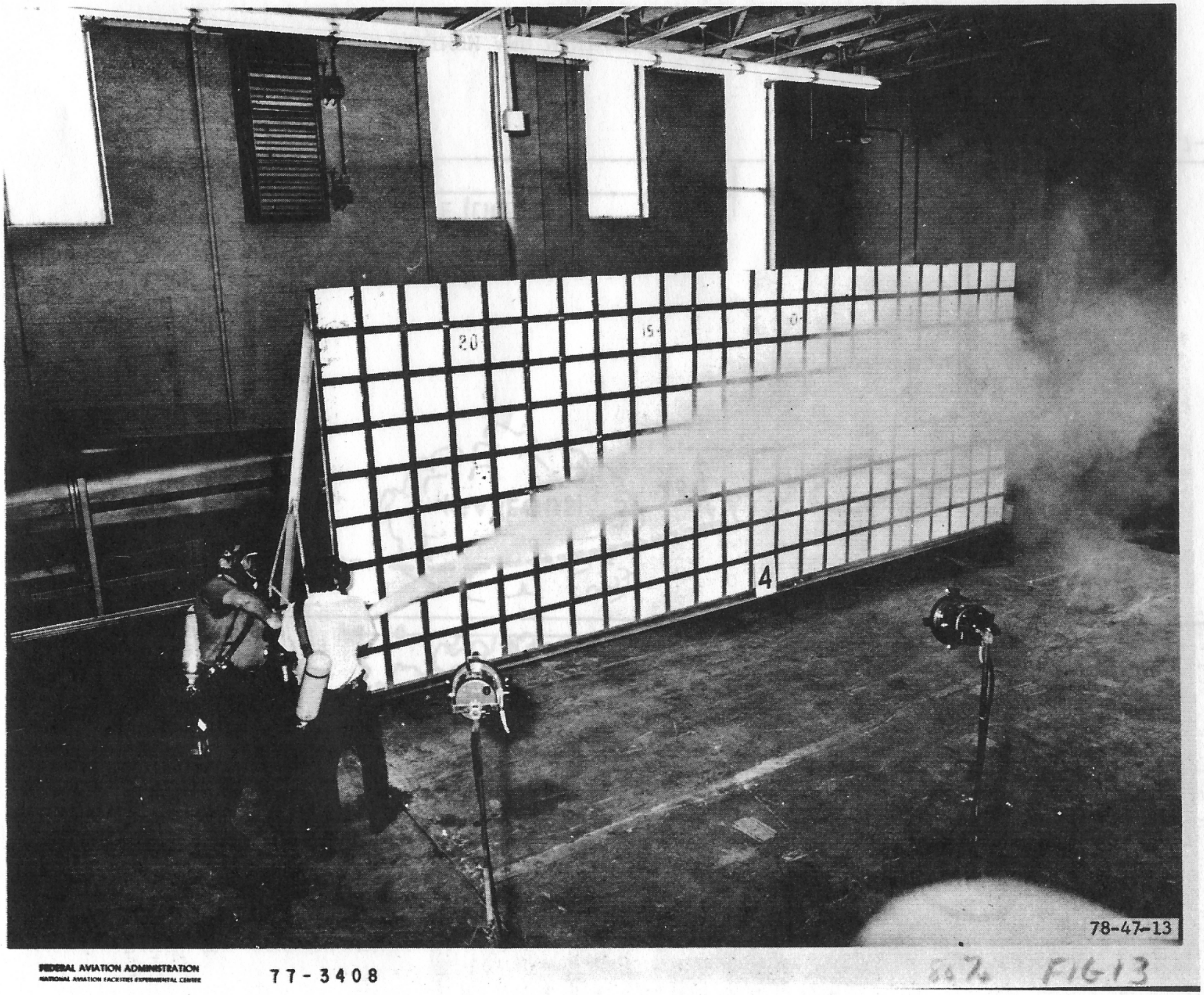

FIGURE 13. TYPICAL THROW RANGE TEST

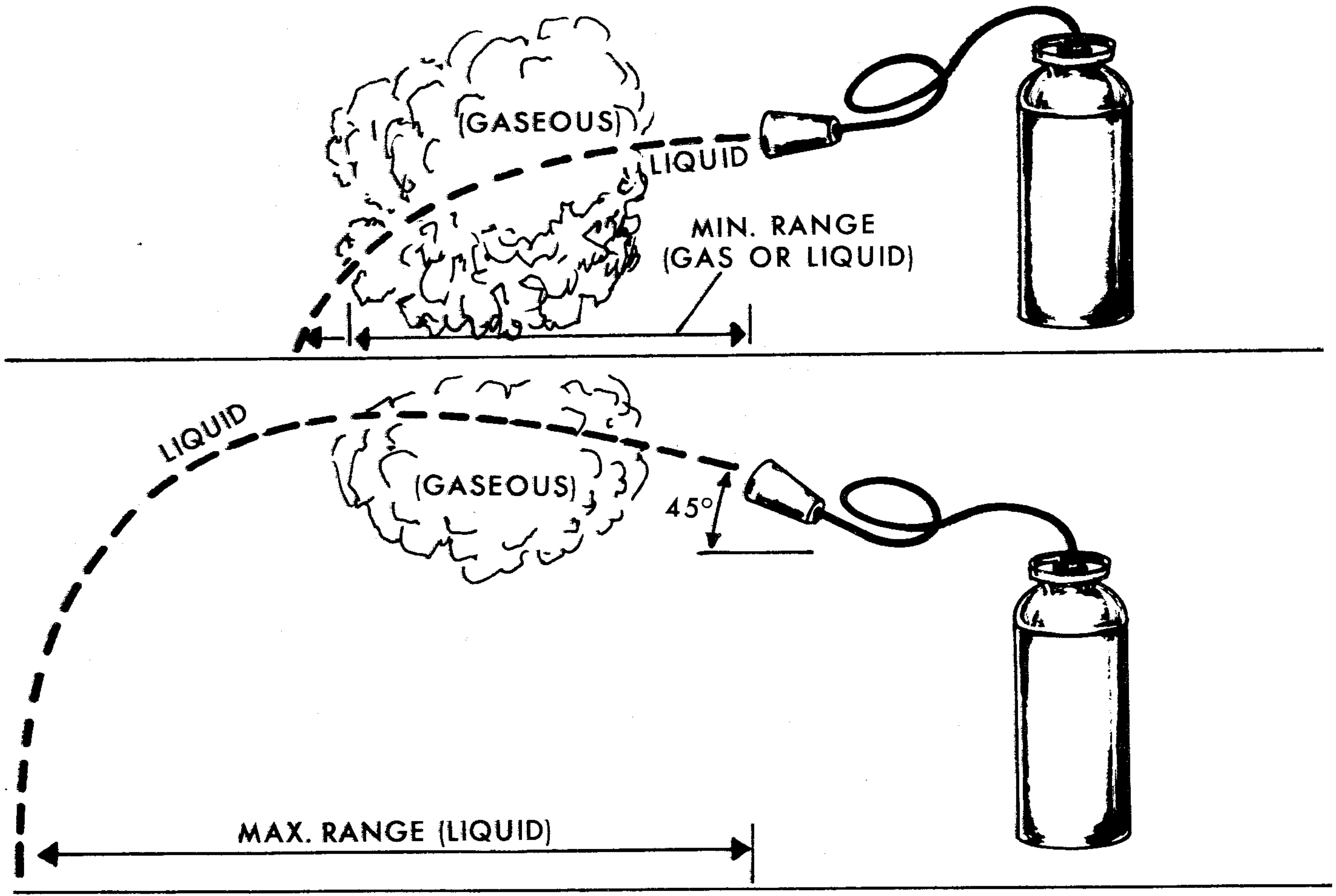

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FIGURE 14. MAXIMUM AND MINIMUM THROW RANGE DETERMINATIONS

TABLE 10. THROW RANGE

TEST NO.	AGENT	SIZE	MIN. RANGE (ft)[1]	MAX. RANGE (ft)[2]
1	1011	1 qt	22	29
2	1011	1 qt	18	29
3	1011	1 gal	41	(3)
4	1011	1 gal	41	50
5	1211	1 qt	12	(4)
6	1211	1 qt	12	(4)
7	1211	1 gal	16	(4)
8	1211	1 gal	16	(4)
9	Foam	1 qt	10	(4)
10	Foam	1 qt	10	(4)
11	Foam	1 gal	22	(4)
12	Foam	1 gal	24	(4)
13	1301	1 qt	5	(4)
14	1301	1 qt	7	(4)
15	1301	1 gal	16	(4)
16	1301	1 gal	16	(4)

Legend:

1 Agent discharged horizontally
2 Agent discharged 45° to horizontal
3 Maximum range not determined
4 Maximum range indeterminate for gaseous agents.

TABLE 11. EFFECTIVE RANGE--1-GALLON UNITS

	CLASS A FIRE		CLASS B FIRE		
AGENT	EXT. DIST (ft)	EXT. TIME (s)	EXT. DIST. (ft)	EXT. TIME (s)	DISCH. RATE (lb/s)
1011+	4	13	<5*	--	0.84
1211	12	2	12	3	2.25
1301	10	6	<4*	--	1.70
Halon Foam	8	2	12	1	1.30

+ Agent applied only in form of solid stream.

* Extinguishment not effected at range noted. Extinguishment at shorter distances not attempted.

For tests requiring a Class A fire, the fire load consisted of 8 lbs of matted yarn waste per Federal Specification DDD-W-101C, Class 1. Since there were no dyed yarns in the Class A fire material, the composition was approximately that described as follows:

Cotton Yarns	Weight (percent)
Undyed, bleached soft spun yarns	80 min.
Slasher yarns	20 max.

As stated in the specification, each of the components may have 20 ±2 percent nonbright, spun-rayon yarns in lieu of the same quantity by weight of cotton yarns. Although the precise amount of rayon is not known, the same material was used for all tests. Prior to ignition, the cotton waste was moistened with one pint of JP-4 jet fuel. The flammables were evenly distributed in a 3-ft by 3-ft by 6-inch steel pan. The preburn time was 1 minute. The same fire tray was used for the Class B fire. The fire load was 5.6 gallons of JP-4 which filled the tray to a depth of 1 inch. The preburn time with the liquid fuel was 30 seconds. These tests were conducted within an enclosure with a large open bay, to eliminate weather effects.

The number of fire extinguishing tests conducted with each type of agent was predicated upon gaining reasonable assurance that the fire could be extinguished at the maximum possible distance. This was accomplished by taking into account the information obtained from Phase III (See Figures 15 and 16 which show typical extinguishment attempts).

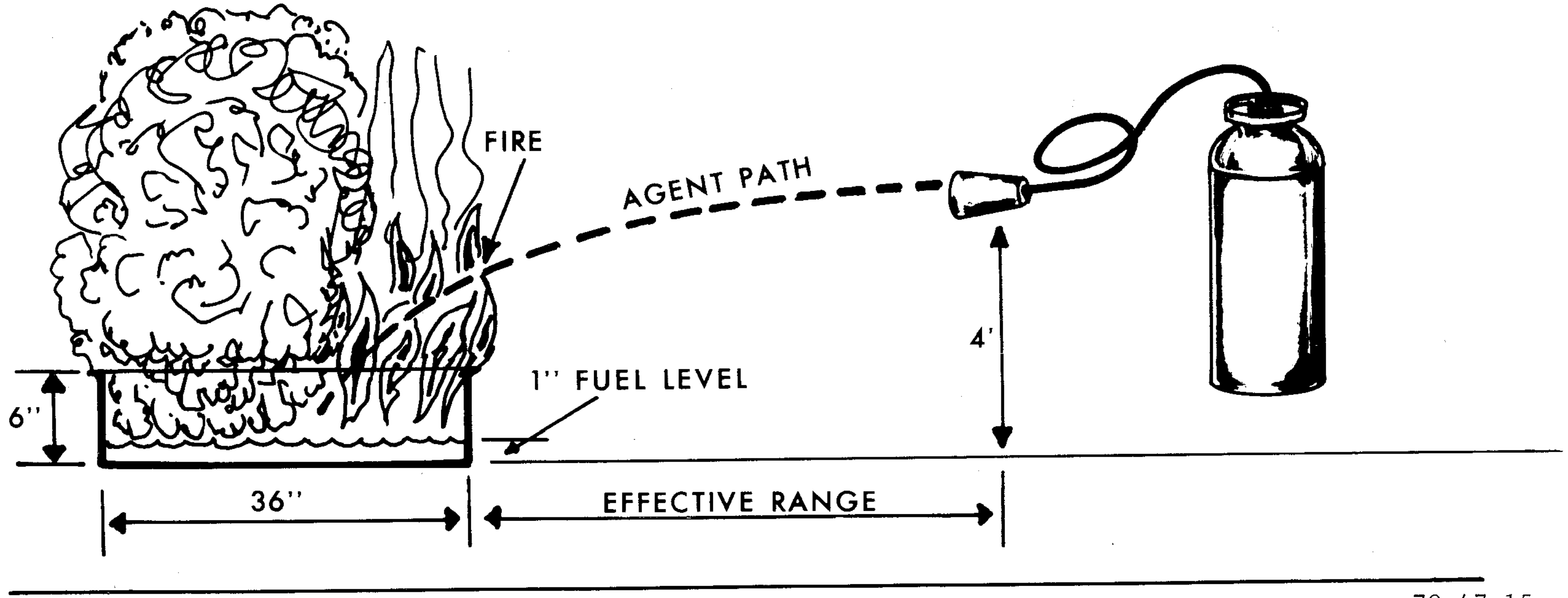
The basic procedure followed was to establish a minimum distance at which extinguishment was assured and a maximum distance at which extinguishment was marginal or not probable. Distances between these two extremes were selected to define more precisely a maximum effective range. When the fire was eventually extinguished, confirming tests were conducted at that same distance and, also, at a distance increased by 1 foot. For the Class A fire, extinguishment was considered effected if reignition did not occur within 5 minutes of initial flame extinguishment. All tests were conducted in front of the 24 ft by 8 ft backdrop. The tests were also recorded on 16 mm color film and video tape. The results are shown in Table 11.

Prefacing any comments made hereafter, it is appropriate to note that these test results should be viewed as a guide only. Fire sizes were fixed and each test was conducted as consistantly as possible. Numerous factors can alter test results; e.g., fire size, type of combustible, ventilation or ambient wind, amount of agent, and discharge rate. It is important to note that optimization of technique was not considered. In a real-life fire situation, one would knock down the fire at a reasonably comfortable distance, then approach as close as possible and attack the base of the fire.

As noted in Table 11, the same 1-gallon extinguisher was used for both 1301 and Halon Foam. The nozzle was specifically intended for use with the latter. It must be taken into account, therefore, that for use with 1301 this was probably not an optimum nozzle configuration. Also, the 1301 extinguishers were not pressurized with nitrogen which may have affected the performance.

The data shown in Table 11 represent those distances at which extinguishment was assured. Increasing the distance by 1 or 2 feet created a marginal situation which indicates that distance is a critical factor for all the agents tested. Had a sufficient number of tests been conducted in this same manner, a 1- or 2-foot greater distance could possibly have been established with a percent effectiveness; i.e., a ratio between the number of extinguishments to the number of test fires. Against a Class A fire, 1011 was least effective and 1211 most effective. Note, however, that the 1011 was discharged as a straight stream and not as a mist. Against Class B fires, only 1211 and Halon Foam were effective. Considering extinguishment time, the foam was slightly more efficient, extinguishing the fire in 1 second as compared to 3 seconds for 1211. For practical purposes, the minimum distance between the extinguisher and the fire was held to 4 to 5 feet. Neither the 1011 nor the 1301 extinguished the fire at this distance. The 6-inch lip did prevent the agents from contacting the entire fire area (Figure 15). In some instances, the fire was extinguished except for the inside edge nearest the extinguisher. When the agent was expended, the fire would buildup again, eventually rekindling the entire tray.

All of the agents produced smoke with an acrid and offensive odor during extinguishment attempt. Higher humidities tended to result in a more dense and lingering cloud of smoke. Also, the longer the extinguishment times, generally, the more volume and denser the smoke produced. An inspection of the test area following this test phase revealed that some exposed metal



78-47-15

FIGURE 15. TYPICAL EXTINGUISHMENT ATTEMPT

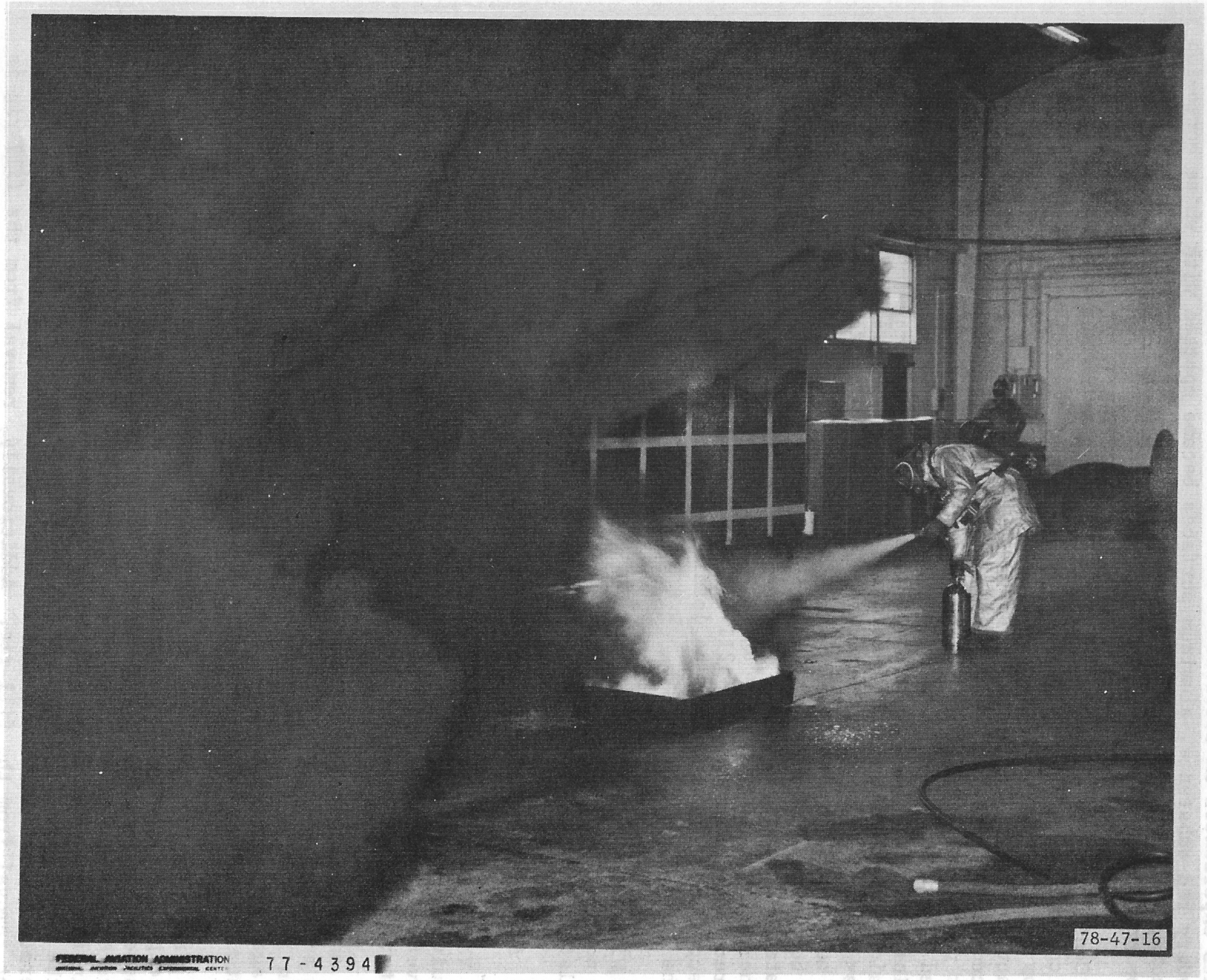


FIGURE 16. TYPICAL EFFECTIVE RANGE TEST

objects experienced an accelerated corrosion. Mild steel became covered with a powdery red substance, aluminum surfaces became spotted with white corrosion products, and even stainless steel was affected. The exact nature of these corrosion products was not determined.

Considering effective range only and the constraints under which the tests were conducted, Halon Foam and 1211 are the most effective. If one were to narrow this down to a single agent, other aspects must be considered. From a practical standpoint, loading a foam bottle is time consuming, and it must be accomplished with protective gear. The fumed silica consists of extremely light particles. Disturbing this material by handling and the air currents caused by exhaust fans in the loading room resulted in these particles remaining suspended in the air for long periods of time. This constituent of Halon Foam represents an inhalation health hazard. The surfactant, unless it is kept at room temperature, will solidify in the container. This does not occur, however, when the foam bottles are loaded. Each constituent must be precisely weighed and when the halons are loaded, the bottle must be repeatedly disconnected from the fill line for accurate weight measurements. Further, the bottles must be agitated and cooled periodically to achieve desired loaded weight. The 1211 bottles used in this program were charged by the supplier. With appropriate loading equipment for both agents, 1211 would be the least time consuming.

With regard to cleanup after the effective range tests, 1211 and 1301 left no residue, but Halon Foam left a slippery coating that is difficult to completely remove.

2.5 Agent Selection

There was no outstanding feature of any agent tested which made it unequivocally the ideal replacement for Halon 1011. An attempt will be made, however, to summarize the information obtained from this study to support the agent recommended as a replacement for Halon 1011.

As a result of the testing described herein, Halon 1211 was selected as a suitable agent for use in emergency first-aid fire situations. Since Halon 1301 was least effective in effective range testing and Halon 1011 is the agent to be replaced, these will be eliminated from the discussion. The agents remaining, 1211 and Halon Foam, are those with the most promise.

From a purely practical standpoint, Halon Foam is undesireable. Refilling expended extinguishers is time consuming and requires precise measurement of several individual constituents. Further, protective breathing apparatus is required to preclude inhalation of the fumed silica. This material, which is in the form of extremely light particles, remains in constant suspension in the air. This is unavoidable because of handling and air currents generated by the fill room exhaust fan. Precise loaded weights require frequent removal from the fill rig. Additionally, removal from the fill rig is required for extinguisher agitation and immersion in cold water when charging with 1301. Halon Foam leaves a slippery residue which can be hazardous for a person trying to move quickly in a fire situation. Because of this residue, cleanup is difficult, requiring a copious amount of water. (For this reason, its use on electronic equipment may be undesireable, despite the fact that the residues have been found to have little deleterious effects on electronic circuits (AFAPL-TR-72-62).

Considering its use as an effective fire extinguishant, 1211 outperformed all other agents on Class A fires and was about equal to Halon Foam on Class B fires.

The one aspect of 1211 which is the most tenuous in establishing its advantages over the other agents is its ability to reduce severity of the fire environment and pyrolysis products levels. As discussed previously, Table 9 shows 1211 somewhat better than the other agents in reducing the fire environment intensity. With regard to compartment visibility, the reader must keep in mind that stratification, particularly in nonventilated tests, is a significant factor in reducing the severity of this parameter. But, likewise, it would allow a seated individual a higher level of visibility.

Where data are available, Halon 1211 fared better than Halon Foam regarding pyrolysis products. As noted previously, stratification may account for this since the sample station was above the stratification level. But, again, it also places the seated individual above this level.

SECTION III

CONCLUSIONS

a. After using the entire contents of the 1-quart extinguishers, a 4-pound fire load of absorbent cotton batting will continue to smolder after initial flame extinguishment.

b. Halon Foam does not display any lingering or agent time-release effect different from the pure agents.

c. In fixed-distance, effective-range testing on Class A and B fires using 1-gallon, nominal-size extinguishers, the most effective agent was Halon 1211 while the least effective was Halon 1011.

d. In the absence of fire, the temperature drop caused by the discharge of gaseous agents into small volumes can result in some obscuration to vision due to fog formation under high humidity conditions.

e. All agents when discharged into a fire result in the generation of smoke with resultant obscuration to vision.

f. The presence of liquid Halon 1011 on a smoldering fire can result in continuing decomposition of the agent.

g. The maximum expected volumetric concentration of agent for 100 ft^3 per pound of agent discharged is: 2.3 percent for 1301, 2.1 percent for 1211, and 1.9 percent for Halon Foam.

h. Under quiescent conditions, Halons 1211 and 1301 will cause a stratified smoke layer to settle near the floor.

SECTION IV

RECOMMENDATIONS

a. As a result of the tests described in this report, Halon 1211 is recommended over 1301 or Halon Foam as a replacement for Halon 1011 in hand-portable fire extinguisher units.

b. A comprehensive effective range test program for 1-quart extinguishers employing fixed distances and optimization techniques against Class A and B fires should be conducted.

c. To minimize hardware cost in the replacement of current A-20 units, a development program is recommended to modify this unit for use with Halon 1211.

d. Due to the stratification effects of the agents, a further effort is recommended to define and characterize the environment particularly its vertical variation.

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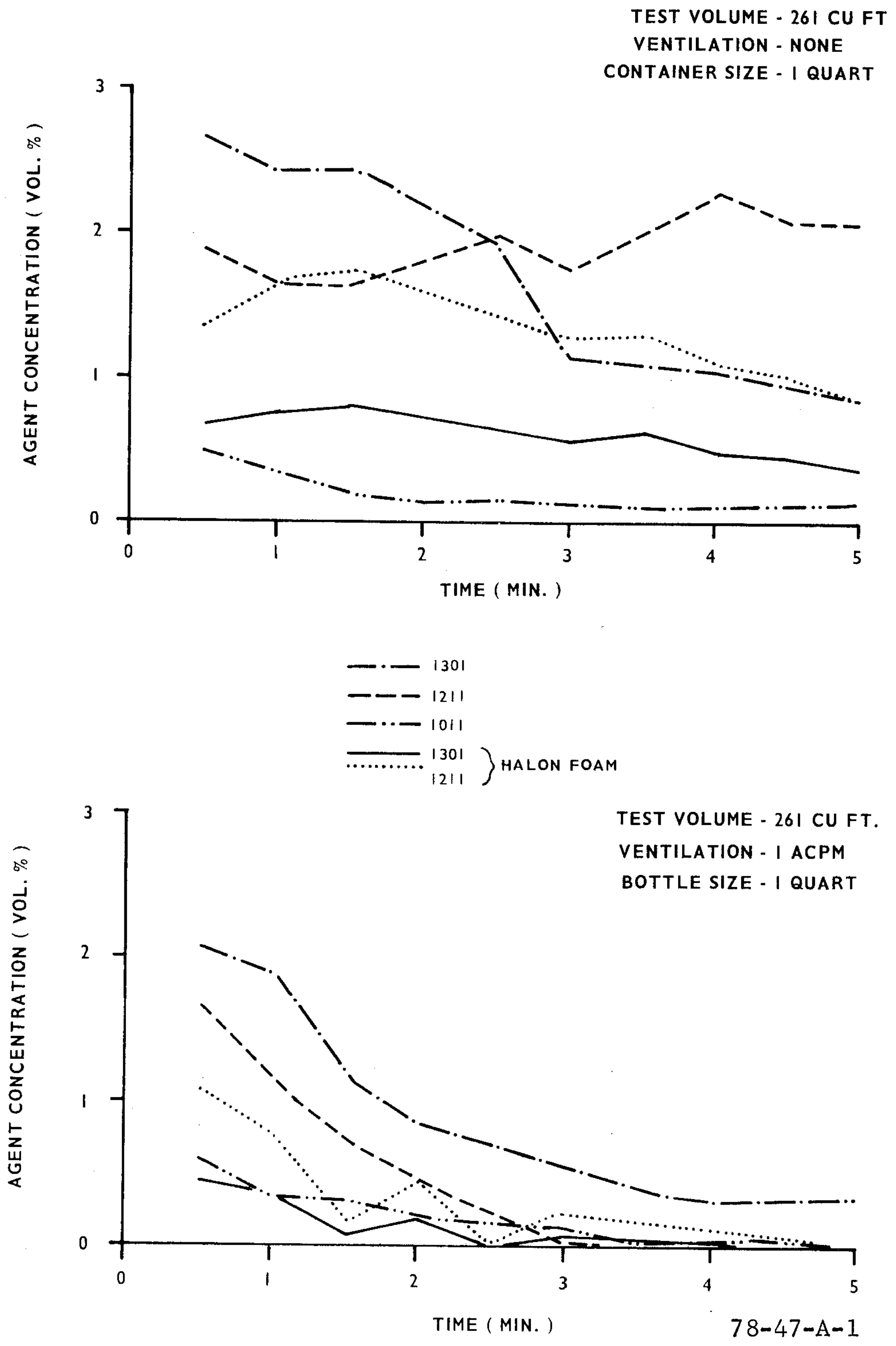
APPENDIX A

TEST DATA



78-47-A-1

FIGURE A-1. AGENT CONCENTRATION IN SMALL VOLUME USING 1-QUART EXTINGUISHERS

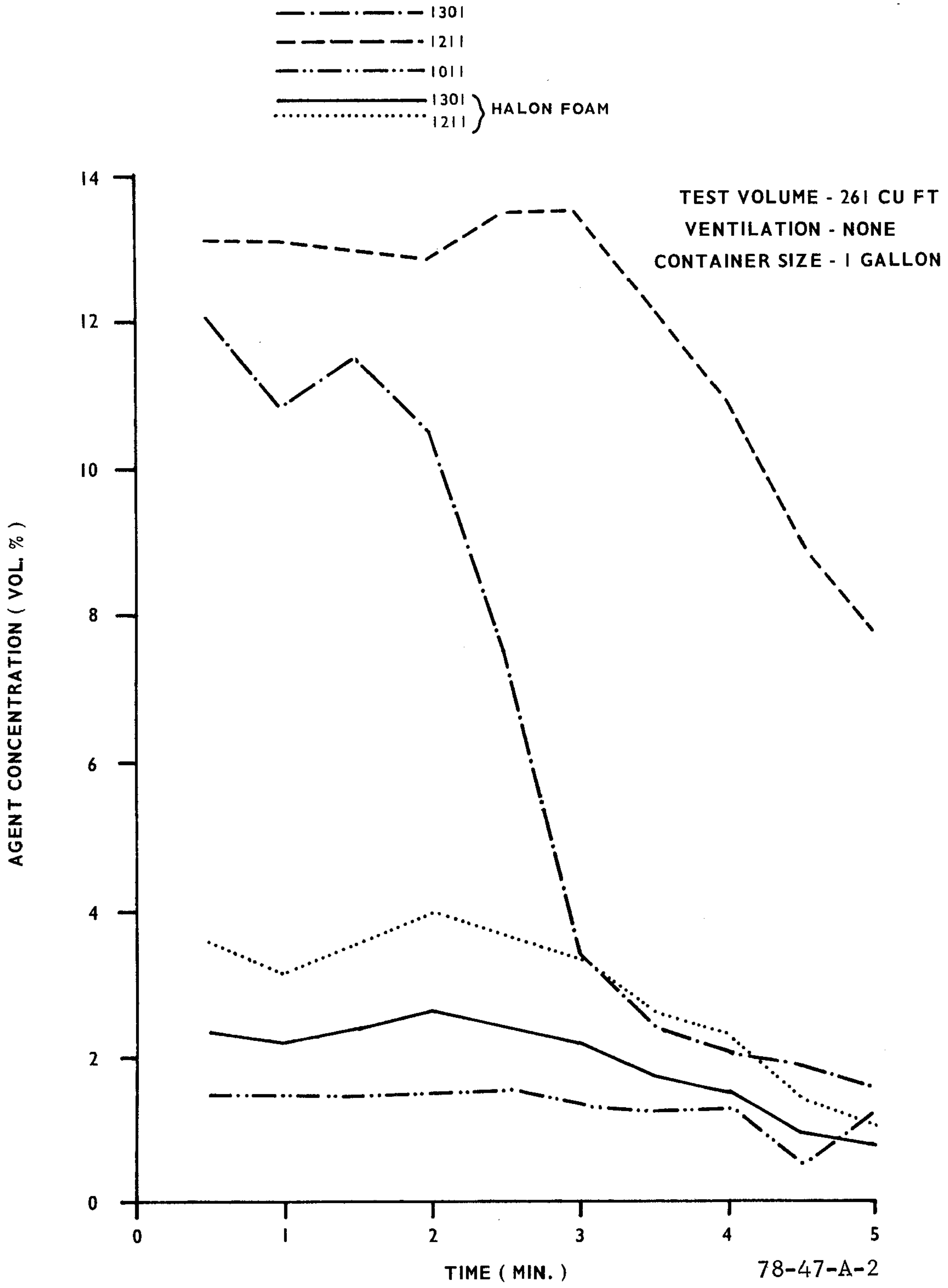


FIGURE A-2. AGENT CONCENTRATION IN SMALL NONVENTILATED VOLUME USING 1-GALLON EXTINGUISHERS

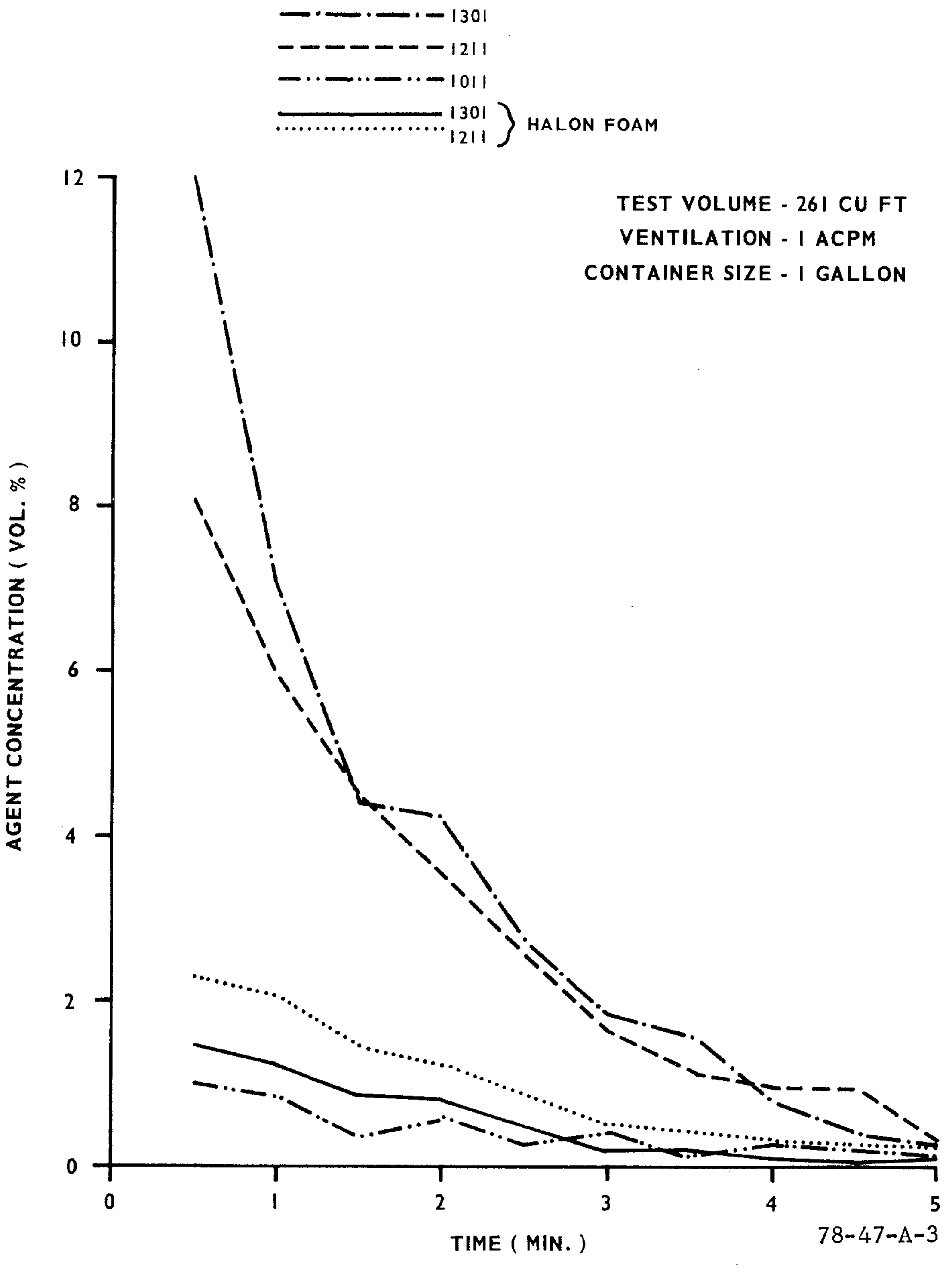


FIGURE A-3. AGENT CONCENTRATION IN SMALL VENTILATED VOLUME USING 1-GALLON EXTINGUISHERS

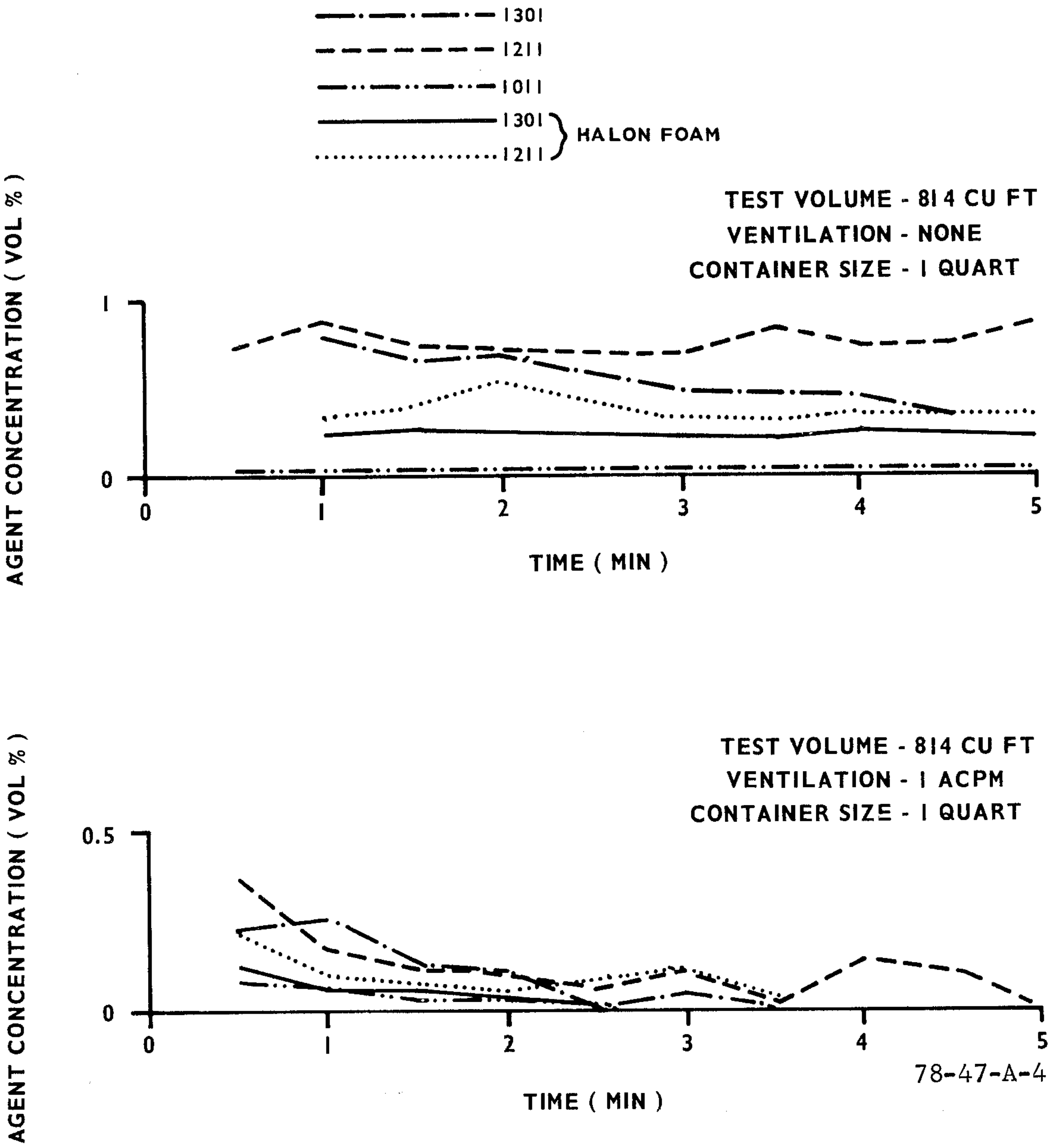


FIGURE A-4. AGENT CONCENTRATION IN LARGE VOLUME USING 1-QUART EXTINGUISHERS

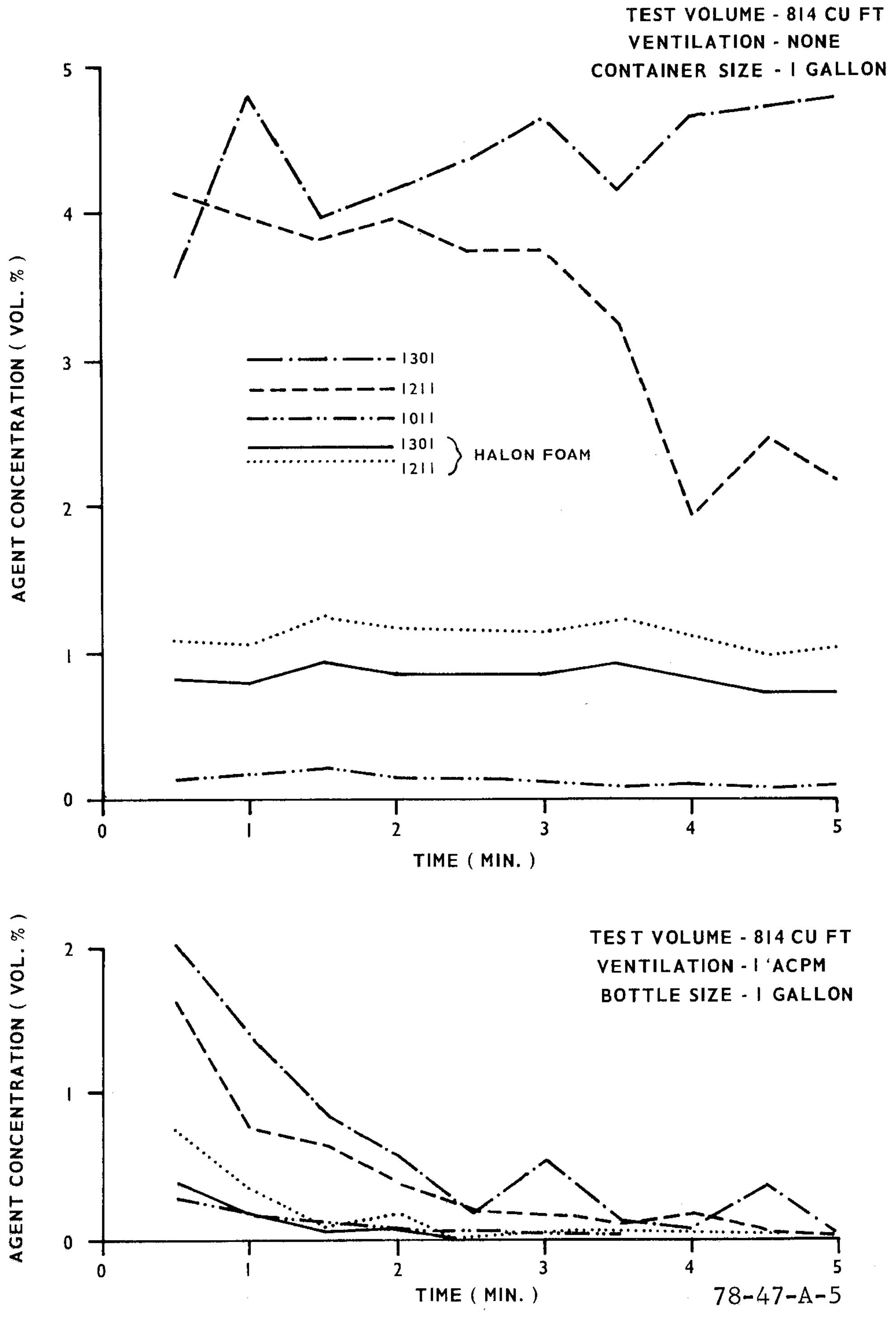


FIGURE A-5. AGENT CONCENTRATION IN LARGE VOLUME USING 1-GALLON EXTINGUISHERS

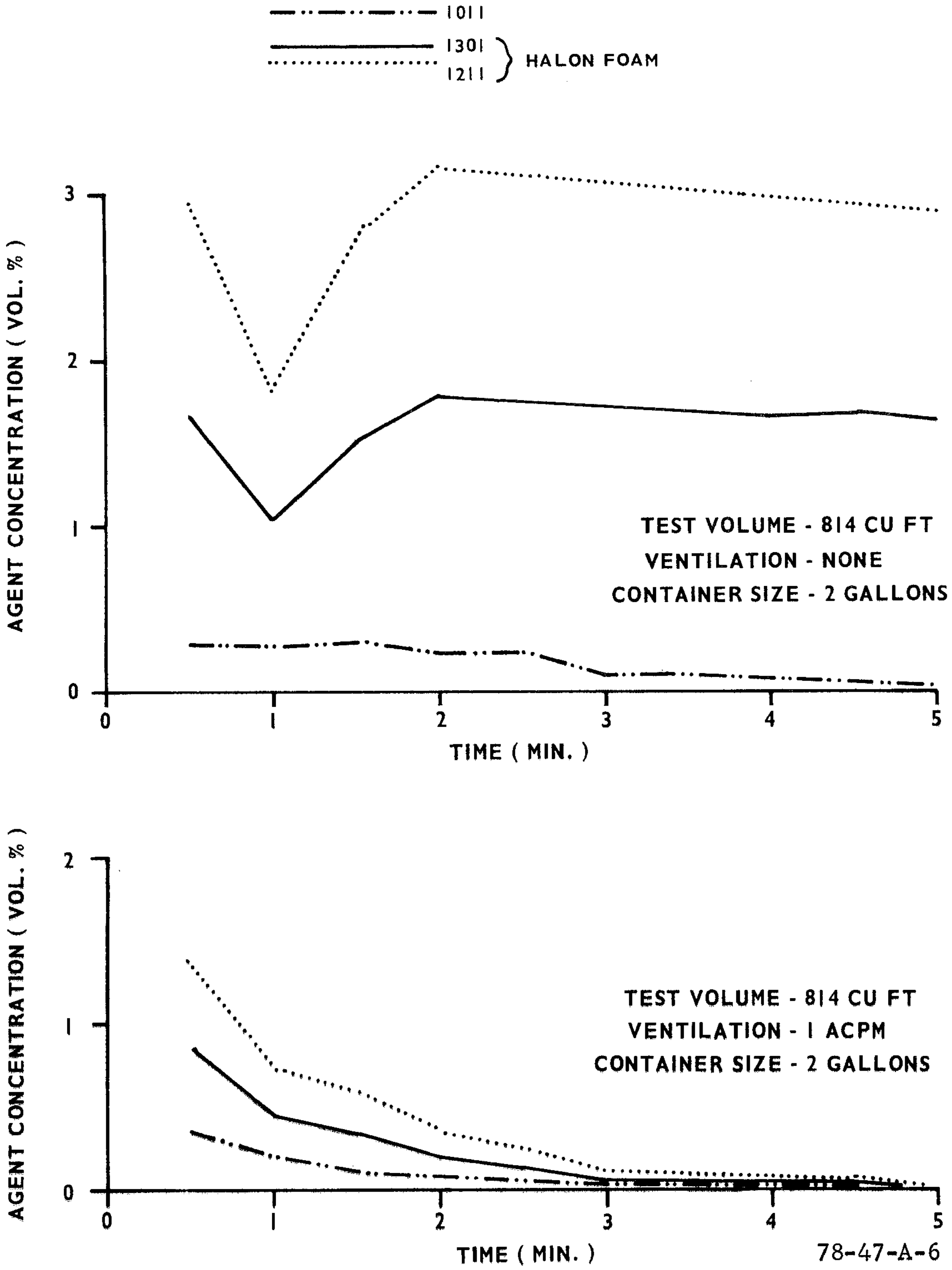


FIGURE A-6. AGENT CONCENTRATION IN LARGE VOLUME 2-GALLON EXTINGUISHERS

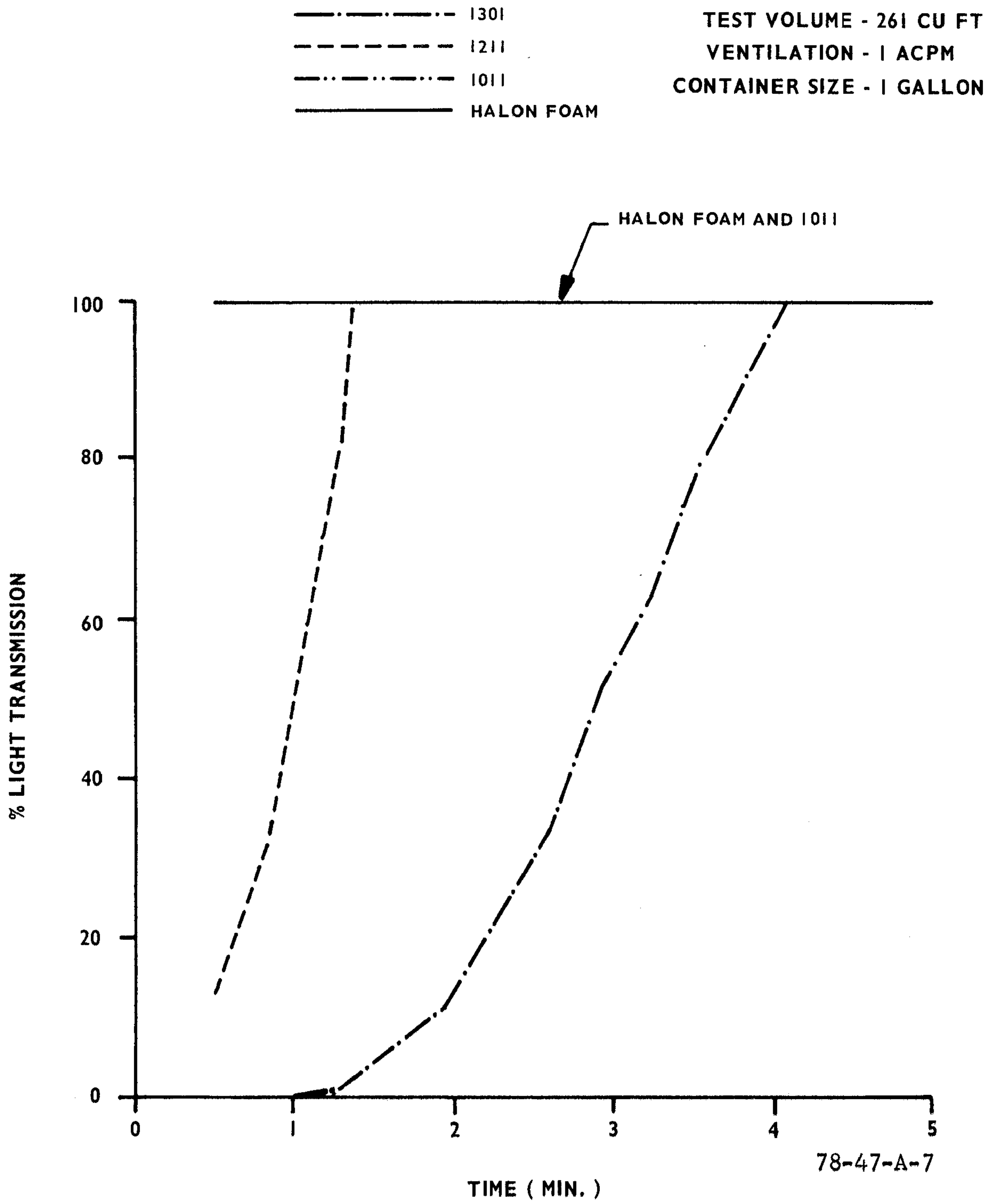


FIGURE A-7. LIGHT OBSCURATION IN SMALL VENTILATED VOLUME USING 1-GALLON EXTINGUISHERS

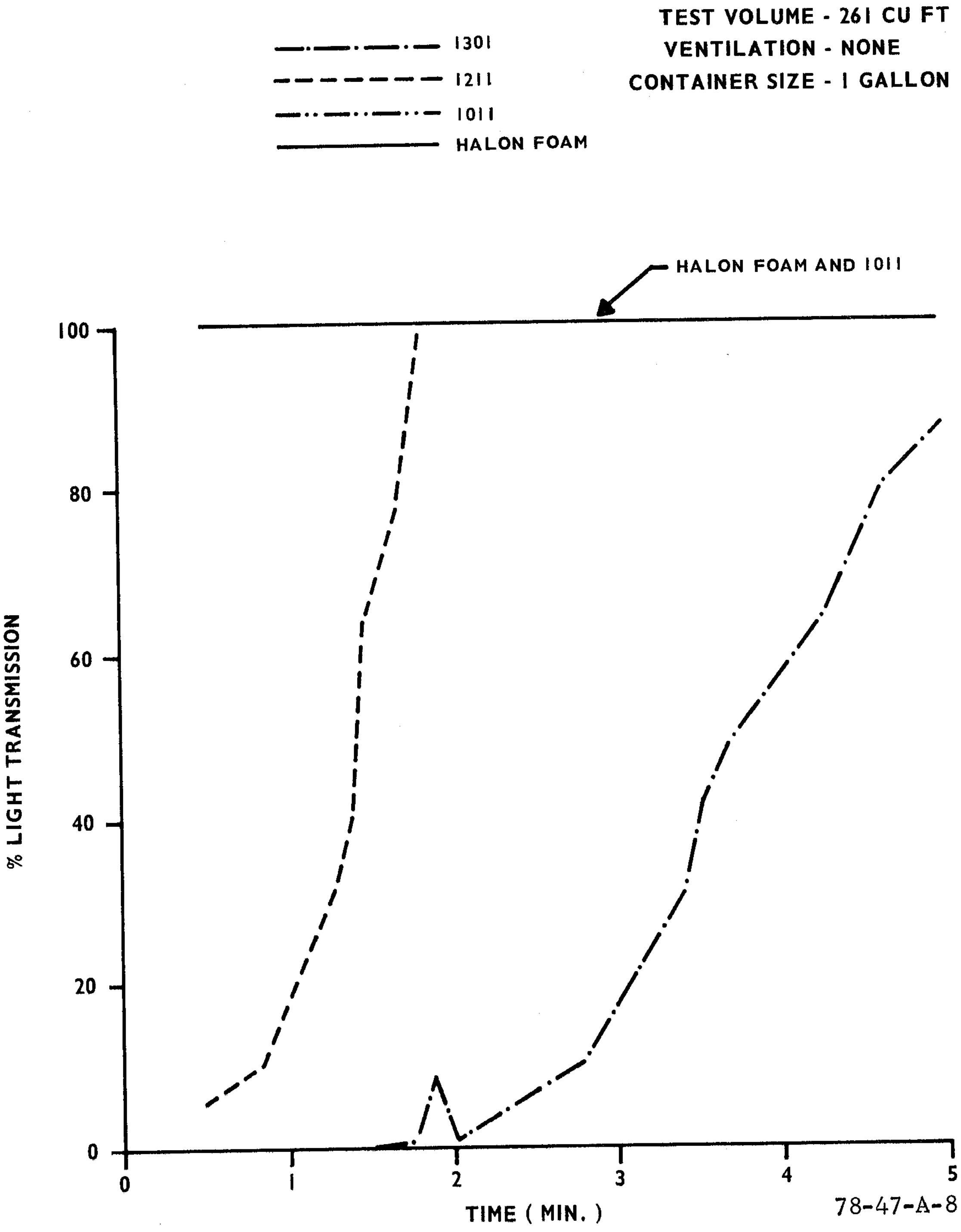


FIGURE A-8. LIGHT OBSCURATION IN SMALL NONVENTILATED VOLUME USING 1-GALLON EXTINGUISHERS

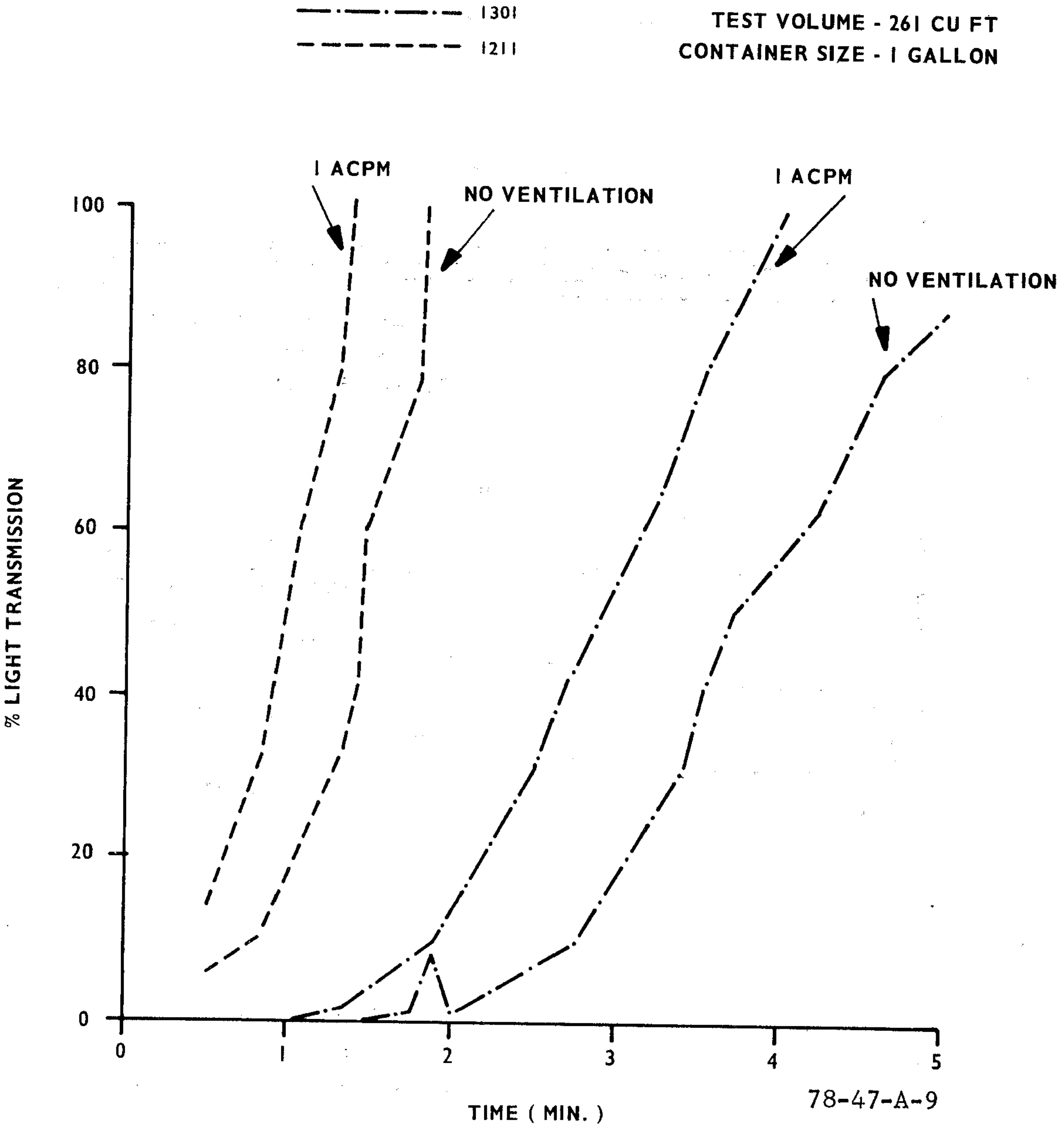


FIGURE A-9. EFFECT OF VENTILATION ON LIGHT OBSCURATION IN SMALL NONVENTILATED VOLUME USING 1-GALLON EXTINGUISHERS

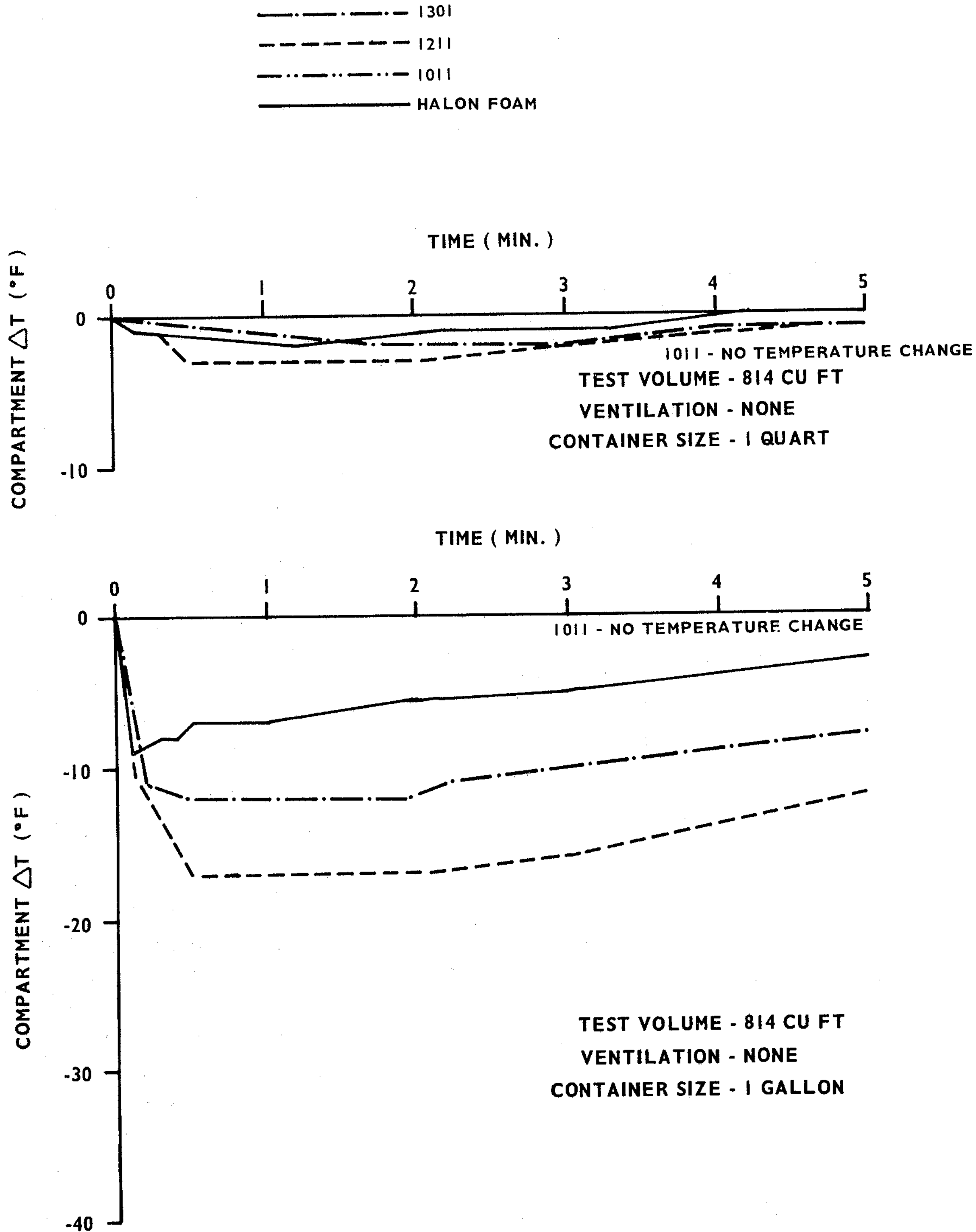


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FIGURE A-10. AGENT DISCHARGE COOLING EFFECT IN LARGE NONVENTILATED VOLUME USING 1-QUART AND 1-GALLON EXTINGUISHERS

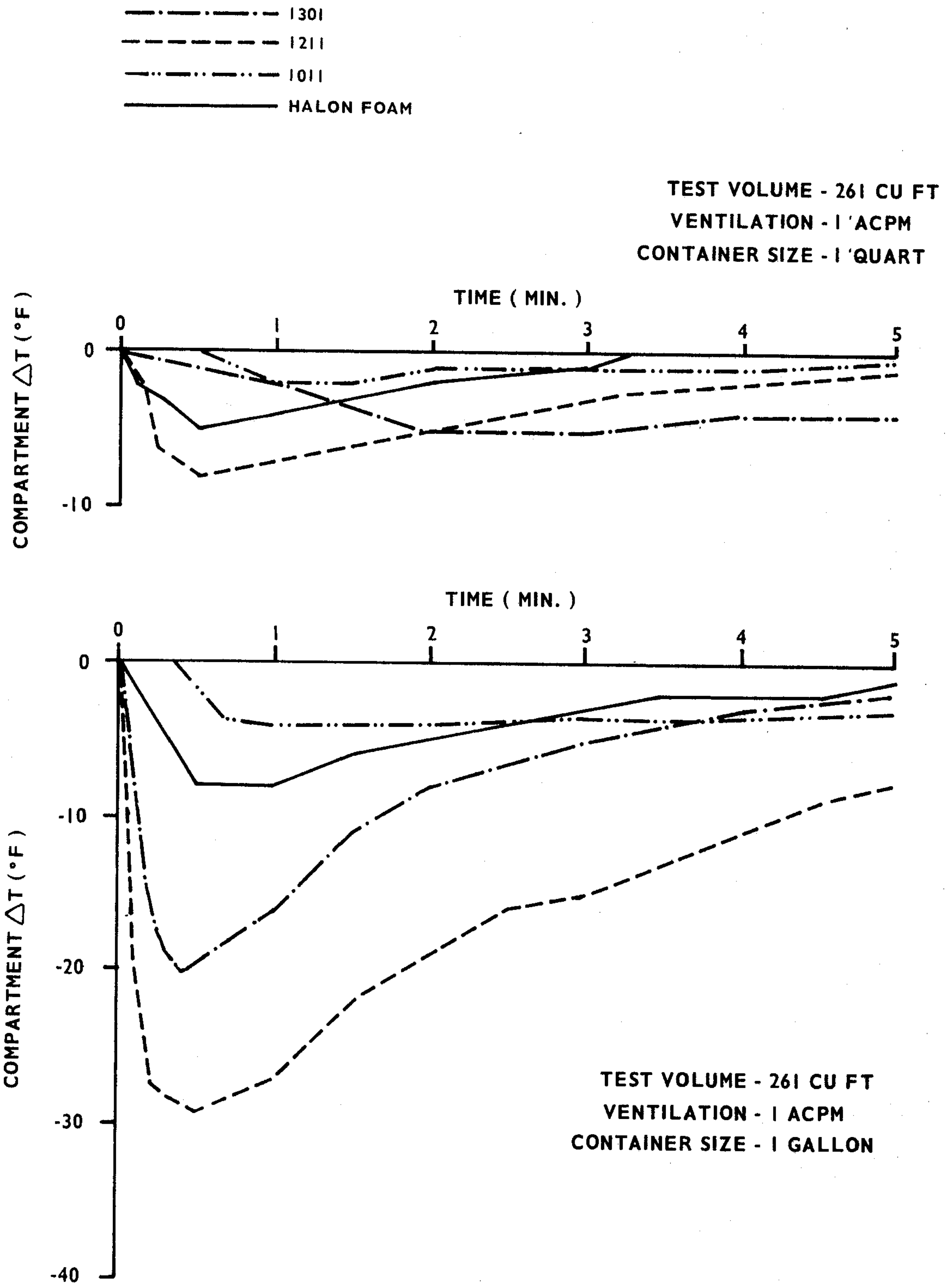

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FIGURE A-11. AGENT DISCHARGE COOLING EFFECT IN SMALL VENTILATED VOLUME USING 1-QUART AND 1-GALLON EXTINGUISHERS

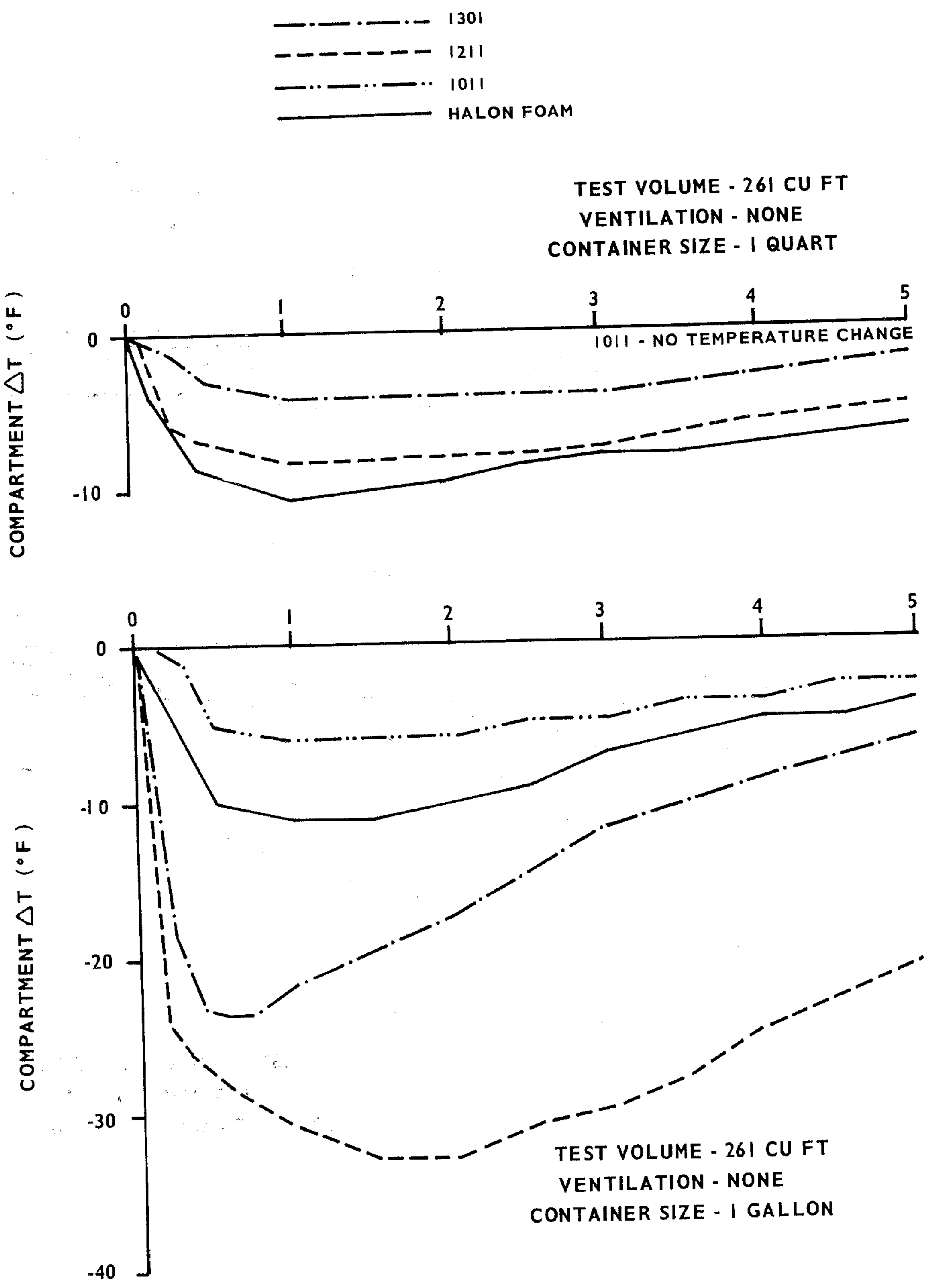

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FIGURE A-12. AGENT DISCHARGE COOLING EFFECT IN SMALL NONVENTILATED VOLUME USING 1-QUART AND 1-GALLON EXTINGUISHERS

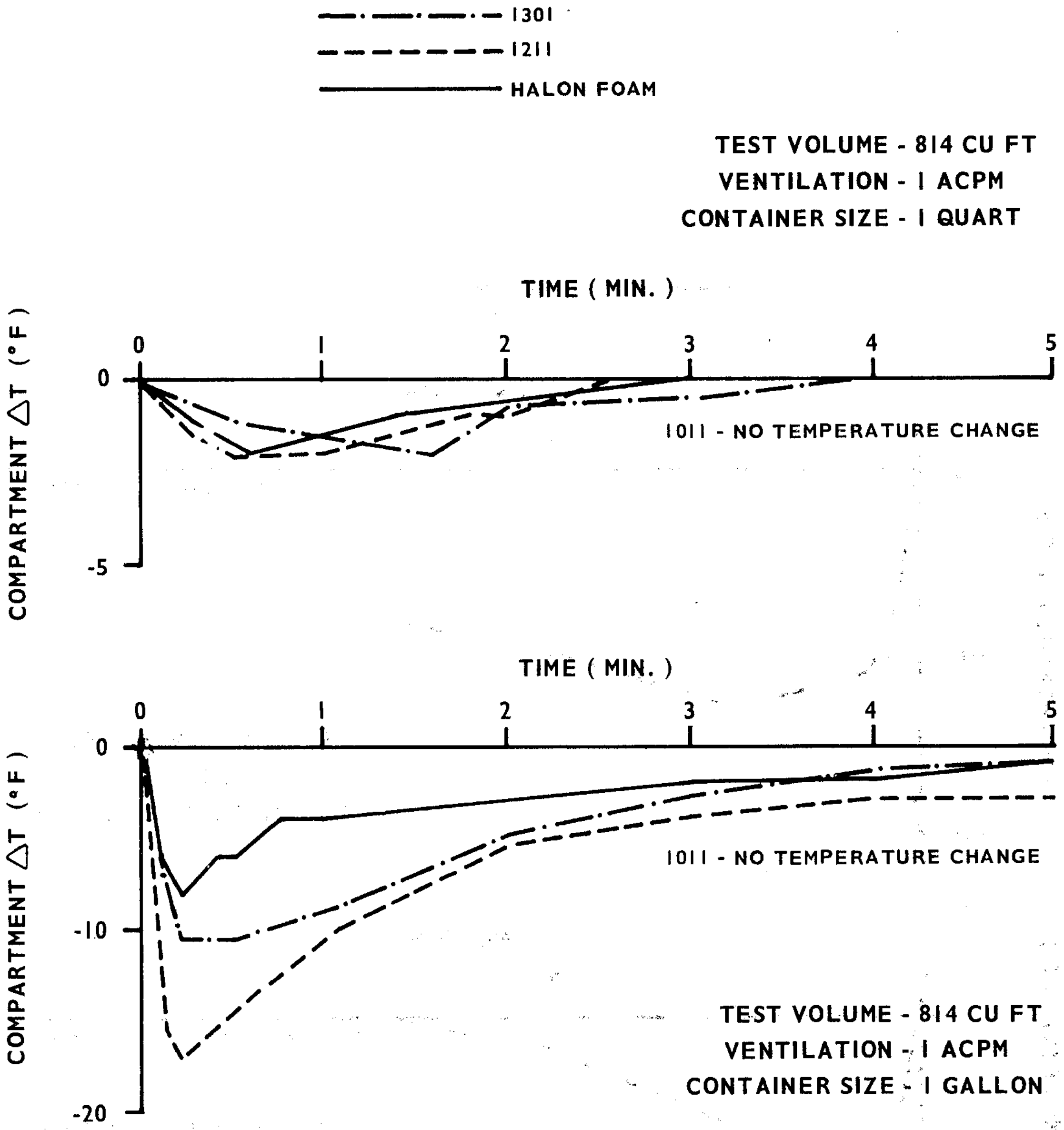

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FIGURE A-13. AGENT DISCHARGE COOLING EFFECT IN LARGE VENTILATED VOLUME USING 1-QUART AND 1-GALLON EXTINGUISHERS

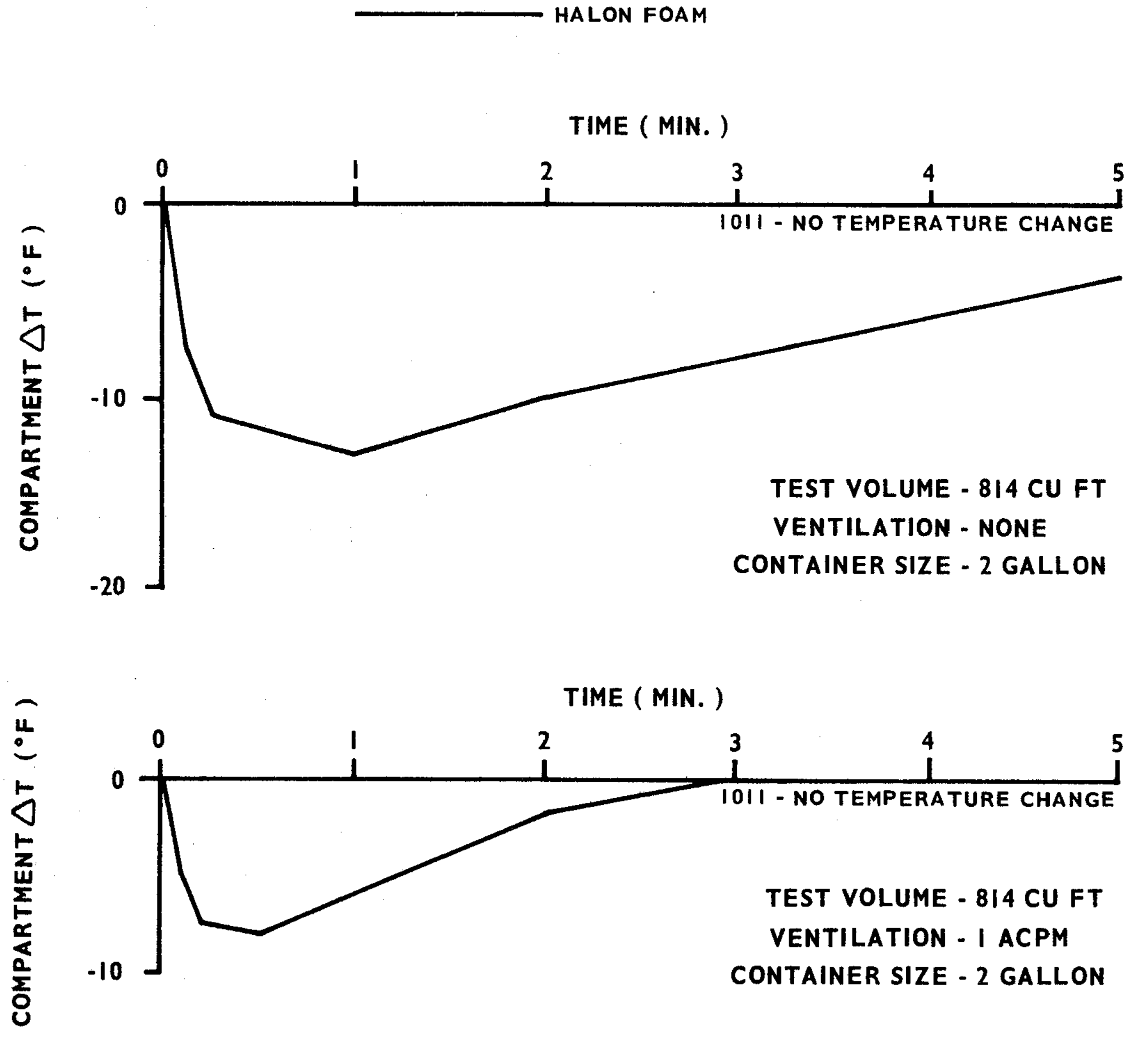

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FIGURE A-14. AGENT DISCHARGE COOLING EFFECT IN LARGE VOLUME USING 2-GALLON EXTINGUISHERS

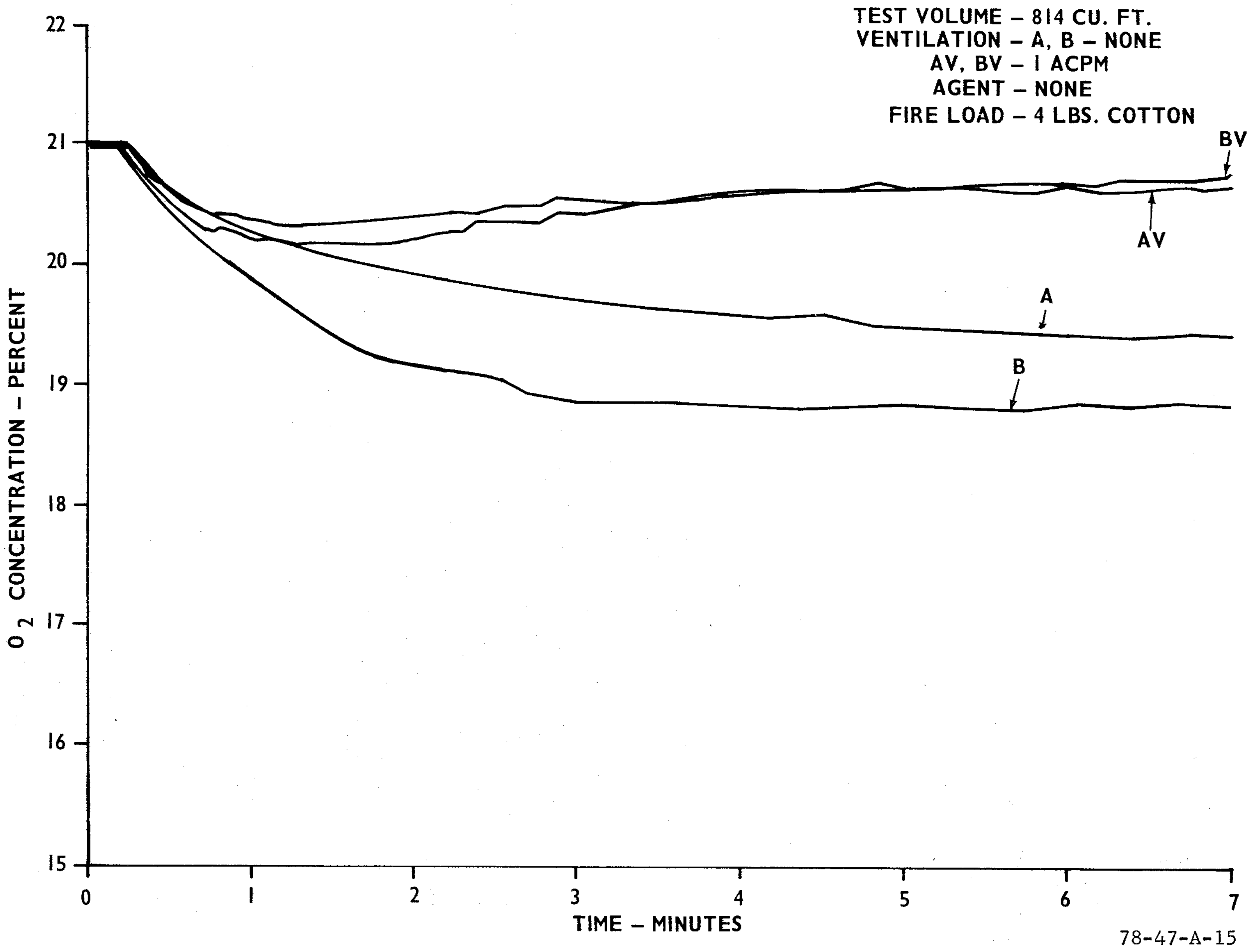

FIGURE A-15. OXYGEN CONCENTRATION--BASELINE FIRE TEST

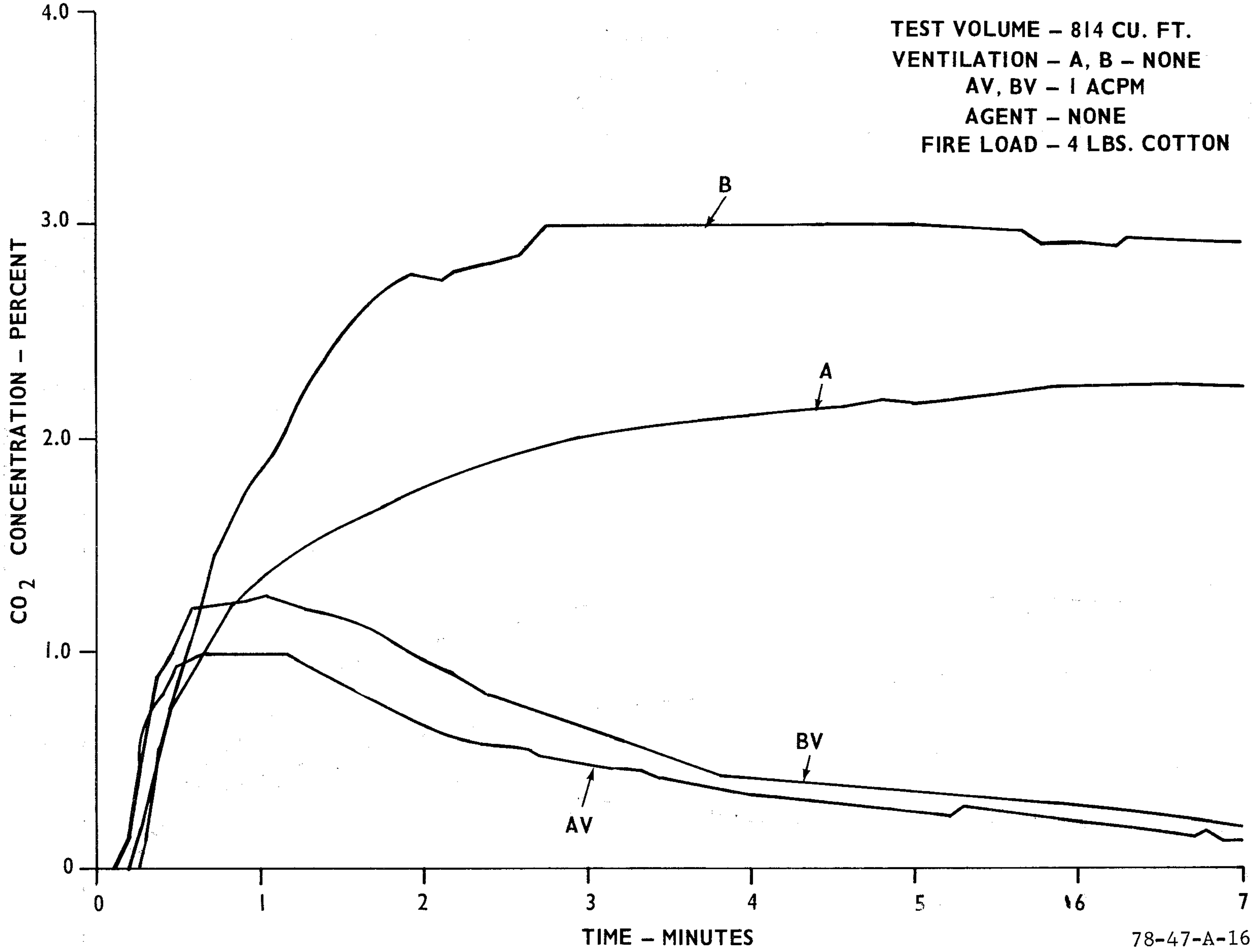

FIGURE A-16. CARBON DIOXIDE CONCENTRATION--BASELINE FIRE TEST

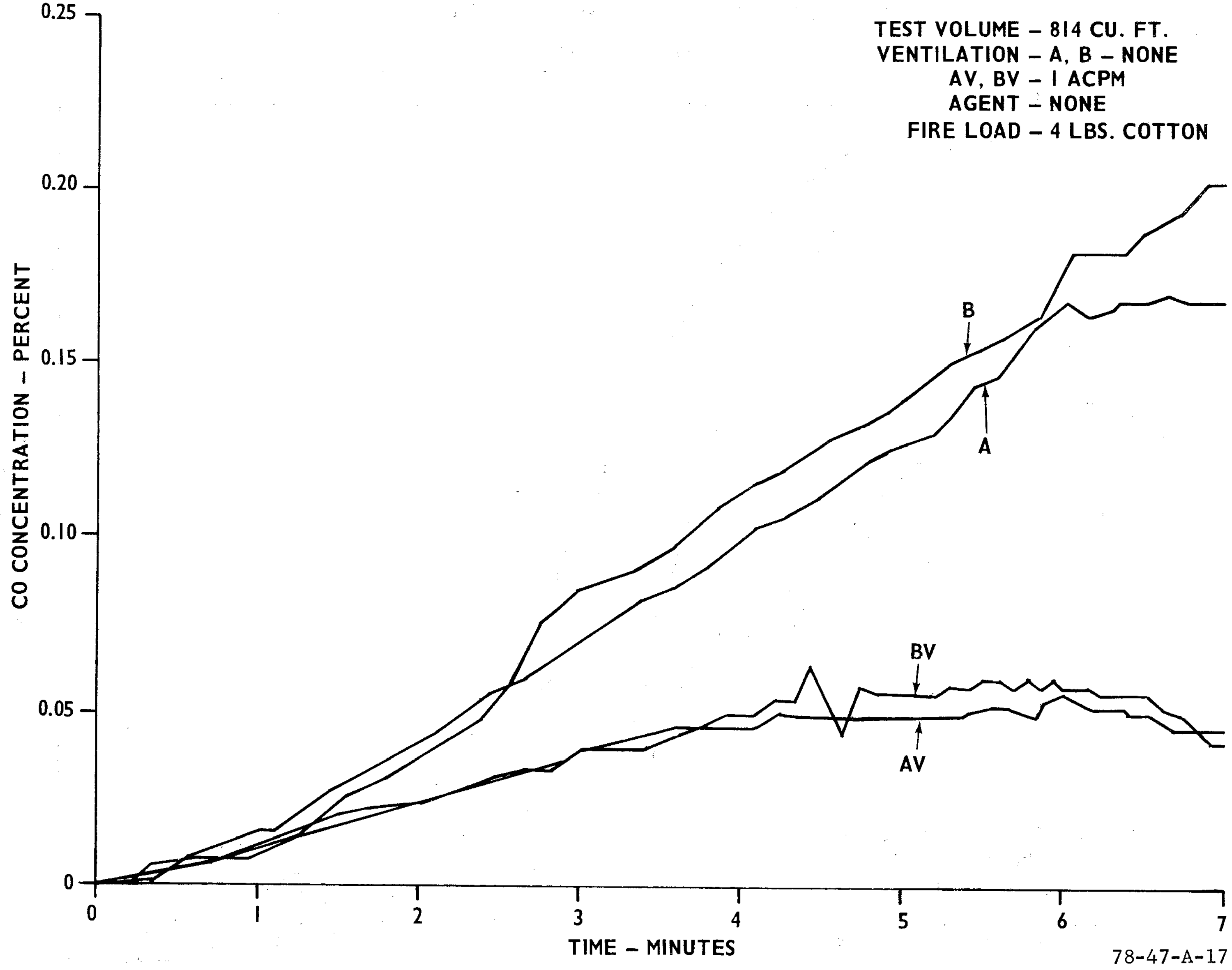

FIGURE A-17. CARBON MONOXIDE CONCENTRATION--BASELINE FIRE TEST

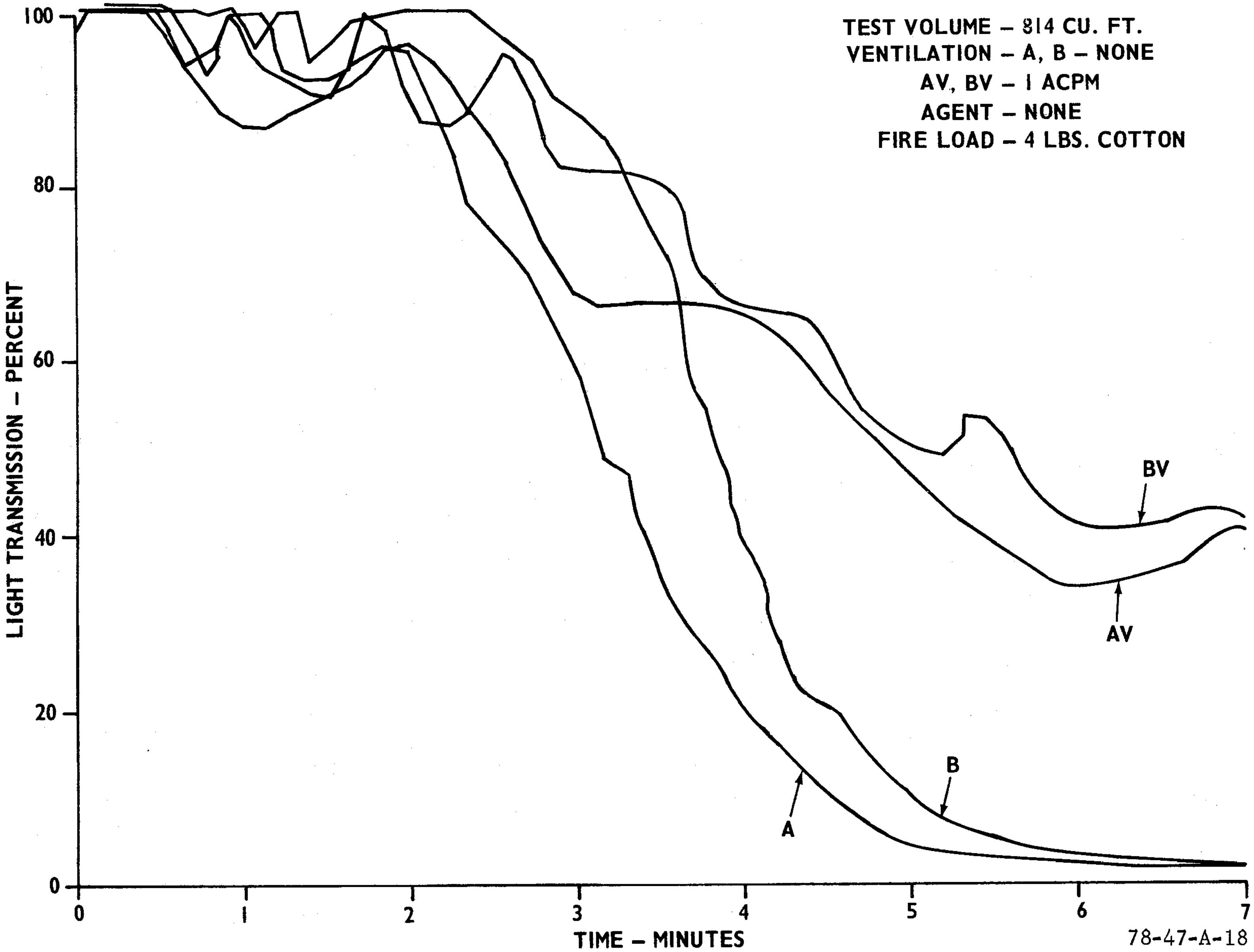

FIGURE A-18. LIGHT TRANSMISSION--BASELINE FIRE TEST

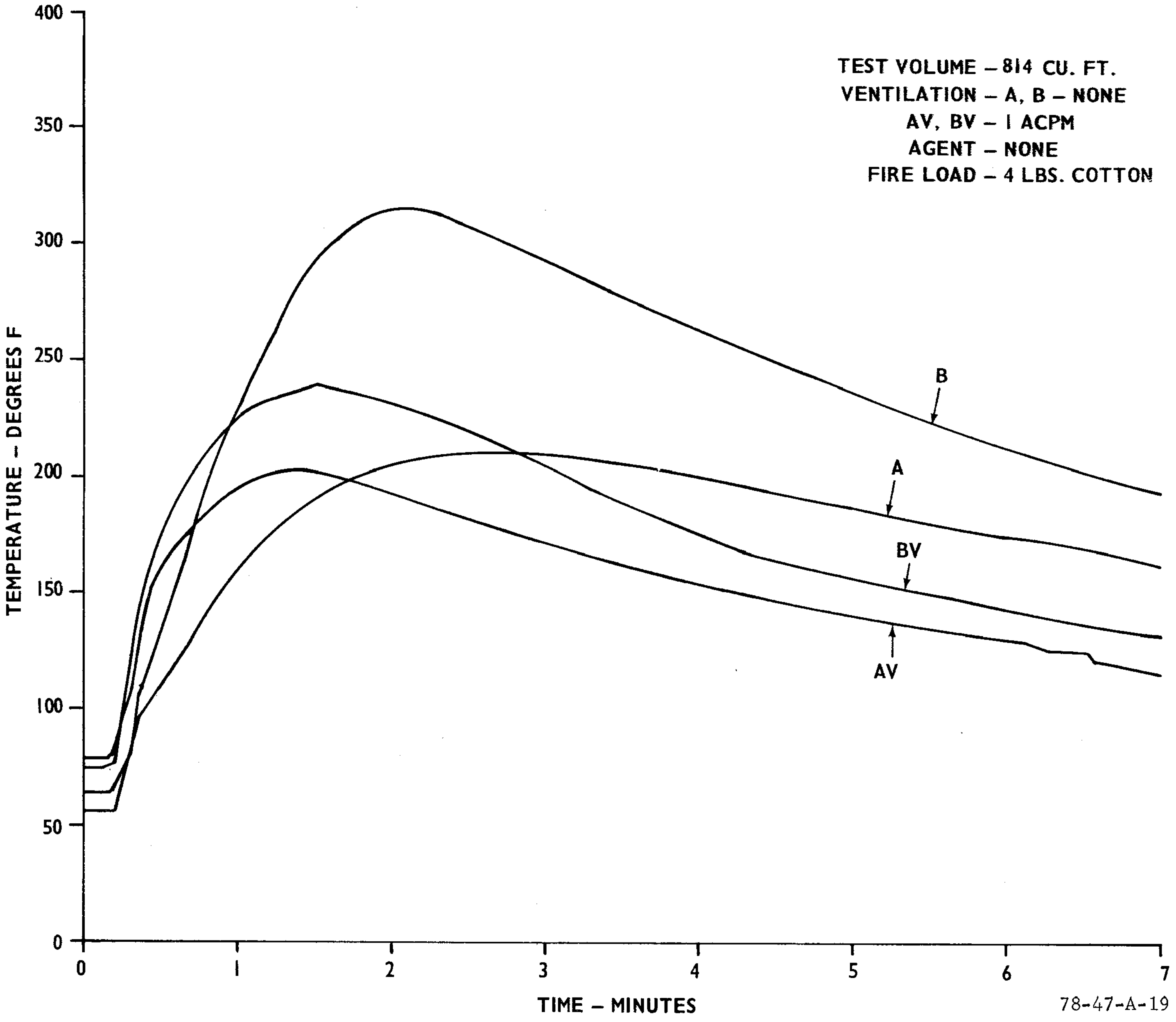

FIGURE A-19. COMPARTMENT TEMPERATURE--BASELINE FIRE TEST

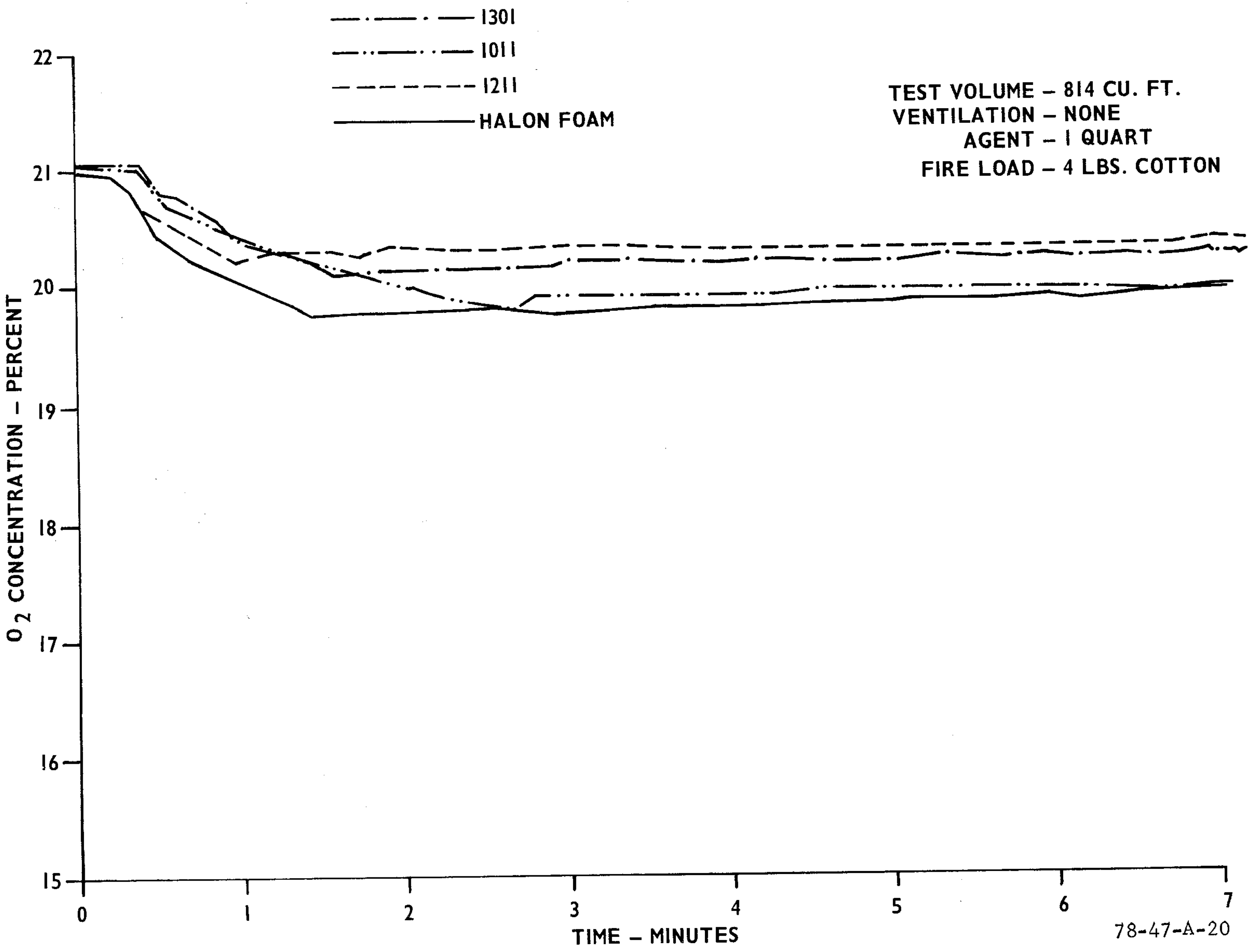

FIGURE A-20. OXYGEN CONCENTRATION--NONVENTILATED AGENT FIRE TEST

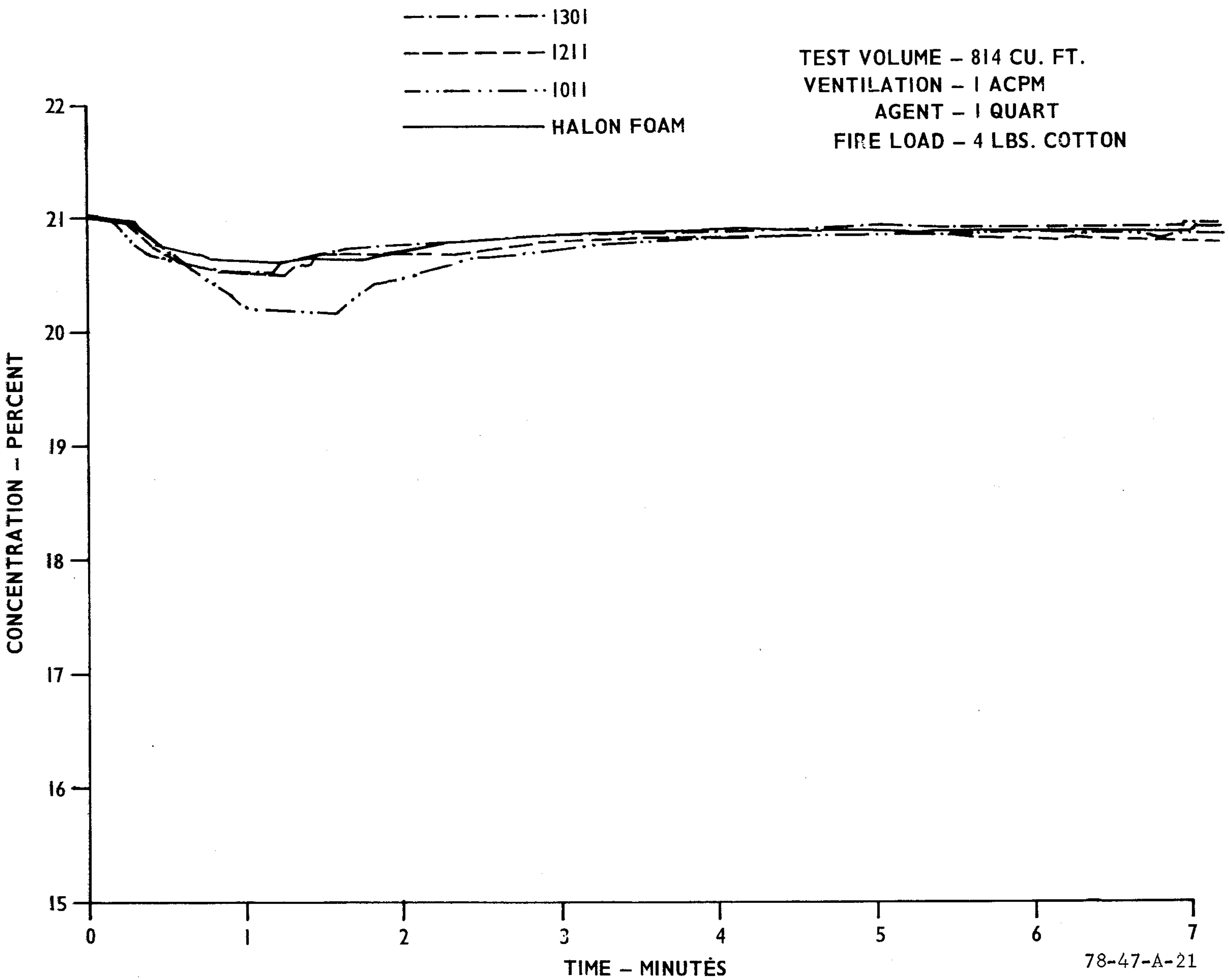

FIGURE A-21. OXYGEN CONCENTRATION--VENTILATED AGENT FIRE TEST

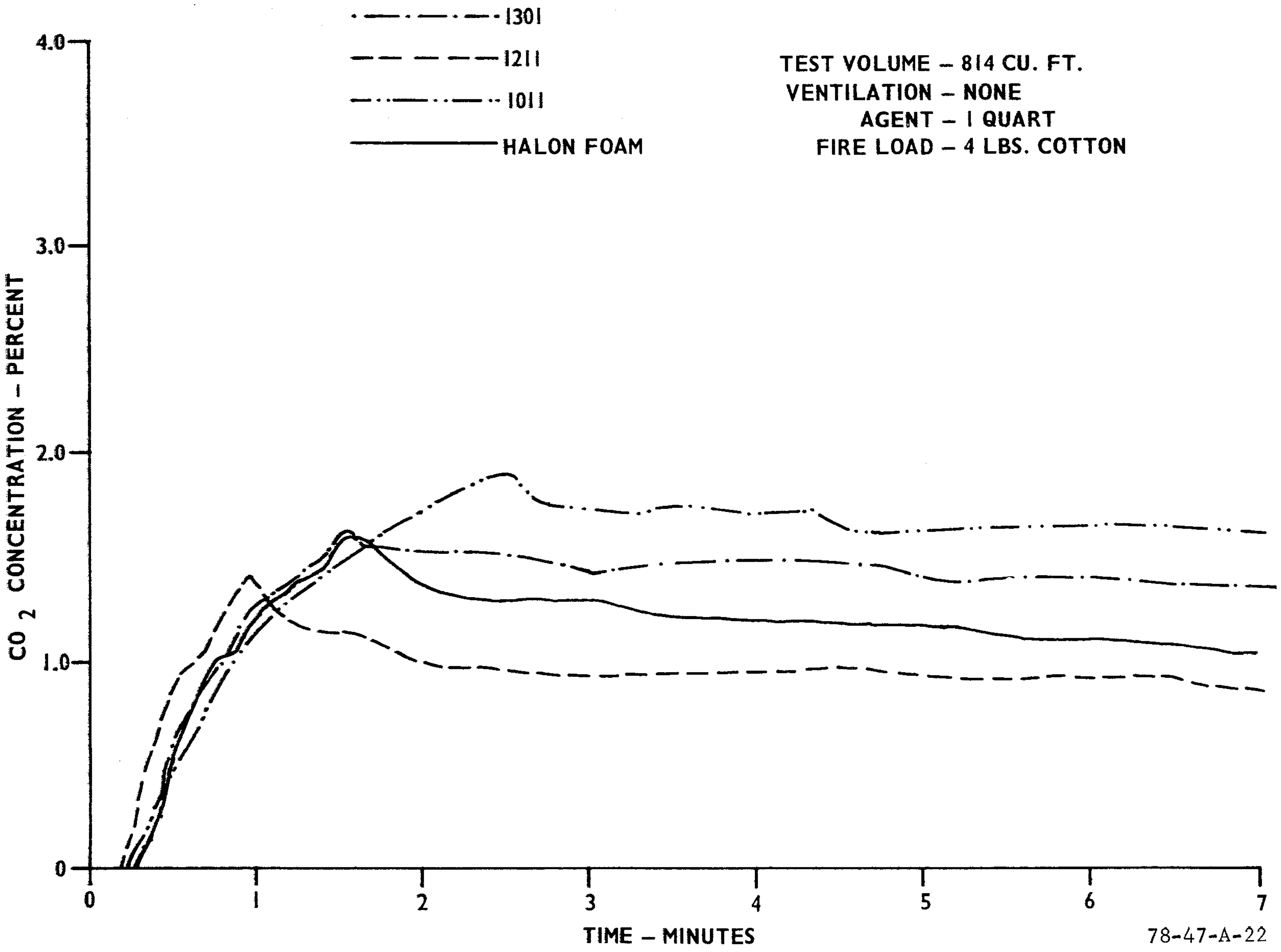

FIGURE A-22. CARBON DIOXIDE CONCENTRATION--NONVENTILATED AGENT FIRE TEST

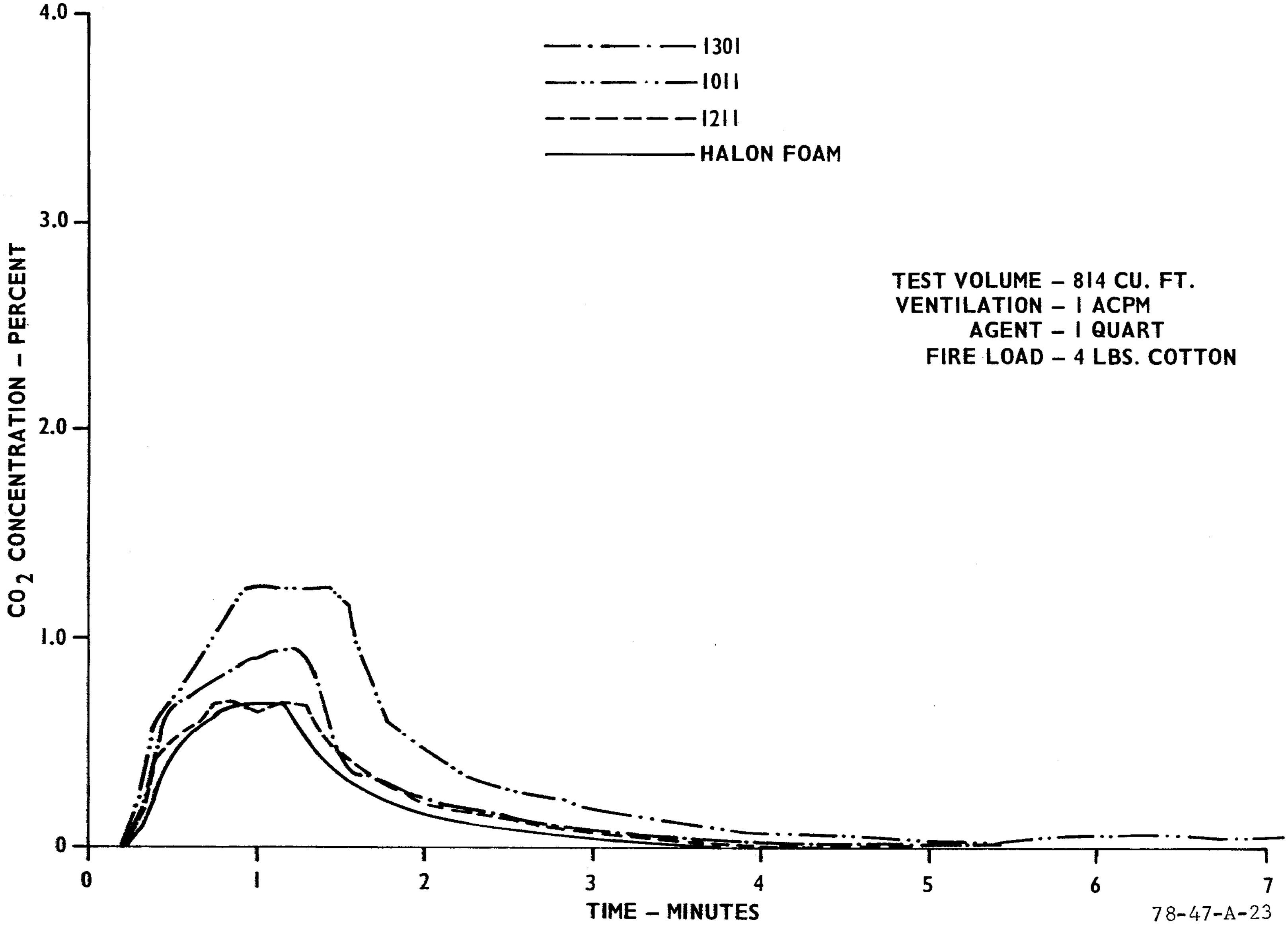

FIGURE A-23. CARBON DIOXIDE CONCENTRATION—VENTILATED AGENT FIRE TEST

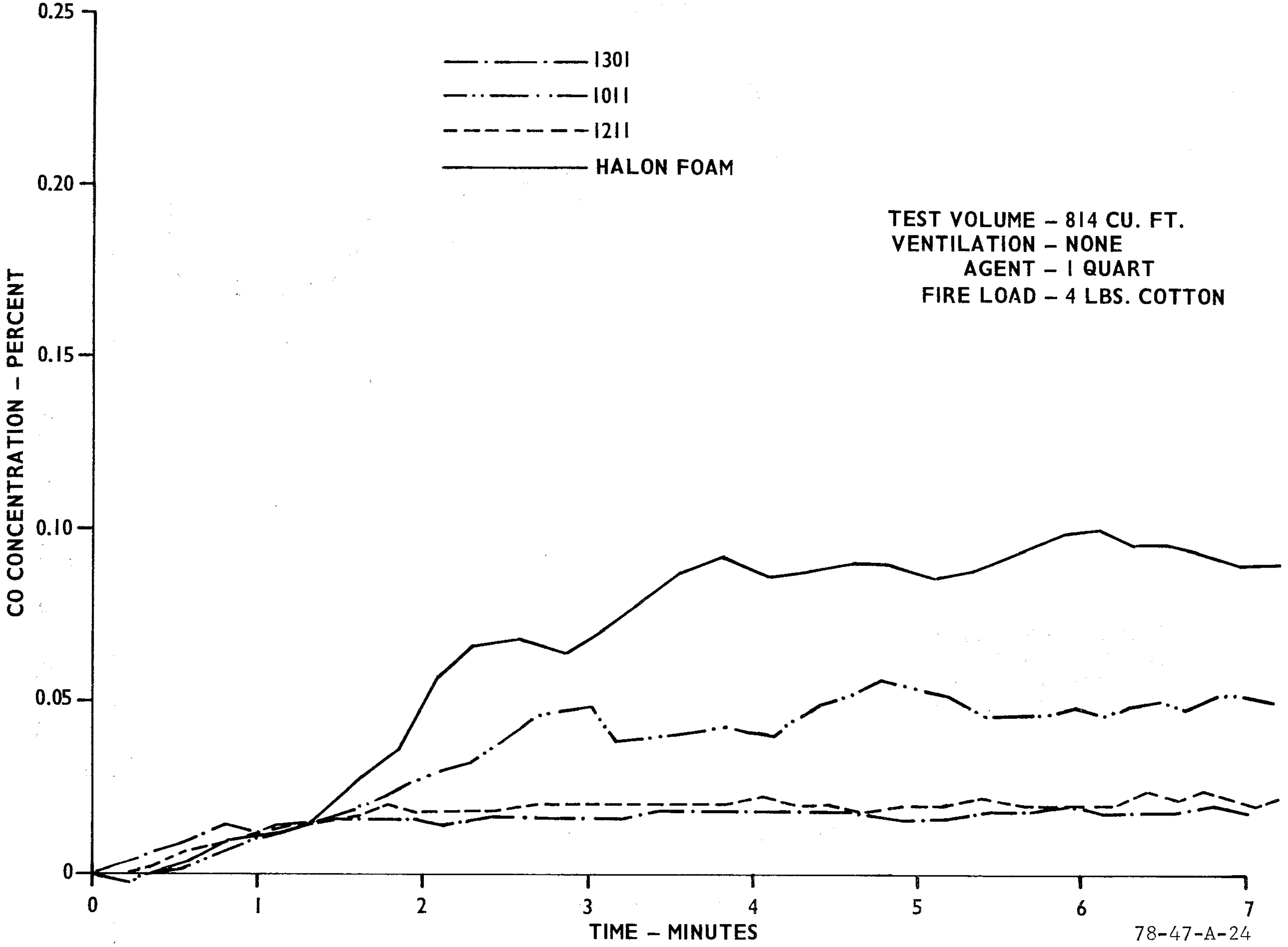

FIGURE A-24. CARBON MONOXIDE CONCENTRATION--NONVENTILATED AGENT FIRE TEST

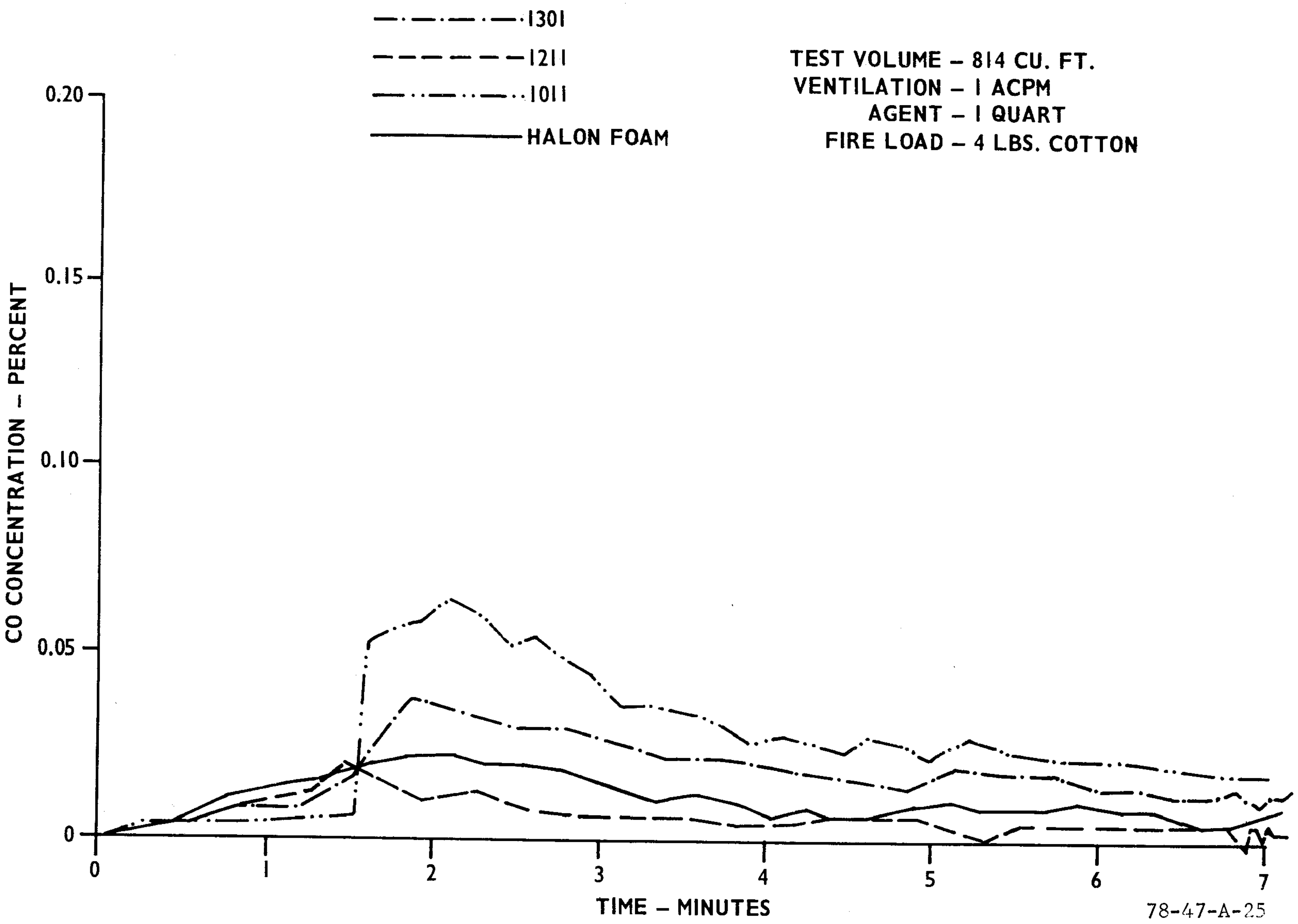

FIGURE A-25. CARBON MONOXIDE CONCENTRATION--VENTILATED AGENT FIRE TEST

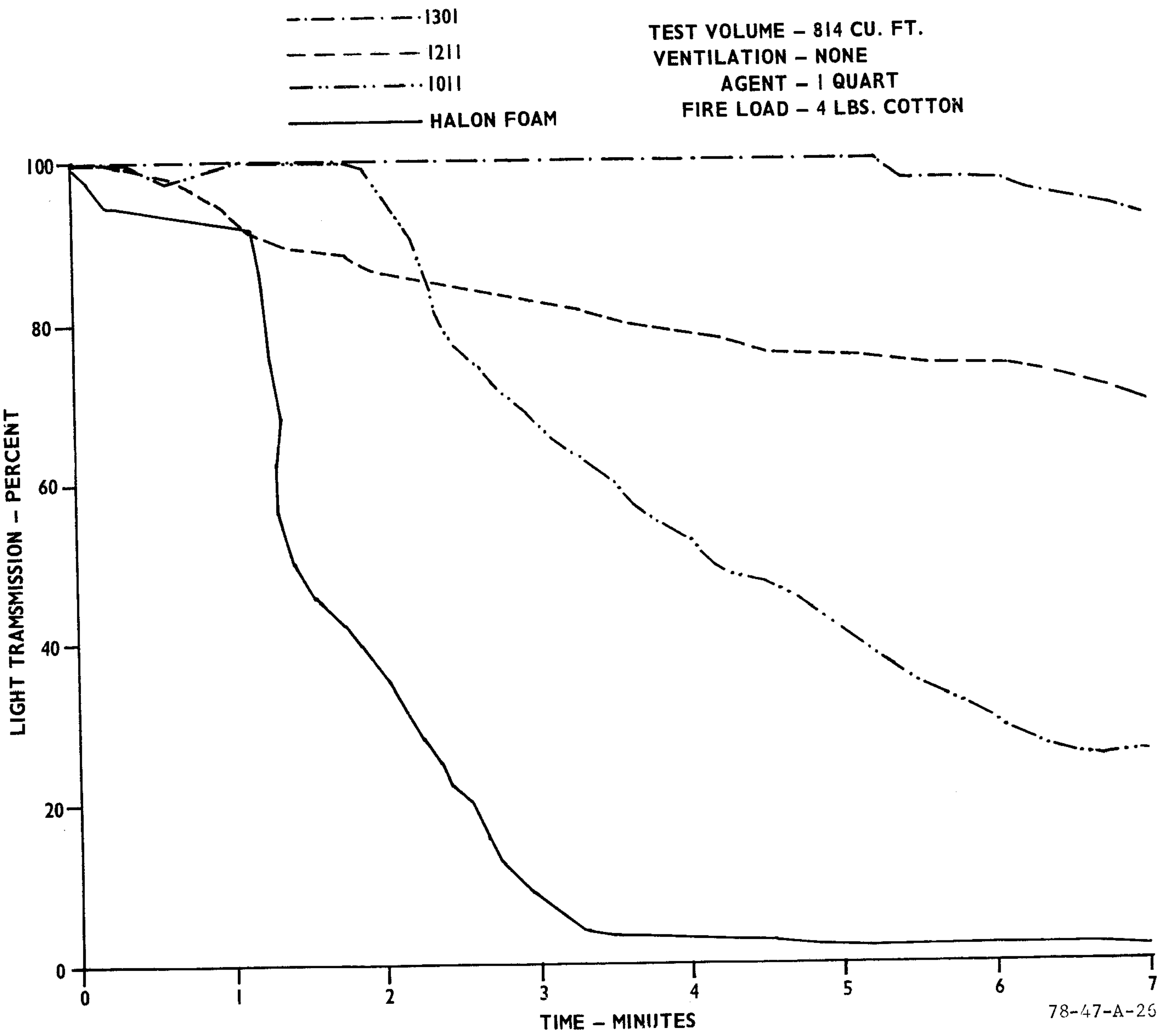

FIGURE A-26. LIGHT TRANSMISSION--NONVENTILATED AGENT FIRE TEST

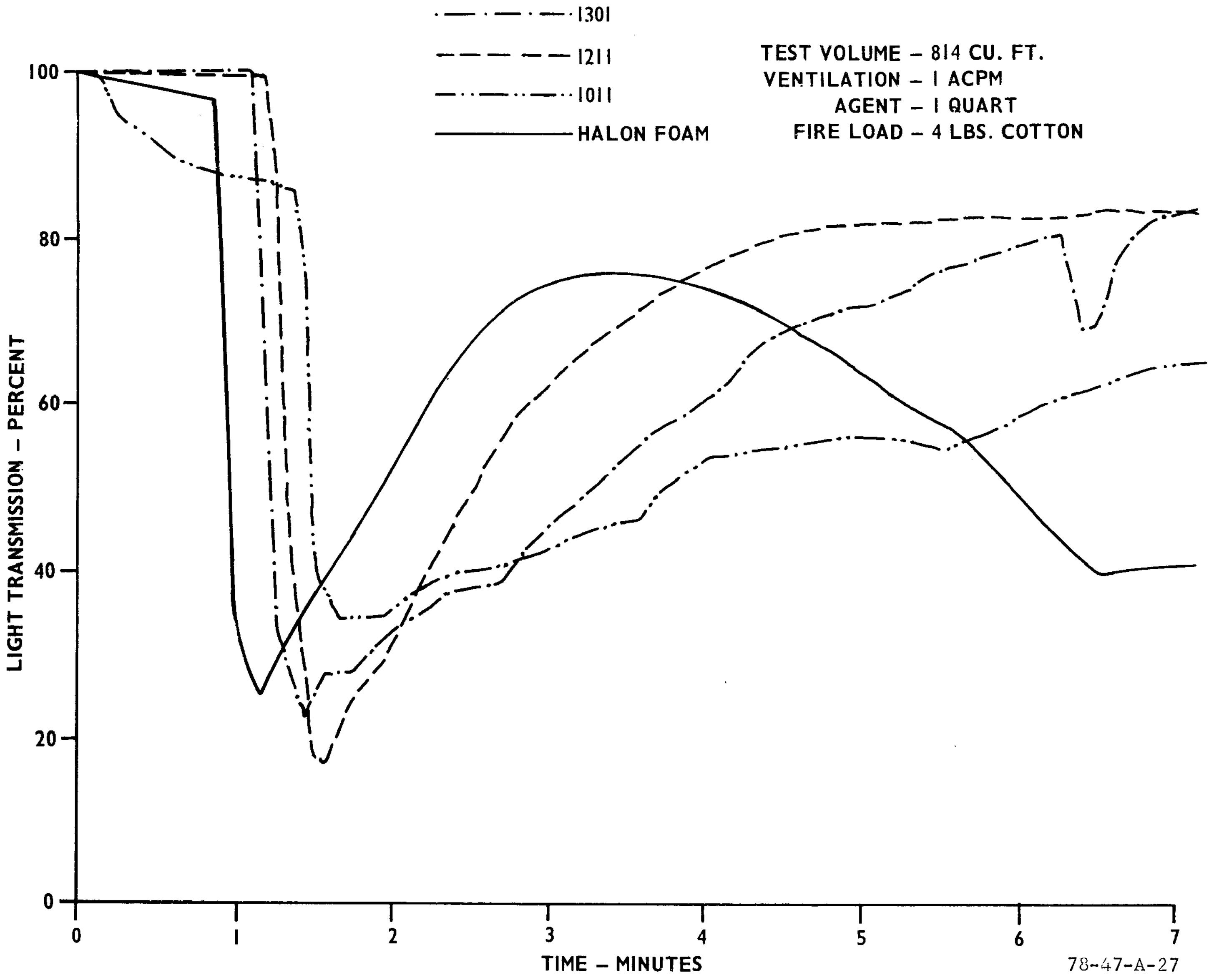

FIGURE A-27. LIGHT TRANSMISSION—VENTILATED AGENT FIRE TEST

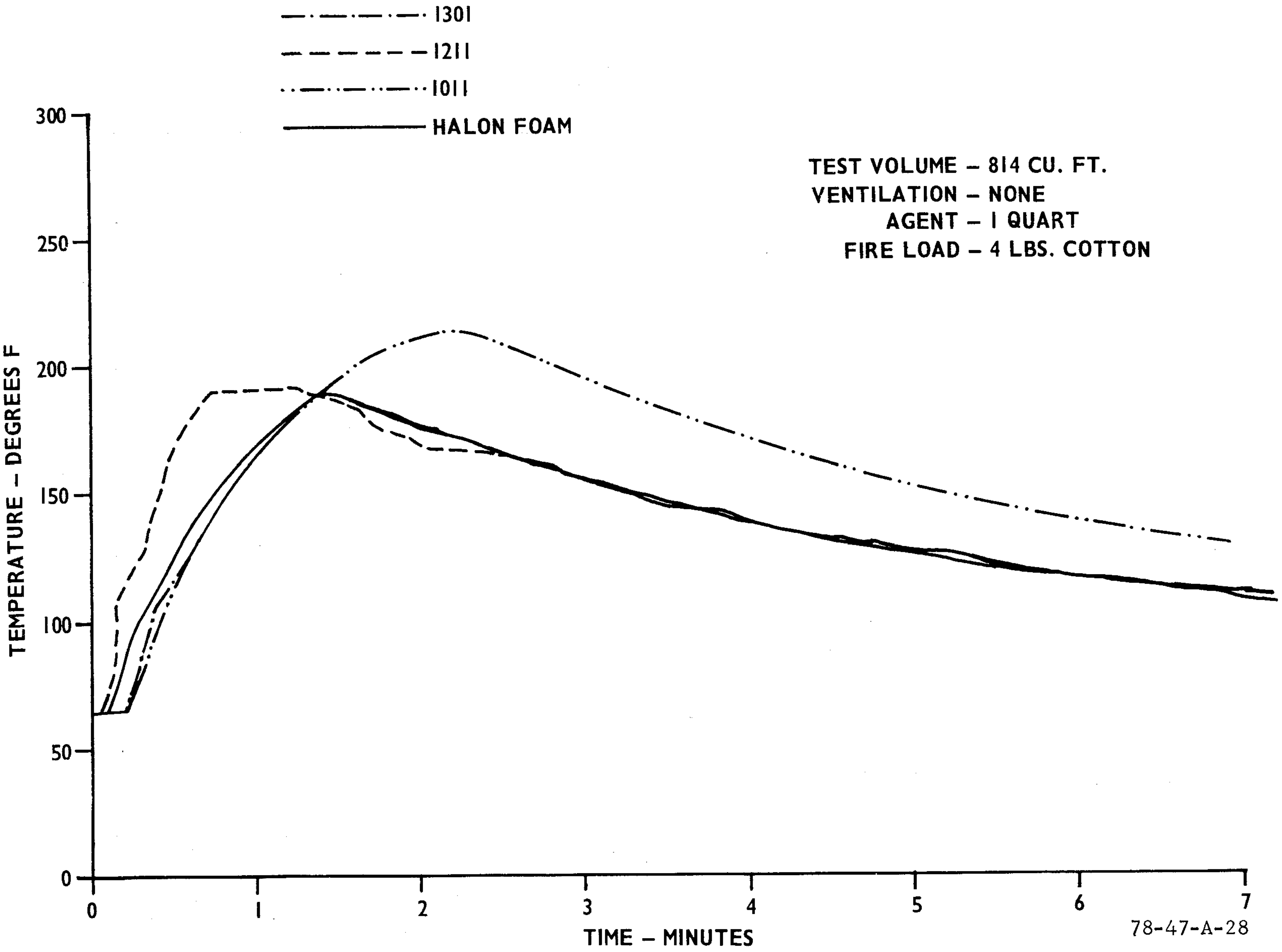

FIGURE A-28. COMPARTMENT TEMPERATURE--NONVENTILATED AGENT FIRE TEST

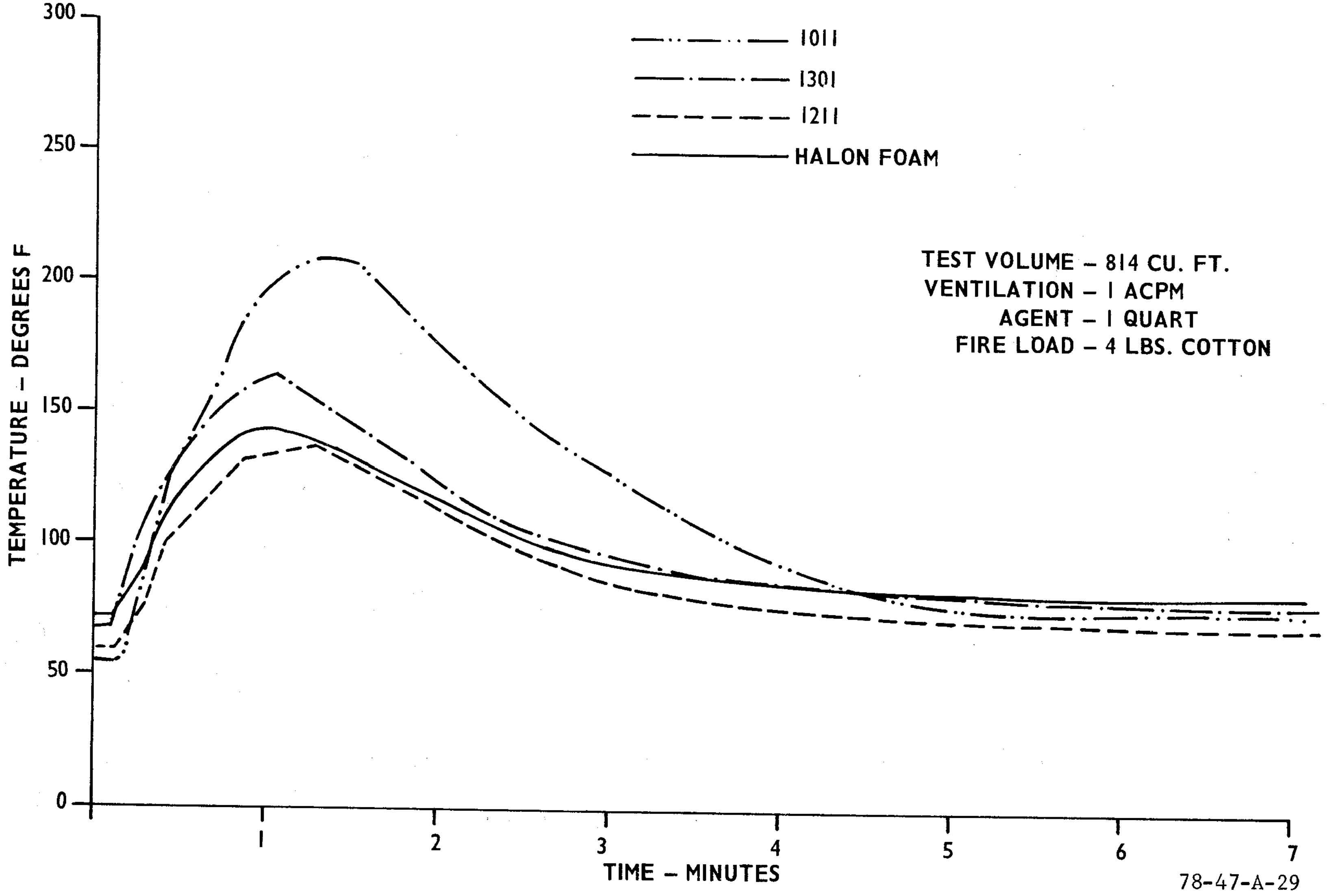

FIGURE A-29. COMPARTMENT TEMPERATURE--VENTILATED AGENT FIRE TEST

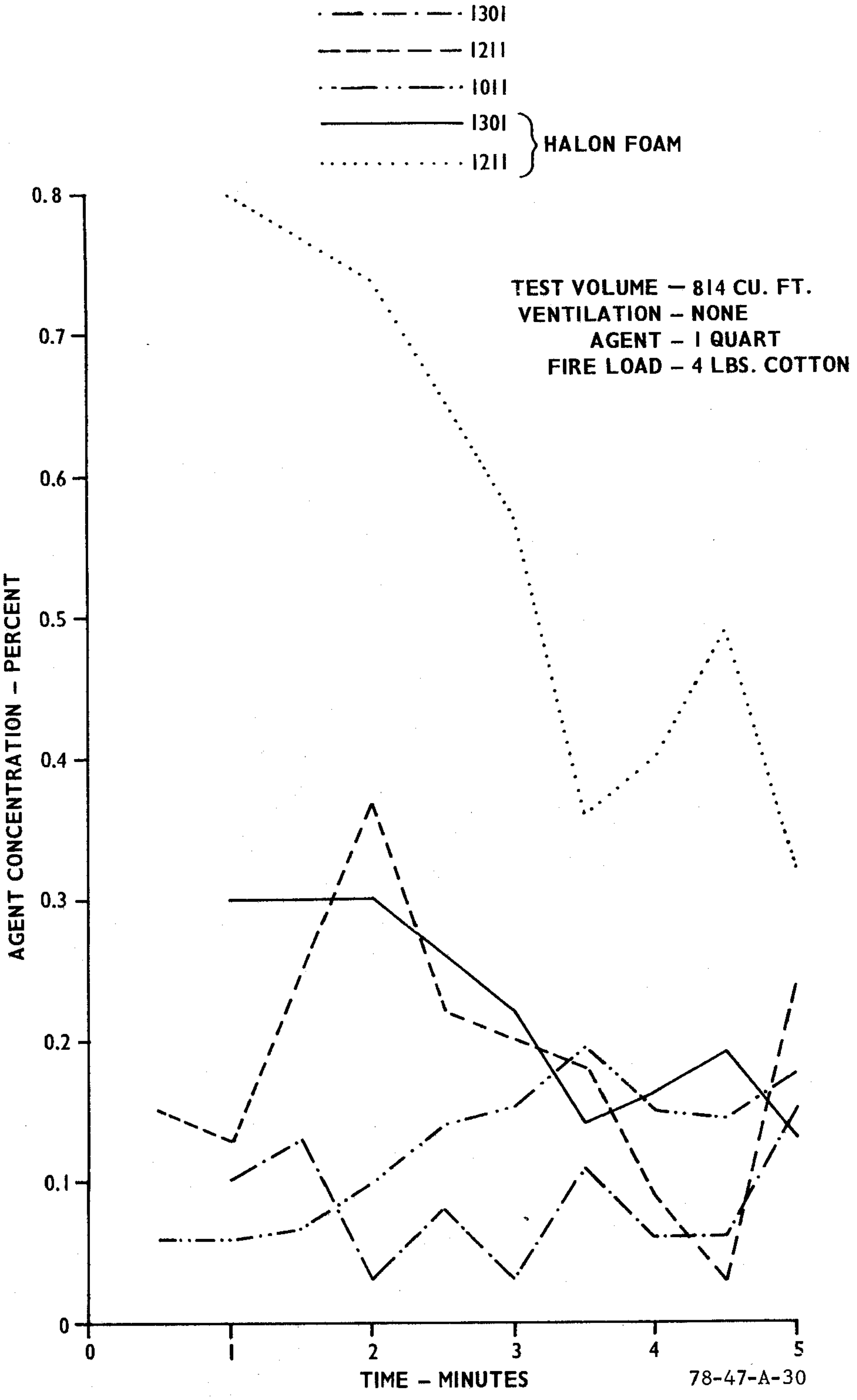

FIGURE A-30. AGENT CONCENTRATION USING 1-QUART EXTINGUISHERS DURING NONVENTILATED FIRE TEST

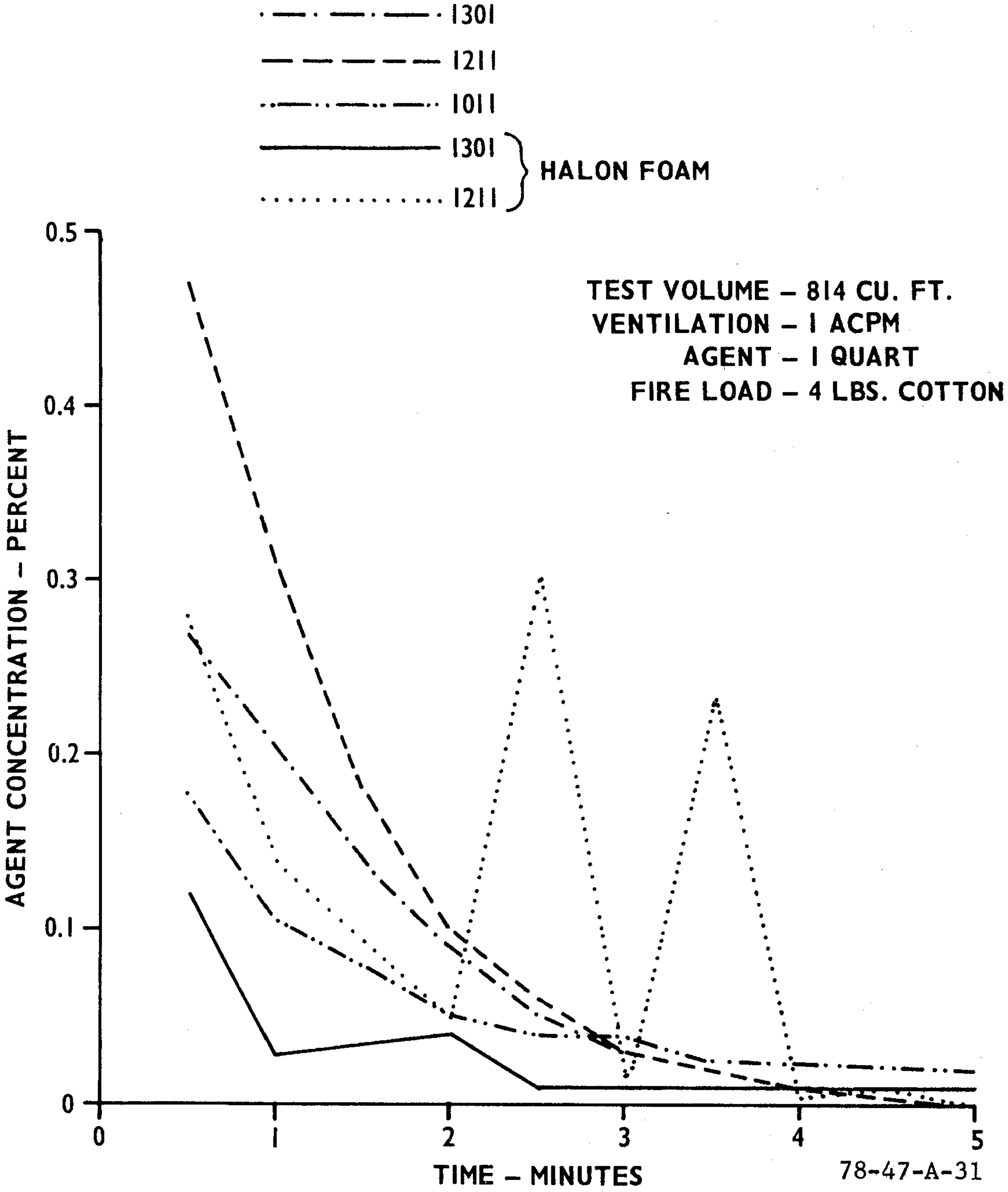

FIGURE A-31. AGENT CONCENTRATION USING 1-QUART EXTINGUISHERS DURING VENTILATED FIRE TEST

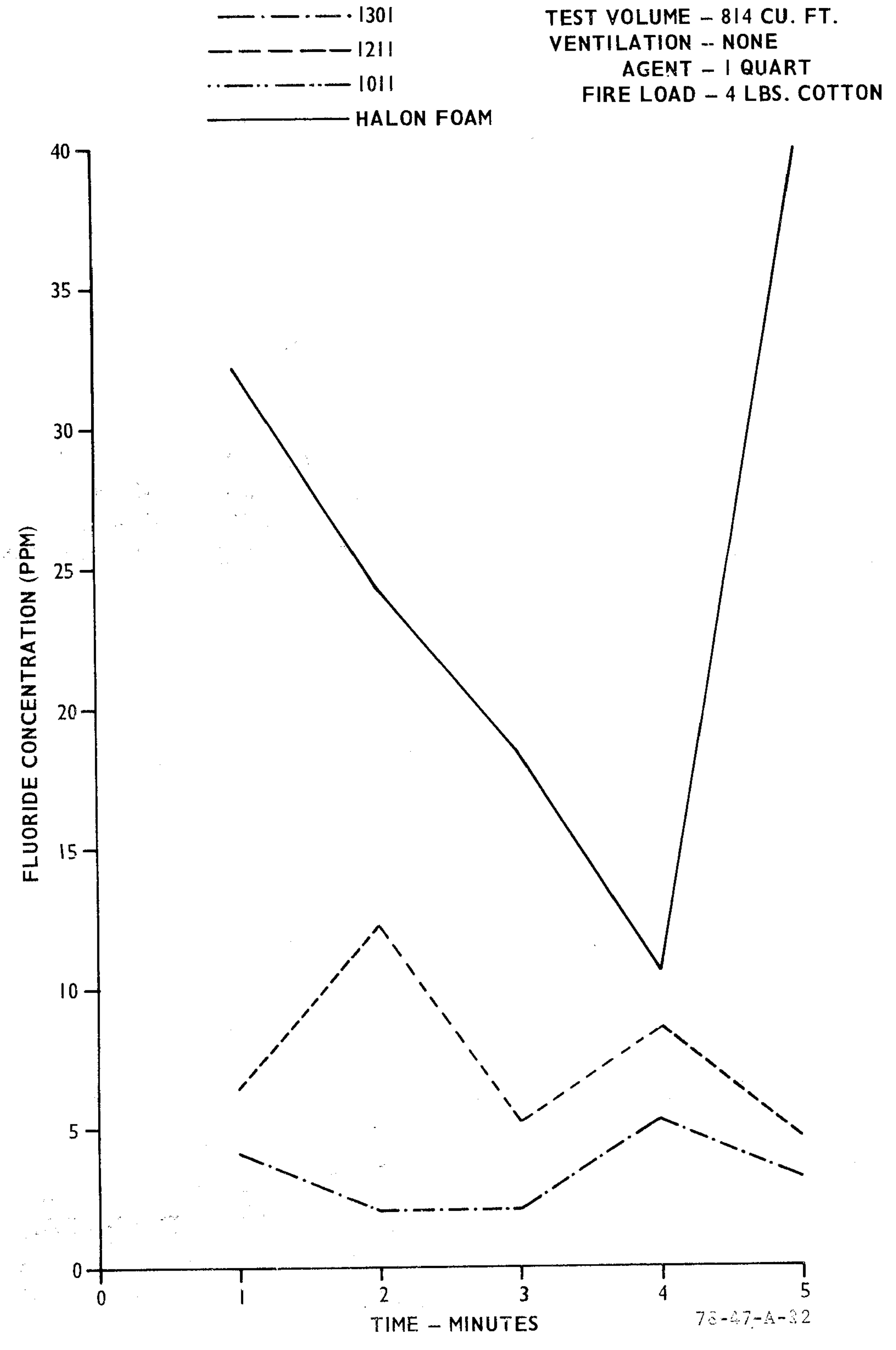

FIGURE A-32. FLUORIDE CONCENTRATION USING 1-QUART EXTINGUISHERS DURING NONVENTILATED TESTS

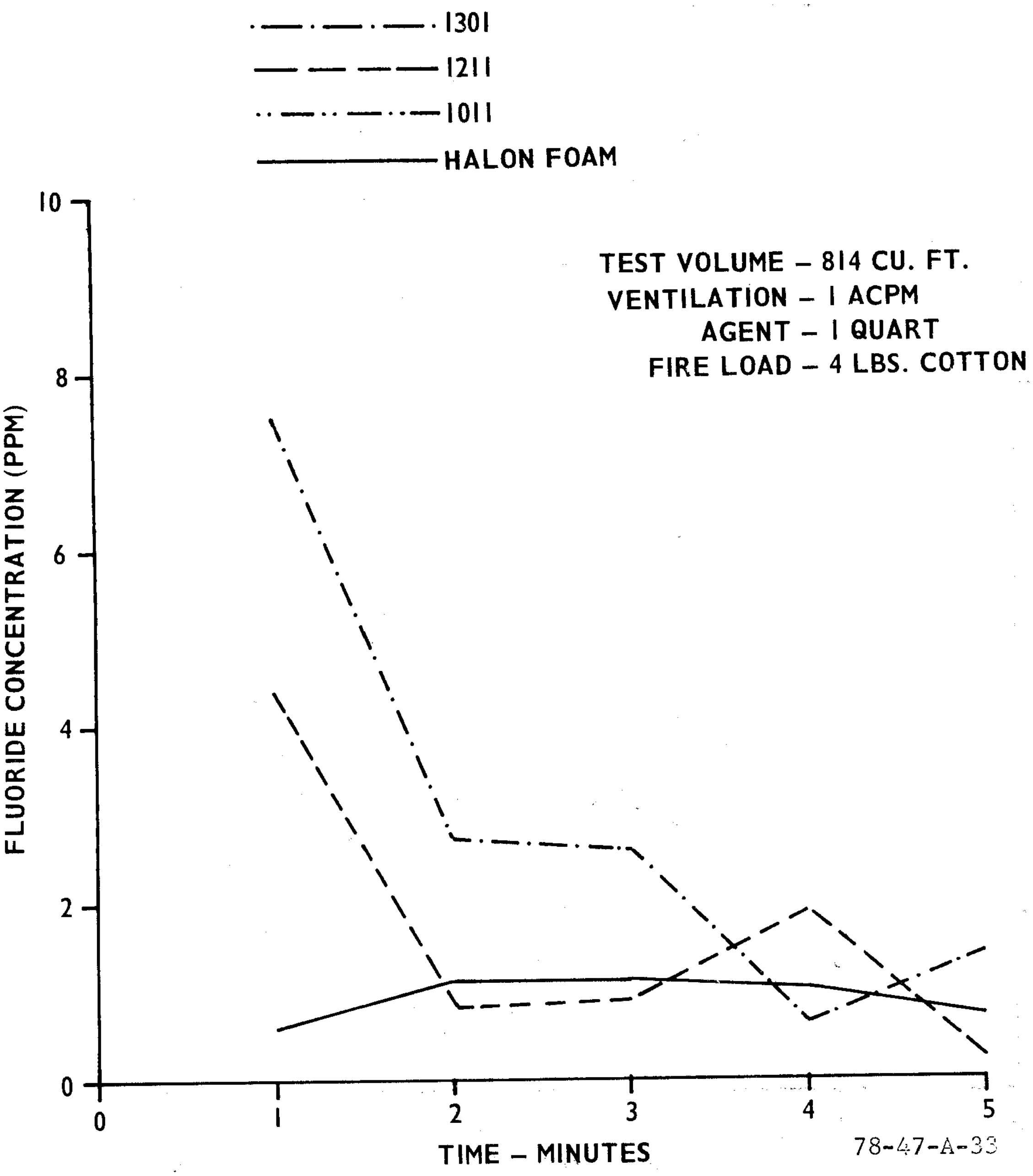

FIGURE A-33. FLUORIDE CONCENTRATION USING 1-QUART EXTINGUISHERS DURING VENTILATED FIRE TESTS

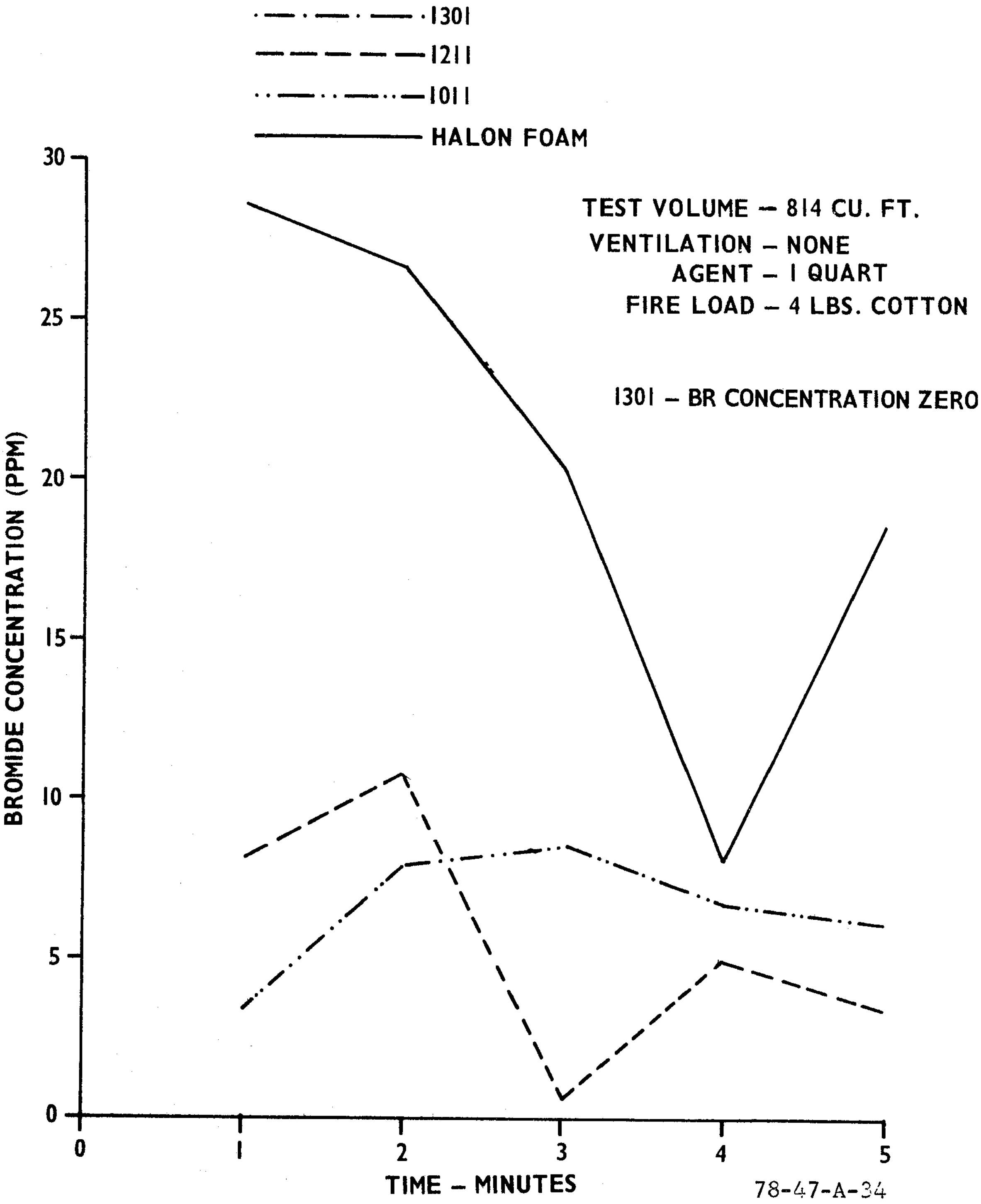

FIGURE A-34. BROMIDE CONCENTRATION USING 1-QUART EXTINGUISHERS DURING NONVENTILATED FIRE TEST

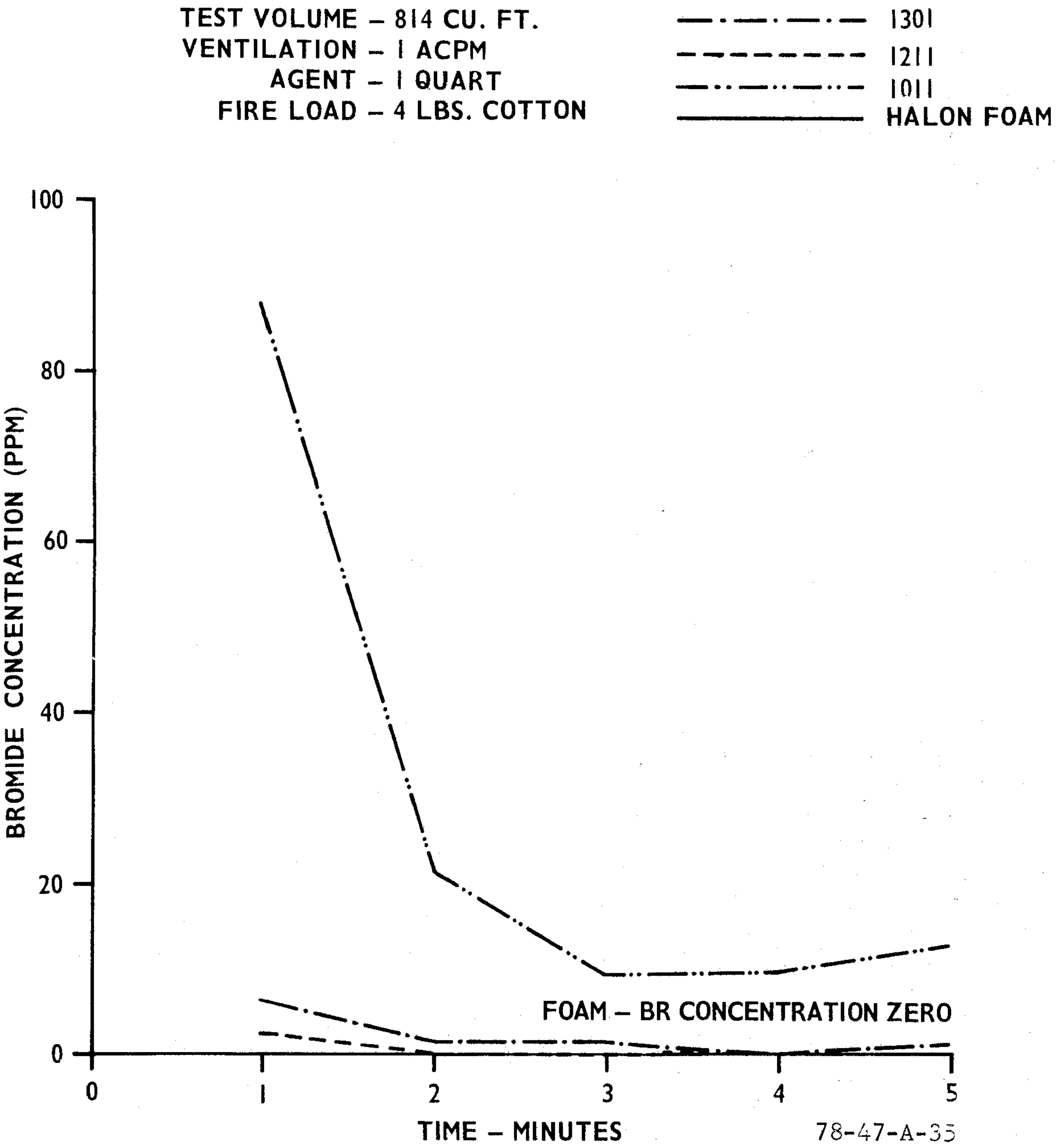

FIGURE A-35. BROMIDE CONCENTRATION USING 1-QUART EXTINGUISHERS DURING VENTILATED FIRE TEST

APPENDIX B

EXTINGUISHING AGENT AND HYDROGEN HALIDE ANALYSIS/ANIMAL RESPONSE

B.1 Fire Extinguishing Agent Analysis

The analysis for Halons 1211, 1301, and 1011 was accomplished using a Perkin-Elmer model 3920 gas chromatograph (GC) with a flame ionization detector and a Perkin-Elmer M-1 digital integrator. The conditions for analysis were:

Injector temperature	150° Celsius (C)
Interface temperature	225°C
Carrier gas	Helium @ 20 milliliters per minute (ml/min)
Detector gas	Zero air @ 500 ml/min; hydrogen @ 20 ml/min
Column (1211 and 1301)	12 ft x 1/8 in. stainless steel packed with Chromosorb 102, 100/120 mesh size @ 180°C
Column (1011)	4 ft x 1/8 in. stainless steel packed with Chromosorb 102, 100/120 mesh size @ 175°C

The test samples, which were provided in stainless steel cylinders as described in the body of this report, were drawn after first fitting one end with a Swagelok® nut and a w-type septum disc cut to fit the nut and nylon back ferrule. The valve on the bottle was opened for at least 2 minutes prior to drawing a sample with a 1 ml Precision Sampling (PS) series A-2 push-button valve syringe. It was then injected into the gas chromatograph.

Calibration for Halons 1211 and 1301 was accomplished by drawing a fraction of a mililiter (mℓ) of the 100 percent agent, used as the calibration gas, with a 100 microliter (μl) PS A-2 syringe. The exact amount of the gas drawn was predicated upon the estimated peak concentration of the test sample. It was then injected into the gas chromotograph. Since the equipment output is very nearly linear within the concentration ranges, this procedure was followed to establish a calibration point near the expected peak of the test sample. For Halon 1011, which is a liquid under ordinary conditions, the calibration procedure varied somewhat. A calibration solution of Halon 1011 in reagent grade carbon tetracholoride was formulated using a known concentration in grams per milliliter in a volumetric flask. One microliter of this standard was injected into the gas chromotograph. Thus, by knowing the concentration of the standard and using proportional relationships and the Ideal Gas

Law, the value of the unknown can be determined and presented in parts per million. For Halon 1011 test samples, the cylinders containing the unknowns were placed in an oven at 45° C to assure complete volatilization.

B.2 Hydrogen Halide Analysis

B.2.1. Sample Collection and Recovery. The method for collecting compartment air samples was similar to that described in DOT Report No. FAA-RD-76-132 except that 1-liter bottles were used. A description of the absorption tube is shown in Figure B-1.

The recovery of the sample was similar to that described in NAFEC Data Report No. 121 dated April 1976. The primary differences were that the absorption tubes were wetted with 0.10 molar (M) Na_2CO_3 prior to test and washed with 0.10 M Na_2CO_3 for sample recovery.

B.2.2 Methods of Analysis. The contents of the absorption tubes were analyzed for hydrogen fluoride using the ion selective electrode technique, hydrogen chloride using differential pulse polarography, and hydrogen bromide by ion chromatography. The contents of the sample cylinders to which the absorption tubes were affixed were analyzed for the appropriate Halon agent as described in paragraph B.1. The instruments, analytical procedures, and limits of detection employed for each gas covered in this appendix are summarized in Table B-1.

An Orion model 801 pH/mV meter with an Orion solid-state fluoride electrode and Orion double junction reference electrode were used for the analysis of hydrogen fluoride. Absorbtion tube contents, as well as calibration samples, were buffered to pH 5.0 with 0.4 M acetate buffer as described in the manual for the model 94-09 fluoride electrode.

A Princeton Applied Research (PAE) model 174A polarographic analyzer equipped with a model 172A drop timer and a model 315 automated electroanalysis controller was used for the determination of hydrogen chloride concentrations. The polarograph was operated in the differential pulse mode using a three-electrode configuration which included a dropping-mercury, working electrode, a platinum ribbon counter electrode, and a saturated calomel reference electrode (SCE). The SCE was isolated from the sample solution by a 1.0 M sodium nitrate salt bridge. The sample cell is maintained at a temperature of 25° C. Instrumental parameters include a scan rate of 1 millivolt per second (mV/S) for hydrogen cloride, a drop time of 1 second, and a pulse amplitude of 10 mV.

A Dionex model 10 ion chromotograph with a 3 by 150 mm anion precolumn, a 3 x 500 mm analytical column, and a 6 x 250 mm supressor column was used for the analysis of hydrogen bromide. The columns are maintained at a temperature of 25° C. An eluant of 3.6 millimolar (mM) Na_2CO_3 and 3.0 mM $NaHCO_3$ is pumped through the columns at a flow rate of 1.92 ml/min. Four milliliters of sample is passed through a cation exchange filter and the resin is then rinsed with 4 ml of deionized water. The filtrate is injected using a 100 $\mu\ell$ sample loop.

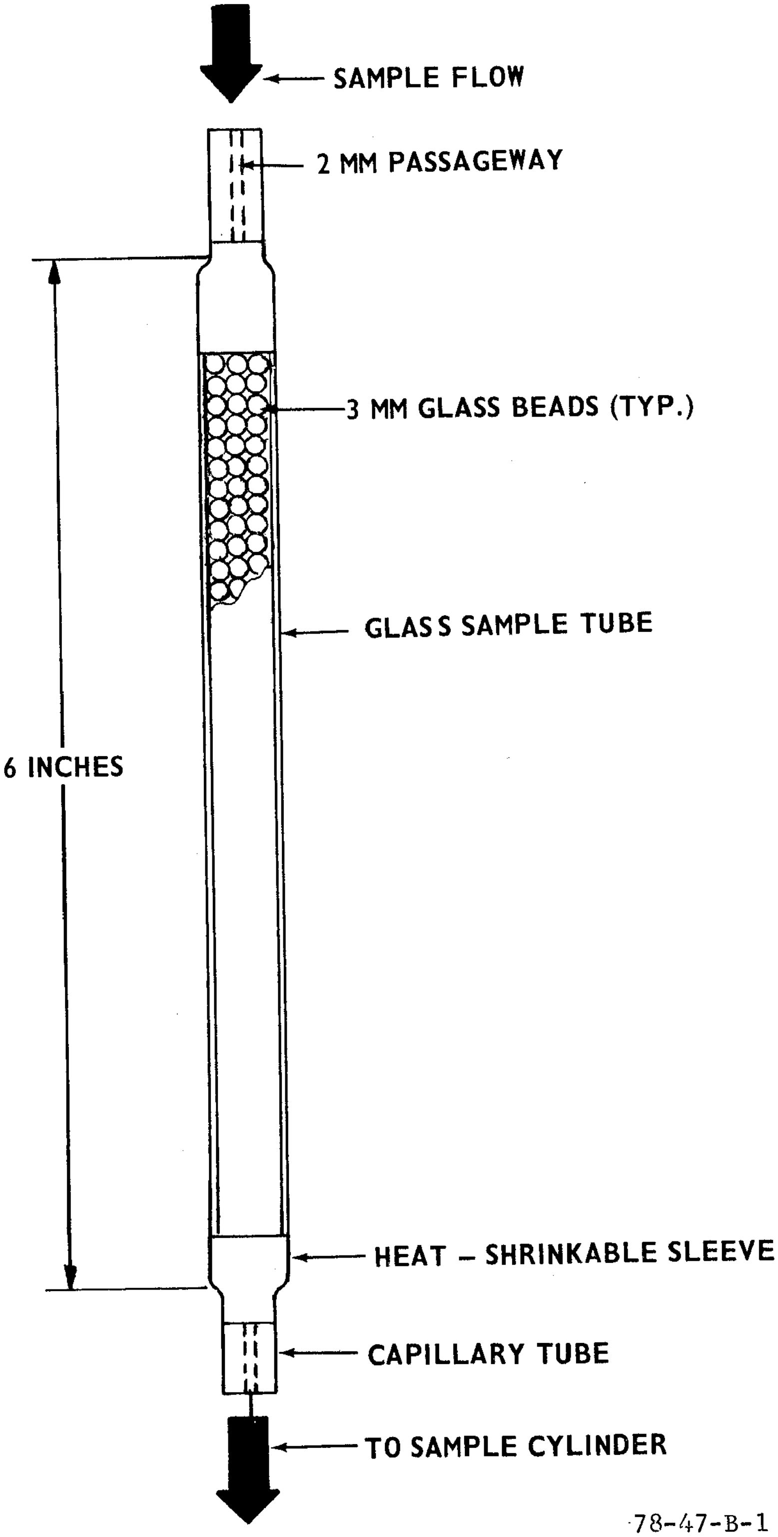

FIGURE B-1. HYDROGEN HALIDE ABSORPTION TUBE

TABLE B-1. SAMPLING AND ANALYTICAL PROCEDURES

GAS	COLLECTION METHOD	INSTRUMENTATION	ANALYTICAL PROCEDURE	LIMITS OF DETECTION (PPM)
HF	Absorption Tubes	Orion Model 801 pH/millivolt meter with Orion model 94-09 solid-state fluoride electrode and Orion model 90-02 double junction reference electrode.	Calibration curve in .4 M acetate buffer (pH5)	0.1
HCl	Absorption Tubes	PAR Model 174A Polarographic Analyzer (differential pulse mode)	Add 1 ml sample to 4 ml deaerated 0.1 M $NaNO_3$ and 0.05 M HNO_3 Scan from 0.2 V to 0.4 V versus SCE.	12.0
HBr	Absorption Tubes	Dionex Model 10 ion chrometograph with a 3 x 150 mm onion precolumn, a 3 x 500 mm analytical column, and a 6 x 250 mm supressor column sample size 100 µℓ	An eluant of 3.6 mM Na_2CO_3 and 3.0 mM $NaHCO_3$ is pumped through the columns at a flow rate of 1.92 ml/min. Add 4 ml sample to cation exchange filter and rinse with 4 ml deionized water. Inject filtrate.	1.0
Halon 1011 Halon 1211 Halon 1301	Evacuated Bottles	Perkin Elmer Model 3920GC Flame ionization detector 1211, 1301, 12 ft x 1/8 inch stainless steel (SS) Chromosorb 102, 1011 4 ft x 1/8 inch SS Chromosorb 102.	(See section B.1)	

Halon 1211 (CF_2ClBr) was chosen for collection efficiency studies because its chemical composition contained all the halogens of interest. One advantage of conducting collection efficiency studies under actual test conditions is that the concentrations will be similar to those encountered in actual tests. The collection efficiencies for these gases were determined for three concentrations of Na_2CO_3: 0.01M, 0.10M, and 1.00M, and are shown in Table B-2. Each set of piggybacked absorption tubes was wetted with the respective carbonate solutions. In addition, an extra set of piggybacked tubes was prepared for a 0.1M Na_2CO_3 solution to check the reproducibility of sampling. Five evacuated bottles, four of which are connected to the piggybacked absorption tubes, were opened simultaneously, 7 1/2 minutes after discharging Halon 1211 in an unventilated compartment.

The cotton fuel was also tested by itself in order to establish a baseline concentration of HF, HCl, and HBr. The gas yields obtained are listed in Table B-3.

B.2.3 Analysis Accuracy. The analysis for neat agent concentration was within ±5 percent as was the analysis for Br-. The accuracy for F- was within ±10 percent. Using the procedures described herein, the chloride concentrations could not be quantified in the presence of bromide. In none of the agents tested was there chlorine in the chemical composition without bromine. From experience with prepared samples containing known amounts of bromide and chloride, it can be surmised that for 1211 and 1011 the chloride concentrations fell between a minimum of one-third to a maximum equal to the bromide concentrations. This statement cannot be made for Halon Foam because it contains both 1211 and 1301.

TABLE B-2. COLLECTION EFFICIENCIES OF ABSORPTION TUBES WETTED WITH SOLUTIONS OF VARIOUS Na_2CO_3 CONCENTRATIONS

		GAS YIELDS					
		HF (PPM)			HBr (PPM)		
TUBE NO.	CONC. Na_2CO_3	A	B	COLLECT. EFFIC.	A	B	COLLECT. EFFIC.
1	1.0	9.3	0.7	93	7.9	0	100
2	0.1	3.3	0	100	7.3	1.0	88
3	0.01	4.9	0	100	7.5	0.8	90
4	0.1	20.1	0.5	98	11.1	1.0	92

TABLE B-3. BASELINE CONCENTRATIONS WITHOUT AGENT (PPM)

TIME (MIN)	HF	HCl	HBr
0	0	0	0
1	0	0	0
2	0	0	0
3	0	0	0
4	1.3	29.7	0
5	0	18.5	0

B.3 Animal Response. The animals for this experiment were lawfully acquired and treated in accordance with the "Guide for the Care and Use of Laboratory Animals" prepared by the Committee on Revision of the Guide for Laboratory Animal Facilities and Care of the Institute of Laboratory Animal Resources, National Research Council, DHEW Publication No. (NIH) 74-23.

To examine the applicability of the NAFEC-modified rotating wheel under conditions more approximating actual full-scale fire tests, a brief series of tests were conducted in conjunction with the USAF study of Halon extinguishing agents. The tests conducted had all factors encountered in an actual fire situation: heat, carbon monoxide buildup, oxygen depletion, moderate organic chemical concentration, and irritating decomposition products.

The NAFEC-modified rotating wheel assembly is constructed as discussed in NA-78-22-LR to employ three test animals. The module was situated adjacent to and behind the analytical station with the animals 5 ft further away from the fire than the sampling inlets and 10 inches lower to avoid the higher temperatures encountered at the analytical station. The test subjects were male Sprague-Dawley strain white rats from Charles River Breeding Laboratories and weighed between 350 and 450 grams. Only nonventilated tests were conducted with test animals present. The test duration was 30 minutes from ignition of the fire until exhaust of the test article. Results are shown in Figure B-2.

The test using only Halon 1301 or 1211 did not produce total incapacitation in any test animal. In both tests, animal stress became apparent at 17 minutes with two animals, one in each test, incapacitating, but recovering during the test. At the end of the test, all animals were still mobile. After venting the compartment, the animals showed no adverse affects

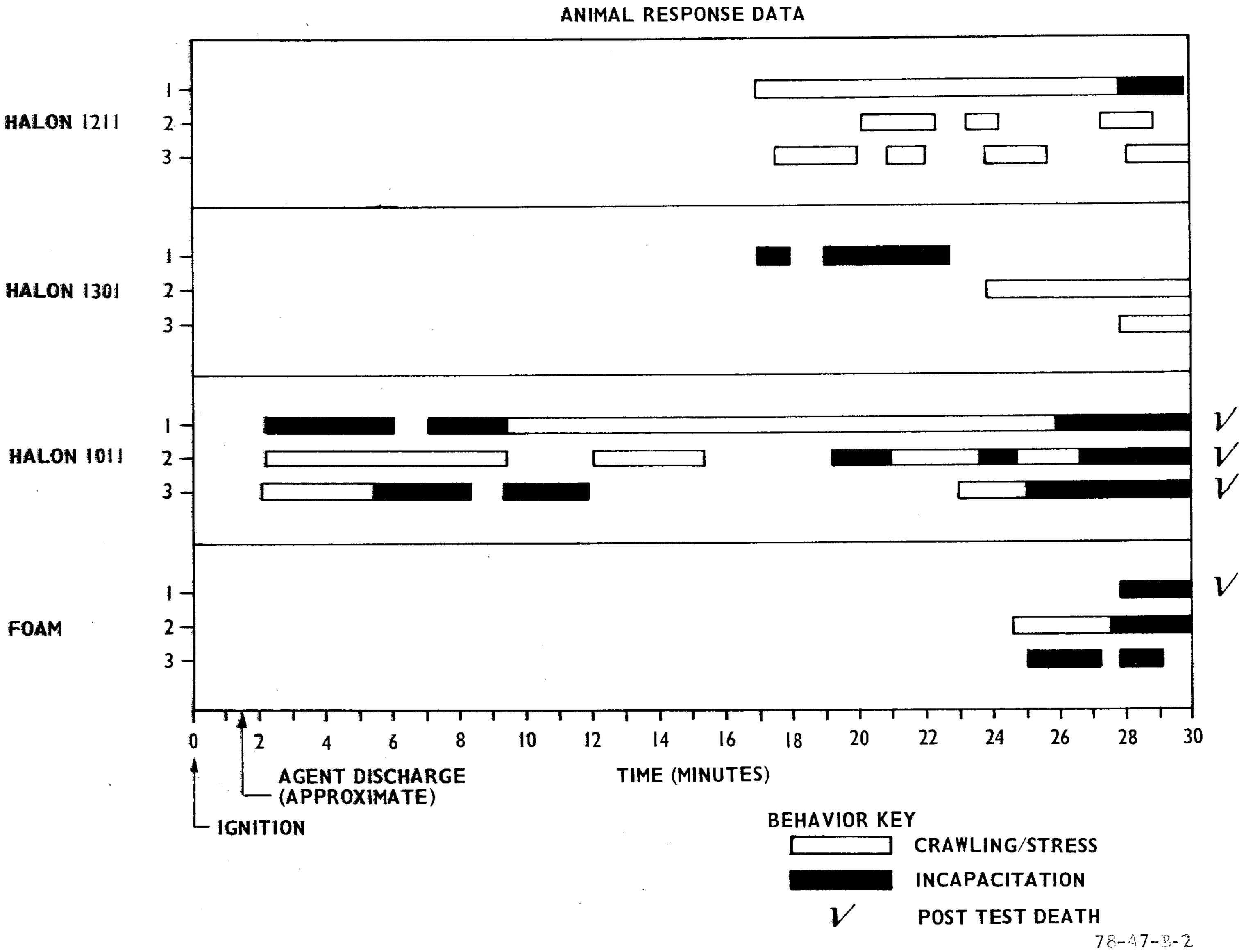

FIGURE B-2. ANIMAL RESPONSE

other than lethargy. Breathing was normal and animals ate and drank as soon as food and water were available. The test of the mixed Halon 1211 and 1301 with foaming agent showed no adverse effects on the animals through 24 minutes, but produced two total incapacitations and one partial incapacitation by 30 minutes. After venting, all but one animal revived. A slight cough-like response was observed in one animal, but breathing was not abnormal and the animals appeared in good condition. By the next day, one animal was very lethargic and showed traces of blood around the nose. Approximately 22 hours after the test, the animal began convulsing and died. The other two animals were observed for two more days and appeared completely normal.

The test of Halon 1011 caused incapacitation in one animal and stress in the other two immediately upon discharge. For this test the preburn time was about 2 minutes at which time the agent was discharged. By the 12-minute point, the animals showed signs of revival, however, all animals were totally incapacitated between 25.4 and 26.8 minutes. All animals remained incapacitated after venting and breathed with a pronounced wheeze indicating fluid in the respiratory tract. The animals showed no desire for food or water when offered. Bleeding from the nose and mouth was seen in all three animals. The first animal died approximately 4 hours after the test. Examination of the remaining animals revealed a rough textured cornea in one with no effort made to close the eye when it was approached. The animal was blind. This animal died approximately 5 hours after the test. The remaining animal was wheezing violently the next day and cried on exhaling. He died later that day. Necropsy of one animal showed many blood clots formed in the lung tissue.

Direct comparison of toxicity of the agent for each test is impossible from one test with such a small sample set and cannot produce statistically valid data. One significant factor in the apparently less toxic atmosphere of the Halon 1211 and 1301 test was that the stratification level was below the animals until it began to dissipate 10 to 15 minutes into the test. The incapacitations produced in the mixed agent foam may also have been produced with the individual agent had stratification not occured. Halon 1011 seems to show considerably higher toxicity in that response is seen immediately on agent discharge, all animals became incapacitated and showed no recovery when introduced to fresh air, and all animals died as a result of the test.

Incomplete extinguishment during the Halon 1011 tests caused continued smoldering of the fire load and produced a somewhat higher CO level than the Halon 1211 and 1301 tests, but this was still less than the mixed agent foam test. Also, a brief 2-minute period occured where temperatures at the animal station were 10° F higher than all the other tests. Therefore, no conclusive statement can be made of either agent or decomposition product toxicity without additional testing to elucidate a trend.

As demostrated in this brief program, the NAFEC-modified rotating wheel shows promise as a test article for a full-scale fire situation. All animals were remotely monitored with a strip chart recorder which provided a permanent description of their activity. No malfunctions of the equipment occured. It appears that this method is a relatively simple and inexpensive means of obtaining acute toxicity data in areas unsuitable for human observers.

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