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FIRE SUPPRESSION FOR AEROSPACE VEHICLES

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FOREWORD

This report was prepared by the Safety Research Center of the U. S. Bureau of Mines under USAF Contract No. F33615-69-M-5002. The contract was initiated under Project No. 3048 "Fire and Explosion Hazards Assessment, Prevention and Suppression Techniques for Aerospace Vehicles." It was administered under the direction of the Air Force Aero Propulsion Laboratory, with J. R. Manheim (APFL) acting as project engineer.

This report is a summary of the work recently completed as part of this current contract during the period 1 January to 31 December 1969. This report was submitted by the authors March 24, 1970.

Dr. Robert W. Van Dolah was the administrator for the U. S. Bureau of Mines and Messrs. George H. Martindill, Irving Spolan, and Joseph M. Kuchta participated in this work at the U. S. Bureau of Mines Safety Research Center, Bruceton, Pa.

This technical report has been reviewed and is approved.

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ABSTRACT

Fire extinguishing experiments were conducted to evaluate Halon 1301 as an extinguishant of Class A fires by the total flooding mode for possible use in advanced aircraft. The effectiveness of the extinguishant was determined by burning cotton sheeting in a 216 ft^3 chamber at various combustible loadings, preburn times, and extinguishant discharge pressures or rates. Extinguishing times increased with increased combustible loading but varied little with preburn time and Halon discharge pressure when the Halon concentration in the chamber was 6 volume percent. With this concentration, cotton sheeting fires at a loading of 0.035 oz/ft^3 were extinguished within 2 seconds or less using Halon discharge pressures of 220, 350, and 700 psig. A 3 percent Halon concentration appeared to be inadequate under most test conditions.

With 6 percent Halon, the toxicity hazard from the formation of CO, HF, or HBr was relatively small for preburn times of 15 seconds or less. The concentration of toxic product vapors increased noticeably when the total burning period before extinguishment was increased from 15 to 25 seconds. Under all test conditions, the toxic product concentrations after equilibrium conditions prevailed were much less than the letha. concentrations reported for short exposure times. Data are also presented on the rates of pressure rise and mass consumption that characterized the cotton sheeting fires.

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INTRODUCTION

The present investigation is concerned with the semi-full scale evaluation of fire suppression systems and techniques that may be suitable for use in aerospace vehicles. This work was undertaken as part of an Air Force-sponsored program on the "Fire and Explosion Hazards Assessment, Prevention and Suppression Techniques for Aerospace Vehicles." Although the work proposed initially was for application to oxygen-rich hypobaric environments, the emphasis was changed at the request of the Air Force and limited in scope to aircraft flight environments. Of immediate interest is the possible use of halogenated hydrocarbon extinguishing agents for advanced aircraft such as the F-111. In such applications, the extinguishing system must be effective within a matter of seconds to provide adequate protection against the spread of fire and the formation of toxic gases. Accordingly, large-scale experiments were designed to evaluate Halon 1301 (bromotrifluoromethane) in extinguishing Class A fires by the total flooding mode.

Halon 1301 is much more effective than carbon dioxide, nitrogen, or water vapor in quenching the flames of hydrocarbons and other gaseous fuels in air atmospheres. It is also superior to many other halogenated hydrocarbons[1/] and is one of the few agents that is effective against certain Class A fires in oxygen-enriched atmospheres.[2/] Although it can form toxic decomposition products, the undecomposed vapors are not highly toxic and are more thermally stable than most halogenated extinguishing agents.[3/] In the present work, the effectiveness of Halon 1301 as an extinguishant was determined for cotton sheeting fires in air using a 6-foot cubic chamber; the combustible specimens were burned in the vertical position to simulate the most severe condition. Data are presented on the effects of agent concentration, agent discharge pressure, position of discharge, combustible loading, and preburn time. In addition, data were obtained on the toxic decomposition products that formed under the various extinguishing conditions.

PHYSICAL PROPERTIES

Halon 1301 is a colorless, odorless gas with a density approximately 5 times that of air. It is ordinarily shipped as a liquefied gas and is used as a refrigerant as well as a fire extinguishing agent. Some of the physical properties of this material are listed in table I. As noted, Halon concentrations to at least 17 volume percent are not lethal for a 15-minute

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1/ Purdue University, Final Report on Fire Extinguishing Agents. Contract W44-009-eng-507, Army Engrs. Res. and Dev. Labs., June 30, 1950.

2/ Botteri, B. P., Fire Protection for Oxygen-Enriched Applications, Fire Journal, Vol. 62, No. 1 (January 1968), p. 48.

3/ Engibous, David L., and Theodore R. Torkelson, A Study of Vaporizable Extinguishants, WADC Technical Report 59-463, January 1960, p. 67.

TABLE I. - Properties of Halon 1301[1/]

Chemical Name	Bromotrifluoromethane
Chemical Formula	CF_3Br
Molecular Weight	148.93
Boiling Point at Atmospheric Pressure	-72° F
Vapor Pressure, 70° F	199 psig
Heat of Vaporization at Boiling Point	51.08 BTU/lb
Liquid Density, 70° F	13.1 lb/gal[2/]
Specific Volume (Vapor)	2.6 ft^3/lb
Decomposition Temperature	~ 900° F
Limits of Flammability	Nonflammable[3/]
Approximate Lethal Concentration (15 minute exposure)	
Undecomposed Vapor	>17 volume percent[4/]
Decomposed Vapor (1470° F)	14,000 ppm[2/]
Decomposition Products,	
HF	2,500 ppm
Br_2	550 ppm

1/ Data from reference 4 except where noted.
2/ Freon FE 1301 Fire Extinguishing Agent, DuPont Bulletin B-29B, 1969, p. 5.
3/ Perlee, H. E., G. H. Martindill, and M. G. Zabetakis, Flammability Characteristics of Selected Hydrocarbons, BuMines RI 6748, 1966, p. 9.
4/ No data available for human exposures at higher concentrations.

exposure; however, a maximum concentration of about 10 percent is recommended for protection against any harmful effects to humans. Although the approximate lethal Halon concentration for rats is reported to be 83.2 percent,[3] the oxygen concentration was far below that (~16%) which humans require to sustain life. Table I also shows the high toxicity level of decomposed Halon 1301. Additional data on the properties and safe use of this extinguishing agent are given in a NFPA tentative standard.[4]

EXPERIMENTAL APPARATUS AND PROCEDURE

A few small-scale burning and extinguishing experiments were conducted in a 2-ft diameter by 4-ft high chamber (12 ft^3) to develop gas sampling techniques and to obtain other information for the design of the large-scale experiments. The experimental procedure was similar to that used in the large-scale runs. The latter were made in a 6-ft cubic chamber (216 ft^3) designed to withstand a pressure of approximately 15 psig. A sketch of the experimental setup and a photograph of this chamber are shown in figures 1 and 2, respectively. A 6-inch glass port was mounted on each of three sides of the chamber for visual observation and for obtaining motion picture records of the burning and extinguishing. The chamber was instrumented for monitoring pressure and temperature changes and for sampling combustion products during a run. Chromel-Alumel thermocouples (30-gage) were located as shown in figure 1 for measuring the gas temperatures; TC_1, TC_2, and TC_4 were 2 inches to the side of the igniter and 2, 18, and 14 inches, respectively, above the igniter; TC_3 was 18 inches to the side and 18 inches above the igniter.

The combustible specimen, 36- by 27-inch cotton sheeting (5.1 oz/yd^2), was mounted on a rack suspended in the center of the 216-ft^3 chamber. A single layer (3.81 ozs) represented a combustible loading of 0.018 oz/ft^3 and a double layer corresponded to a 0.035 oz/ft^3 loading in the large chamber. Ignition was effected by a single supported Nichrome coil along the entire bottom edge of the specimen. For a 0.070 oz/ft^3 loading, two racks each with a 0.035 oz/ft^3 loading were used and these were spaced approximately 1 inch apart. The 0.035 oz/ft^3 loading was selected for most of the experiments as this was the highest loading which did not seriously deplete the available oxygen supply. For runs in the smaller chamber, the cotton sheeting specimens were 16 inches long by 4 or 8 inches wide.

The Halon 1301 was discharged from a 378-$inch^3$ spherical container* mounted near one corner of the chamber as shown in figure 1. The bursting of a retaining disc by a pyrotechnic charge released the Halon to impinge

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4/ NFPA No. 12 A-T, Tentative Standard on Halogenated Fire Extinguishing Agent Systems (Halon 1301), National Fire Protection Assoc., 60 Batterymarch St., Boston, Mass., May 1968, 62 pp.

* Liquid Agent Fire Extinguisher Bottle, Part No. 391941, Walter Kidde & Company, Inc.

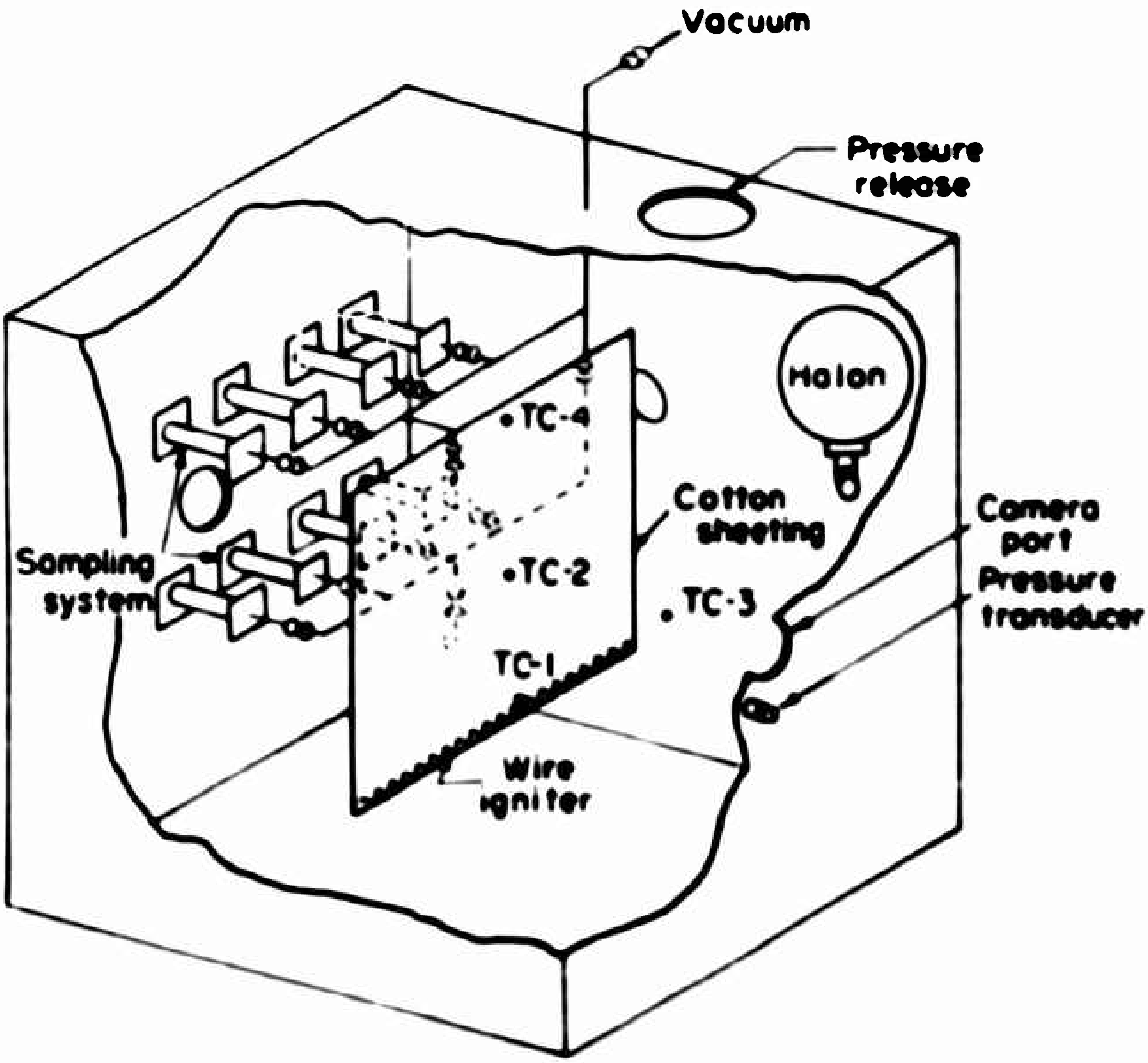

FIGURE 1. - Sketch of experimental setup for fire extinguishing experiments in 6-foot cubical chamber (216 ft^3).

FIGURE 2. - Photograph of 216 ft^3 chamber showing burning rack (end-on view), extinguishant container, and gas sampling system.

on a chamber wall at a 45° angle, 20 inches below the top of the chamber; a few runs were also made for comparison with the discharge 20 inches from the bottom of the chamber. Sufficient Halon was injected to form either a 3 or 6 volume percent mixture. The total pressure propelling the extinguishant was varied by the use of nitrogen at 700, 350, or 220 psig, the vapor pressure of Halon 1301 at 75° F. The rate of discharge at these pressures was determined in separate runs in which a pressure transducer was mounted on the Halon container and connected to an oscilloscope; average mass discharge rates were calculated from the pressure-time measurements obtained at each Halon loading. Table II lists the average discharge rates that were obtained from measurements with the container charged to yield 6 percent Halon (4.78 lbs), at various discharge pressures; nitrogen was used to pressurize the container above the vapor pressure of the extinguishant.

TABLE II. - Average Discharge Rates for Halon 1301 (4.78 lbs) From a 378-in^3 Container at Various Pressures.

Halon Discharge Pressure, psig	Discharge Time, sec	Initial Discharge Rate, lb/sec	Avg Discharge Rate, lb/sec
700 (Nitrogen)	0.75	15.8	6.3
350 (Nitrogen)	.78	11.8	6.1
220 1/	.90	6.1	5.3

1/ Vapor pressure of Halon 1301.

As noted, the average discharge rates were between 5.3 and 6.3 lbs/sec, whereas the initial rates for approximately 50 percent discharge were substantially higher and varied more consistently with increased discharge pressure.

To obtain samples of the gaseous products during a run, sampling ports were placed 6 inches from the top and bottom of the cotton sheeting specimen. Each port was located 6 inches away from the specimen and connected to individual sets of sample bottles, four at each level. Because of the highly corrosive nature of the fluorides in the gaseous products, acrylic sampling containers were used. Evacuation of the bottles and sampling of combustion products was remotely controlled by stainless steel solenoid valves. The sequence of the sampling and the firing of the pyrotechnic charge were regulated by a program timer. Gas samples were taken at various time intervals, depending upon the experiment. In experiments with extinguishment, at least one sample was taken 5 seconds after the Halon discharge and another 3 to 4 minutes later when the system was under essentially equilibrium conditions.

Conventional gas chromatographic techniques using a molecular sieve column were employed to analyze for oxygen, nitrogen, carbon monoxide, hydrogen and methane. Carbon dioxide was analyzed on a Poropak Q column and Halon 1301 on a Chromosorb P column with Silicone 200. Initially, hydrogen fluoride was analyzed by a spectrophotometric method based on the reaction between the fluoride and a zirconium-dye lake. Also, total bromine was determined by measuring the optical absorption of a silver bromide suspension (at 500 mμ) formed by the reduction of bromine and reaction with silver nitrate; Br_2 was determined by measuring the yellow oxidation product resulting from its reaction with o-tolidine. However, the presence of fluoride ions interfered with the spectrophotometric procedure for determining total bromine; therefore the following analytical procedure was then selected.

The hydrogen bromide and hydrogen fluoride are absorbed into water from the collected gas samples and are determined electrometrically using specific ion electrodes.[5,6] An expanded scale meter is used to read the potential between the specific ion electrode (bromide or fluoride), and a calomel reference electrode. The weight of the bromide or fluoride absorbed from the gas sample is then read from a previously prepared calibration curve relating micrograms versus emf for each electrode. The weight is then converted to vapor volume concentration for the sample as collected.

RESULTS AND DISCUSSION

A. Small-Scale Experiments

Data from the burning of cotton sheeting in the 12 ft^3 chamber indicated that a pressure rise of 4 to 5 psi could be expected with a 0.035 oz/ft^3 combustible loading. The pressure rise at 0.070 oz/ft^3 loading was over 5 psi and the burning was less complete than at the 0.035 oz/ft^3 loading as a result of oxygen depletion. Table III compares the gas analysis data obtained during the runs at the two combustible loadings. These data indicate that a 0.035 oz/ft^3 loading should be near-optimum for use in the large-scale work, although larger loadings should also be satisfactory if the preburn time before extinguishment is relatively short, that is, the oxygen depletion is not serious.

Since the peak pressure at the 0.035 oz/ft^3 loading was attained after approximately 20 seconds, a run was made at this loading in which the fire was extinguished after a 20-second preburn period. In this run, Halon 1301, equivalent to 6.3 volume percent of the chamber, was propelled under its own vapor pressure and directed toward the wall of the chamber near the middle of the specimen. Samples of the products were taken near the top and bottom of the specimen at various times, both before and after extinguishment. Table IV gives the results from this experiment using

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5/ Frant, M. S., J. W. Ross, and J. M. Riseman, Ion-Selective Electrodes, American Laboratory, January 1969, pp. 14-22.

6/ Srinivasan, K., G. A. Rechnitz, Activity Measurements With a Fluoride-Selective Membrane Electrode, Anal. Chem., Vol. 40, 1968, pp. 509-512.

TABLE III. - Gas Analyses and Pressure Rises From Burning of Cotton Sheeting in a 12-ft^3 Chamber With an Air Atmosphere.

Combustible Loading, oz/ft^3	Max. Pressure Rise, psi	Max. Pressure Rise, sec	Sampling Time, sec	Gas Analysis, Vol. %: O_2	N_2	CO_2	CO
0.035[1]	4.3	24	15	20.7	78.9	0.4	< 0.02
			30	16.7	79.1	4.2	0.04
			60	17.3	78.9	3.7	0.07
0.070[2]	> 5	33	15	20.2	79.0	0.8	< 0.02
			30	13.8	79.0	7.1	0.07
			60	12.4	79.3	8.1	0.20

1/ Average data for 3 runs.
2/ 90 percent consumed.

TABLE IV. - Gas Analysis Data from a Fire Extinguishing Experiment in a 12-ft^3 Chamber With Cotton Sheeting (0.035 oz/ft^3) in Air and 6.3 Percent Halon 1301.

Halon Injection Pressure - 220 psig

Time, secs.	10	20[1]	25		55		240	
	Gas Analysis, Vol. %							
Sampling Port	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
Oxygen	20.5	21.0	17.3	20.3	17.1	17.0	16.9	18.4
Nitrogen	78.4	78.9	73.5	78.2	75.2	75.9	75.6	74.0
Carbon dioxide	0.3	0.05	1.6	0.2	1.5	1.4	1.4	1.5
Carbon monoxide	0.8	0.05	1.4	0.7	0.2	0.2	0.2	0.9
Halon 1301	--	--	6.2	--	6.0	5.5	5.9	5.2
	Gas Analysis, Parts per Million							
Total bromine[2]	--	--	103	93	196	93	125	34
Hydrogen fluoride	--	--	360	278	690	400	300	354

1/ Time at which Halon 1301 injected.
2/ Includes bromine and bromide ion.

spectrophotometric methods for the hydrogen fluoride and total bromine analyses. Although the fire was extinguished within 1 second, high concentrations of hydrogen fluoride, hydrogen bromide or bromine, and carbon monoxide were formed. The highest concentrations of these toxic compounds were found in the samples taken near the top of the burning specimen, the Halon concentration also was higher at the top than at the bottom, although the variation was not great. Generally, the samples taken within 35 seconds after the Halon injection gave higher concentrations of toxic products than those taken much later when the system was at equilibrium.

B. Large-Scale Experiments

1. Cotton Sheeting Fires Without Extinguishment

Some differences in burning behavior were observed when the experiments in the 12 ft^3 chamber were scaled up to the 216 ft^3 chamber. In particular, the maximum pressure rises developed were higher and the total burning times were longer for experiments in the larger size chamber. For example, at a combustible loading of 0.035 g/ft^3, the maximum pressure rise was about 1 psi higher and the burning time about 10 seconds longer in the larger chamber. The pressure rise during a run appeared to vary as a simple power function of time over most of the burning period. Figure 3 shows a log-log plot of pressure rise and time derived from a least squares fit of experimental data at combustible loadings of 0.035 oz/ft^3 (5 trials) and 0.070 oz/ft^3 (2 trials). The straight lines drawn to represent the data at each loading are given by the following expressions:

0.035 oz/ft^3 Loading ($t < 32$ seconds)

$$\ln\Delta P = -7.306 + 2.712 \ln t; \qquad s = 0.127 \qquad (1)$$

0.070 oz/ft^3 Loading ($t < 34$ seconds)

$$\ln\Delta P = -3.948 + 1.745 \ln t; \qquad s = 0.065 \qquad (2)$$

where ΔP is the pressure rise in psi, t is the time in seconds, and s is the standard deviation; most of the data points fit within two standard deviations. At times greater than those specified, the rate of pressure rise tended to decrease since the fires at this stage were near completion.

As indicated by these expressions, the variation of pressure rise with time was greater at a loading of 0.035 oz/ft^3 than at 0.070 oz/ft^3 although the pressure rises at a given time were higher with the larger loading. Thus, the material consumption rate of the cotton sheeting depended upon the effective surface area exposed for burning and decreased as the number of double layers was increased from one (0.035 oz/ft^3) to two (0.070 oz/ft^3). Similarly, it was observed that a single layer of cotton sheeting burned more rapidly than a double layer. Measured flame spread rates did not vary greatly with combustible loading although they were generally higher at a loading of 0.018 oz/ft^3 ($\sim$2.8 in/sec) than at 0.035 or 0.070 oz/ft^3 ($\sim$2.3 in/sec). At the same time, some variation in the results could be

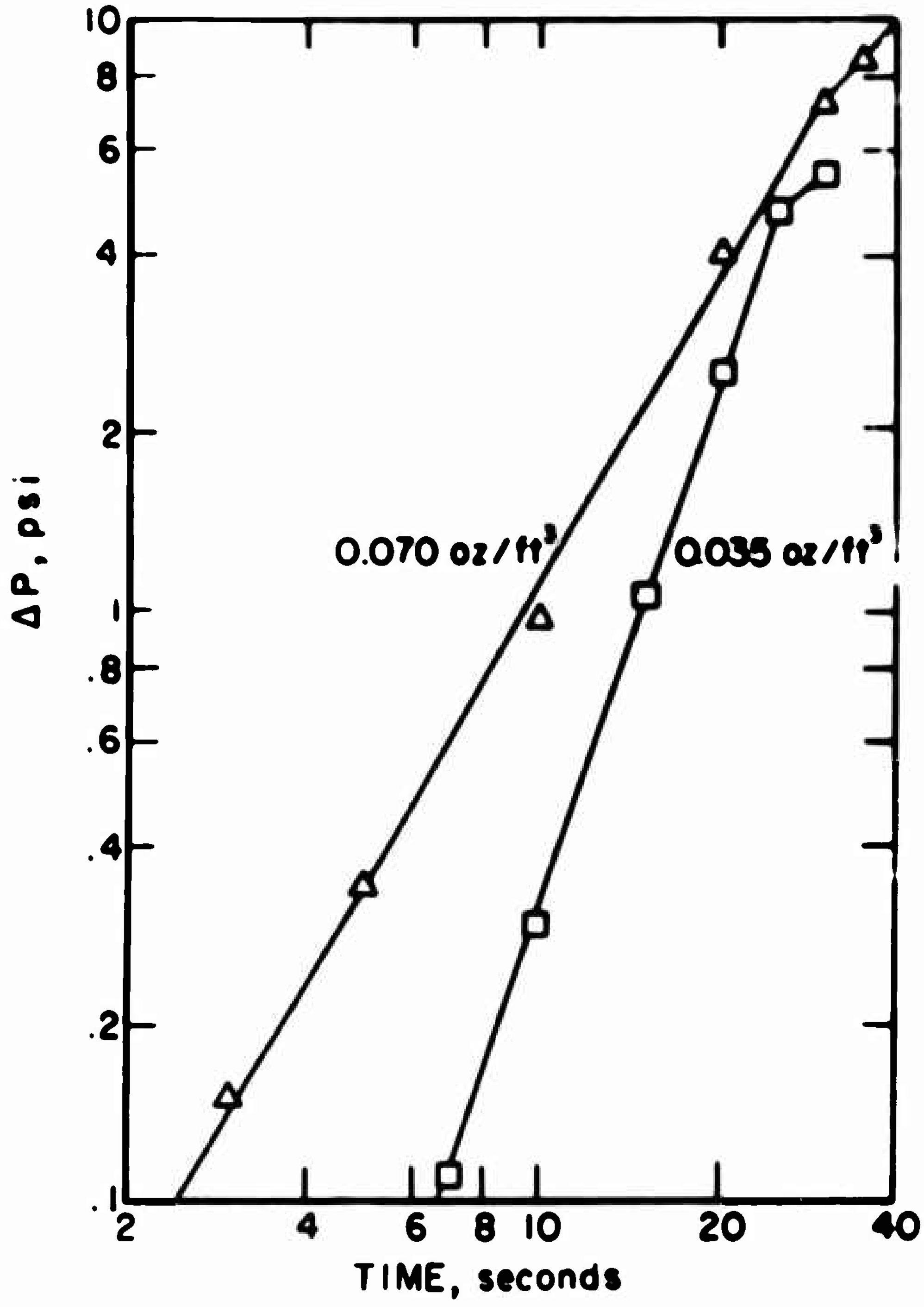

FIGURE 3. - Pressure rise vs time for cotton sheeting burning at combustible loadings of 0.035 and 0.070 oz/ft^3 in air at atmospheric pressure (216 ft^3 chamber).

expected, depending upon the uniformity and completeness of the ignitions. For example, uneven contact with the igniter coil could increase the time to attain full ignition.

The rate of pressure rise in the cotton sheeting fires appeared to correlate well with the rate of mass consumption. Figure 4 shows a log-log plot in which the variation of pressure rise and weight loss of the cotton sheeting with time are compared at a loading of 0.035 oz/ft^3. Here again, the individual points were derived from a least squares fit of the data (5 trials) that yielded the following expressions for the variation of percent weight loss with time:

$$\ln W = -1.549 + 1.811 \ln t \quad ; \quad s = 0.045 \qquad (3)$$

where ΔW is the percent weight loss, t is the time (< 20 seconds), and s is the standard deviation.

2. <u>Cotton Sheeting Fires With Extinguishment</u>.

Most of the fire extinguishing experiments were made at a combustible loading of 0.035 oz/ft^3 and with the extinguishant discharged from a container (378 in^3) mounted near the top of the 216 ft^3 chamber. Since exploratory experiments indicated that a concentration of at least 3 volume percent Halon 1301 in air was borderline for extinguishment of certain class A fires, 6 percent was selected for the present work although 3 percent was also used for comparison.

Typical temperature and pressure records from an extinguishing experiment at a combustible loading of 0.035 oz/ft^3 and a Halon concentration of 6 percent are shown in figure 5; the preburn time was 25 seconds and the Halon discharge pressure was 700 psig. While the temperatures at the top (TC-4) and middle (TC-2) stations close to the cotton sheeting dropped sharply following the addition of extinguishant, the chamber pressure increased momentarily before decreasing and leveling off. In this and other experiments, the lowest temperatures were obtained at the bottom (TC-1) of the cotton sheeting or at the station (TC-3) 18 inches away from the burning specimen. Wind effects during extinguishment at this high Halon discharge pressure were much greater than at the lower discharge pressures used. Figure 6 shows motion picture records from runs made with a preburn time of 25 seconds and 6 percent Halon at discharge pressures of 700 and 350 psig. The greater turbulence observed at the higher discharge pressure appears to produce almost immediate quenching within 0.12 second after injection of the extinguishant. However, the extinguishment was not complete and the actual times required were approximately the same at both discharge pressures, 0.74 sec at 700 psig and 0.64 sec at 350 psig.

The dependence of extinguishing time upon discharge pressure was greater with 3 percent than with 6 percent extinguishant concentration. Figure 7 compares data obtained in runs at these two concentrations and

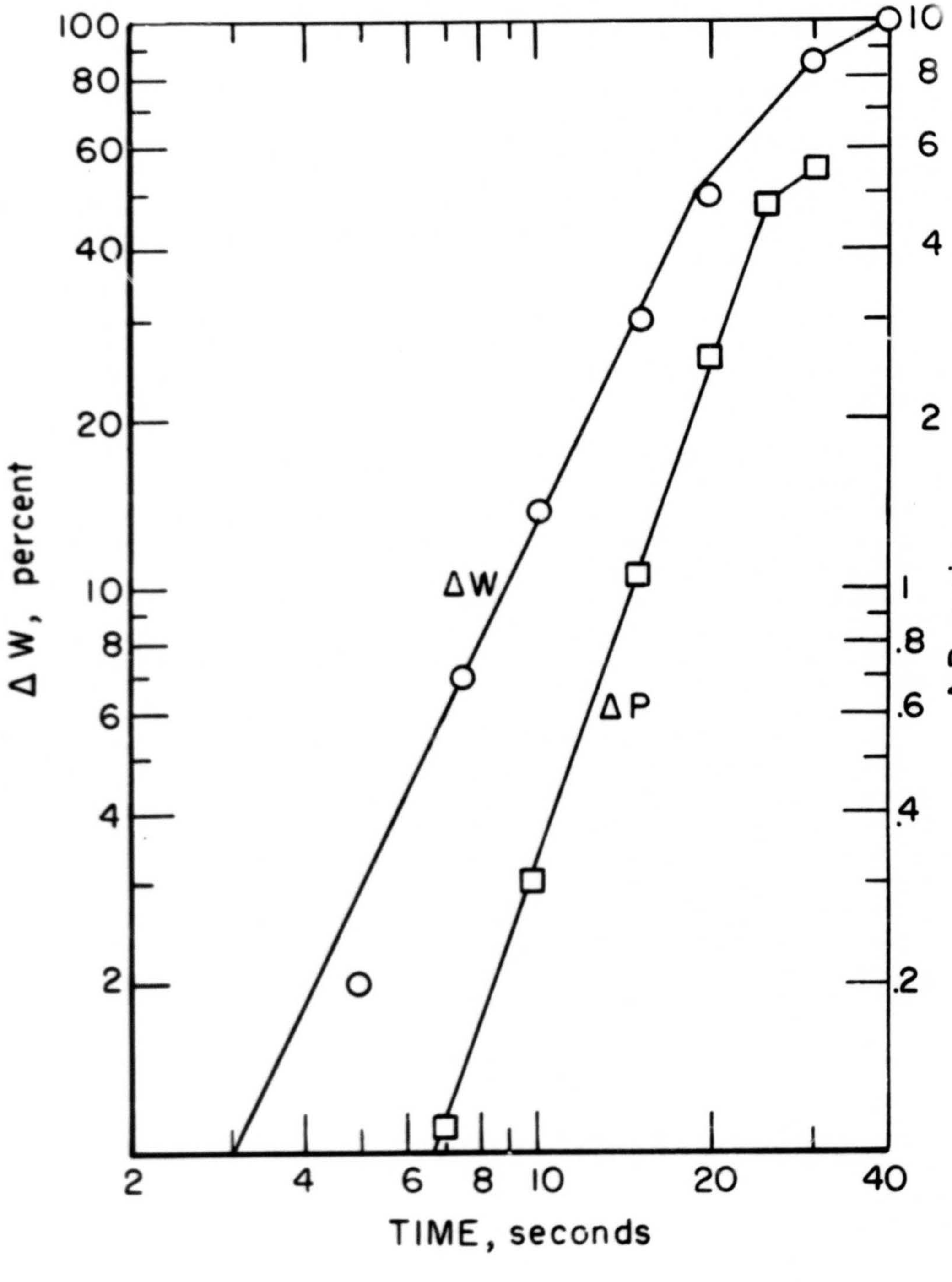

FIGURE 4. - Weight percent loss of combustible and corresponding pressure rise vs time for cotton sheeting burning at a combustible loading of 0.035 oz/ft^3 in air at atmospheric pressure (216 ft^3 chamber).

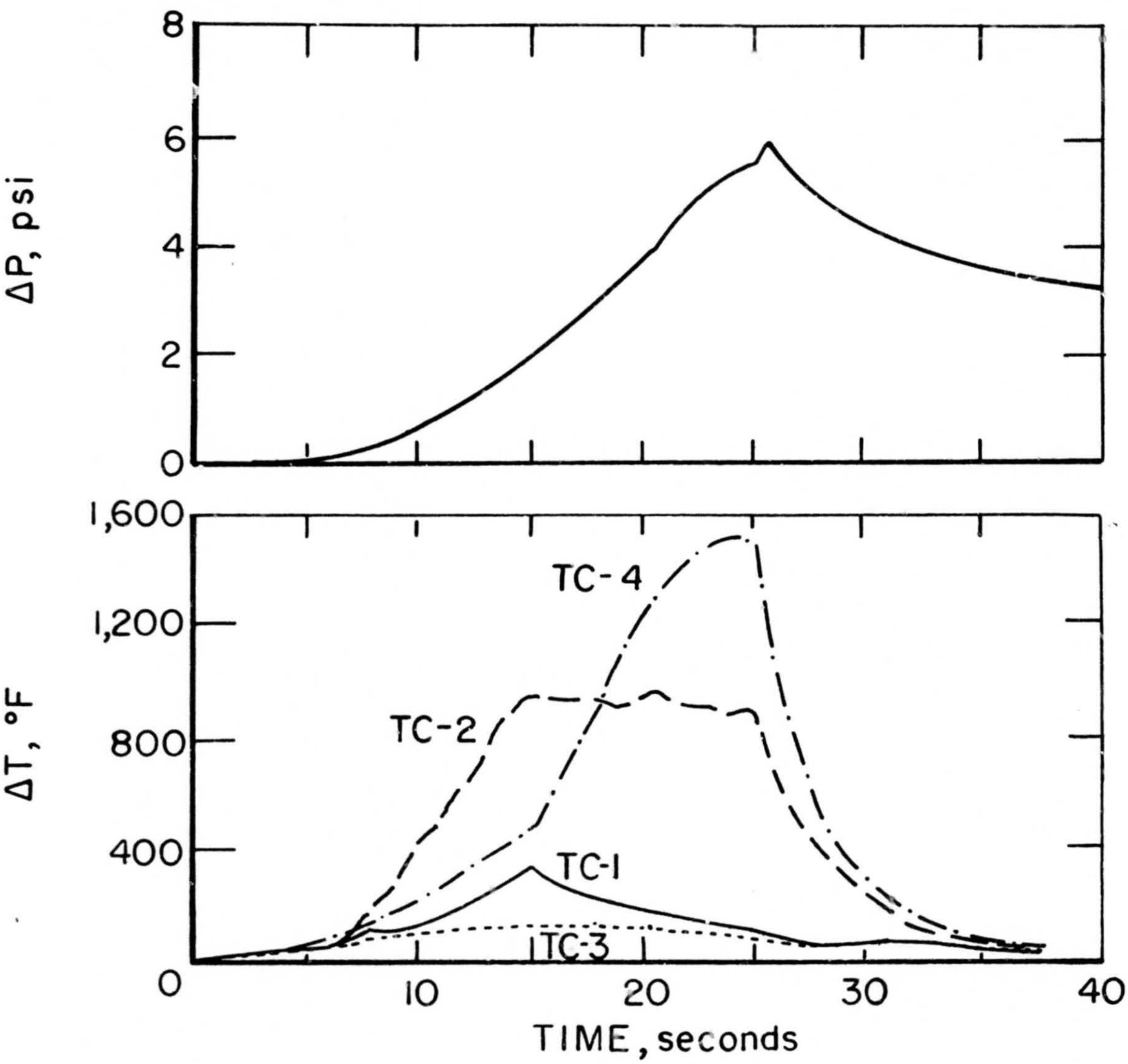

FIGURE 5. - Typical pressure and temperature rise records from the burning and extinguishment of cotton sheeting fires (0.035 oz/ft^3) after 25 seconds by 6 percent Halon 1301 at a 700 psig discharge pressure (216 ft^3 chamber).

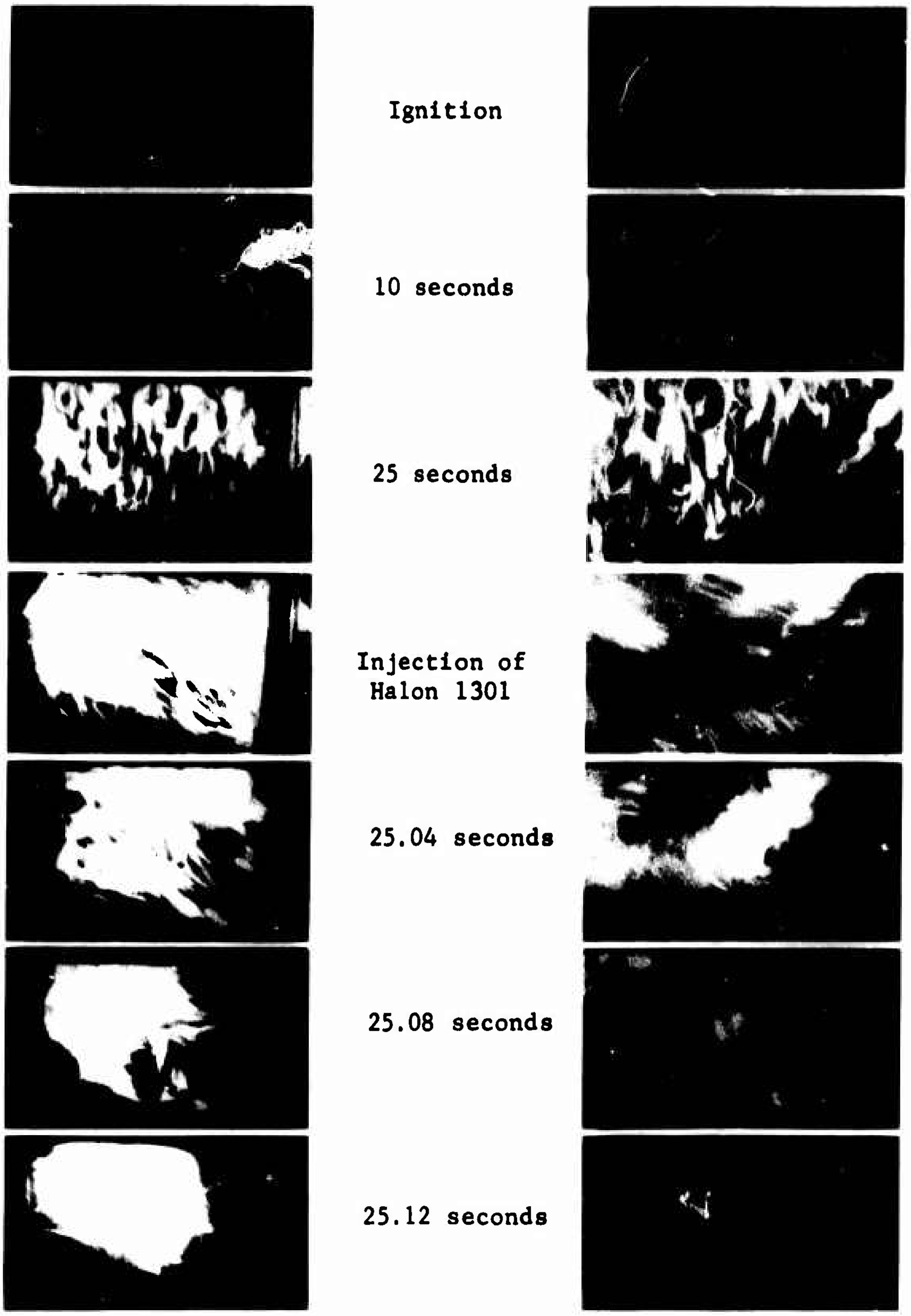

FIGURE 6. - Photographic sequence of cotton sheeting (0.035 oz/ft^3) fire and extinguishment after 25 seconds of burning by 6 percent Halon 1301 at 350 psig (left) and 700 psig (right) discharge pressures.

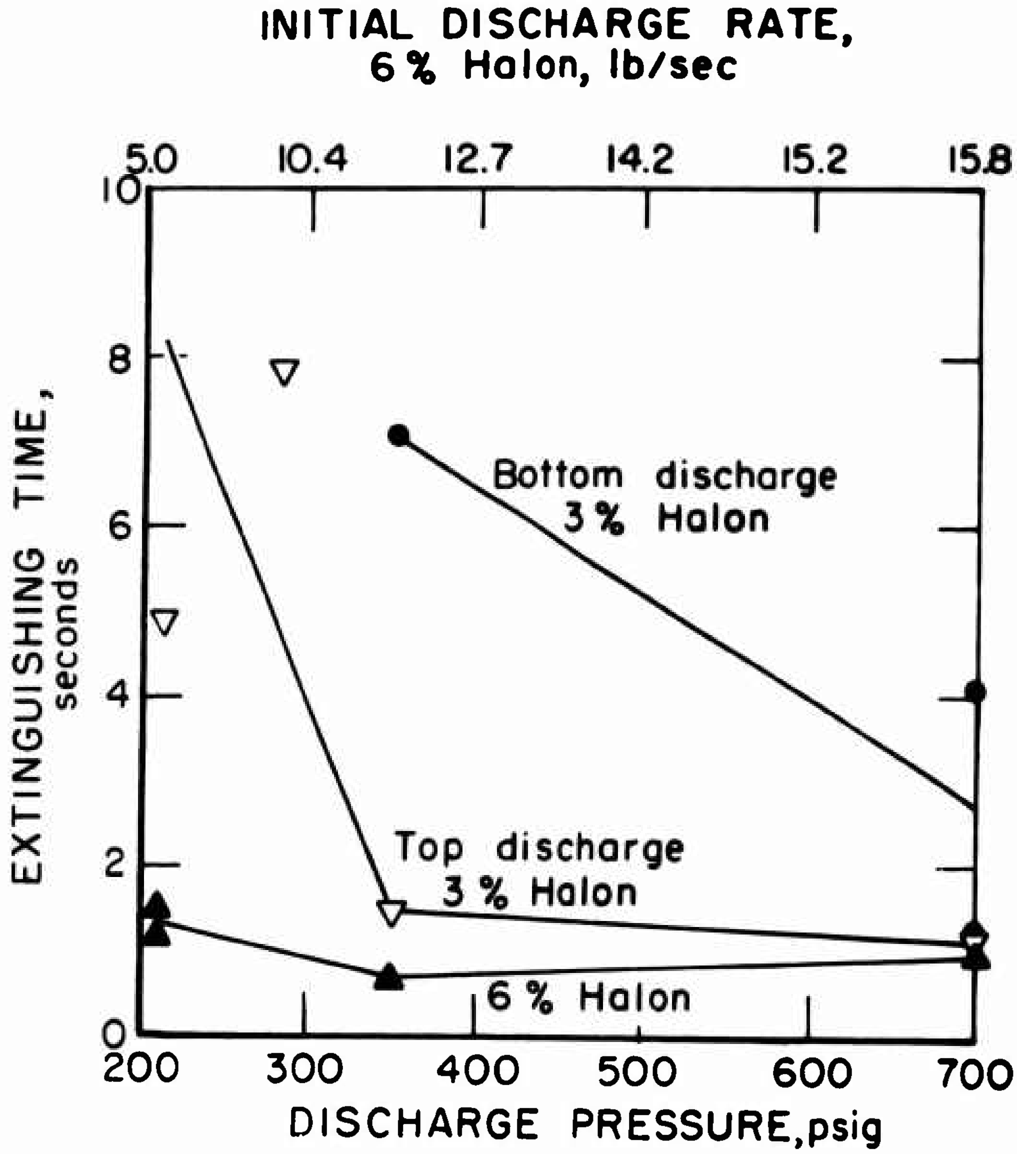

FIGURE 7. - Variation of extinguishing time with Halon discharge pressure for cotton sheeting fires (0.035 oz/ft^3) with 3 or 6 percent Halon 1301 after a 25-second preburn time. (Halon discharged at top or bottom locations in 216 ft^3 chamber).

various discharge conditions; the preburn time was 25 seconds with a combustible loading of 0.035 oz/ft^3. With discharge of the Halon from near the top of the chamber, the extinguishing times for a 6 percent concentration were less than 1-3/4 seconds and varied little with discharge pressure. The use of an extinguishant container with two discharge ports at 700 psig did not affect the results significantly. In comparison, the 3 percent concentration required much longer extinguishing times when the discharge pressure was decreased below 350 psig. Also, the 3 percent concentration was less effective when discharged from the lower part of the chamber, probably because the burning level after 25 seconds was near the top of the chamber, in which case top discharge should be more effective.

With a 6 percent concentration, the effectiveness of Halon also did not vary greatly with preburn time, which was varied from 5 to 25 seconds. As noted in figure 8, the extinguishing times are one second or less at a 6 percent Halon concentration and a 700 psig discharge pressure. The corresponding values at 220 and 350 psig pressures are slightly higher. Again the lower Halon concentration of 3 percent is much less effective, particularly at preburn times less than 25 seconds. The data at this lower concentration and 700 psig discharge pressure also display an anomalous trend in that the extinguishing times decrease with increased preburn time. Apparently, the turbulence caused by the discharge at this pressure and the proximity of the burning level to the Halon discharge area at the given time influenced the results noticeably at the lower Halon concentration.

A few experiments were made to show the effect of combustible loading on the extinguishment time. The extinguishing effectiveness of 6 percent Halon pressurized to 350 psig was compared at 0.018, 0.035 and 0.070 oz/ft^3 loadings with a preburn time of 10 seconds. The results, which are included in table V, indicate that this Halon concentration is highly effective at a loading of 0.018 oz/ft^3 and the extinguishing times are approximately in direct proportion to the combustible loading. Pressure rise data are also summarized in this table from experiments at various Halon discharge pressures and preburn times. Generally, the maximum pressure rises at a given combustible loading increased with increasing preburn time but varied little with the discharge pressure, 220 to 700 psig.

3. Gas Analyses in Extinguishing Experiments

Gas analyses were obtained of the oxidation and decomposition products that formed in the fire extinguishing experiments with cotton sheeting after various preburn times. The combustible loading was 0.035 oz/ft^3 and the extinguishant was discharged from near the top of the chamber. Samples were taken at both the top and bottom sampling ports and represent the average concentrations that prevailed at near-equilibrium conditions, 240 seconds after ignition. Figure 9 shows the variation of CO, CO_2 and O_2 that was observed in extinguishment with 6 percent Halon at a discharge pressure of 700 psig after preburn times of 5 to 25 seconds. These data were obtained for samples taken at the top of the burning specimen and did

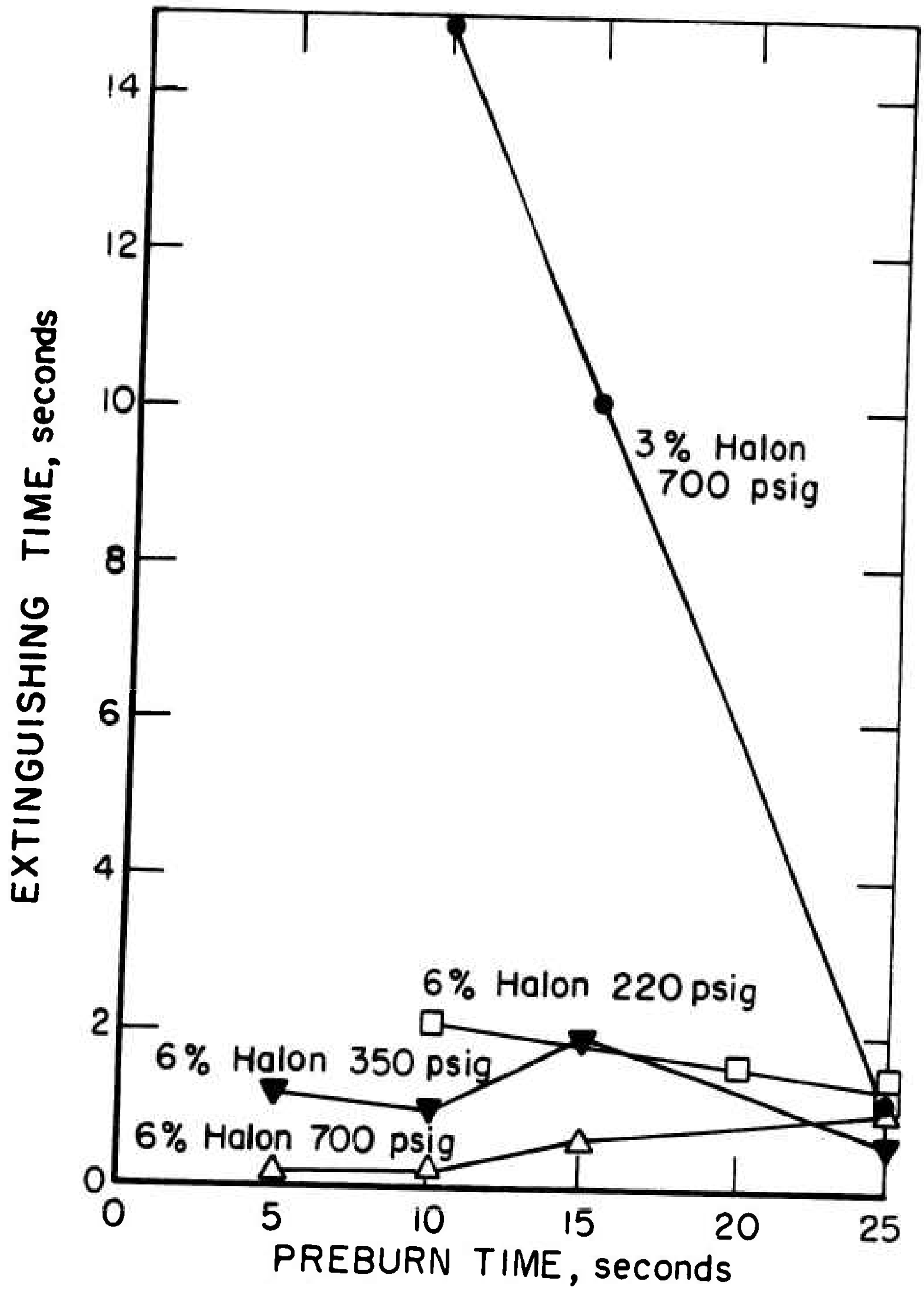

FIGURE 8. - Variation of extinguishing time with preburn time and Halon discharge pressure for cotton sheeting fires (0.035 oz/ft^3) extinguished with 3 or 6 percent Halon 1301 (216 ft^3 chamber).

TABLE V. - Extinguishing Times and Maximum Pressure Rises From Extinguishing Experiments at Various Combustible Loadings and Preburn Times.

Halon 1301 concentration - 6 volume percent

Combustible Loading oz/ft^3	Preburn Time, sec	Max. Pressure Rise, psi	Extinguishing Time, sec
	Halon Discharge Pressure - 350 psig		
0.018	10	1.2	0.4
.035	10	0.7	1.0
.070	10	1.7	1.8
	Halon Discharge Pressure - 220 psig		
0.035	10	1.2	2.1
.035	20	4.2	1.6
.035	25	4.9	1.5
	Halon Discharge Pressure - 350 psig		
0.035	5	0.5	1.2
.035	10	0.7	1.0
.035	15	1.2	1.9
.035	25	4.2	0.6
	Halon Discharge Pressure - 700 psig		
0.035	5	0.8	0.2
.035	10	0.9	0.2
.035	15	1.8	0.6
.035	25	5.9	1.0

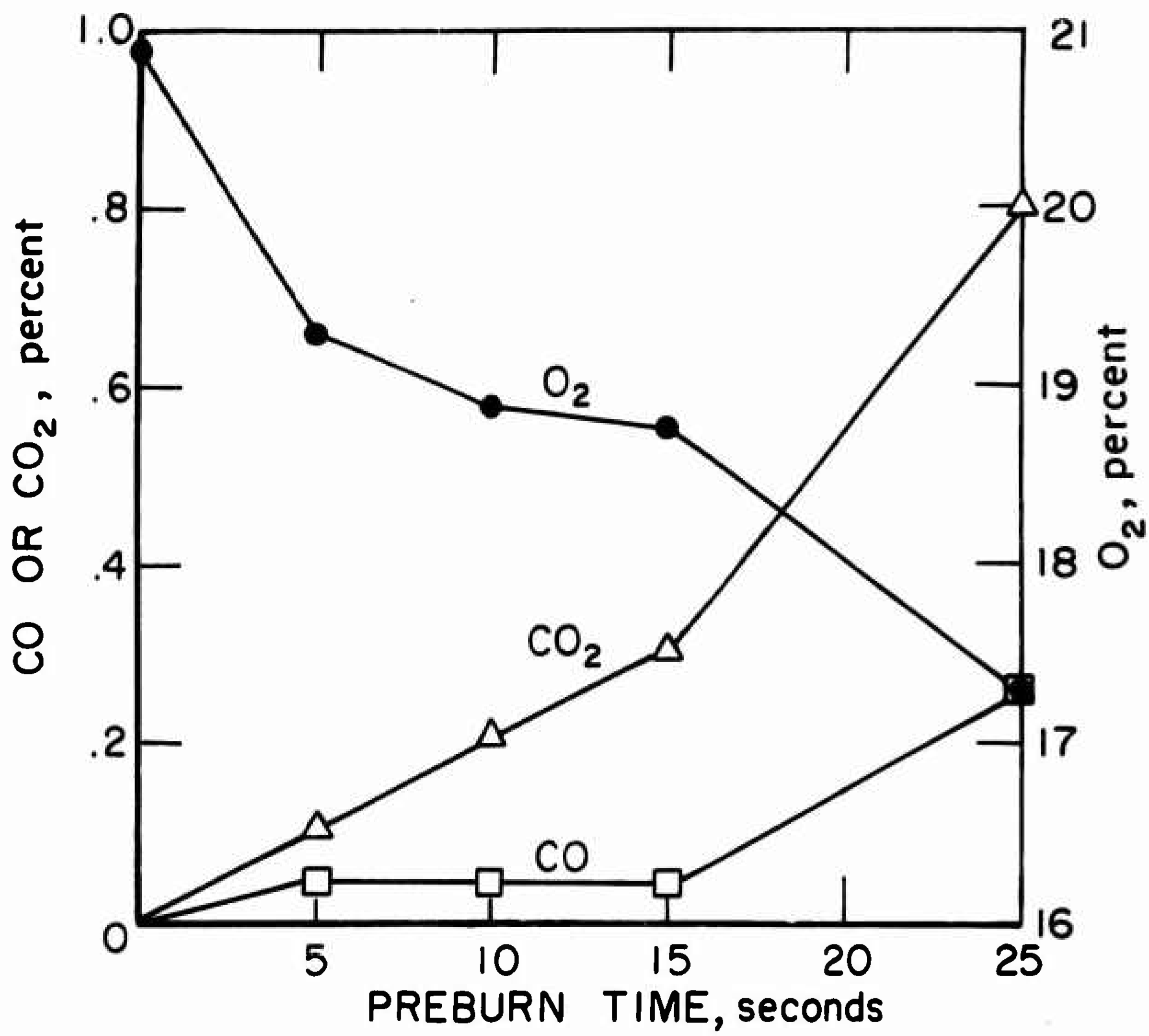

FIGURE 9. - Effect of preburn time on the oxygen (O_2) depletion and carbon monoxide (CO) or dioxide (CO_2) formation in fire extinguishing experiments with cotton sheeting (0.035 oz/ft^3) and 6 percent Halon 1301 at 700 psig discharge pressure (216 ft^3 chamber).

not differ significantly from those taken at the bottom (see table VI). The oxygen depletion was not serious under any of the test conditions. Although the CO concentration tended to increase noticeably when the preburn time was increased from 15 to 25 seconds, the level of hazard was not necessarily great; the approximate lethal CO concentration for a 15-minute exposure is 1.5 percent.[7] Essentially, similar results were obtained when the Halon discharge pressure was decreased to 350 psig.

The extent of decomposition of the Halon extinguishant in the cotton sheeting fires varied with the preburn time and the extinguishant discharge pressure. Hydrogen fluoride and hydrogen bromide were the only toxic decomposition products detected and these were determined by the specific ion electrode method, as described in the section on experimental procedure. Figures 10 and 11 show the variation of HBr and HF concentrations, respectively, with preburn time for runs made at Halon discharge pressures of 220, 350, and 700 psig; the Halon concentration was 6 percent. As expected, the amount of toxic vapors increased with increased preburn time, although all the data are not consistent, particularly at low preburn times where only about 10 ppm or less were detected. The concentration of toxic vapors at a Halon discharge pressure of 220 psig was generally greater than that at 350 psig, but less than observed at 700 psig. The high, anomalous results at 700 psig were attributed partly to the greater turbulence and spread of flame that were produced at the higher discharge pressure (see figure 6); with increased turbulence, the total flame surface area should increase and, therefore, the amount of Halon decomposition should also increase, depending upon the contact or exposure time. Although experiments were repeated at only a few test conditions, the results tended to verify the trends shown here.

According to the gas analyses, the potential toxicity hazard from the formation of HF or HBr was rather small in the fire extinguishing experiments with short preburn times of less than 15 seconds. With longer preburn times, the concentrations of the toxic vapors were much higher, particularly those of HF. Although the observed concentrations were not higher than the lethal HF or Br_2 concentrations specified for short exposure times (table I), they would not be safe for long exposure times. In addition, it was observed that exposure to even small concentrations of the product vapors irritated the eyes and nostrils.

Since the amount of smoke produced in extinguishing a fire can be important in some situations, visibility in the chamber after extinguishment was also observed. With a combustible loading of 0.035 oz/ft^3 and 6 percent Halon, no object was visible in the chamber after extinguishment at the 25-second preburn interval. With extinguishment after a 15-second preburn time, the chamber atmosphere was quite hazy but the igniter coil and

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7/ Footnote 2 in table I.

TABLE VI. - Gas Analysis Data From Fire Extinguishing Experiments in a 216 ft^3 Chamber With Cotton Sheeting (0.035 oz/ft^3) in Air and 6 Percent Halon 1301. Halon injection pressure - 700 psig.

Time, secs.	10		20		25[1/] 30		240	
	Gas Analysis, Volume Percent							
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
O_2	20.2	20.3	19.4	20.4	16.3	16.4	17.3	16.4
N_2	79.5	79.4	79.6	79.5	77.4	77.4	77.2	77.1
CO_2	0.3	0.2	0.9	0.1	1.0	1.0	0.8	1.0
CO	0.05	0.05	0.07	0.04	0.2	0.19	0.26	0.27
Halon 1301					5.1	5.0	4.4	5.2
	Gas Analysis, ppm							
HBr					140	40	90	70
HF					720	640	750	1000

Time, secs.	10		15[1/] 20		30		240	
	Gas Analysis, Volume Percent							
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
O_2	20.6	21.0	18.9	19.1	18.8	18.9	18.8	19.9
N_2	79.1	79.0	75.7	75.7	75.4	75.4	75.6	77.0
CO_2	0.3	Trace	0.3	0.2	0.3	0.3	0.3	0.1
CO	0.0	0.0	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Halon 1301	--	--	5.1	5.0	5.5	5.4	5.3	3.0
	Gas Analysis, ppm							
HB_r	--	--	5.8	3.7	5.5	6.6	11.5	3.9
HF	--	--	0.0	2.0	2.0	3.4	11.2	1.7

Time, secs.	5		10[1/] 15		30		240	
	Gas Analysis, Volume Percent							
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
O_2	20.9	20.7	19.1	19.6	19.1	19.0	18.9	19.0
N_2	79.0	79.2	75.7	75.8	75.5	75.2	75.4	75.2
CO_2	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2
CO	<0.05	--	--	--	--	<0.05	--	--
Halon 1301	--	--	5.1	4.5	5.3	5.6	5.5	5.6
	Gas Analysis, ppm							
HB_r	--	--	19.0	8	15	12	12	11
HF	--	--	6.3	5.5	5.8	5.0	5.8	4.4

1/ Time at which Halon 1301 injected.

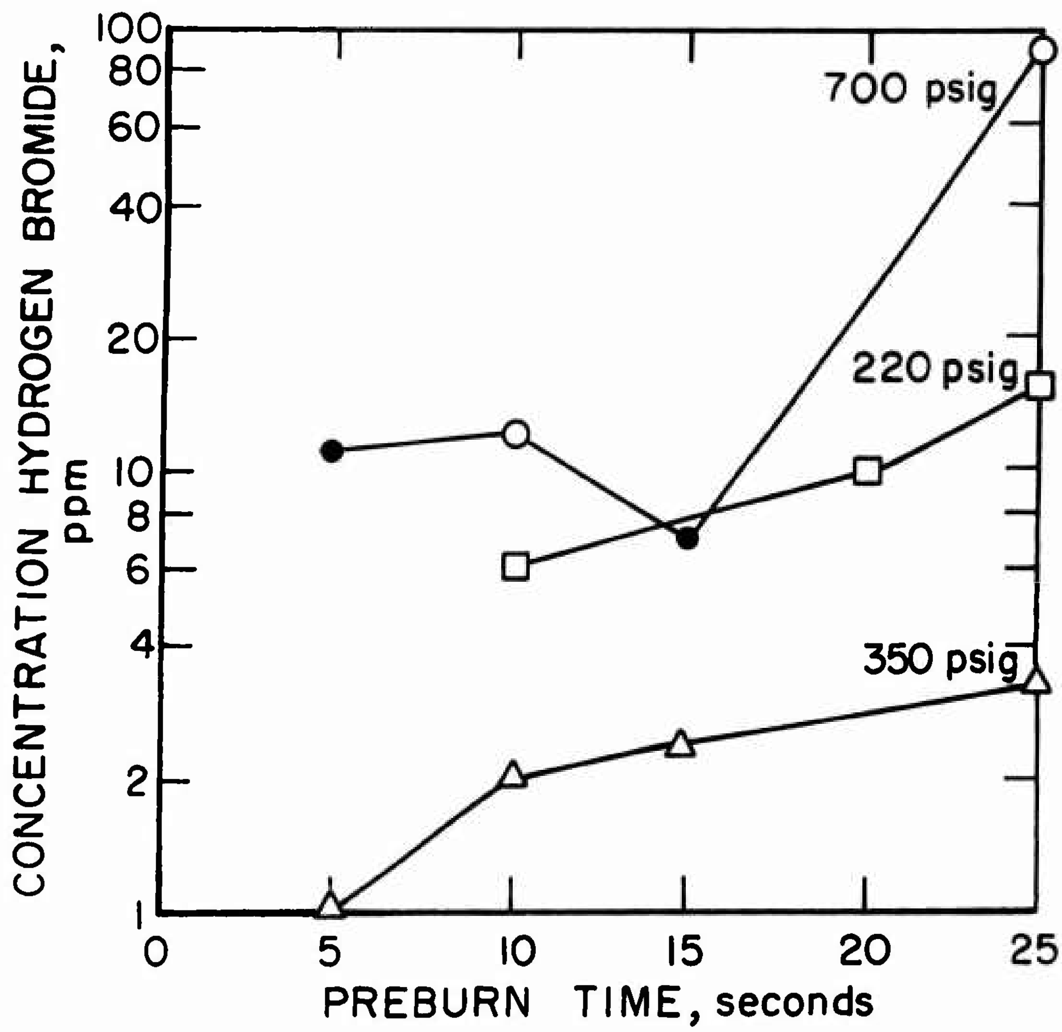

FIGURE 10. - Effect of preburn time on the concentration of hydrogen bromide produced in fire extinguishing experiments with cotton sheeting (0.035 oz/ft^3) and 6 percent Halon 1301 at various discharge pressures. (Solid circles are average of two runs in 216 ft^3 chamber).

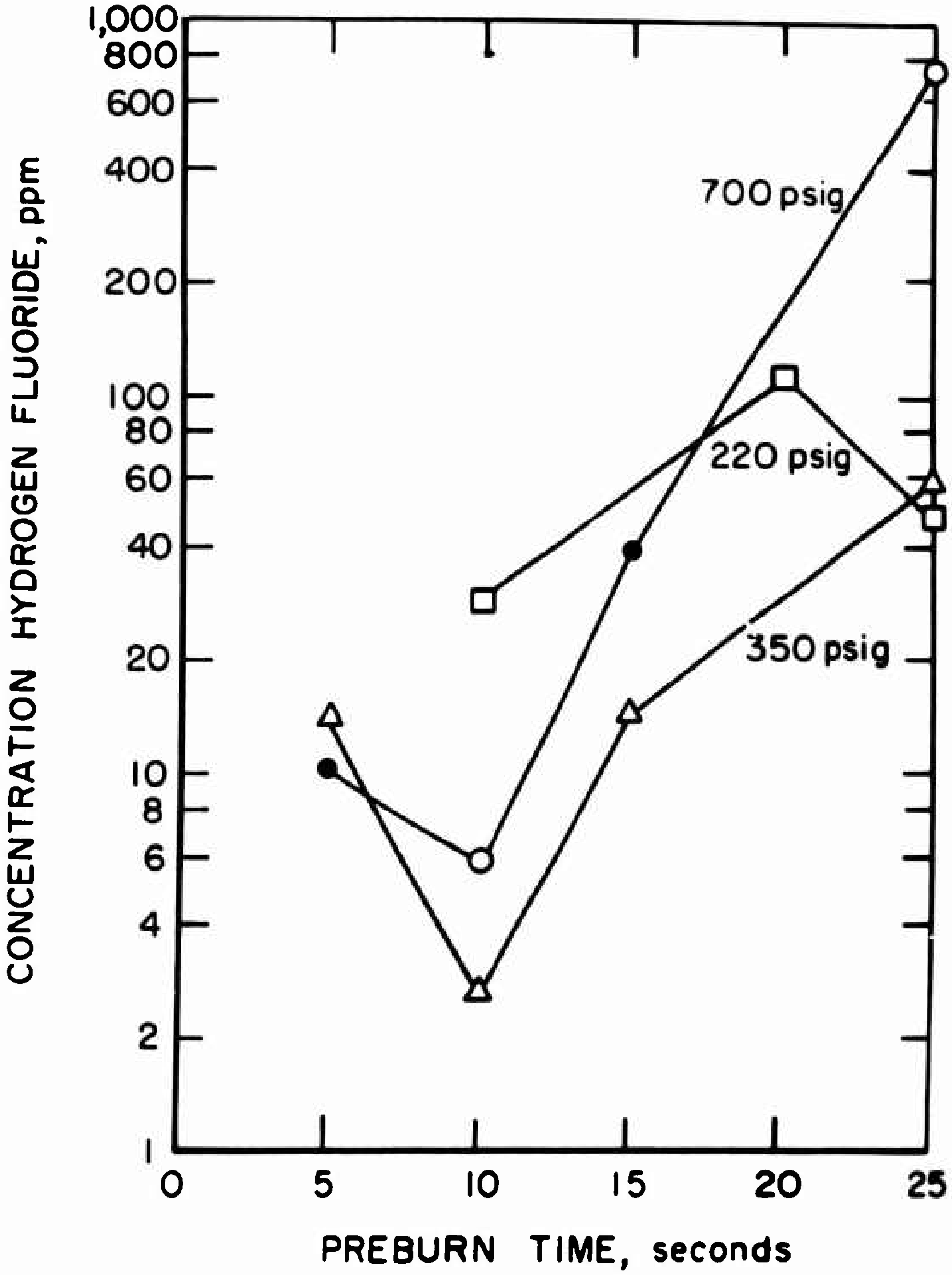

FIGURE 11. - Effect of preburn time on the concentration of hydrogen fluoride produced in fire extinguishing experiments with cotton sheeting (0.035 oz/ft^3) and 6 percent Halon 1301 at various discharge pressures. (Solid circles are average of two runs in 216 ft^3 chamber).

a placard with 3/4-inch lettering was easily distinguished at a distance of 3 feet. With shorter burning periods, visibility was not noticeably impaired. In addition, it was observed that the chamber atmosphere after extinguishment at 5 seconds would not sustain combustion; the cotton sheeting could not be ignited and burning specimens thrust into the chamber were immediately quenched.

CONCLUSIONS AND RECOMMENDATIONS

Cotton sheeting fires can be rapidly extinguished by the use of Halon 1301 in the total flooding mode, depending upon such variables as the agent concentration, agent application rate, and the size of the fire. At combustible loadings of 0.018 to 0.070 oz/ft^3, cotton sheeting specimens burning vertically in a 216 ft^3 chamber can be extinguished within 2 seconds by a 6 percent Halon concentration at an average discharge rate of 6.3 lb/sec. With the 6 percent concentration, the extinguishing times varied little with preburn time or discharge rate (5.3 to 6.3 lb/sec). A 3 percent concentration appeared to be inadequate for rapid extinguishment under most test conditions employed. Generally, the extinguishant was more effective when discharged near the top rather than the bottom of the burning specimen.

Extinguishment of the fires after short preburn times ($\leq$ 15 seconds) resulted in only small pressure rises and concentrations of toxic products. With preburn times greater than about 15 seconds, the concentration of toxic products (HF, HBr, CO) increased greatly under most of the test conditions; the amount of HF was much greater than that of HBr or total bromine. In addition, visibility in the test chamber was poor after long preburn times.

In order to evaluate the effectiveness of Halon 1301 in other class A fires and under other discharge conditions, the following recommendations are made for future work.

1. Compare performance of Halon 1301 in total flooding mode extinguishment with other types of class A material fires, including paper and plastic sheeting.

2. Investigate effectiveness of other extinguishant discharge methods including the use of multiple point discharge and shower manifold discharge systems.

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13. ABSTRACT

Fire extinguishing experiments were conducted to evaluate Halon 1301 as an extinguishant of Class A fires by the total flooding mode for possible use in advanced aircraft. The effectiveness of the extinguishant was determined by burning cotton sheeting fires in a 216 ft^3 chamber at various combustible loadings, preburn times, and extinguishant discharge pressures or rates. Extinguishing times increased with increased combustible loading but varied little with preburn time and Halon discharge pressure when the Halon concentration in the chamber was 6 volume percent. With this concentration, cotton sheeting fires at a loading of 0.035 oz/ft^3 were extinguished within 2 seconds or less using Halon discharge pressures of 220, 350, and 700 psig. A 3 percent Halon concentration appeared to be inadequate under most test conditions.

With 6 percent Halon, the toxicity hazard from the formation of CO, HF, or HBr was relatively small for preburn times of 15 seconds or less. The concentration of toxic product vapors increased noticeably when the total burning period before extinguishment was increased from 15 to 25 seconds. Under all test conditions, the toxic product concentrations after equilibrium conditions prevailed were much less than the lethal concentrations reported for short exposure times. Data are also presented on the rates of pressure rise and mass consumption that characterized the cotton sheeting fires.

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