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Great Lakes
Chemical Corporation

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January 9, 1984

Mr. Martin Greif, Executive Secretary
TSCA Interagency Testing Committee
Environmental Protection Agency (TS-792)
401 M Street
Washington, DC 20460

Contains No CBI



84940000152

Dear Mr. Greif,

Enclosed is information on bromotrifluoromethane (CAS No. 75-63-9) requested by the ITC in the Federal Register, November 9, 1983. Included are a Great Lakes material safety data sheet, a product information bulletin, and a discussion of the toxicity literature by Dr. Gary Carlson, Professor of Toxicology at Purdue University who is a consultant to our Company. Also enclosed are several references on experiments with human volunteers which we feel provide improved insight to the safety of this compound.

Bromotrifluoromethane, also known as Halon 1301, is a very effective fire extinguishing agent. It has been extensively tested in military and civilian laboratories. Halon 1301, a gas, is manufactured and handled in totally enclosed systems. Exposure to plant personnel is not expected, except during upset conditions or occasional maintenance.

Halon 1301 is employed in engineered fire extinguishing installations to protect valuable property such as main frame computers. The extinguishing systems have alarms to prompt the evacuation of areas before discharge of Halon 1301 occurs. The areas are aired-out before personnel return. Any exposure would be expected to occur quite infrequently and only to the relatively small population employed directly in working with protected equipment. Halon 1301 provides unique benefits in fire fighting compared to the risks posed to life by its minimal toxicity.

Great Lakes believes the toxicity information in the literature accurately indicates the negligible toxicity of Halon 1301 and coupled with the limited opportunity for exposure to small populations renders the need for environmental testing unnecessary.

Sincerely,

GREAT LAKES CHEMICAL CORPORATION

Dennis L. McFadden
Dennis L. McFadden
Product Safety Coordinator

DLMcF/kb

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125 Burke Court
West Lafayette, IN 47906
November 9, 1982

12-41

Mr. Dennis McFadden
Great Lakes Chemical Corporation
P. O. Box 2200
West Lafayette, IN 47906

Dear Mr. McFadden:

In response to your inquiry regarding the toxicity of the fire-fighting chemicals Halon 1301 (bromotrifluoromethane) and Halon 1211 (bromochlorodifluoromethane), I would like to comment on both the chemicals themselves and their pyrolysis products. These observations are based on the materials which you provided to me and those which I have ready access to from my own files and library.

General Toxicology.

The material from the Fire Protection Handbook of the National Fire Protection Agency and that developed by the group at the Wright-Patterson Air Force Base, as provided by ASP International, is quite correct in pointing out that these two materials are much less lethal in animals than many similar compounds such as carbon tetrachloride, dibromodifluoromethane, methylbromide, etc. which appear in the list of chemicals prohibited from use in fire extinguishers in Michigan. The results clearly demonstrate that experimental animals can tolerate over 800,000 ppm of Halon 1301 and 300,000 ppm of Halon 1211. Although these data cannot be directly extrapolated to humans, they demonstrate the safety of these agents in comparison with the other agents tested including carbon dioxide which falls somewhere between the two.

Extrapolation of animal data to the human situation is difficult with these or other agents. Nevertheless, a number of statements can be made regarding the toxicity of these two Halons. First, it is quite evident that they are not hepatotoxins as are some of the other compounds such as carbon tetrachloride. The two chief worries then are narcotizing or other effects on the central nervous system and cardiac arrhythmias. The study supported by the Department of Energy through the Nevada Operations Office indicates that inhalation of Halon 1211 at concentrations of greater than 4 percent might lead to some dizziness or incoordination although they do not suggest that this would be incapacitating. Their comparisons with high levels of carbon dioxide point out that under conditions of actual use this latter compound might have much more profound effects in cases of large discharges of fire-fighting materials in enclosed spaces.

Effects on the Heart in Experimental Animals.

Concern about the possibility of the generation of cardiac arrhythmias, especially under the conditions of the stress and excitement associated with fire-fighting which would lead to high

epinephrine (adrenaline) levels, has prompted animal studies on both Halons. Beck et al. (Toxicol. Appl. Pharmacol. 24, pp. 20-29, 1973) found that Halon 1211 caused central nervous system stimulation in rats, mice, guinea pigs, dogs and monkeys at concentrations ranging from 5 to 36 percent. Cardiac arrhythmias resulted from exposure to one and four percent in dogs and rabbits respectively when challenged with intravenous epinephrine.

Halon 1301 has been studied in considerable detail. Van Stee and Beck (Toxicol. Appl. Pharmacol. 15, pp. 164-176, 1969) exposed both dogs and monkeys to 10 to 80 percent Halon 1301. They found spontaneous cardiac arrhythmias in those animals exposed to high concentrations (40 percent and above). In dogs, an exposure to 50 to 80 percent caused convulsions in about one-half the animals. In monkeys, there were no convulsions although lethargy was noted. More recently, Trochinowicz et al. (J. Occup. Med. 18, pp. 26-30, 1976) studied lower concentrations in dogs. They noted that serious cardiac arrhythmias were observed in dogs breathing 7.5 percent Halon 1301 or greater and administered epinephrine iv. Dogs with experimentally induced myocardial infarctions were no more sensitive than normal dogs. This model is important in that it closely resembles the human condition in a number of ways both functionally and pathologically. The lack of greater risk in these experimental animals suggests that an individual who may have had a myocardial infarct in the past would be at no greater risk than the healthy, normal individual. It is worth noting that in this study, trichlorofluoromethane (FC11) caused severe arrhythmias and death at 0.5 percent. Thus, dramatic differences can be observed among the halogenated methanes. Similar studies by this group (Mullin et al., Amer. Ind. Hyg. Assoc. J. 40: pp. 653-658, 1979) revealed that while maximum levels were rapidly attained, they did not increase with time, and the material was rapidly eliminated from the body. Thus, it is clear that the compound does not accumulate and is not stored. A report by Harris et al. (AMRL-TR-75-125, pp. 227-241, 1975) indicated that dogs exposed to a combination of 8 to 12 percent Halon 1301 and 1.5 to 2 percent Halon 1211 did not experience arrhythmias. This study is especially pertinent since these are the levels which would be of interest in the actual use of Halons.

Effects in Humans.

The most critical data to assess the potential toxicity of these compounds come from human experiments and human use. Smith and Harris (Aerospace Med. 44, pp. 198-201, 1973) exposed human volunteers to concentrations of 4 to 7 percent Halon 1301 and monitored their ECGs and other effects and noted no cardiac arrhythmias or other adverse reactions. Call (Aerospace Med. 44, pp. 202-204, 1973) studied volunteers under similar conditions. He found no changes in post-exposure physical examinations and no changes in pulmonary function. Although there were some changes in complex reaction times, there were no deficits in maze tracking tasks, and he concluded that Halon 1301 was a safe fire extinguishing agent in occupied aircraft.

November 9, 1982

The American Conference of Governmental Industrial Hygienists concluded that Halon 1301 has a low order of toxicity and set a TLV of 1000 ppm (Documentation of Threshold Limit Values, 4th Ed. ACGIH, 1980). This was based on a number of studies similar to those cited above which indicated little likelihood of interference with mental functions or production of cardiac arrhythmias at reasonable concentrations. It should be noted that these values are concerned with workers exposed eight hours per day for a working lifetime and considerable latitude could be allowed for short, infrequent exposures.

Toxicity of Pyrolysis Products.

Evidence indicates little or no production of the very toxic phosgene as would be the hazard of considerable concern with carbon tetrachloride. A study by Haun and co-workers (Amer. Ind. Hyg. Assoc. J. 30, pp. 551-558, 1969) looked at the toxicity of the pyrolysis products of Halon 1301 and found an LC50 value in rats of 2300 ppm. They attributed this toxicity to the HF formed. The pyrolysis products of this compound were much less toxic than those of bromochloromethane whose pyrolysis products gave an LC50 of 465 ppm, again demonstrating less toxicity for Halon 1301 compared to other halogenated methanes.

Because of the nature of the very highly controlled conditions of the experiments where pyrolysis tends to be maximized, it is difficult to make comparisons to conditions of use. The products of concern are hydrogen chloride, hydrogen bromide and hydrogen fluoride. At low concentrations, these chemicals cause irritation of the eyes and respiratory system and at high concentrations can cause decreases in pulmonary function and damage the lungs (Documentation of Threshold Limit Values, 4th Ed., ACGIH, 1980). Thus, TLVs have been established for HBr, HCl and HF as 3 ppm, 5 ppm and 3 ppm, respectively. These concentrations are readily detectible because of their irritant effects. The documentation notes that the irritating nature of higher concentrations can be tolerated if need be if not prolonged. Furthermore, Kane *et al.* (Amer. Ind. Hyg. Assoc. J. 40, pp. 207-229, 1979) suggested from their studies on hydrogen chloride in mice that 30 ppm was uncomfortable but tolerable in man and that minimal or no effect would be seen at 3 ppm. This was supported by their review of the literature in which they reported that at 10 to 50 ppm HCl, work was difficult but possible and that at 10 ppm, work was undisturbed although irritation was evident.

Sayers reported in 1973 (77th NFPA Annual Meeting) that a three pound unit of Halon 1211 in putting out a fire generated in a 2,500 cubic foot room generated only 2 ppm hydrogen chloride and hydrogen bromide and 0.5 ppm hydrogen fluoride. As noted in the review published in Informations Chimie Special Export (pp. 35-46, 1977), higher concentrations have been measured for Halon 1301 but under appropriate conditions of use, the levels would be expected to be in range of three to five ppm. Thus while irritating, they would not be expected to be especially harmful in terms of deficits in lung function or lasting damage.

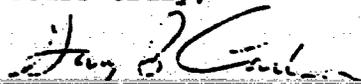
November 9, 1982

SUMMARY

To place the assessment of the toxicity of Halon 1301 and Halon 1211 in the proper perspective, their hazards compared to other fire-fighting agents must take into account the conditions of use. The following conclusions can be drawn:

1. The danger of lethal effects resulting from oxygen deprivation are very small. At 5 percent, the normal oxygen level would only decrease from 21 percent to 20 percent whereas for carbon dioxide at the recommended level of 40 percent, the oxygen concentration would drop to only 1.5 percent.
2. Under conditions of use, for example 5 to 7 percent Halon 1301 and somewhat lower concentrations of Halon 1211, human experience would indicate that there is no interference with normal mental functioning to any significant degree.
3. Although these agents are capable of eliciting cardiac arrhythmias at high concentrations, both animal and human experimental data have shown that such abnormalities would not be expected at the levels of intended use. This is even true for an individual who had suffered a previous myocardial infarction.
4. The pyrolysis products, HBr, HCl, and HF are highly irritating. While high concentrations are certainly capable of causing injury to the lungs, the levels generated in a real fire situation would not be expected to cause serious harm. Furthermore, it is quite likely that their irritating nature would serve as a warning against premature re-entry following termination of a fire.

Yours truly,



Gary P. Carlson, Ph.D.
Professor of Toxicology
Purdue University

GPC:rh

PROFESSIONAL RESUME1961-1965:

At this time Dr. Carlson attended St. Bonaventure University in Olean, New York, where he majored in chemistry and minored in biology. Emphasis was also placed on mathematics and liberal arts. In 1965 he graduated magna cum laude and received the American Institute of Chemists' award as the outstanding chemistry student.

1965-1969:

In 1965, Dr. Carlson began graduate studies at the University of Chicago as a University fellow. From 1966 to 1969 he worked in the University of Chicago Toxicity Laboratory under the direction of Dr. Kenneth P. DuBois. His work on the toxicology of pesticides led to the thesis "Studies on the Toxicity and Mechanism of Action of Moresstan" and to his receiving the Ph.D. in 1969. He also conducted basic studies on the drug metabolism pathways involved in nitro-reduction.

1969-1975:

In 1969, Dr. Carlson became an assistant professor in the Department of Pharmacology and Toxicology at the University of Rhode Island. He was promoted to associate professor in 1974. During this time period he was engaged in several areas of research in both pharmacology and toxicology, including:

- the identification of the pharmacological activity of materials of marine origin
- studies on the mechanism of the biologically active marine compounds
- drug metabolism in invertebrates
- the relationship between the metabolism of carbon tetrachloride and other halogenated solvents and their hepatotoxicity
- the influence of halogenated benzenes on xenobiotic metabolism
- the inhibition of ATPase by polychlorinated biphenyls

1975-1980:

In 1975 Dr. Carlson accepted a position as Associate Professor of Toxicology in the Department of Pharmacology and Toxicology in the School of Pharmacy and Pharmacal Sciences at Purdue University. His research interests in the actions of halogenated compounds, both aromatic and aliphatic, has been both extended and expanded to include:

- structure-activity relationships in regard to halogenated benzene induction of xenobiotic metabolism
- the influence of alterations in drug metabolism on the sensitization of the heart to arrhythmias by chlorinated hydrocarbons
- porphyrin effects of halogenated benzenes

Dr. Carlson's research in these areas has been supported by a variety of agencies, including the Environmental Protection Agency, National Institute of Environmental Health Sciences, National Institute of General Medical Sciences, Sea Grant, and Water Resources.

More recent work has focused on the area of chemical carcinogenesis particularly the relationship of distribution, metabolism and binding of inducers to tumor locations. Other studies are examining the influence of altered workshifts on the kinetics of solvents using an animal model and the effect of carbon monoxide exposure on anaerobic metabolism.

Dr. Carlson was promoted to the rank of Professor. He was appointed to the National Academy of Sciences-National Research Council Toxicology Information Program Committee and is currently chairman. He is also a member of the Safe Drinking Water Committee and the Board on Toxicology and Environmental Health Hazards (ex officio). He has been appointed to the U.S. Environmental Protection Agency Health Effects Review Panel for grants. He is also a member of the Toxicology Study Section of the National Institutes of Health.

In addition to his research efforts, Dr. Carlson teaches pharmacology and toxicology to pharmacy, nursing, health science and medical students and has been especially active in graduate education in the areas of drug metabolism and toxicology. A number of students have received their M.S. and Ph.D. degrees under his direction. He has published more than 80 abstracts and papers in the scientific literature.

Dr. Carlson has also been concerned with department, college and university committees, including the following:

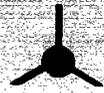
Use of Human Research Subjects
Curriculum
Awards

At the University of Rhode Island, he served on the executive and membership committees of Sigma Xi and was advisor to the Student American Pharmaceutical Association as well as an American Chemical Society Student Affiliate speaker. He was director of URI's Poison Control Center and was a member of the Rhode Island Task Force on Cancer Prevention.

Currently, Dr. Carlson is co-director of the NIEHS Training Grant in Environmental Toxicology. He is also serving a three year term on the Purdue University Graduate Council.

Chemical Fire Extinguishing Agent

GLCC HALON 1301



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Introduction

GLCC HALON 1301 Fire Extinguishing Agent—monobromotrifluoromethane, CBrF_3 —provides unusual advantages against Class A (cellulosic materials), Class B (flammable liquid), and Class C (electrical) fires.

By weight, HALON 1301 is the most effective gaseous extinguishing agent available. It is approximately equivalent to sodium-base dry powder, somewhat less effective than potassium-base powder, but up to three times more effective than carbon dioxide and most other halogenated agents.

GLCC HALON 1301 can function with hand extinguishers, local application systems, and total flooding systems (extinguishing systems which mix all of the air in the given enclosure with the extinguishant). While each method is effective and offers certain advantages for a given situation, total flooding systems using 1301 are especially attractive because of their compact storage volumes, low vision blockage, lack of particulate residue, rapid mixing with air, ready penetration of blocked or baffled spaces, and the low toxicity of the affected atmosphere.

The combination of HALON 1301's effectiveness and low toxicity became apparent in 1948, and it has served as a fire extinguishing agent from that time forth. Medical data and a considerable body of experience show that HALON 1301 may be used safely in a wide variety of fire extinguishing situations when recommended application procedures are followed. These situations include the protection of computers and data processing equipment; electrical and electronic equipment; file rooms; libraries, museums and historic buildings; chemical and physical laboratories; hoods and glove boxes; aircraft engines, cargo compartments and passenger cabins; military vehicles such as tanks, trucks, and personnel carriers; conventional and nuclear power plants; radioactive "caves" and hot cells; marine engines and engine rooms; racing cars and boats; and flammable liquids and vapors.

This manual describes the properties of GLCC HALON 1301 in more detail.

The Effectiveness of GLCC HALON 1301

Portable Extinguishers

Used in portable extinguishers, GLCC HALON 1301 extinguishes Class B (flammable liquid) and Class C (electrical) fires very effectively. The U.S. military uses large numbers of portable extinguishers containing 2.75 lb. of HALON 1301. Just such an extinguisher protects the NASA Space Shuttle. Regulatory agencies rate extinguishers on the size of fire that could be extinguished by a non-professional user. Factors affecting this rating are the speed of agent discharge and the shape of the discharge horn. The shape of the discharge horn must provide for a discharge pattern which not only allows the agent to reach the far side of the fire pan but also sufficiently covers the entire area without splashing fuel from the pan.

Total Flooding Systems

GLCC HALON 1301 functions especially well in total flooding systems. The concentrations of HALON 1301 required to extinguish most kinds of fires involve little risk of harm to people who are exposed for limited times. In addition, atmospheric chilling and obscuring of vision are minimal in most applications. The high dielectric strength of HALON 1301 and its lack of particulate residue make it an especially attractive extinguishing agent around electrical and electronic equipment. Where over pressurization of an enclosure could present a problem, the low volume of discharge is attractive. Also, the cost of a GLCC HALON 1301 based total flooding system may be lower than those based on other agents.

A total flooding system releases a predetermined amount of an extinguishing agent into an enclosure and so develops a uniform extinguishing concentration throughout. The size of the enclosure and the concentration needed in the particular case determine that amount. The concentration required depends on the specific fuels (by definition: all combustible materials) involved. A 5% concentration of GLCC HALON 1301 extinguishes flaming combustion of most fuels, but definition of appropriate concentrations for given fuels requires testing. As a rule of thumb, discharging one pound of GLCC HALON 1301 for each 50 cubic feet of enclosed volume will produce a 5% concentration. This concentration is sufficient for most fuels with a substantial safety factor; thus it is considered a reasonable design concentration for general applications.

A variation of the total flooding concept, which is growing in commercial usage, involves storing the GLCC HALON 1301 in a cylinder with its own fuseable head which releases the agent when sufficient heat is present. This approach is especially useful in marine engine room applications and similar service.

NFPA Standard 12A "Halogenated Fire Extinguishing Agent Systems—HALON 1301," provides many design principles and procedures for HALON 1301 systems.

Flammable Liquids and Gases—Class B

Fires fueled by most flammable liquids die quickly upon the flooding of the surrounding atmosphere with fairly low concentration of GLCC HALON 1301. There are two levels of 1301 concentrations to consider—one adequate for extinguishing flames, the other for inerting flammable mixtures of the fuel and air. Flame extinguishing concentrations apply to diffusion flames and should not be used when an explosive mixture of fuel and air can occur. When the situation exceeds flame extinguishing limitations, or when an explosive atmosphere might develop before or after ignition, inerting concentrations should be used. Inerting concentrations prevent the ignition of any concentration of fuel vapor. See Table I for GLCC HALON 1301 design concentrations appropriate for flame extinguishing and inerting with several fuels.

Combustible Materials—Class A

Fires involving ordinary combustible materials (including wood, cloth, paper, rubber, plastics) usually involve both flaming combustion of gases vaporized from the solid and surface combustion. A 3% concentration of GLCC HALON 1301 readily extinguishes flaming combustion of most Class A fuels.

The "soaking" (prolonged contact) in the HALON 1301-air mixture that follows flame extinguishing will extinguish surface combustion of many fuels, including most plastics. Stopping the radiant heat feedback from the flame to the solid effectively smothers surface combustion and may prevent the fire from becoming deep-seated. An automated system which picks up early decomposition through ionization detection will provide early warning of the presence of deep-seated fires and prevent further flame spread.

With some solid fuels, smoldering combustion may continue even after extended soaking. NFPA-12A defines deep-seated fires as ones where smoldering continues after 10 minutes soaking with 5% HALON 1301. Deep-seated combustion relates to the preservation of heat from smoldering combustion which becomes well insulated from heat loss and depends not only on the specific fuel but also on its geometric configuration and burning time before GLCC HALON 1301 application. Thus, an extinguishing system which incorporates an early detection function offers obvious and important advantages.

Wherever the potential for deep-seated combustion exists, the extinguishing system must include provision for two related effects: decomposition of the agent and rekindling of the fire after dissipation of the agent. Limiting the quantity of fuels with deep-seated potential in an enclosed area provides the best control of decomposition. Appropriate manual or automatic extinguishing effectively controls rekindling hazards.

Live Electrical Equipment—Class C

GLCC HALON 1301 effectively extinguishes several types of electrical equipment fires—especially those involving computer and data processing equipment. Tests show that a 5% concentration of HALON 1301 extinguishes fires of fuels common to computer rooms without detrimental side effects on the computing equipment.

Limitations

HALON 1301 is not effective in preventing combustion or reaction of chemicals capable of oxidation without air (e.g., cellulose nitrate or gunpowder); reactive metals (e.g., sodium, potassium, magnesium, titanium); metal hydrides; and chemicals capable of autothermal decomposition (e.g., organic peroxides or hydrazine).

Table I

**GLCC HALON 1301 DESIGN CONCENTRATIONS REQUIRED FOR FLAME
EXTINGUISHMENT AND INERTING FOR VARIOUS FUELS IN AIR AT 1 ATM., 25° C**

**GLCC HALON 1301 Concentrations
per cent by volume**

Fuel	For Flame* Extinguishment	For** Inerting
Acetone	5.0	7.6
Benzene	5.0	5.0
Ethanol	5.0	11.1
Ethylene	8.2	13.2
Methane	5.0	7.7
n-Heptane	5.0	6.9
Propane	5.2	6.7

*Includes safety factor over average experimental extinguishing concentration and further increase to a minimum of 5% for design considerations.

**Includes 10% safety factor on experimental determination, 5% minimum.
Source: NFPA-12A

0 0 1 3

The Theory of Fire Extinguishing with GLCC HALON 1301

Traditionally, fire extinguishing theory attributes the effectiveness of fire extinguishing agents to one of three physical effects: cooling, as with water; excluding oxygen or smothering, as with CO₂; or mechanically separating fuel from oxidizer, as with foam. But none of these satisfactorily explains the action of GLCC HALON 1301.

Rather, GLCC HALON 1301 extinguishes through a chemical action. Researchers believe that HALON 1301 reacts with the transient combustion products which rapidly propagate violently flaming combustion. The reaction interrupts the combustion chain reaction thus stopping flame propagation. Two theories explain the extinguishing process—one involves a free radical process; the other, an ionic activation of oxygen during combustion.

According to the free radical theory, thermal decomposition of HALON 1301 forms a bromine radical:



The reaction of the bromine radical with hydrogen in the fuel produces hydrogen bromide:



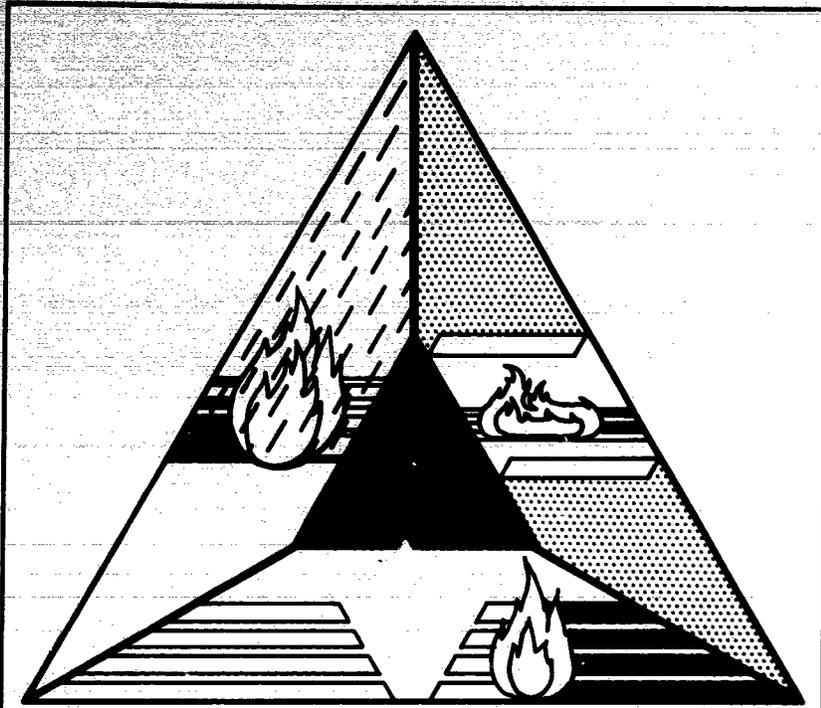
Then the hydrogen bromide reacts with active hydroxyl radicals:



The bromine radical is again free to react with more fuel, so the process repeats and removes more active radicals from the fire.

According to the ionic theory, elemental oxygen must absorb free electrons to activate itself before it can react with a fuel. The bromine atom on HALON 1301 presents a much larger target for the capture of electrons than the oxygen; thus its presence reduces the likelihood of oxygen activation.

In either theory, relatively small quantities of the extinguishing agent break the chain reaction of the fire.



This diagram is an artistic representation of the fire triangle. The three subparts show traditional approaches to fire extinguishing. The symbol breaking up the parts of the lower triangle depicts Halon 1301, which introduces a new dimension in fire extinguishing.



IV



The Physical Properties of GLCC HALON 1301

GLCC HALON 1301 is a low-boiling, colorless gas having high density and low viscosity and is stored as a liquified compressed gas. Table II summarizes its general physical properties.

The basis for the vapor pressure, liquid and vapor densities, liquid viscosity, and liquid heat capacity values is direct measurement. Estimates from generalized relationships determine the vapor viscosity and liquid thermal conductivity values. Tables III and IV provide more detailed values of those properties of most interest in fire extinguishing applications.

Table II
PHYSICAL PROPERTIES OF GLCC HALON 1301

		GLCC HALON 1301	
Chemical Formula,		CBrF ₃	
Molecular weight,		148.9	
Boiling point at atmospheric pressure,	°F	-71.95	
	°C	-57.75	
Freezing point,	°F	-270.0	
	°C	-168.0	
Critical temperature,	°F	152.6	
	°C	67.0	
Critical pressure,	psia	575.0	
	atm	39.6	
Critical density,	lbs/cu ft	46.5	
	kg/m ³	745.0	
Density at 70°F, liquid,	lbs/gal	13.1	
	lbs/cu ft	98.0	
	grams/cc	1.57	
	vapor sat'd,	lbs/cu ft	7.49
		grams/cc	0.12
Heat of vaporization, @ boiling point,	btu/lb	51.08	
	kJ/kg	118.8	
Surface tension of liquid,	dynes/cm		
	@ 77°F	4.0	
	@ 40°F	6.5	
	@ 0°F	9.7	

Table III
HEAT CAPACITY AND THERMAL CONDUCTIVITY OF LIQUID GLCC HALON 1301

Temp., °F	Heat Capacity Btu/lb-°F	Estimated Thermal Conductivity Btu-ft/hr-°F-ft ²
-40	0.166	0.041
-20	0.170	0.038
0	0.176	0.035
20	0.182	0.032
40	0.189	0.029
60	0.198	0.026
80	0.211	0.023
100	0.228	0.020
120	0.257	0.017
140	0.350	0.013

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Table IV
VAPOR PRESSURE, DENSITY, AND VISCOSITY OF GLCC HALON 1301

Temp., °F	Vapor Pressure		Density, lb/cu. ft.			Viscosity, Centipoise	
	psig	Liquid	Sat'd Vapor	Vapor @ 1 atm	Liquid	Vapor @ 1 atm	
-50	10.7	121.0	0.906	0.513	0.332	0.0122	
-45	13.8	120.2	1.010	0.506	0.321	0.0124	
-40	17.2	119.4	1.122	0.500	0.310	0.0125	
-35	20.9	118.5	1.244	0.493	0.300	0.0127	
-30	24.9	117.7	1.376	0.487	0.290	0.0128	
-25	29.2	116.9	1.519	0.481	0.281	0.0130	
-20	33.9	116.0	1.672	0.475	0.272	0.0131	
-15	38.9	115.2	1.838	0.470	0.263	0.0133	
-10	44.4	114.3	2.016	0.464	0.255	0.0134	
-5	50.2	113.4	2.208	0.459	0.247	0.0135	
0	56.5	112.5	2.414	0.453	0.240	0.0137	
5	63.2	111.6	2.635	0.448	0.233	0.0138	
10	70.3	110.6	2.872	0.443	0.226	0.0140	
15	77.9	109.7	3.125	0.438	0.220	0.0141	
20	86.1	108.7	3.397	0.433	0.213	0.0142	
25	94.7	107.7	3.688	0.429	0.207	0.0144	
30	103.9	106.7	4.000	0.424	0.202	0.0145	
35	113.6	105.7	4.334	0.420	0.196	0.0147	
40	123.9	104.7	4.691	0.415	0.191	0.0148	
45	134.8	103.6	5.073	0.411	0.186	0.0150	
50	146.3	102.5	5.482	0.407	0.181	0.0151	
55	158.5	101.4	5.921	0.403	0.176	0.0152	
60	171.3	100.2	6.391	0.399	0.171	0.0153	
65	184.8	99.0	6.896	0.394	0.167	0.0155	
70	199.0	97.8	7.439	0.391	0.163	0.0156	
75	214.0	96.5	8.022	0.387	0.159	0.0157	
80	229.7	95.2	8.651	0.383	0.155	0.0158	
85	246.1	93.9	9.331	0.379	0.151	0.0160	
90	263.4	92.5	10.07	0.376	0.148	0.0161	
95	281.6	91.0	10.86	0.372	0.144	0.0162	
100	300.6	89.4	11.73	0.369	0.141	0.0164	
105	320.4	87.8	12.68	0.365	0.137	0.0165	
110	341.2	86.1	13.73	0.362	0.134	0.0166	
115	363.0	84.2	14.89	0.359	0.131	0.0167	
120	385.7	82.2	16.18	0.356	0.128	0.0169	
125	409.4	80.0	17.64	0.353	0.125	0.0170	
130	434.2	77.6	19.31	0.349	0.123	0.0171	
135	460.1	74.9	21.26	0.346	0.120	0.0172	
140	487.1	71.6	23.61	0.343	0.117	0.0174	
145	515.2	67.4	26.60	0.341	0.115	0.0175	
150	544.5	60.7	30.89	0.338	0.112	0.0176	
152.6 (critical)	560.2	46.5	46.5				

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Liquid GLCC HALON 1301 is miscible in many organic solvents though its solubility is greatest in compounds of like chemical structure and least with those whose structure and properties differ from it. Table V shows the solubility of HALON 1301 vapor in various solvents. Of course, both temperature and pressure influence solubility.

The same holds for the solubility of GLCC HALON 1301 in water, carbon dioxide, and nitrogen, which follow well-known parameters. For example, the solubility of HALON 1301 in water at 77°F and a pressure of 100 psia is 0.0017 gram of HALON 1301 for each cu of water. At 70°F the solubility of water in liquid HALON 1301 is 95 ppm. Similarly, Raoult's Law calculates the solubility of carbon dioxide in liquid GLCC HALON 1301 to be about 30±5 mole percent at room temperature and 300 psig pressure. Although the solubility of nitrogen is low in liquid HALON 1301, its solubility characteristics will markedly affect total container pressure when nitrogen is used as a pressurizing gas for HALON 1301. As with most gases, its solubility in liquid HALON 1301 increases with increasing pressure; but its solubility decreases with increasing temperatures up to 40°F and then increases as the critical temperature of 152°F is approached. This interaction of pressure and temperature of the solubility of nitrogen can be calculated using the Henry's Law Constant.

Table V
SOLUBILITY OF VAPORIZED GLCC HALON 1301 IN VARIOUS LIQUIDS AT ATMOSPHERIC PRESSURE AND 77°F

Solvent	GLCC HALON 1301 in Solution, Per Cent by Weight
n-Heptane	6.3
Acetone	4.8
Toluene	4.1
Methanol	3.7
White Oil (Avg. M. W. 225)	3.1
Water	0.03

REQUIREMENTS FOR HALON 1301 (BROMOTRIFLUOROMETHANE)
SPECIFICATION MIL-M-122138

Property	Requirement
Bromotrifluoromethane, mole percent minimum	99.6
Chlorotrifluoromethane, trifluoromethane, difluorodichloromethane, chlorodifluoromethane, tetrafluoromethane, mole percent maximum	0.385
Bromodifluoromethane, mole percent maximum	0.005
Dibromodifluoromethane, mole percent maximum	0.005
Fixed gases in vapor phase, percent by volume maximum	1.5
Moisture in liquid phase, percent by weight maximum	0.001
High boiling residue, percent by volume	0.05
HF, HBr, halonics and other acids, mole percent maximum	None
Suspended matter, maximum	None

The Toxicity of GLCC HALON 1301

GLCC HALON 1301 has a low inhalation toxicity. Its high degree of effectiveness as an extinguishant coupled with its excellent thermal stability makes properly applied HALON 1301 the safest gaseous extinguishing agent available. However, GLCC HALON 1301, like all chemicals, cannot be considered non-toxic in every circumstance. Four factors affect its overall toxicity: equipment design, the toxicity of natural (undecomposed) HALON 1301, the toxicity of the decomposition products of HALON 1301, and the toxicity of common fire combustion products.

Equipment Design

The safety of any fire extinguishing system depends, first, on the nature of the equipment used. In general, the agent is safer if it can be applied at an early stage of combustion when the fire is usually smaller, not yet deep-seated, and has not created large quantities of toxic combustion products.

In part, size and weight determine the promptness with which hand portable extinguishers can be applied. The weight advantage of GLCC HALON 1301 extinguishers can save precious seconds in beginning to attack a fire.

In automatic systems, the detectors determine the stage at which the attack on the fire begins. The ionization detection alarm which can be used with a GLCC HALON 1301 system provides the optimum in rapid sensing thus enabling agent discharge at an early combustion stage. The agent discharge should be as rapid as possible. Besides extinguishing the fire more quickly, thus reducing fire damage and the quantity of toxic combustion products, rapid discharge will lower the extent of agent decomposition. Typical discharge times of systems using GLCC HALON 1301 range from less than one second for flammable gases or highly volatile liquids up to 30 seconds for slower burning fuels.

A qualified fire protection engineer should coordinate selection of proper detectors and agent discharge rate after a thorough study of the individual situation.

Natural (undecomposed) GLCC HALON 1301

Not only practical experience but also more than 20 years of medical research involving both test animals and humans attest to the safety of HALON 1301. Given that experience, the National Fire Protection Association has formulated these guidelines for the use of HALON 1301 in occupied areas: if the concentration by volume is 7% or lower, human exposure should be under 5 minutes; if the concentration is 7-10%, human exposure should not exceed one minute. Related research at the Underwriter's Laboratories, based on animal exposures, classifies HALON 1301 in Group 6, the least toxic classification in those studies. Table VI explains the UL rating system. Of all the gaseous extinguishing agents which UL tested, only HALON 1301 qualifies for Group 6. Also, the U.S. Army Chemical Center has produced data which correlate closely with the UL classifications. According to the Army study, the approximate lethal concentration, ALC (this term, commonly used to describe a compound's toxicity, refers to the lowest concentration which is lethal to one or more of a group of test animals exposed for a given time), for HALON 1301 in 15 minute exposures to rats is 834,000 ppm (83.4%) by volume. Table VII compares that ALC value with those of several other gaseous extinguishing agents.

Since GLCC HALON 1301 quickly extinguishes fires involving most combustible materials, at concentrations of 7% or less, its vapor presents little or no danger to people. Furthermore, according to medical tests, people may inhale these concentrations for up to 5 minutes without risk of cardiac or harmful central nervous system effects.

Studies of HALON 1301 with regard to cardiac sensitization suggest that exposure according to the above guidelines does not increase the risk of cardiac arrhythmia. However, high 1301 concentrations, if combined with high adrenaline levels, may affect human cardiac rhythm. Given related test results, exposures to concentrations greater than 10% may pose a risk to some people and should be avoided in normally occupied areas. Thus, adrenaline should not be used to treat HALON 1301 overexposure.

Decomposition Products of GLCC HALON 1301

GLCC HALON 1301, upon exposure to flames or surfaces hotter than 950° F, decomposes to form, primarily, hydrogen bromide (HBr) and hydrogen fluoride (HF). Trace quantities of bromine (Br₂), carbonyl halides (carbonyl fluoride, COF₂, and carbonyl bromide, COBr₂) may occur, but in quantities too small to be of concern. With most automatic extinguishing systems using GLCC HALON 1301, the concentrations of HF and HBr remain below 20 ppm and are usually barely detectable to the nose.

The primary effect of the decomposition products of HALON 1301 is irritation. They emit a sharp, acrid odor which, even in low concentrations, provides a built-in warning system—unlike such odorless agents as CO₂. In fact, the irritation becomes severe well before there are really hazardous levels. After exposure to nonlethal levels of decomposed HALON 1301, test animals seem to recover completely, and the effects of exposure appear noncumulative.

Obviously, the amount of HALON 1301 which decomposes in a given fire depends on the kind of fuel, the size of the fire, the nature of the enclosure, and the speed of discharge. Table VIII presents some representative test results. Again, the importance of early detection and rapid agent delivery, which lead to rapid extinguishing of the fire, cannot be overemphasized. That, more than anything else, produces a safe post-fire atmosphere.



Common Fire Combustion Products
 The study of fire toxicology raises the question whether the toxicity arising from the decomposition of the extinguishing agent presents a greater hazard than the toxicity due to the fire combustion products. How dangerous the fire combustion products are depends on the location, the kind of fuel, the availability of air, and the length of time people are exposed to the fire. Most fires form carbon monoxide, an odorless and colorless gas fatal to humans in concentrations above 1.5% (15,000 ppm). It is present in every fire, though the largest quantities occur in cases of incomplete combustion. In general, the decomposition products of the fire itself—smoke, heat, oxygen depletion, and especially carbon monoxide—pose greater danger than do the decomposition products of GLCC HALON 1301.

This discussion, however, should not be taken to minimize the potential hazards of the decomposition products of HALON 1301. Rather, it intends to demonstrate the importance of choosing a fire extinguishing agent with the lowest possible toxicity relative to its ease of handling and its effectiveness and reliability.

Table Vi
UNDERWRITERS' LABORATORIES' CLASSIFICATION OF COMPARATIVE LIFE HAZARD OF FIRE EXTINGUISHING AGENTS

Group	Definition	Examples
6 (least toxic)	Gases or vapors which in concentrations up to at least 20 per cent by volume for durations of exposure of the order of 2 hours do not appear to produce injury.	Halon 1301
5	Gases or vapors much less toxic than Group 4 but more toxic than Group 6.	Dibromotetrafluoroethane (Halon 2402) Bromochlorodifluoromethane (Halon 1211) Carbon dioxide
4	Gases or vapors which in concentrations of the order of 2 to 2½ per cent for durations of exposure of the order of 2 hours are lethal or produce serious injury.	Dibromodifluoromethane (Halon 1202) Methyl Chloride (Halon 101)
3	Gases or vapors which in concentrations of the order of 2 to 2½ per cent for durations of exposure of the order of 1 hour are lethal or produce serious injury.	Bromochloromethane (Halon 1011) Carbon tetrachloride (Halon 114)
2	Gases or vapors which in concentrations of the order of ½ to 1 per cent for durations of exposure of the order of ½ hour are lethal or produce serious injury.	Methyl bromide (Halon 1001)

Source: NFPA 12A

Table VII
U.S. ARMY CHEMICAL CENTER FINDINGS COMPARED TO UNDERWRITERS' LABORATORIES' CLASSIFICATIONS

Material	Formula	U.L. Class	U.S. Army Chemical Center Approximate Lethal Concentration-ppm by vol.*	
			Undecomposed	Decomposed
Halon 1301	CBrF ₃	6	834,000 ppm	14,000 ppm
Carbon Dioxide	CO ₂	5	657,000	—
Bromochloromethane	CH ₂ BrCl	3	65,200**	4,180
Carbon Tetrachloride	CCl ₄	3	28,600	320
Carbon Monoxide	CO	2	15,000	—
Methyl Bromide	CH ₃ Br	2	5,900	9,600

*Approximate Lethal Concentrations to rats for 15 minutes' exposure.

**Another report (Ind. Hyg. and Occupational Med. 7 157, Feb. 1953) indicates that a concentration of 29,000 ppm is lethal to rats after 15 minutes' exposure.

Table VIII
DEEP-SEATED TEST FIRE INDICATED ONLY MODERATE LEVELS OF DECOMPOSITION PRODUCTS USING TRASHBASKET-SIZE FIRE IN AVERAGE ROOM.

Sampling Time Min	Mean Concentration, ppr. vol.	
	HBr	HF
1	16	9
10	17	11
20	9	8
30	10	10

Conditions: 5 lbs. mixed paper (sheets, cards, and tape) in 18" x 30" open wire basket
 50% by weight preburn
 1729 cu. ft. enclosure volume
 5.1% Halon 1301 concentration
 2 second discharge time
 Sampling times are minutes after completion of discharge.

Other Safety Considerations

Pressure

GLCC HALON 1301 is under considerable pressure at normal temperatures, so all containers and transfer equipment must be strong enough to withstand the maximum service pressure expected and to meet Department of Transportation shipping regulations. Relief devices suitable to HALON 1301 fill density and temperature should be installed.

Effect on Skin and Eyes

Frostbite may result from contact with liquid HALON 1301. Protective clothing and eye protection help to prevent that; but should frostbite occur, the affected area should be warmed to body temperature and eyes should be flushed liberally and quickly with water. Prompt medical attention is important—as in all frostbite cases.

Oxygen Level Reduction

Like other chemical extinguishers, HALON 1301 causes some reduction in oxygen level. However, while using CO₂ at the normal 40% level reduces oxygen content from the normal 21% to 12.5% (a level too low to sustain life), GLCC HALON 1301 at the normal 5% level only reduces oxygen from 21% to 20%, which corresponds to the oxygen level found at moderate altitudes.

Projectile Hazard

The discharge pressure of Halon 1301 automatic systems is sufficiently high that the discharging agent can hurl loose objects, placed in close proximity to the discharge nozzles, with considerable force. It is important to take care not to keep any loose objects in the vicinity of the discharge nozzles.



The Effect of GLCC HALON 1301 on Construction Materials

Metals

Laboratory tests show that GLCC HALON 1301 does not adversely affect any metals commonly used in fire extinguishers or automatic total flooding systems because the presence of the fluorine atom in a molecule generally reduces its chemical reactivity and corrosiveness while increasing its stability.

The tests involved ten types of metal. HALON 1301 and test strips of the metals were sealed in glass tubes and stored at temperatures of 250°, 130°, and room temperature. Samples which contained 2 ppm moisture represented commercial material while samples which contained 72 ppm moisture represented a 75% saturation level in HALON 1301. Table IX summarizes those tests.

In examining results, researchers found that the samples of stainless steel, aluminum, commercial titanium, and titanium A110 AT had not undergone changes in appearance. The steel had rusted slightly under saturation, and the brass and magnesium samples showed spotty tarnish. Other tests show that copper is not affected by HALON 1301. Thus, all of these metals are acceptable in systems using GLCC HALON 1301.

Stability Tests at High Temperatures

Tests with three kinds of steel at temperatures of 600° determined the stability, and effect on metals, of HALON 1301 in the kind of high temperature situation that aircraft engine protection systems must handle. Inconel is safest for use with HALON 1301 both with regard to decomposition of the agent and corrosion of the metal. Stainless steel 316 and mild steel follow.

Most halocarbons tend to react violently with such highly reactive materials as the alkali and alkaline earth metals, sodium, potassium and barium in their free metallic state—especially when those materials are finely ground or powdered, in which case even magnesium and aluminum may react with fluorocarbons especially at higher temperatures. It seems best to avoid contact between such highly reactive materials and fluorocarbons until there has been careful study and definition of appropriate safety precautions.

Table IX

CORROSION OF COMMON METALS NEGLIGIBLE IN HALON 1301
(Exposure at 2 Moisture Levels for 44 Months)

	Moisture Content (PPM)	Penetration Rate (in/mo × 10 ³) 44 Months	Metal Appearance After Test
Aluminum 1100	2 72	0.09 ±0.06 0.1 ±0.06	Unchanged Unchanged
Aluminum 2024	2 72	2.2 ±0.06 1.5 ±0.06	Unchanged Unchanged
Aluminum 6061	2 72	2.3 ±0.07 0.3 ±0.07	Unchanged Unchanged
Yellow Brass	2 72	0.01 ±0.02 -0.02* ±0.02	Entire strip is very slightly tarnished A moderate number of spotty-black stains
Magnesium AZ-91C	2 72	4.1 ±0.09 3.4 ±0.09	Very slight spotty tarnish in the vapor phase Very slight spotty tarnish in the vapor phase
1020CR Steel	2 72	-0.05* ±0.02 0.01 ±0.02	Unchanged Rust observed in vapor phase
Type 302 S/S	2 72	1.1 ±0.02 -0.01* ±0.02	Unchanged Unchanged
Type 321 S/S	2 72	0.8 ±0.02 2. ±0.1	Unchanged Unchanged (1 yr. test)
Commercial Titanium	2 72	-0.6* ±0.2 0.1 ±0.05	Unchanged (1 yr. test) Unchanged
Titanium A110 AT	2 72	1.4 ±0.04 2.0 ±0.04	Unchanged Unchanged

*Negative penetration rate indicates a weight gain of test strip.

Elastomers and Plastics

Because GLCC HALON 1301 is inert toward most elastomers and plastics, suitable material for gasketing, insulation, and tubing abounds. Tests in which a sample of the material and the agent were sealed in a tube over time, and then the material measured for linear expansion, reveal that most of the elastomers except silicone rubber and most of the plastics except ethyl cellulose and perhaps cellulose acetate/butyrate are suitable for use with GLCC HALON 1301. See Table X for a complete list of materials tested and results.

Table X

EFFECT OF HALON 1301 ON PLASTIC MATERIALS AT ROOM TEMPERATURE

Rating

The following rating system is based on linear swell, change in weight and physical changes in the plastic test piece.

- A—Unchanged and suitable for use
- B—Slightly changed but probably suitable
- C—Moderately changed and probably not suitable
- D—Severely changed and not suitable

Plastic	Rating	Linear Swell, %
"Delrin" acetal resin	A	0
"Mylar" polyester film, Type A	A	0.3
Nylon	A	-0.3
Polychlorotrifluoroethylene	A	1.4
Polystyrene	A	0.9
Polyvinyl alcohol	A	-0.8
Polyvinyl chloride	A	0.3
Polyvinyl chloride/acetate	A	0.8
"Saraloy" copolymer based on vinylidene chloride	A	0
"Saran" polyvinylidene chloride	A	2.0
"Alathon" polyethylene resin	B	3.0
Cellulose acetate	B	0.7 _a
"Lucite" acrylic resin	B	0.1
"Teflon" tetrafluoroethylene resin	B	2.0
Cellulose acetate/butyrate	C	4.0
Ethyl cellulose	D	17.0 _b
"Alathon" linear polyethylene	A	0.9

Condition of Test Sample

a—Crazed slightly after removal from the liquid. b—Softened and warped.

0022

The information contained in this manual is intended for use by technically trained personnel at their discretion and risk. The information is believed to be accurate, but since the use of this data is outside the control of Great Lakes Chemical Corporation, Great Lakes assumes no liability for results obtained, or damage caused from the use of this information.

The publication of this information in no way constitutes permission or encouragement for the use of HALON 1301 in violation of any patents.



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SECTION VI - SPECIAL PROTECTION INFORMATION (This section is to be completed only in the presence of gases or vapors: Hydrogen fluoride, hydrogen cyanide, hydrogen sulfide, hydrogen chloride, and hydrogen bromide)		
Hazardous concentrations	Yes <input type="checkbox"/> No <input checked="" type="checkbox"/>	Conditions to avoid
Other information	Yes <input type="checkbox"/> No <input checked="" type="checkbox"/>	

SECTION VII - SPILL OR LEAK PROCEDURES

(This section is to be completed only in the presence of gases or vapors)

Spill or leakage areas in case of inadvertent discharge of Halon 1301.

Other information:

SECTION VIII - SPECIAL PROTECTION INFORMATION

(This section is to be completed only in the presence of gases or vapors)

Concentrations greater than 10% are expected.

Special protection	Special equipment	SPECIAL
Other information	Indoor areas should be well ventilated	OTHER
Eye protection	EYE PROTECTION	

SECTION IX - SPECIAL PROTECTION INFORMATION

(This section is to be completed only in the presence of gases or vapors)

Other information:

0025

C. Extinguishing Characteristics

The extinguishing mechanism of the halogenated agents is not clearly understood. However, there is undoubtedly a chemical reaction which interferes with the combustion process. They act by removing the active chemical species involved in the flame chain reactions (a process known as "chain breaking"). While all the halogens are active in this way, bromine is much more effective than chlorine or fluorine.

A number of possible mechanisms by which bromine inhibits combustion have been proposed. The most active species in hydrocarbon combustion are oxygen and hydrogen atoms, and hydroxyl radicals (OH, H, and OH). Under fire conditions, the halogenated agent—for example, bromotrifluoromethane (Halon 1301)—will release a bromine atom:



The Br atom can react with a hydrocarbon molecule to form hydrogen bromide, HBr:



The HBr then reacts with an active hydrogen or hydroxyl radical, releasing the bromine atom for further inhibition reaction.



In this way, chain carriers are removed from the system while the inhibiting HBr is continuously regenerated.

Another "ionic" theory supposes that the uninhibited combustion process includes a step in which oxygen ions are formed by the capture of electrons which come from ionization of hydrocarbon molecules. Since bromine atoms have a much larger cross section for the capture of slow electrons than has oxygen, the bromine inhibits the reaction by removing the electrons that are needed for activation of the oxygen.*

The Extinguishing Effectiveness

The effectiveness of the different halons as extinguishing agents has been the subject of many studies. The initial results of some of the early studies are contained in the October 1954 issue of the NFPA Quarterly.¹ It is now recognized that comparison of effectiveness of agents depends on whether portable extinguishers or fixed systems are being considered and, particularly in tests on portable units, whether the agents were being used at optimum super-pressure with nitrogen. Therefore, the following information should be used only as a general guide because other considerations, such as range of the unit (which varies on the gas or liquid characteristic of the individual halon and the total weight and volume of the equipment), may be of equal importance, depending upon use.

Table 18-2C gives the approximate pounds of agent required for a unit of Class B rating obtained with small portable extinguishers listed with UL within the last ten years.

Table 18-2C. Relative Effectiveness of Halogenated Agents on Small UL Class B Fires

Agent	Halon No.	Weight of Unit	UL D:C	Pounds Per Unit B Rating
Bromobromomethane	1011	4*	2	2.0
Bromotrifluoromethane	1301	2.5	4†	0.8
Bromochlorodifluoromethane	1211	3.0	5	0.8
Carbon Dioxide	—	5	5	1.0

* One quart = 4 lbs.

† Originally rated 4 B:C by UL until this rating was dropped.

In total flooding systems, the effectiveness of the halogenated agents on flammable liquid and vapor fires is quite dramatic. Rapid and complete extinguishment is obtained with low concentrations of agent. On a worldwide basis the development of systems using Halon 1301 and Halon 1211 together with the development of realistic test methods, which have been applied to both these agents recognized by the NFPA, have shown that in total flooding application for flame extinguishment or inerting, Halon 1301 requires an average of 10 percent less material on a gas-volume basis than does Halon 1211 for any given fuel. Table 18-2D shows a comparison of flame extinguishment values included in NFPA 12A and 12B. It is generally recognized that on a weight-of-agent basis, both

Table 18-2D. Comparison of Flame Extinguishment Values for Bromotrifluoromethane (Halon 1301) and Bromochlorodifluoromethane (Halon 1211)

Fuel	Percent by Volume of Agent Required for Flame Extinguishment	
	Halon 1301	Halon 1211
Methane	5	5
Propane	5.2	5
n-Heptane	5	6
Ethylene	8.2	7
Benzene	5	5
Ethanol	5	6
Acetone	5	5

Note: At this writing, the above values have not been formally adopted by the NFPA Committee on Halogenated Fire Extinguishing Agent Systems for inclusion in NFPA Standards 12A and 12B, and therefore may be subject to change before appearing in future editions of the respective Standards.

agents are approximately 2½ times more effective than carbon dioxide.

The effectiveness of halogenated agents on Class A fires is less predictable. It depends to a large extent upon the specific burning material, its configuration, and how early in the combustion cycle the agent is applied. Most plastics behave as flammable liquids; they can be extinguished rapidly and completely with 4 to 6 percent concentrations of Halon 1211 or 1301. Other materials, particularly cellulosic products, can in certain forms develop deep-seated fires in addition to flaming combustion. The flaming portion of such fires can be extinguished with low 4 to 6 percent concentrations, but the glowing deep-seated portion may continue under some circumstances.² Even so, the deep-seated fire will be controlled, in that its rate of burning and consequent heat release will be reduced. Considerably higher concentrations (18 percent to 30 percent) are required to achieve complete extinguishment, and these levels are seldom economical to apply. However, the concept of controlling deep-seated fires with halogenated agents has been accepted in the respective NFPA Standards.

D. Toxic and Irritant Effects

The toxicology of Halon 1301 and Halon 1211 has been studied extensively in both animals and humans. As a result, comprehensive safety guidelines for these agents can be written.

Early animal studies by the U.S. Army Chemical Center, summarized in Table 18-2E, determined the approximate lethal concentration (ALC) for 15-minute exposures to Halon

Table 18-2E. Approximate Lethal Concentrations for 15-min Exposure to Vapors of Various Fire Extinguishing Agents*

Agent	Formula	Halon No.	Approximate Lethal Concentration in Parts Per Million	
			Natural Vapor	Decomposed Vapor
Bromotrifluoromethane	CF ₃ Br	1301	832,000	14,000†
Bromochlorodifluoromethane	CF ₂ ClBr	1211	324,000	7,650
Carbon Dioxide	CO ₂	—	658,000	658,000
Dibromodifluoromethane	CF ₂ Br ₂	1202	54,000	1,850
Bromochloromethane	CH ₂ ClBr	1011	65,000	4,000
Dibromotetrafluoroethane	C ₂ F ₄ Br ₂	2402	126,000	1,600‡
Carbon tetrachloride	CCl ₄	104	28,000	300
Methyl bromide	CH ₃ Br	1001	5,900	9,600

* Based on tests with white rats by the Medical Laboratories, U.S. Army Chemical Center.

† Subsequent tests by Kettering Laboratory of the University of Cincinnati (unpublished data) with a commercial Halon 1301 of improved quality indicated that the lethal concentration of decomposed vapor is at least 20,000 ppm. Other tests have given the ALC (Approx-

imate Lethal Concentration) value of Halon 1301 decomposition products as low as 2,500 ppm. The variance is based on differing analytical procedures.

‡ This figure does not agree with manufacturer's data on this product.

1301 and 1211 to be 83 percent and 32 percent by volume, respectively. The ALC for decomposed vapors of these agents is also shown.⁹

Animals exposed to concentrations below lethal levels exhibit two distinct types of toxic effects: (1) central nervous system changes, such as tremors, convulsions, lethargy, and unconsciousness at high air-borne concentrations (above 30 percent by volume for Halon 1301 and 10 percent for Halon 1211); and (2) cardiovascular effects including hypotension, decreased heart rate, and occasional cardiac arrhythmias (lack of rhythm in the heartbeat), from air-borne concentrations of approximately 10 percent for Halon 1301⁹ and 4 to 5 percent for Halon 1211.⁹ Effects are transitory and disappear rapidly after exposure.

Cardiovascular effects on animals include changes in blood pressure, heart rate, and production of spontaneous cardiac arrhythmias at concentrations above 14 percent Halon 1301¹⁰ and 4 to 5 percent Halon 1211. No significant adverse health effects have been reported from the use of Halon 1301 or 1211 as a fire extinguishant since their introduction into the marketplace 25 years ago.

Human exposures to both Halon 1301 and to Halon 1211 have shown that Halon 1301 concentrations up to about 7 percent by volume, and Halon 1211 concentrations of 2 to 3 percent by volume, have little noticeable effect on the subject. At Halon 1301 concentrations between 7 and 10 percent (Halon 1211 concentrations between 3 and 4 percent), subjects experienced dizziness and tingling of the extremities, indicating mild anesthesia. At Halon 1301 concentrations above 10 percent (Halon 1211 concentrations above 4 to 5 percent) the dizziness becomes pronounced, the subjects feel as if they will lose consciousness (although none have), and physical and mental dexterity is reduced.^{9,10,11,14,20} In human subjects exposed to 7 percent Halon 1301 for periods up to 30 min, the effects appeared within the first 5 to 10 min of exposure, remained constant throughout the remainder of the exposure, then disappeared quickly after exposures were stopped.¹¹

Recently, Halon 1301 has been tested for potential mutagenic and teratogenic effects, but no serious problems were found.

A mutagen is a chemical which causes changes in the DNA structure of a cell. A standardized test, called the Ames test or assay, performed on a special strain of salmonella bacteria, provides a preliminary indication that a chemical may be a mutagen and possibly a carcinogen in humans. A high propor-

tion of known carcinogens do exhibit mutagenic activity in the Ames assay. Halon 1301 concentrations up to 40 percent by volume did not exhibit mutagenic activity in this test.¹¹

A teratogen is a chemical which causes permanent structural or functional alteration of the normal processes of fetal development. Pregnant female rats were exposed (by inhalation) to 5 percent by volume Halon 1301. No evidence of teratogenic or embryotoxic (growth retardation or death of the fetus) effects was seen in their offspring.¹²

From the extensive medical data now available, the following guidelines have been produced (see Table 18-2F) for use of Halon 1301 and 1211 in total flooding fire extinguishing systems.

Table 18-2F. Permitted Exposure Times to Halon 1301 and Halon 1211

	Concentration Percent by Volume	Permitted Time of Exposure
Halon 1301	Up to 7	15 min
	7-10	1 min
	10-15	30 sec
	Above 15	Prevent exposure
Halon 1211	Up to 4	5 min
	4-5	1 min
	Above 5	Prevent exposure

NFPA 12A permits Halon 1301 design concentration up to 10 percent in normally occupied areas, and up to 15 percent in areas not normally occupied. Because the required extinguishing concentration of Halon 1211 is near or above its limit for safe exposures, Halon 1211 systems are not recognized in NFPA 12B for normally occupied areas.

E. Decomposition Products of Halons

Consideration of the life safety of halogenated agents must also include the effects of breakdown products, which have a relatively higher toxicity. Decomposition of halogenated agents takes place on exposure to flame, or to surface temperatures above approximately 900 °F. In the presence of available hydrogen (from water vapor or the combustion process itself) the main decomposition products of Halon 1301 are

the halogen bromide amounts early tests presence of Halon 121 and free of

The app to some of 18-2G. Co that have posures.¹⁶

Even in million, th have chara provides a same time who must as a warn tion (such :

It is nece countered and to relat the toxic ef

The conc expected de fire, preser before extir situation in and Halon an exampl tinguish 0.1 enclosure, results are s position pre and flame e to attack th release the

For a bromochlor portable un 2,500 cu ft tion in 1 sec 10 sec, are tion, the b allowed by (The exte

Table 18-2 for Proc

Complex

Hydrogen Flu
Hydrogen Bro
Hydrogen Chl
Hydrogen Br
Hydrogen Cl
Carbonyl Flu
Carbonyl Chl
Carbonyl Bro

Source: Materials.

the following acids: hydrogen fluoride (HF) and hydrogen bromide (HBr), and less bromine Br₂. Although small amounts of carbonous halides (COF₂, COBr₂) were reported in early tests, more recent studies have failed to confirm the presence of these compounds. The decomposition products of Halon 1211 are similar, but include hydrogen chloride (HCl) and free chlorine (Cl₂) as well.

The approximate lethal concentrations for 15-min exposures to some of these compounds are given in Column 1 of Table 18-2G. Column 2 gives the concentrations of these materials that have been quoted by Sax as "dangerous" for short exposures.¹

Even in minute concentrations of only a few parts per million, the decomposition products of the halogenated agents have characteristically sharp, acrid odors. This characteristic provides a built-in warning system for the agent, and at the same time creates a noxious, irritating atmosphere for those who must enter the hazard area following a fire. It also serves as a warning that other potentially toxic products of combustion (such as carbon monoxide) will be present.

It is necessary to establish the concentrations likely to be encountered when extinguishing fires with halogenated agents and to relate them not only to the absolute toxicity, but also to the toxic effects of the normal products of combustion.

The concentration of decomposition products which may be expected depend upon many factors (i.e., size of room, size of fire, presence of large quantities of hot surfaces, and time before extinguishment). Test results which may help to put the situation into perspective have been made for both Halon 1301 and Halon 1211 in total flooding and portable applications. As an example of total flooding, Halon 1301 was used to extinguish 0.1, 1.0 and 10 sq ft n-Heptane fires in a 1695 cu ft test enclosure, at agent discharge times of 15, 10, and 5 sec. The results are shown in Table 18-2H, relating the resulting decomposition products to the ratio of fuel area to enclosure volume and flame extinguishment time. "It is obviously advantageous to attack the fire at an early stage while it is still small, and to release the extinguishing agent as rapidly as practical.

For a similar example in portable extinguishers, bromochlorodifluoromethane (Halon 1211) was used in 3-lb portable units to extinguish a 2.5 sq ft n-Heptane fire in a 2,300 cu ft room. The results of two tests, one normal extinction in 1 sec, and the second deliberately extended extinction in 10 sec, are given in Table 18-2I. In the case of normal extinction, the levels of breakdown products are below the limits allowed by OSHA regulations for 8 hr continuous exposure.¹

The extensive studies on the toxicological effects of

Table 18-2H. Halon 1301 Decomposition Produced by n-Heptane Fires†
Enclosure volume: 1695 cu ft
Halon 1301 concentration: 4% by volume

Fuel Surface Area Per Unit Enclosure Volume, ft ² Per ft ³	Flame Extinction Time, Second	Total Decomposition Products* ppm
0.08	11.5-15.4	4.5-5.8
0.08	7.1-7.8	2.8-4.2
0.08	4.0-4.8	3.3-4.5
0.8	20-37	94-289
0.8	11.5-13.5	64-284
0.8	4.7-6.7	11.5-169
8.0	20-22	2252-2304
8.0	13.0-16.3	1292-1590
8.0	5.2-10.0	358-778

* Sum of HF, HBr and Br₂.

† Source: Reference 23.

Table 18-2I. Concentrations of Breakdown Products Obtained from Extinguishing 2.5 sq ft n-Heptane Fires with Halon 1211
Portable Extinguishers

Compounds	Concentration of Breakdown Products—ppm by Volume	
	Test I Normal Extinction In One Second	Test II Prolonged Extinction In Ten Seconds
HCl + HBr	2	50
HF	0.5	10
Cl ₂ + Br ₂	Not detected ¹	2.5
COCl ₂	Not detected ²	Not detected ²

¹ Limit of detection 0.1 ppm.

² Limit of detection 0.25 ppm.

halogenated agents indicate that little, if any, risk is attached to the use of Halon 1301 or Halon 1211 when used in accordance with provisions of NFPA Standards which recognize the use of these agents.

F. Application Systems

A system differs from a portable or mobile appliance primarily in that the agent discharge stream is not directed by a person. The discharge stream or pattern is usually determined in advance, as is either the quantity of agent or the discharge rate or both, and the number and types of nozzles provided. A system consists of a supply of agent, a means for releasing or propelling the agent from its container, and one or more discharge nozzles to apply the agent into the hazard or directly onto the burning object. A system may also contain other elements, such as one or more detectors, remote and local alarms, a piping network, mechanical and electrical interlocks to shut down ventilation, close fire doors, etc., directional control valves, installed reserve agent supplies, etc. The extent of the auxiliary functions of a system is usually dependent upon the nature of the hazard, in keeping with the desires and resources of the end-user.

A system is usually a fixed or stationary apparatus, but some portable or mobile systems have been designed. A portable or

Table 18-2G. Approximate Lethal Concentrations for Predominant Halon 1301 and Halon 1211 Decomposition Products

Compound	ALC for 15-min Exposure ppm by Volume in Air	Dangerous Concentrations ppm by Volume in Air ^a
Hydrogen Fluoride, HF	2800	50-360
Hydrogen Bromide, HBr	4760	—
Hydrogen Chloride, HCl	—	—
Bromine, Br ₂	580	—
Chlorine, Cl ₂	—	50
Carbonyl Fluoride, COF ₂	1800	—
Carbonyl Chloride, COCl ₂	100-150	—
Carbonyl Bromide, COBr ₂	—	—

^a Source: Sax, N. Irving; Dangerous Properties of Industrial Materials.

of measuring initial agent concentrations, distribution, and maintenance of concentration. Full-scale discharge tests have been described by Brennesman and Charney,²³ and outlined in a publication by Cardox, Div. of Chematron Corporation.²⁴

Maintenance of Halogenated Agent Systems

The NFPA Halon 1301 and Halon 1211 Standards specify certain items that must be checked at semiannual and annual intervals. Semiannually, the system should be given a visual inspection for evidence of corrosion or other damage, and the storage containers checked for loss of agent. This latter item involves a two-fold check. First, the pressure corrected for temperature should be measured to insure no loss of pressurizing gas. Second, each container must be weighed to determine loss of agent. Neither check alone is sufficient; both are required. In large systems, liquid level indicators are often provided to indicate the quantity of agent, rather than weighing. There is a liquid level indicator available for smaller containers to replace weighing, which is often cumbersome and time consuming.

At least annually, the operational characteristics of the system should be retested. This generally involves repeating Stages 1 and 2 as previously outlined. A full-scale discharge test is rarely required as a part of an annual inspection.

Both the semiannual and annual inspections should be performed by knowledgeable and qualified personnel. The NFPA Halon 1301 and Halon 1211 Standards recommend that they be performed under contract by the equipment manufacturer or installer. Reports of the inspection should be filed with the authority having jurisdiction and with the owner of the system. Needless to say, all impediments found in these inspections must be corrected promptly.

SI Units

The following conversion factors are given as a convenience in converting to SI units the English units used in this chapter.

1 sq ft	= 0.929 m ²
1 in.	= 25.400 mm
1 ft	= 0.305 m
1 lb (mass)	= 0.454 kg
1 psi	= 6.895 kPa
$\frac{5}{9} (F - 32)$	= C
1 (U.S.) gal	= 3.785 litres
1 cu ft	= .0283 m ³

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⁹Clark, D.G., "The toxicity of bromotrifluoromethane (FE 1301) in animals and man," *Ind. Hyg. Res. Lab., Imperial Chemical Industries, Alderley Park, Cheshire, England*, 1970.

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- NFPA 10, Portable Fire Extinguishers.
- NFPA 12A, Standard on the Halogenated Fire Extinguishing Agent Systems—Halon 1301.
- NFPA 12B, Standard on the Halogenated Fire Extinguishing Agent Systems—Halon 1211.
- NFPA 75, Standard on Electronic Computer/Data Processing Equipment.

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The "free radical" theory supposes that the bromide radical reacts with the fuel to give hydrogen bromide,



which then reacts with active hydroxyl radicals in the reaction zone:



The bromide radical again reacts with more fuel, and so on, with the result that active $H \cdot$, $OH \cdot$, and $O \cdot$ radicals are removed, and less reactive alkyl radicals are produced.

The "ionic" theory supposes that the uninhibited combustion process includes a step in which O_2 -ions are formed by the capture of electrons which come from ionization of hydrocarbon molecules. Since bromine atoms have a much higher cross section for the capture of slow electrons than has O_2 , the bromine inhibits the reaction by removing the electrons that are needed for activation of the oxygen.

A-1-6.1 Hazards to Personnel. The discharge of Halon 1301 to extinguish a fire may create a hazard to personnel from the natural Halon 1301 itself and from the products of decomposition that result from exposure of the agent to the fire or other hot surfaces. Exposure to the natural agent is generally of less concern than is exposure to the decomposition products. However, unnecessary exposure of personnel to either the natural agent or to the decomposition products should be avoided.

Other potential hazards to be considered for individual systems are:

- (a) **Noise.** Discharge of a system can cause noise loud enough to be startling but ordinarily insufficient to cause traumatic injury.
- (b) **Turbulence.** High velocity discharge from nozzles may be sufficient to dislodge substantial objects directly in the path. System discharge may cause enough general turbulence in the enclosures to move unsecured paper and light objects.
- (c) **Cold Temperature.** Direct contact with the vaporizing liquid being discharged from a Halon 1301 system will have a strong chilling effect on objects and can cause frostbite burns to the skin. The liquid phase vaporizes rapidly when mixed with air and thus limits the hazard to the immediate vicinity of the discharge point. In humid atmospheres, minor reduction in visibility may occur for a brief period due to the condensation of water vapor.

Natural or Undecomposed Halon 1301. When Halon 1301 is used in systems designed and installed according to this NFPA standard, risk to exposed individuals is minimal. Its toxicity is very low in both animals and humans. The main physiologic actions of Halon 1301 at high inhaled levels are central nervous system (CNS) depression and cardiovascular effects.

Animals. Halon 1301 has a 15-min approximate lethal concentration (ALC) of 83 percent (O_2 added)¹⁶ suggesting a very low degree of acute inhalation toxicity. In monkeys and dogs, mild CNS effects occur after a few minutes' exposure above 10 percent, progressing to lethargy in monkeys and tremors and convulsion in dogs at levels above 20 percent¹⁷.

Spontaneous effects on blood pressure and cardiac rhythm occur at much higher levels, approximately 20 percent and 40 percent, respectively.¹⁸

It has also been known since the early 1900s that the inhalation of many halocarbons and hydrocarbons, like carbon tetrachloride and hexane, can make the heart abnormally sensitive to elevated adrenalin levels, resulting in cardiac arrhythmia and possibly death. This phenomenon has been referred to as cardiac sensitization. Halon 1301 can also sensitize the heart, but only at high inhaled levels. For example, in standard cardiac sensitization screening studies in dogs using 5-min exposures and large doses of injected adrenalin, the threshold for sensitization is in the 7.5 to 10 percent range.^{19,20}

In other studies on dogs, a certain critical blood level was associated with inspired levels needed to sensitize the heart.²¹ With exposure to Halon 1301, a relatively insoluble fluorocarbon, blood concentrations rise rapidly, equilibrate within 5-10 min, and fall rapidly upon cessation of exposure. There is no accumulation of Halon 1301 as indicated by similar blood concentration at 5-10 min and at 60 min of exposure. When dogs exposed to Halon 1301 for 60 min are given a large dose of adrenalin, the threshold for cardiac sensitization remains the same as for 5-min exposures - 7.5 to 10.0 percent. In addition, studies have shown that sensitization is only a temporary effect, since adrenalin injections given 10 min after exposure to known sensitizing levels have not resulted in arrhythmias.²²

Using the standard cardiac sensitization test protocol and large doses of adrenalin, dogs with experimentally induced myocardial infarction were tested to determine whether this type of heart condition might significantly lower the threshold for cardiac sensitization.²³

^{21,22} All percentage levels in this section refer to volumetric concentrations of Halon 1301 in air.

²³ See B-1-5 for references.

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Results on Halon 1301 showed no greater potential for cardiac sensitization among dogs having recovered from myocardial infarction than for normal, healthy animals.

Halon 1301 has also been tested for mutagenic and teratogenic effects. In a standard 48-hr Ames Test at levels of 40 percent, no evidence of mutagenicity was seen in *Salmonella typhimurium* bacteria with or without metabolic activation.⁹ Pregnant rats exposed to Halon 1301 at levels as high as 5 percent exhibited no embryotoxic or teratogenic effects.¹⁰

The preceding animal studies show that Halon 1301 is very low in toxicity. Although high inhaled levels can affect the CNS and cardiovascular system, such effects are rapidly and completely reversible upon removal from exposure, if the exposure conditions were not severe enough to produce death.

Humans. The very low toxicity of Halon 1301 in animal studies has been confirmed by over 20 years of safe manufacture and use. There has never been a death or any permanent injury associated with exposure to Halon 1301.

Exposure to Halon 1301 in the 5 to 7 percent range produces little, if any, noticeable effect. At levels between 7 and 10 percent mild CNS effects such as dizziness and tingling in the extremities have been reported.¹¹ Above 10 percent, some subjects report a feeling of impending unconsciousness after a few minutes, although test subjects exposed up to 14 percent for 5 min have not actually lost consciousness.¹¹ These types of CNS effects were completely reversible upon removal from exposure.

In many experimental studies on humans, no subject has ever had a serious arrhythmia at Halon 1301 levels below 10 percent. One arrhythmia has been observed at a 14-percent level after a few minutes' exposure, but the subject reverted to a normal rhythm upon removal to fresh air.¹¹ In recent studies at the Medical College of Wisconsin, exposure to Halon 1301 up to 7.1 percent for 30 min did not produce sufficient adverse effects to harm, confuse, or debilitate human subjects or prevent them from performing simple mechanical tasks, following instructions, or exiting from the Halon 1301 exposure area. In addition, these subjects experienced no significant EKG or EEG abnormalities during or after exposure.

It is considered good practice to avoid all unnecessary exposure to Halon 1301 and to limit exposures to the following times:

7 percent and below - 15 min

7-10 percent - 1 min

10-15 percent - 30 sec

Above 15 percent - prevent exposure

Anyone suffering from the toxic effects of Halon 1301 vapor should immediately move or be moved to fresh air. In moving persons suffering toxic effects due to exposure to this agent, the use of epinephrine (adrenaline) and similar drugs must be avoided because they may produce cardiac arrhythmias, including ventricular fibrillation.

Halon 1301 is colorless and odorless. Discharge of the agent may create a light mist in the vicinity of the discharge nozzle, resulting from condensation of moisture in the air, but the mist rarely persists after discharge is completed. Thus, little hazard is created from the stand-point of reduced visibility. Once discharged into an enclosure, it is difficult to detect its presence through normal human senses; in concentrations above approximately 5 percent, voice characteristics are changed due to the increased density of the agent/air mixture.

In total flooding systems, the high density of Halon 1301 vapor (5 times that of air) requires the use of discharge nozzles that will achieve a well-mixed atmosphere in order to avoid local pockets of higher concentration. It is also possible to develop local pockets of higher concentration in pits or low-lying areas adjacent to local application systems. Once mixed into the air, the agent will not settle out.

Decomposition Products of Halon 1301. Although Halon 1301 vapor has a low toxicity, its decomposition products can be hazardous. The most accepted theory is that the vapor must decompose before Halon 1301 can inhibit the combustion reactions (see A-1-1.2). The decomposition takes place on exposure to a flame, or to a hot surface at above approximately 900°F (482°C). In the presence of available hydrogen (from water vapor, or the combustion process itself) the main decomposition products are the halogen acids (HF, HBr), and free halogens (Br₂), with small amounts of carbonyl halides (COF₂, COBr₂).

Approximate lethal concentration values for 15-min exposures to some of these compounds are given in Column 1 of Table A-1-6.1. Column 2 gives the concentrations of these materials that have been quoted as "dangerous for short exposures" by Sax.[†]

[†]Sax, N. Irving: *Dangerous Properties of Industrial Materials*, Fourth Edition; Section 12; Reinhold Publishing Corporation; New York, NY; 1976.

Table A-1-4.1
Approximate Lethal Concentrations for
Predominate Halon 1301 Decomposition Products

Compound	ALC for 15-Minute Exposure ppm by Volume in Air	Dangerous Concentration* ppm by Volume in Air
Hydrogen Fluoride, HF	2500	50-250
Hydrogen Bromide, HBr	4750	—
Bromine, Br ₂	550	50***
Carbonyl Fluoride, COF ₂	1500	—
Carbonyl Bromide, COBr ₂	100-150**	—

*Sax, N. Irving; Dangerous Properties of Industrial Materials, Fourth Edition; Section 12; Reinhold Publishing Corporation; New York, NY, 1975.
**Value is for carbonyl chloride, COCl₂ (phosgene); value for carbonyl bromide is not available.
***Value is for chlorine (Cl₂); value for bromine is not available.

The decomposition products of Halon 1301 have a characteristic sharp, acrid odor, even in minute concentrations of only a few parts per million. This characteristic provides a built-in warning system for the agent, but at the same time creates a noxious, irritating atmosphere for those who must enter the hazard following the fire.

The amount of Halon 1301 that can be expected to decompose in extinguishing a fire depends to a large extent on the size of the fire, the concentration of Halon vapor and the length of time that the agent is in contact with flame or heated surfaces above 900°F (482°C). If there is a very rapid buildup of concentration to the critical value, then the fire will be extinguished quickly, and there will be little decomposition. The actual concentration of the decomposition products must then depend on the volume of the room in which the fire was burning, and on the degree of mixing and ventilation. For example, extinguishment of a 25-sq ft (2.3-m²) heptane fire in a 10,000-cu ft (283-m³) enclosure within 0.5 sec produced only 12 ppm HF. A similar test having an extinguishment time of 10 sec produced an average HF level of 250¼ ppm over a 9-min period.

Clearly, longer exposure of the vapor to temperatures in excess of 900°F (482°C) would produce greater concentrations of these gases. The type and sensitivity of detection, coupled with the rate of discharge, should be selected to minimize the exposure time of the vapors to the elevated temperature if the concentration of breakdown products must be minimized. In most cases the area would be untenable for human occupancy due to the heat and breakdown products of the fire itself.

A.1-6.1.2 Safety Requirements. The steps and safeguards necessary to prevent injury or death to personnel in areas whose atmospheres will be made hazardous by the discharge or thermal decomposition of Halon 1301 may include the following:

- (a) Provision of adequate aiseways and routes of exit and keeping them clear at all times.
- (b) Provision of emergency lighting and directional signs as necessary to ensure quick, safe evacuation.
- (c) Provision of alarms within such areas that will operate immediately upon detection of the fire.
- (d) Provision of only outward swinging self-closing doors at exits from hazardous areas, and, where such doors are latched, provision of panic hardware.
- (e) Provision of continuous alarms at entrances to such areas until the atmosphere has been restored to normal.
- (f) Provision of warning and instruction signs at entrances to and inside such areas. These signs should inform persons in or entering the protected area that a Halon 1301 system is installed, and may contain additional instructions pertinent to the conditions of the hazard.
- (g) Provision for prompt discovery and rescue of persons rendered unconscious in such areas. This may be accomplished by having such areas searched immediately by trained personnel equipped with proper breathing equipment. Self-contained breathing equipment and personnel trained in its use, and in rescue practices, including artificial respiration, should be readily available.
- (h) Provision of instruction and drills of all personnel within or in the vicinity of such areas, including maintenance or construction people who may be brought into the area, to ensure their correct action when Halon 1301 protective equipment operates.
- (i) Provision of means for prompt ventilation of such areas. Forced ventilation will often be necessary. Care should be taken to really dissipate hazardous atmospheres and not merely move them to another location. Halon 1301 is heavier than air.
- (j) Prohibition against smoking by persons until the atmosphere has been purged of Halon 1301.
- (k) Provision of such other steps and safeguards that a careful study of each particular situation indicates is necessary to prevent injury or death.

B-1-8 ASTM Publications. This publication makes reference to the following ASTM standards and the year dates shown indicate the latest edition available. They are available from American Society for Testing and Material, 1916 Race Street, Philadelphia, PA 19108.

- ASTM A55-78, *Specifications for Welded and Seamless Steel Pipe*
- ASTM A106-78a, *Specifications for Seamless Carbon Steel Pipe for High-Temperature Service*
- ASTM A197-78, *Specifications for Castable Iron*
- ASTM A234-78a, *Specifications for Piping Fittings of Wrought Carbon Steel and Alloy Steel for Moderate and Elevated Temperatures*
- ASTM A358-77, *Specifications for Ferritic Ductile Iron Pressure Retaining Castings for Use at Elevated Temperatures*
- ASTM B98-78a, *Specifications for Seamless Copper Water Tube*
- ASTM E290-76, *Standard for Metric Practice*

B-1-4 ASME Code. This publication makes reference to the following ASME code and the year date shown indicates the latest edition available. It is available from the American Society of Mechanical Engineers, 345 East 47th Street, New York, NY 10017.

ASME Boiler and Pressure Vessel Code-1980

B-1-6 Toxicology References

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**TOXICOLOGY OF HALOGENATED FIRE EXTINGUISHING AGENTS
HALON 1301 (BROMOTRIFLUOROMETHANE)**

Charles F. Reinhardt and Ruth E. Reinke

E. I. du Pont de Nemours & Company

Halon 1301, bromotrifluoromethane, has been established as an excellent fire extinguishing agent. It has been used in portable extinguishers by the U.S. Army since 1959 and a portable extinguisher containing Halon 1301 has been listed by Underwriters' Laboratories, Inc. (1) since 1961. Currently, Halon 1301 is finding its widest use in total flooding systems.

Toxicity studies with Halon 1301 show that it is one of the safest of the halogenated fire extinguishing agents. In evaluating the toxicology of fire extinguishing agents, three factors must be considered:

1. toxicity of the undecomposed agent,
2. Toxicity of the thermal decomposition products of the agent, and
3. toxicity of the common products of combustion from the fire.

As the title suggests, this discussion will be limited to the first factor, namely, the toxicity of undecomposed or natural Halon 1301. The toxicology of Halon 1301 has been studied extensively by numerous laboratories and includes both animal and human inhalation studies.

ANIMAL STUDIES

The original toxicological studies on Halon 1301 were carried out in 1950 by Chambers and Krackow (2), Comstock et al. (3), and MacNamee (4) at the U.S. Army Chemical Center. They determined the approximate lethal concentration (ALC) of various fire extinguishing agents and found the ALC for Halon 1301 in rats to be 83.2 percent in air for a 15-minute exposure. Although there was evidence of edema and hemorrhage of the lungs, death probably resulted from oxygen deficiency. This low order of acute toxicity was confirmed by Dufour (5) at Underwriters' Laboratories in tests which involved four halogenated fire extinguishing agents. Guinea pigs exposed to concentrations of up to 20 percent Halon 1301 for two hours showed no significant toxic effect. On the basis of these data, Underwriters' classified Halon 1301 in Group 6 (least toxic) in their classification of life hazards.

Factor (6) subacute toxicity studies in which rabbits, mice, guinea pigs, and rats were exposed for two hours to concentrations of Halon 1301 up to 80 percent, with the oxygen concentration maintained at 20 percent, without any mortalities. Mice exposed to concentrations of 20 to 80 percent showed central nervous system effects associated with hyperactivity. At the 80 percent level a depressant effect was noted in rats and guinea pigs while mice and rabbits showed effects associated with hyperactivity, including brief convulsions and tremors in rabbits. Subacute toxicity studies on mice, rats, and guinea pigs in which the animals were exposed to 50 percent Halon 1301, two hours a day for 15 consecutive days, resulted in no signs of toxicity.

MacFarland (7) at Hazleton Laboratories reported a study in which monkeys, rabbits, guinea pigs, and rats were exposed for two hours to Halon 1301 at concentrations of 10, 15, and 20 percent, respectively. Blood chemistry determinations performed on the monkeys revealed no abnormalities resulting from the exposure. All animals appeared normal following exposure. Pathological examination showed no evidence of gross or histopathological effect.

Comstock et al. (8) conducted a chronic study in which rats and dogs were exposed six hours daily, five days per week for 18 weeks to 2.3 percent Halon 1301. No clinical signs of toxicity were observed. On autopsy there was evidence of some diffuse congestion throughout the respiratory tract but no other noteworthy tissue changes.

Up to this point, the primary toxicological action ascribed to Halon 1301 has been its effect upon the central nervous system. However, as is characteristic of many halogenated and unsubstituted hydrocarbons, Halon 1301 would be expected to sensitize the heart to the effects of epinephrine with the production of cardiac arrhythmias. These arrhythmias are frequently ventricular in origin and may result in sudden death. This phenomenon is commonly referred to as cardiac sensitization. Several investigators have studied this aspect of Halon 1301 toxicity.

At the Hine Laboratories (9), mongrel dogs were exposed to Halon 1301 concentrations ranging from 10 to 40 percent for intervals of less than one hour after a fright-producing situation. The purpose of this experiment was to ascertain whether endogenously released epinephrine would cause ventricular fibrillation. No fatal arrhythmias occurred although central nervous system effects and shortness of breath were observed at the higher concentrations. Since the electrocardiographic activities of the dogs were not measured, it is not known whether any arrhythmias were produced. In some of the experiments, the dogs were exposed to a combination of Halon 1301 and 10 percent carbon dioxide, but, as above, no fatal arrhythmias occurred.

Van Stee and Back (10) exposed both unanesthetized and anesthetized dogs and monkeys to 10 to 80 percent Halon 1301. Most of the animals developed spontaneous cardiac arrhythmias within one to three minutes of exposure to 40 percent or more Halon 1301 but no particular consistency of response could be ascertained. The typical arrhythmic

response could, however, be elicited with the intravenous injection of 2 to 3 $\mu\text{g}/\text{kg}$ epinephrine. Larger doses, 5 to 10 $\mu\text{g}/\text{kg}$, caused ventricular fibrillation with cardiac arrest in dogs. Monkeys receiving the higher doses of epinephrine were observed to have brief episodes of ventricular fibrillation but no deaths occurred. Epileptiform convulsions were seen in about 50 percent of the unanesthetized dogs exposed to 50 to 80 percent Halon 1301. Unanesthetized monkeys, on the other hand, became lethargic and no convulsions were seen. Most animals exposed to Halon 1301 while anesthetized with sodium pentobarbital exhibited an initial decrease in mean arterial blood pressure of 10 to 60 mm Hg depending on the concentration of Halon 1301.

These same investigators (11) also reported that anesthetized dogs showed a steady drop in mean arterial blood pressure and a significant fall in heart rate during exposure to 70 percent Halon 1301. Open-chested monkeys and dogs exposed to 80 percent of the agent showed a fall in systolic pressure accompanied by a slight rise in left ventricular and diastolic pressure. The authors reason that the hypotension observed with exposure to Halon 1301 results from a decrease in total peripheral vascular resistance and decreased myocardial contractility.

In experiments conducted to examine the characteristics of the cardiac arrhythmias which, as previously reported, often appeared spontaneously during exposure of monkeys to Halon 1301, Van Stee and Back (12) found that a minimal blood pressure threshold is required for their production and that the individual susceptibility to the spontaneous occurrence of arrhythmias is the result of differences in individual ability to maintain blood pressure during exposure to Halon 1301. These findings suggest that a hypertensive individual might be expected to develop arrhythmias more readily than a normo- or hypotensive one. Acidosis and epinephrine were found to decrease the blood pressure threshold required to trigger arrhythmias.

Reinhardt (13) has conducted studies in which unanesthetized dogs were exposed to either 5, 7.5, 10, 15, or 20 percent Halon 1301 for five minutes and then given an intravenous injection of 8 to 10 $\mu\text{g}/\text{kg}$ epinephrine. No significant cardiac arrhythmias developed at the 5 percent level. However, at the four highest concentrations, serious arrhythmias, either multiple consecutive ventricular beats or ventricular fibrillation, were observed. The percentage of responses increased with increasing concentration of Halon 1301. One death occurred at the 10 percent level while two animals died at the 20 percent concentration. In no instance were any cardiac abnormalities noted when the animals were exposed to Halon 1301 without the injection of epinephrine. The results are summarized in Table 1.

In another series of experiments, Van Stee and Back (14) exposed rats up to five minutes to 70 to 75 percent Halon 1301 to determine the accumulation and diminution of this material in the brain, heart, and blood. Tissue samples were collected within 30 seconds after termination of each of the 1-, 2-, 3-, 4-, and 5-minute exposures or serially during the 55-minute period following the five-minute exposures. The

Mean heart concentrations reached 300 µg/gm of tissue. The brain concentrations of Halon 1301 were significantly higher than those of the heart at all times during exposure and reached a mean concentration of 760 µg/gm of tissue. Intracardiac blood samples showed that the concentrations of Halon 1301 in cardiac blood closely paralleled those of the heart. Only trace amounts of Halon 1301 were found in the same tissues 10 minutes post-exposure.

TABLE I

<u>Concentration Percent (v/v)</u>	<u>Number Dog Exposures</u>	<u>Number Marked Responses*</u>	<u>Percent Marked Responses</u>
5.0	62	0	0.0
7.5	18	1	5.6
10.0	69	8	11.6
15.0	7	2	28.6
20.0	13	8	61.5

* Either multiple consecutive ventricular beats or ventricular fibrillation.

The favorable toxicity data obtained on animals suggested that Halon 1301 might have a sufficiently low order of toxicity to permit its use in environments normally occupied by man. However, since the concentration of Halon 1301 required to extinguish most fires is of the order of 5 to 6 percent, it was considered necessary to determine precisely the effects of these and somewhat higher concentrations of Halon 1301 in man.

HUMAN STUDIES

Clark (15) exposed subjects to various concentrations of Halon 1301 by means of a face mask. Exposure to 6 percent of the agent for three minutes produced slight paresthesia and very slight dizziness. There was an increase in the heart rate but otherwise there were no electrocardiographic (ECG) changes. At the 9 percent level, increasingly unpleasant dizziness caused one subject to terminate the exposure after two minutes. Again, there was an increase in heart rate but no arrhythmia. Exposures at the three highest concentrations (10, 12, and 15 percent) lasted only one minute. At the 10 percent level, slight dizziness and slight paresthesia were noted. A general rise in heart rate and blood pressure was accompanied in two subjects by depression of the T wave as noted on the ECG, but all subjects felt that continued exposure could have been tolerated. At the 12 and 15 percent concentrations, there were paresthesias and severe dizziness. All subjects showed an increased heart rate and depression of the T wave. The subjects felt that exposure continued beyond one minute would be intolerable due to dizziness and fear of losing

consciousness. Recovery occurred within one to five minutes after termination of exposure.

Reinhardt and Stopps (16) also conducted a series of human exposures. Three men were exposed twice each, in sequence to concentrations of 1, 3, 5, 7, and 10 percent Halon 1301. Each exposure lasted approximately 3 to 3-1/2 minutes. A small exposure booth measuring 2-1/2 x 3 x 5 feet was used. The desired exposure concentrations inside the chamber were achieved within \pm 1/2 percent 30 seconds after the release of Halon 1301 directly into the top of the chamber.

Electrocardiograms made periodically before and continuously during each exposure showed no abnormality in any of the subjects. A force platform test for evaluation of equilibrium and a simple reaction time test in response to a visual signal were used to assess effects of the exposures on the subjects. The results of these two tests were not conclusive but suggested a slight disturbance in balance and reaction time, especially at the 7 and 10 percent levels of exposure.

All three subjects noted a characteristic subjective impression, independently described by each as a feeling of light-headedness, a feeling similar to having a couple of "stiff drinks," or as the sensation experienced just prior to unconsciousness when being given a general anesthetic. At the 7 percent level this sensation came on rapidly and then remained at a constant intensity until the exposure ended when it quickly subsided. At the 10 percent level, however, the sensation increased throughout the exposure and all three subjects felt that continued exposure might have induced unconsciousness. At the 10 percent concentration, each subject noticed a slight disturbance in his ability to respond to the visual stimulus of the reaction time device as shown by the fact that greater effort and concentration were required to make the response.

The Hine Laboratories (9) exposed 10 men, under static conditions, to 5 and 10 percent Halon 1301. In addition, the same subjects were exposed, under dynamic conditions using a Heidbrink anesthetic inhalator, to concentrations ranging from 5 to 17 percent.

The static exposures lasted 20 to 25 minutes and were conducted in a cubicle exposure chamber with an 8064-liter capacity. A battery of tests for mental alertness and muscular coordination were given during the exposures: an adjective check list for description of the subject's mental and emotional state, a modified Romberg test for evaluation of balance, a finger-to-finger test, a pursuit rotor test, and a reaction time test using three different colored lights and levers. The results of these tests at the 5 percent level were judged to indicate overall improvement in one subject, no significant changes in two, and a decrease in performance in the fourth subject; the general evaluation was that some subjects showed a minimal decrease in judgment and skill. At the 10 percent level, there was a general decrease in judgment, alertness, and neuromuscular skill. While hand steadiness was not scored, the Maze tests were revealing in that the drawn lines were wavy and irregular in all subjects at the 10 percent level in contrast to the smooth lines drawn in the control runs. The self-appraisal from the descriptive

word list showed a decrease in words describing mental acuity and alertness with an increase in words describing mild depression. Most subjects felt drowsy or light-headed and there was an increase in sense of well-being.

In the Heidbrink anesthetic inhalator tests, Halon 1301 was administered either alone or in the presence of increased carbon dioxide. Total exposure time ranged from 15 to 25 minutes. Nine subjects reported central nervous system effects; reactions were variously described as tingling, light-headedness, buzzing in the ears, and numbness or the feeling of impending unconsciousness at concentrations above 14 percent. One subject exposed up to 15.7 percent Halon 1301 reported no central nervous system effect.

Recordings of ECG, pulse, and blood pressure were made in connection with these inhalator exposures. No ECG changes were observed in seven subjects. One subject exposed to 16.9 percent Halon 1301 showed flat T waves; exposure to 14 percent Halon 1301 36 hours later resulted in cardiac arrhythmia characterized by flattening of T waves, premature ventricular contractions forming bigeminy, A-V dissociation with no pacemaker, and premature beats from various foci. Two other subjects showed ECG changes at five of the ten readings taken after exposure to 8.2 percent to 15.7 percent Halon 1301. In one case, changes were described as a lowering of the T wave on two occasions. In the other case, flattening of the T wave occurred on one occasion and increased sinus arrhythmia occurred on two other occasions. (This last subject was noted to have an initial pattern of varying T waves.) The overall tendency was towards an increased pulse and lowered blood pressure but considerable variability existed. Little, if any, cardiovascular effect was noted in those instances where the amount of inspired carbon dioxide was increased.

During and following exposure, two of the subjects reported headaches which in one case persisted for 12 hours, but otherwise recovery was prompt. The investigators concluded that Stage I anesthesia occurs at 12 to 15 percent concentrations of Halon 1301 and Stage II anesthesia would be reached at approximately 20 percent Halon 1301.

SUMMARY AND CONCLUSION

Animal experiments showed two principal toxic actions of Halon 1301: 1) stimulation or depression of the central nervous system with effects ranging from tremors and convulsions to lethargy and unconsciousness, and 2) cardiovascular effects including hypotension, decreased heart rate, and cardiac arrhythmias. Variations in both the nature and intensity of these actions existed both between species and at different concentrations of Halon 1301.

Experiments involving man clarified the nature of these target actions. The central nervous system effects are characteristic of those produced by a weak general anesthetic. To date, a state of unconsciousness has not been induced in man, either experimentally or during the use of Halon 1301. In exposures to concentrations up to 17 percent, the subjects were always sufficiently aware of their reactions to request

termination of exposure when necessary. The rapid recovery of human subjects after cessation of exposure is consistent with studies in rats indicating rapid post-exposure clearance of Halon 1301 from the brain and heart.

Human subjects exposed to Halon 1301 have shown both an increase and decrease in blood pressure and heart rate as well. The apparent intrinsic pharmacological tendency of this agent to induce hypotension is undoubtedly modified in many instances by endogenous epinephrine released in response to stimulation of the central nervous system. In addition, human subjects have developed spontaneous electrocardiographic changes including one instance of a definite cardiac arrhythmia when exposed to relatively high concentrations of Halon 1301.

The data supplied by three separate human studies indicate that concentrations of Halon 1301 exceeding 10 percent may produce definite cardiac and central nervous system effects and that concentrations of the order of 15 to 20 percent may lead to unconsciousness and conceivably death. On the other hand, no cardiac effects and only negligible central nervous system effects would be expected to occur at concentrations not exceeding 7 percent Halon 1301 for exposures five minutes or less in duration. No significant adverse health effects have been reported from Halon 1301 in more than 10 years of practical use as a fire extinguishant.

On the basis of the toxicity data presently available, it is concluded that Halon 1301 is safe for use in total flooding systems where personnel are normally present provided the concentrations and conditions of egress conform to those prescribed in the National Fire Protection Association 12A standard on Halogenated Fire Extinguishing Agent Systems - Halon 1301 (17). Currently, Halon 1301 is not recommended for use as an inerting agent in normally occupied areas.

In conclusion, it must be emphasized that some degree of risk is generally attendant upon the use of chemical extinguishing agents, and Halon 1301 is no exception. It does have toxic properties which could be dangerous under certain circumstances. However, the toxicity of the agent must be put in perspective, and any risk must be balanced against the benefits. The prompt extinguishing action of Halon 1301 minimizes the formation of pyrolysis products from the agent itself as well as the major hazards of a conflagration; namely, smoke, heat, carbon monoxide formation and oxygen depletion. These latter hazards far outweigh any due to the extinguishant itself. It is therefore of paramount importance that the fire be detected and extinguished quickly after inception.

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DISCUSSION

Mr. Wood: My question perhaps relates to all three of these papers. I noted in the case of 70 to 80 percent concentrations that the mixture must have been with oxygen. Otherwise the oxygen deficiency would have been present. In the case of the lower concentrations, such as 5 to 20 percent, was there oxygen enrichment to compensate or were these with as little as 16 percent oxygen, which would correspond to about a 20 percent mixture? In other words, in the lower concentrations, 20 percent and below, was the oxygen enriched to compensate and make it a normal oxygen concentration? If not, could some of these effects be partly attributable to oxygen deficiency?

Dr. Reinhardt: In the studies which we carried out, we did not add oxygen at those lower levels. However, I think the control studies would

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HUMAN AND RAT EXPOSURES TO HALON 1301
UNDER HYPOBARIC CONDITIONS

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INTRODUCTION

Halon 1301 (bromotrifluoromethane, CBrF_3) is a convenient and highly efficient fire extinguishing agent for use on several types of fires (1, 2, 6). This gas is used in portable extinguishers as well as in total flooding systems.

Engine nacelles and cargo compartments of many military and commercial aircraft carry Halon 1301 fire suppressing systems. Similar systems have been proposed for protecting the occupants and contents of aircraft cabins and flight decks.

Several studies, conducted at normobaric conditions, indicate that laboratory animals and humans can be exposed briefly to Halon 1301 concentrations necessary to extinguish fires in enclosed spaces without developing the central nervous system or cardiac effects that sometimes attend inhaling low levels of other halogenated hydrocarbons (2, 3, 4, 11). However, little information is available concerning the toxicity of Halon 1301 at reduced atmospheric pressures, such as would accompany its use in flight.

To test possible potentiating effects of hypobaric conditions and the resulting hypoxia on any physiologic alterations produced by Halon 1301 inhalation, the following investigation was conducted.

METHODS AND MATERIALS

Rat Studies:

Seventy-two ad-libitum fed, male, Charles River rats weighing 450-550 grams were divided into four groups. Individual animals in each group were exposed to one of the following four conditions:

1. simulated altitude with added Halon 1301 (27 rats);
2. simulated altitude without Halon 1301 (9 rats);
3. simulated altitude with added Halon 1301 and injected epinephrine (27 rats); and

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3. Controlled animals without Halon 1301 but with injected anesthetic (9 rats).

Each rat was lightly anesthetized with ether (50 mg./Kg., I.P.), prepared for continuous electrocardiographic recording (lead II), then placed in a small hypobaric chamber. The chamber door was secured and the desired barometric pressure -- 760 mm.Hg. (sea level), 632 mm.Hg. (5,000 ft.), or 380 mm.Hg. (18,000 ft.) -- was obtained.

After the rat had been at these conditions for three minutes, pre-measured amounts of Halon 1301 to produce concentrations of approximately 8, 16, or 24 percent by volume were added directly into the top of the chamber. A metal baffle placed over the inlets served to disperse the incoming gas throughout the enclosure. The final Halon 1301 concentration was measured by gas chromatography.

In each control exposure (Groups 2 and 4), a pulse of compressed air which produced similar noise and pressure changes was added in place of the CBrF_3 .

After a five-minute exposure to the experimental gas, the rat was returned to ambient conditions. Two-thirds of these animals were then sacrificed immediately by a blow on the head and sections of their lungs were excised and fixed in 10 percent N-buffered formalin and prepared for histologic study. The remaining rats were observed daily for one month.

The rats in Groups 3 and 4 were treated the same as all others except that they received an intramuscular I.M. dose of ten $\mu\text{g.}/\text{Kg.}$ epinephrine just before they were placed in the hypobaric chamber.

Electrocardiographic records were made at frequent intervals on all rats during each exposure.

Human Exposures:

Eight active-duty military personnel (ages 20-35 years) were exposed for three minutes to either four or seven percent Halon 1301 in air in a hypobaric chamber maintained at 760 mm.Hg., 632 mm.Hg., or 380 mm.Hg. In control exposures, compressed air was admitted to the chamber environment in place of Halon 1301. The gaseous composition of the chamber was monitored by gas chromatography.

Before, during, and after exposure to the experimental gas, each volunteer performed a battery of psychomotor tests which included complex reaction time measures and a finger-maze tracking task. Each subject had 20 training sessions on the psychomotor tasks over a two-week period prior to the experiment.

Electrocardiographs (lead II) were obtained on each subject at regular intervals during all exposures. Physical examinations and pulmonary function measurements were performed on all subjects before and after each exposure.

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This was a single blind experiment in that the subject was not aware of which experimental gas was inhaled.

RESULTS

Rat Studies:

No rats died during any chamber exposure. Three animals developed cardiac arrhythmias during inhalation of Halon 1301. One rat breathing 24 percent Halon 1301 at a simulated altitude of 5,000 ft., and one exposed to 16 percent CBrF_3 at 380 mm.Hg., developed premature atrial contractions about one minute after the Halon 1301 was admitted to the chamber. Indications of bundle branch blocks appeared as the exposure continued. In both cases, these changes disappeared when the CBrF_3 -air mixture was replaced with room air during the chamber descents.

Premature atrial contractions were also noted in the electrocardiogram of one rat breathing 24 percent Halon 1301 at 632 mm.Hg. This animal had received an epinephrine injection before the exposure. Normal ECG tracings reappeared when the rat was returned to ambient conditions.

No other prolonged cardiac arrhythmias were noted on the electrocardiograms from any other rats.

None of the animals saved for the one month post-exposure observation died during that period.

Histological examination of the lungs from rats sacrificed immediately after exposure showed no pathologic changes which could be directly related to breathing Halon 1301 or exposure to hypobaric conditions.

Human Exposures:

All post-exposure physical examination results and pulmonary function measurements were similar to pre-exposure values.

Subjects' electrocardiograms obtained during the chamber exposures showed only non-specific changes from control tracings. No alterations were noted that could be directly attributed to the Halon 1301 exposure or to the simulated altitude attained.

Complex reaction time test: An analysis of variance showed statistically significant increases in complex reaction time with Halon 1301 exposure $F(2,28) = 7.39$; $p < 0.01$. No other effects were observed.

Maze tracking task: Analyses of variance were performed on the following measures: (1) total time; (2) number of errors; (3) time in error; and (4) average time per error. Inhalation of Halon 1301 produced no significant changes in any of these measures. However, the number of errors on the maze tracking task was found to be significantly influenced by exposure to simulated altitude $F(2,28) = 3.72$; $p < 0.05$.

Two of the three subjects noted subjective symptoms of dizziness, headache, or discomfort during exposure to seven percent CBrF_3 . These symptoms subsided with nearly equal frequencies at each simulated altitude. These subjects reported these symptoms during each exposure to seven percent Halon 1301.

Similar subjective descriptions were given by three subjects while inhaling four percent CBrF_3 . These symptoms were reported once at each of the three chamber pressures.

Two subjects experienced the above symptoms during control exposures at 300 mm.Hg.

It was not possible to directly correlate the incidence of subjective symptoms during exposure to the experimental gases to psychomotor performance evaluations.

DISCUSSION

Rat Studies:

Halon 1301 is a member of a large family of halogenated hydrocarbons that are known to induce cardiac arrhythmias when inhaled during times of elevated blood epinephrine levels. These changes often originate in the ventricular myocardium and can produce sudden death. Several investigators have studied this effect in both animals and humans (2, 5, 9, 10, 11).

The cardiac arrhythmias noted in the three rats in the present study were not as serious, nor did they appear as frequently, as those reported by the Haskell Laboratory (2) for a group of dogs breathing similar concentrations of CBrF_3 at sea level. However, all of these dogs received an intravenous injection of 8-10 mg./Kg. epinephrine during the exposure to Halon 1301. No abnormal heart rhythms were observed in animals that did not receive exogenous epinephrine. Van Stee and Back (11) demonstrated that dogs and monkeys exposed to 10-80 percent CBrF_3 developed spontaneous cardiac arrhythmias at different rates and to different degrees. These two species also exhibited contrasting central nervous system responses to the gas. Earlier, Paulet (8) had established that rabbits, mice, guinea pigs, and rats vary in their susceptibilities to the toxic effects of Halon 1301. Therefore, it is not possible to directly compare the myocardial response of the rats in this study to those observed on other laboratory animals breathing similar Halon 1301 air mixtures.

The low incidence of discernable electrocardiogram changes, and the nature of these arrhythmias, indicate that under the conditions studied Halon 1301 is not a very potent cardiac sensitizing agent in rats.

The lack of any pathologic pulmonary changes directly attributable to exposing rats in this study to Halon 1301 at simulated altitude, corroborates the results of another investigation. MacFarland (6)

exposed several laboratory species, including rats to 10, 15 and 20 percent CBrF_3 for two hours at sea level. Lungs, livers, and kidneys taken from some animals immediately after, and from others on the 7th and 14th day post-exposure, revealed no significant changes from control tissues.

Inhaling Halon 1301 at reduced atmospheric pressure does not seem to be any more harmful to laboratory rats than similar exposures at ambient conditions.

Human Exposures:

Two other laboratories have performed human exposures to Halon 1301, both at sea level conditions (5, 10). Reinhardt and Stopps (10) noted no disturbances in cardiac rhythm in three subjects exposed for 3.5 minutes to 1, 3, 5, 7 or 10 percent Halon 1301. At the Hine Laboratory (5), volunteers breathed five or ten percent Halon 1301 in air for up to 20 minutes with no serious cardiac effects. One subject did, however, develop a spontaneous cardiac arrhythmia after inhaling 14 percent Halon 1301 for five minutes. This condition resolved within two minutes after the inhalation was discontinued.

Since no cardiac rhythm changes were noted in the present study that could be directly attributable to Halon 1301 exposure, simulated altitude, or their interaction, it appears that human cardiac response to inhaling this gas at hypobaric conditions is not different from similar exposure at sea level.

Central nervous systems depression is another effect of Halon 1301 inhalation that has been extensively investigated in both laboratory animals and humans (2, 5, 10, 11, 12). In the two sea level human studies (5, 10), volunteers demonstrated a general trend towards loss of muscular coordination and alertness as the CBrF_3 percentages in their breathing mixtures were increased. These impairments in mental and physical skills began to appear at Halon 1301 concentrations of five to seven percent. No statistical analyses of the performance data were presented in either report, so it is not possible to directly compare the magnitude of the changes to those observed on similar tests in the present investigation.

The significant increases in complex reaction time during Halon 1301 inhalation noted in this study seem to agree with the usual effect of the gas. However, the subjects' performances on the maze tracking task were not significantly affected by exposure to Halon 1301. Since different neuromuscular skills are necessary to perform different psychomotor tasks, it is to be expected that these skills could be affected to different degrees by exposure to the same agent. This type of response was demonstrated by the subjects in Hine's experiment (5) while they were inhaling five percent CBrF_3 in air.

The subjective symptoms described by six of the eight subjects in the present survey were similar to those described by the subjects in the reports discussed above (5, 10). These effects were independent of altitude and thus would seem to be related to the Halon 1301 rather than to altitude hypoxia. At no time was any subject affected to such a

shown by this gas that he was unable to do assigned tasks. These symptoms subsided rapidly after oxygen masks were used. Numbness and self-balancing were discontinued to the subjects immediately after leaving the chamber indicated on residual aspects in balance.

The effects of hypoxia on human psychomotor performance are variable and not always directly related to decreasing oxygen partial pressure in the breathing mixtures. Also, some performance tests are more sensitive to the effects of hypoxia than others (4). Therefore, it is not surprising that, during exposure to simulated altitude, subjects in this study made significantly more errors on the maze tracking task than they did at ambient conditions, but no altitude-related performance changes were noted in the other measures.

CONCLUSIONS

This investigation has extended human exposure to Halon 1301 to the concentrations and barometric pressures which might attend its use in a total flooding system in flight. There does not seem to be a significant interaction between hypobaric conditions and the resulting hypoxia and Halon 1301 inhalation on the cardiac or central nervous system effects measured in this study.

Therefore, the presently accepted National Fire Protection Association standard on Halon 1301 total flooding systems for normally occupied spaces (7) may be applicable for aircraft cockpit and cabin installations. However, in all such systems the transient concentration gradient which develops whenever the fire suppressing agent is admitted to the enclosure must be considered. Even though no serious effects seem to accompany breathing seven percent CBrF₃ for three minutes at a simulated cabin altitude of 18,000 feet, there is presently no way to predict if persons seated close to the system outlets could safely tolerate the high agent concentrations which would be briefly present until the gas was thoroughly mixed with cabin air. Perhaps an alarm system is necessary to allow passengers time to put on oxygen masks before the gas is released.

At any rate, the convenience and effectiveness of Halon 1301 as a fire extinguishing agent demand that work continue to find ways to take full advantage of this agent's potential usefulness.

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DISCUSSION

Mr. Hanbury: I have two questions. One is it seems to me an earlier speaker said that actually because of the heart arrhythmia condition, dogs should be used rather than mice and so forth as test animals.

The other is are you advocating this halon in a closed system, a closed environmental system like you have in an aircraft, at a certain altitude, or have you ways to expel this gas?

Dr. Call: In answer to the first part, I think that was Dr. Clark that was talking about the laboratory animal to use. As Dr. Back mentioned earlier, sometimes you use what you have. This is how we started with the rats.

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Human Exposure to Halon 1301 (CBrF₃) During Simulated Aircraft Cabin Fires

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Sarrit, D. G., and D. J. Harris. Human exposure to Halon 1301 (CBrF₃) during simulated aircraft cabin fires. *Aerospace Med.* 44(2):198-201, 1973.

Halon 1301 (CBrF₃) was tested by the U. S. Navy for use as a fire suppression agent in occupied aircraft cabins. A Navy E-2B "Hawkeye" airplane was provided for the tests. Because of the known incidence of cardiac arrhythmias and central nervous system depression caused by exposure to Halon 1301, a careful build-up program was established for the installation, ground testing and flight testing of the agent in the airplane. Flight tests culminated in exposure of three volunteer subjects to 4% to 7% Halon 1301 in air mixtures in-flight. Continuous electrocardiograph (ECG) monitoring and verbal narration by the subjects on their well-being were made during the exposures. During the ground and initial flight tests the optimum method of mixing, distributing and maintaining adequate agent concentrations was determined. Analysis of ECG recordings, and examination of the volunteer subjects during and after exposure to the agent in-flight, revealed no cardiac arrhythmias or adverse biomedical effects. It was concluded that aircrew and passenger safety will not be compromised by brief exposure to the agent in-flight.

may cause central nervous system depression, and produce cardiac arrhythmias when potentiated by high levels of circulating epinephrine.^{1,4}

Recent investigations of the fire suppression characteristics of Halon 1301 at sea level and reduced atmospheric pressures have demonstrated that efficient fire suppression is achieved using concentrations of 4% to 7% Halon 1301 in air.² These concentrations are below the known toxicity levels of 10% Halon 1301 in air at sea level.¹ However, the toxic effects of Halon 1301 on humans at reduced atmospheric pressures were unknown.

As part of a build-up test program prior to the actual airplane tests, human exposures in a low pressure chamber to 4% to 7% Halon 1301 in air at reduced atmospheric pressures equal to sea level, 5,000 and 18,000 feet were conducted by another Navy laboratory. Continuous electrocardiographic and psychomotor performance evaluations were monitored. No adverse biomedical effects were reported.² Therefore, testing of the agent in the E-2B airplane was begun.

FIRES IN AIRCRAFT cabin areas during flight are a constant threat to pilots, aircrewmembers and passengers. Development of sophisticated aircraft with complex avionics, high output electrical systems and massive hydraulic and fuel components makes this threat even more formidable. Recent losses of aircrew and aircraft due to in-flight fires have reinforced the urgent need for a reliable, safe, fast acting fire suppression agent to be used in occupied cabin areas. One agent currently being considered is bromotrifluoromethane (CBrF₃), commonly termed Halon 1301. A Navy sponsored program was established for the installation, ground evaluation and flight testing of a prototype Halon 1301 fire suppression system in a Navy E-2B "Hawkeye" airplane (Figure 1).

Halon 1301 has been used extensively in nonoccupied areas of aircraft such as engine nacelles; however, the agent has never been utilized in aircraft cabins. The toxic effects of the agent on aircrew were of paramount importance in this evaluation. Previous laboratory animal and human exposure studies at sea level conditions have shown that concentrations above 10% Halon 1301 in air

MATERIALS AND METHODS

A fleet configured E-2B airplane was provided for this test program. Static ground tests were conducted to establish the fire suppression system configuration. Primary consideration was given to determining the optimum location for installing the canisters of Halon 1301, the amount of agent needed to provide 4% to 7% Halon

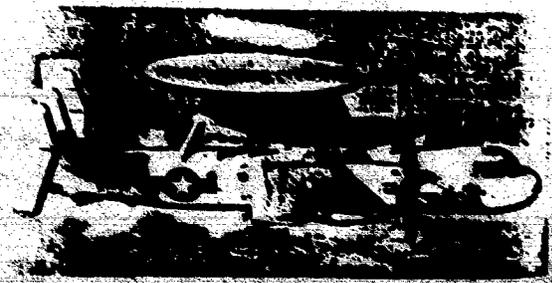


Fig. 1. Navy E-2B "Hawkeye" airplane.

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TABLE I. E-2B AIRPLANE CONFIGURATION DURING EACH IN-FLIGHT TEST OF HALON 1301

Flight Number	Airplane Configuration	Pressure Altitude (Pt)	Airspeed (KIAS)	Cabin Pressurization System	Equipment Cooling System
1	CRUISE	5,000	175	ON	ON
2	CRUISE	5,000	175	OFF	ON
3	CRUISE	5,000	175	OFF	OFF
4	CRUISE	15,000	175	OFF	ON
5	CRUISE	20,000	175	OFF	ON
6	CRUISE	30,000	150	ON	ON
7	TAKE OFF	1,000	120	ON	ON
8	EMERGENCY DESCENT	20,000 to 4,500	195-250	ON	OFF
9	CRUISE	5,000	175	ON	ON
*10	CRUISE	18,000	175	OFF	ON
11	CRUISE	5,000	175	OFF	ON
*12	CRUISE	20,000	175	OFF	ON
13	CRUISE	5,000	175	OFF	OFF

*Human Exposure Flights

1301 in cabin air, and the effect of the airplane equipment cooling and pressurization systems on agent distribution and concentration.

Thirteen flight tests were conducted at cabin pressure altitudes from sea level to 30,000 feet. Table I presents the airplane configuration on each of the flight tests.

Concentrations of Halon 1301 were monitored at head level in areas occupied by flight crewmembers, and in airplane sections where potential fire hazards pose the greatest threat. Figure 2 depicts the locations in the airplane where agent concentrations were monitored.

Concentrations of Halon 1301 were recorded with a Statham Laboratories Model GA-2A gas recorder and accessories, including three analyzer units and sampling tubes, a vacuum pump, oscillograph, and main electrical control unit. The Halon 1301 was released from all canisters simultaneously by actuating an electrical relay on the main electrical control unit. Agent concentrations were recorded continuously for 5 minutes following discharge.

The flight tests culminated in exposure of three volunteer subjects to Halon 1301 during flight. Two of the subjects had been exposed to the agent during the preliminary low pressure chamber tests.³ Three separate flights, one at 5,000 feet, one at 18,000 feet, and one at 20,000 feet, were conducted for the human exposures. Continuous electrocardiograph monitoring and verbal narration by the subjects concerning their well being were recorded. A flight surgeon and an aerospace physiologist accompanied the subjects on all flights. All flight crew, except the subjects, breathed 100% oxygen continuously throughout the flights.

RESULTS

Ground Tests: Eight, 86-cubic inch, spherical canisters containing Halon 1301 pressurized to 600 psi with nitrogen were mounted at various locations throughout the airplane. From initial ground tests it was determined that optimum agent concentrations of 4% to 7% Halon 1301 in air could be achieved using 2.5 pounds of agent per canister. For these tests copper tubing was used to deliver the agent from the canisters to desired locations in the airplane. Initial ground tests were accomplished with the equipment cooling and cabin pressurization systems OFF.

Concentrations of 4% to 7% Halon 1301 were achieved at all desired locations; however, rapid settling of the agent to the floor and into the bilge areas occurred within a minute after discharge leaving critical areas with

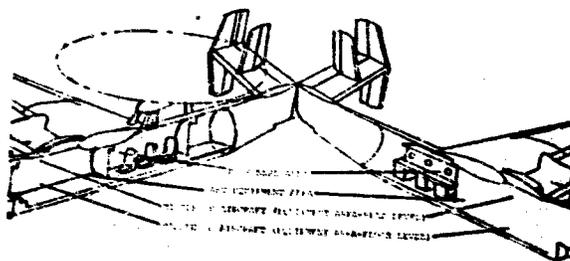


Fig. 2. E-2B cabin sections where Halon 1301 concentrations were monitored.

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Fig. 3. Halon 1301 concentrations during ground test with the equipment cooling system ON.

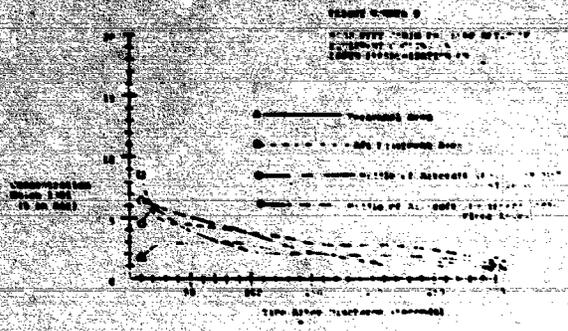


Fig. 5. Halon 1301 concentrations during flight test with equipment cooling and cabin pressurization ON.

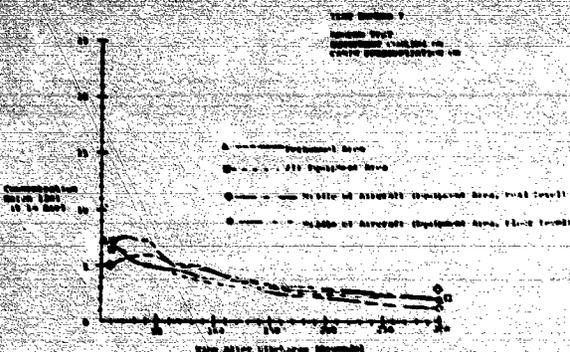


Fig. 4. Halon 1301 concentrations during ground test with equipment cooling and cabin pressurization systems ON.

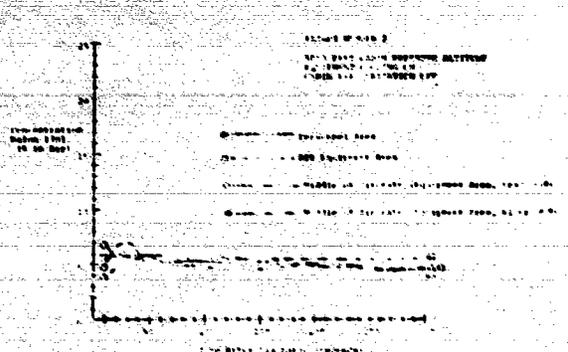


Fig. 6. Halon 1301 concentrations during flight test with equipment cooling ON.

insufficient agent for fire inerting. Subsequent tests were conducted with the airplane equipment cooling system ON. Equipment cooling is a closed-loop system which recirculates only cabin air. The equipment cooling thus provided a method of mechanical mixing and distribution of the agent with cabin air. This mixing stabilized agent concentrations at fire suppression levels at all locations (Figure 3).

The airplane cabin pressurization system had an adverse effect on maintaining adequate agent concentrations even when the equipment cooling system was ON. Because the cabin pressurization is an open-loop system allowing a continuous flow of air through the cabin which is then vented to the outside, agent concentrations were depleted below levels for inerting a fire within one minute after discharge. Figure 4 depicts agent concentrations during ground tests with the cabin pressurization system ON.

Flight Tests: During the flight tests primary consideration was given to establishing the best procedure for distributing the agent and maintaining adequate concentrations of agent for fire inerting in critical locations. During flight, with the cabin pressurization system ON, agent concentrations were depleted below fire inerting levels within 1 minute after discharge (Figure 5).

Further tests were made with the equipment cooling ON and the cabin pressurization OFF. These tests con-

firmed the results of earlier ground tests: best mixing, distribution and sustained concentrations were achieved with the equipment cooling ON and the cabin pressurization OFF (Figure 6).

When both the equipment cooling and cabin pressurization systems were OFF, rapid settling of the agent in the floor and into the bilge areas occurred leaving critical areas with insufficient concentrations for fire inerting (Figure 7).

The procedure established then was to secure the airplane pressurization system and use the airplane equipment cooling system to provide mixing and distribution. However, in some emergency conditions, the use of the equipment cooling system is contraindicated, thus an alternative procedure was also tested. A mechanical means of mixing and distributing the agent with cabin air was devised. Nozzle jets were fabricated for the ends of the copper tubing used for delivering the agent from the canisters to desired locations. Excellent mixing, distribution and sustained concentrations were achieved using the nozzle jets when both the airplane pressurization and equipment cooling systems were OFF. Figure 8 depicts agent concentrations and distribution at 5,000 feet using the nozzle jets.

Human Exposure: After the optimum agent concentration and distribution characteristics had been established in the flight tests, human exposures to Halon 1301 in-

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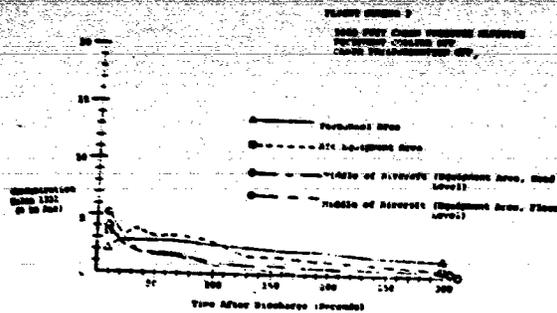


Fig. 7. Halon 1301 concentrations during flight test with equipment cooling and pressurization systems OFF.

flight were conducted. Prior to the flights each volunteer subject was thoroughly briefed on the flight profile and operation of the fire suppression system installed in the E-2B airplane. ECG leads were placed on the subjects 30 minutes before flight. Subjects then donned the personal flight clothing and survival equipment required for flight in the E-2B airplane. Each volunteer underwent a single in-flight exposure. On board the airplane, the subjects were seated in the personnel area. The same seat was used by each subject. Once the test altitude was attained the subjects were instructed to remove their oxygen masks. A 20-second countdown was given prior to the Halon 1301 discharge. Subjects breathed cabin air mixture continuously for 3 minutes following discharge of the agent, and then breathed 100% oxygen again to avoid the hypoxic effects of the highest altitude (20,000 feet) exposure. Continuous ECG monitoring for 5 minutes after discharge, and post flight analysis of the ECG recordings revealed no cardiac arrhythmias in any of the subjects. No adverse effects were narrated by the subjects during exposure. No adverse biomedical signs were noted upon examination of the subjects following the flights.

CONCLUSIONS

A sequential build-up program was conducted for evaluation of Halon 1301 as a fire suppression agent in a Navy E-2B airplane. Installation of the Halon 1301 canisters, and satisfactory routing of the delivery tubing from the canisters to give 4% to 7% Halon 1301 in air concentrations in critical areas were achieved during ground tests. During both ground and flight tests it was determined that best distribution of Halon 1301 was achieved when mechanical mixing of the agent was provided.

The airplane equipment cooling system provided excellent distribution of the agent. However, the optimum method of mixing and distributing the agent was achieved by using nozzle jets on the ends of the delivery tubing.

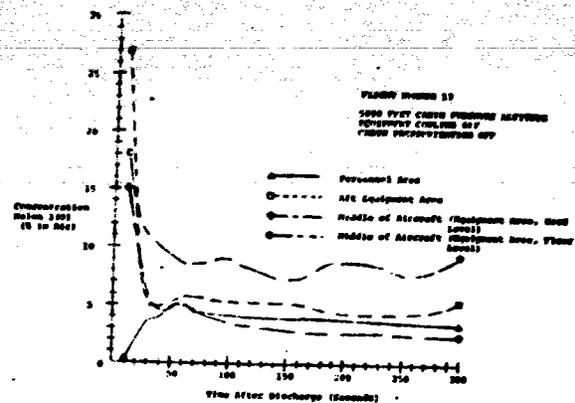


Fig. 8. Halon 1301 concentrations during flight test using nozzle jets for mixing the agent.

The airplane pressurization system must be secured in order for the agent to be optimally effective, because concentrations will be reduced below levels necessary for inerting fires through normal venting of cabin air in the open-loop pressurization system. Human exposure to the agent in concentrations up to 7% Halon 1301 in air for 3 minutes, at reduced atmospheric pressures, may be accomplished with no adverse biomedical effects. Human exposures to the agent in-flight confirmed the test results reported from the preliminary low pressure chamber tests conducted under static conditions.³ These limited tests indicate aircrew and passenger safety will not be compromised during periods of brief exposure to Halon 1301 under in-flight conditions.

The use of Halon 1301 represents a significant advance in control of airplane cabin fires. There appears to be a generous safety margin for human exposure. However, for maximum effectiveness and safety the distribution system and quantity of agent utilized must be carefully tailored for each aircraft type in which Halon 1301 systems are installed.

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A Study of Halon 1301 (CBrF₃) Toxicity Under Simulated Flight Conditions

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CALL, D. W. A study of Halon 1301 (CBrF₃) toxicity under simulated flight conditions. *Aerospace Med.* 44(2):202-204, 1973.

Halon 1301, (CBrF₃), a fire suppressant commonly used in unoccupied aircraft sections, has been proposed for similar use in occupied cabin sections. To test possible toxicity of this gas under hypobaric conditions, such as would accompany its use in flight, eight male military personnel (ages 20-35 years) were exposed for 3 minutes to either 4 or 7% Halon 1301 in air in a hypobaric chamber maintained at 760 torr (sea level), 632 torr (5,000 feet), or 380 torr (18,000 feet). Subjects' electrocardiograms obtained during and after exposures showed no changes from control tracings. Post-exposure physical examination results and pulmonary function measurements were similar to pre-exposure values. Subjects' mean reaction times, as measured by a complex reaction time task administered before, during, and after all exposures, were significantly increased ($p < 0.01$) during inhalation of 4% or 7% CBrF₃. However, no Halon 1301-related performance changes were noted on maze tracking tasks. Results of this study corroborate the findings of other tests conducted at one atmosphere and support the conclusion that Halon 1301 may be a safe fire extinguishing agent for use in occupied aircraft sections.

FIRE IS ONE HAZARD that is common to all aviation operations. Whether they occur in flight, on airport runways, on aircraft carrier decks, or in accident wreckage, aircraft fires continue to claim lives and destroy property each year. Many military and commercial aircraft have fire extinguishing systems installed in engine nacelles and cargo compartments. When these total flooding systems are activated, a predetermined amount of fire suppressant is released directly into the enclosure. However, the flight decks and cabins of few aircraft are as well protected.

Halon 1301 (bromotrifluoromethane, CBrF₃), a fire

Opinions or conclusions contained in this report are those of the author. They do not necessarily reflect the official position of the U. S. Navy or the Department of Defense. Douglas W. Call, Ph.D. (I.T., MSC, USN) is an Aerospace Physiologist currently assigned to the Aerospace Physiology Training Unit, Medical Department, Naval Air Station, Alameda, Ca 94145.

suppressant commonly used in unoccupied aircraft sections, has been proposed for similar use in occupied areas. This gas is an extremely efficient fire extinguishing agent with low toxicity.¹ Two studies, conducted at normobaric conditions, indicate that humans can be exposed briefly to Halon 1301 concentrations necessary to extinguish fires in enclosed spaces without developing the central nervous system or cardiac effects that sometimes accompany inhaling low levels of other halogenated hydrocarbons.^{2,3} However, little information is available concerning the toxicity of Halon 1301 at reduced atmospheric pressures, such as would accompany its use in flight.

To test possible potentiating effects of hypobaric conditions and the resulting hypoxia on any physiologic alterations produced by Halon 1301 inhalation, the following investigation was conducted.

MATERIALS AND METHODS

Eight active-duty male military personnel (ages 20-35 years) were exposed for 3 minutes to either 4% or 7% Halon 1301 in air in a hypobaric chamber maintained at 760 torr (sea level), 632 torr (simulated 5,000 ft.), or 380 torr (simulated 18,000 ft.). In control exposures, pulses of compressed air which generated noise levels and pressure changes similar to those produced by the Halon 1301 release were admitted to the chamber in place of the CBrF₃. This was a single-blind experiment, in that the subject was not aware of whether he breathed air or CBrF₃.

The gaseous composition of the chamber was monitored by a Hewlett-Packard, Model 5750 gas chromatograph fitted with a 6' x 1/4" O. D. stainless steel column packed with 80/100 mesh, Porapak Q. Helium was used as the carrier gas.

Before, during, and after exposure to the experimental gas, each volunteer performed a battery of psychomotor tests which included complex reaction time measures and a finger-maze tracking task. Each subject had 20 training sessions on the psychomotor tasks over

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a 2 week period prior to the experiment.

ECGs (electrocardiograms) (lead II) were obtained on each subject at regular intervals during all exposures. Physical examinations and pulmonary function measurements were performed on all subjects before and after each exposure.

RESULTS

All post-exposure physical examination results and pulmonary function measurements were similar to pre-exposure values. Subjects' electrocardiograms obtained during and after the chamber exposures showed only nonspecific changes from control tracings. No alterations were noted that could be directly attributed to the Halon 1301 inhalation or to the simulated altitude attained. **Complex reaction time test:** An analysis of variance showed statistically significant increases in complex reaction time with exposure to Halon 1301: $F(2,28) = 7.39$; $p < 0.01$ (Fig. 1). Subjects' reaction times were similar while they were breathing 4% and 7% CBrF₃. No other effects were noted. **Maze tracking task:** Analyses of variance were performed on the following measures: (1) time required to perform the task; (2) number of errors committed; (3) time spent in error; and (4) average time per error. Inhalation of Halon 1301 produced no significant changes in any of these measures. The number of errors on the maze tracking task was however, found to be significantly increased by exposure to simulated altitude: $F(2,28) = 3.72$; $p < 0.05$.

Six of the eight subjects noted subjective symptoms of dizziness, faintness, or drowsiness during exposure to 7% Halon 1301. These responses occurred with nearly equal frequencies at each simulated altitude. Three subjects reported these symptoms during each exposure to 7% CBrF₃. Similar subjective descriptions were given by three subjects while inhaling 4% Halon 1301. These symptoms were also reported once at each of the three chamber pressures.

Two subjects experienced the above symptoms during control exposures at 380 torr (simulated 18,000 ft.).

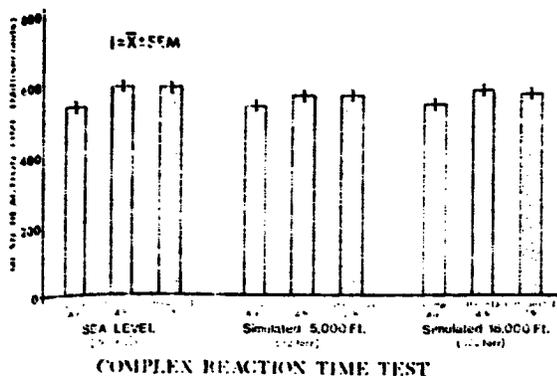


Fig. 1. Subjects' mean reaction times (milliseconds) on complex reaction time tests during exposure to all experimental conditions.

It was not possible to directly correlate the incidence of subjective symptoms during exposure to the experimental gases to psychomotor performance evaluations.

DISCUSSION

Halon 1301 is a member of a large family of halogenated hydrocarbons that are known to induce cardiac arrhythmias when inhaled during times of elevated blood epinephrine levels. These changes often originated in the ventricular myocardium and can be fatal.^{1,2,4,7,9,11} Therefore, both investigators who earlier performed human exposures to CBrF₃ at sea level obtained extensive electrocardiographic records from their subjects.^{4,8} Reinhardt and Stopps⁸ noted no disturbances in cardiac rhythm in three men exposed for 3.5 minutes to 1%, 3%, 5%, 7%, or 10% Halon 1301. At the Hine Laboratory,⁴ volunteers breathed 5% or 10% Halon 1301 in air for up to 20 minutes with no serious cardiac effects. One subject did, however, develop a spontaneous cardiac arrhythmia after inhaling a 14% Halon 1301-air mixture for 5 minutes. This condition resolved within 2 minutes after the inhalation was discontinued. Based on the results of these,^{4,8} and other studies,¹ the National Fire Protection Association (NFPA) has established standards for the use of Halon 1301 in fire extinguishing systems designed for sea level applications.¹ This publication discusses the relative toxicity of various halogenated hydrocarbon fire suppressants and prescribes limits for safe human exposure to CBrF₃ in enclosed spaces. The concentrations of Halon 1301 and duration of exposures employed in the present study were within the limits recommended by the NFPA.⁶ Since no cardiac rhythm changes were noted in the present investigations that could be directly attributable to Halon 1301 exposure, simulated altitude, or their interaction, it appears that human cardiac response to inhaling this gas at hypobaric conditions is not different from similar exposure at sea level.

Central nervous systems depression is another effect of Halon 1301 inhalation that has been extensively studied in both laboratory animals and humans.^{1,3,8,10,11} In the two sea level human studies,^{4,8} volunteers demonstrated a general trend towards loss of muscular coordination and alertness as the Halon 1301 percentages in their breathing mixtures were increased. These impairments in mental and physical skills began to appear at CBrF₃ concentrations of 5%-7%. No statistical analyses of the performance data were presented in either report, so it is not possible to directly compare the magnitude of the changes to those observed on similar tests in the present investigation. The significant increases in complex reaction time during Halon 1301 inhalation noted in this study seem to agree with the usual effect of the gas. However, the subjects' performances on the maze tracking task were not significantly affected by exposure to Halon 1301. Since different neuromuscular skills are necessary to perform different psychomotor tasks, it is to be expected that these skills could be affected to different degrees by exposure to the same agent. This type of response was demonstrated by the subjects in Hine's experiment⁴

The effects of hypoxia on human psychomotor performance are variable and not always directly related to decreasing oxygen partial pressures in the breathing mixture. Also, some performance tests are more sensitive to the effects of hypoxia than others.²⁴ Therefore, it is not surprising that during exposures to simulated altitude, subjects in this study made significantly more errors on the maze tracking task than they did at ambient conditions, but no altitude-related performance changes were noted in the other measures.

CONCLUSIONS

This investigation has extended human exposure to Halon 1301 to the concentrations and barometric pressures which might attend its use in a total flooding system in flight. There does not seem to be a significant interaction between hypobaric conditions and the resulting hypoxia and Halon 1301 inhalation on the cardiac or central nervous system effects measured in this study.

Therefore, the presently accepted National Fire Protection Association standard on Halon 1301 total flooding systems for normally occupied spaces⁴ may be applicable for aircraft cockpit and cabin installations. However, in all such systems the transient concentration gradient which develops whenever the fire suppressing agent is admitted to the enclosure must be considered. Even though no serious effects seem to accompany breathing 7% CBrF₃ for 3 minutes at a simulated

cabin altitude of 18,000 feet, there is presently no way to predict if persons seated close to the system outlet could safely tolerate the high agent concentration which would be briefly present until the gas was thoroughly mixed with cabin air. Perhaps an alarm system is necessary to allow passengers time to put on oxygen masks before the gas is released.

At any rate, the convenience and effectiveness of Halon 1301 as a fire extinguishing agent demand that work continue to find ways to take full advantage of this agent's potential usefulness.

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