TECHNICAL ASSESSMENT FOR THE SNAP PROGRAM

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INTRODUCTION

Section 612 of the US Clean Air Act of 1990 (Reference 1) requires the EPA to enact regulations making it unlawful to replace any Class I or Class II substance with any substitute that may impact human health or the environment and to publish lists of both prohibited and acceptable substitutes. The risk assessments required for each substitute will be conducted under the Significant New Applications Policy (SNAP) Program. In order for the EPA to make informed decisions about the possible substitutes, the New Mexico Engineering Research Institute was tasked under contract to ICF Incorporated to identify the current halon use areas and to suggest viable, near-term substitutes for the specific Halon 1211, 1301, and 2402 applications. Here, the term "substitutes" includes both replacement agents (halon-like chemicals) as well as alternatives (non-halon-like agents such as water, foam, and CO_2). This paper describes the effort undertaken to determine all the halon uses to date and to identify proposed substitutes.

HALON APPLICATIONS

A written and telephone survey was performed to identify the known Halon 1211,1301, and 2402 uses to date. The survey resulted in the list of uses presented in Table 1. Halon 1301 and 1211 were indicated to be in wide use in a variety of applications in fixed systems and portable use, respectively. Halon 2402 was identified as having limited use as a fire extinguishing agent in the United States, except for possible replacement in existing systems (Reference 2). It has been used extensively in other countries, particularly in Italy, in Eastern European countries, and in the Soviet Republics. The properties of Halon 2402 make it most suitable for a streaming discharge from portable systems or in localized applications. At one time, Caterpillar, Inc., had a Halon 2402 fire extinguishing system in their tractors; trucks; and large-wheel loaders for engine compartments, transmission areas, and related non-occupied area use (Reference 3). However, they no longer make this unit. It has been reported that Boeing Aircraft has used Halon 2402 in some of their

TABLE 1. HALON USE SECTORS

A. PORTABLE EXTINGUISHERS FOR FIXED FACILITIES
   1. Residential
   2. Commercial
   3. Military and Government

B. AEROSPACE APPLICATIONS
   1. Handheld Extinguishers for On-Board Aircraft
   2. Ground-Based Aircraft Fire Protection
   3. Aircraft Cargo Bays
   4. Dry Bay Explosion Suppression
   5. Aircraft Engine Nacelle
   6. Spacecraft Fire Protection
   7. Aircraft Manufacture

C. MARINE APPLICATIONS
   1. Crew Quarters
   2. Machinery Spaces
   3. Control Rooms
   4. Automobile Ferry Boats

D. CIVILIAN GROUND TRANSPORTATION
   1. Rail Transportation
   2. Vehicle Fixed Systems
   3. Vehicle Handhelds

E. TOTAL-FLOOD ELECTRONICS PROTECTION
   1. Data Processing
   2. Telecommunications
   3. Production Control Rooms
   4. Nuclear Power Plant Control Rooms
   5. Medical Facilities

F. OIL PRODUCTION, REFINING, TRANSFER, AND STORAGE
   1. North Slope Facilities
   2. Pipeline Pumping Stations
   3. Off-Shore Oil Production
   4. Other Fixed Facilities

G. PROTECTION OF NON-ELECTRONIC FACILITIES
   1. Flammable Liquid Storage
   2. Explosion Suppression
   3. Libraries, Museums, Art Galleries
   4. Records Storage
   5. Bank Vaults and Depositories
   6. Warehouses
   7. Cooking and Food Processing

H. TOTAL-FLOOD PROTECTION OF SPECIAL FACILITIES
   1. Antarctic Research Facilities
   2. Toll Booths
   3. Research Laboratories
   4. Anechoic Chambers

I. APPLICATIONS UNIQUE TO THE MILITARY
   1. Tactical Vehicles
   2. Aircraft Fuel Cell Inerting
   3. Missile Vector Control
   4. High Security Fixed Facilities

J. TRAINING AND TESTING

older 700 series aircraft, possibly the 707,727, and 747; however, personnel now at Boeing have no knowledge of that use (Reference 4). In the past, Frito-Lay, Inc., used a Halon 2402 system in their plant at Rosenberg, Texas. However, this system is no longer in use. They are now primarily using carbon dioxide for their frying vats (Reference 5). Fenwal Safety Systems have used Halon 2402 in some explosion suppression systems in the past.

Some of those systems are still in existence; however, it has proven difficult or impossible to get replacement agent (Reference 6). Halon 2402 has been used for thrust vector control in missiles; however, alternatives are under investigation (Reference 7).

NEAR-TERM REPLACEMENTS

Near-term replacements are defined as halon-like agents (halocarbons) with significant toxicological information in existence with, at the very least, data available on acute toxicity, with fire or explosion suppression testing that indicates the material could be used as a replacement for one or more halon in some applications, and the compound is or is expected to be commercially available. Here, the availability is not necessarily limited to availability as a fire extinguishant. In several cases, the chemical is or is expected to be a CFC replacement in refrigeration and other CFC applications.

Four elements are needed for an agent to qualify as a halon replacement: an acceptable environmental impact (primarily, a low ODP), a low toxicity, cleanliness/volatility, and effectiveness. It is relatively easy to meet any three of these requirements, but a replacement that meets all four requirements well has yet been identified. A number of candidate "near-term" replacement agents have been examined (Table 2), but all have trade-offs. None of the currently available halon replacement agents (or alternative agents) can be used as drop-in substitutes in existing systems and equipment. Here, we use the term "drop-in" to mean no change in equipment design or amount of agent storage required.

TABLE 2. NEAR-TERM REPLACEMENT CANDIDATES		
Candidate	Chemical Formula	Commercialization as Halon Replacement
HBFC-22B1	CHF_2Br	Great Lakes (FM 100)
HCFC-22	$CHClF_2$	Du Pont (FE 232)
HCFC-123	CF_3CHCl_2	Du Pont (FE 241)
HCFC-124	CF_3HClF	
HFC-23	CHF_3	Du Pont (FE 13)
HFC-32	CH_2F_2	
HFC-125	CF_3CHF_2	Du Pont (FE 25)
HFC-134a	CF_3CH_2F	
HFC-227ea	CF_3CHFCF_3	Great Lakes (FM 200)
FC-3-1-10	C_4F_{10}	3M (PFC 410)
FC-5-1-14	C_6F_{14}	3M (PFC 614)
NAF S-III	Blend (Primarily HCFC)	N. A. Fire Guardian
NAF P	Blend (Primarily CFCs)	N. A. Fire Guardian
Halotron I	Blend (Primarily HCFC)	American Pacific Corp.

In an attempt to compare the different replacements, information on several selection parameters was compiled in Table 3 on the list of near-term replacements.

ALTERNATIVE AGENTS

In many applications in which halons have been traditionally used, other types of fire extinguishing agents could be substituted for halogenated extinguishants. Table 4 lists some of the alternative (non-halocarbon)agents available to date. In some cases, the use of these alternative agent would also require alternative engineering or logistical approaches. Generally, water, dry chemicals, foam, and combination alternatives are suitable for some Halon 1211 applications, with CO_2 extinguishers also suitable in certain instances. Water sprinklers, CO_2 flooding, and inert gases are most suitable as Halon 1301 alternatives.

TABLE 3. ASSESSMENT OF HALON REPLACEMENT CANDIDATES

Parameter	Candidates													
	22B1	22	123	124	23	32	125	134a	227ea	3-1-10	5-1-14	NAF S-III	NAF P	Halotron I
ODP, relative to CFC-11[a]	~1.4	0.055	0.02	0.022	0	0	0	0	0	0	0	0.044[b]	0.71	0.02
GWP, relative to CFC-11[c]		0.36	0.018	0.096	13[d]		0.58	0.27	0.7[f]	18.2[e]	6-12[m]	0.31[b]		0.11-0.23[m]
Lifetime, years[c]	~7[f]	15.3	1.6	6.6	400[d]		28.1	15.5		>500[e]	>500[e]			
Availability	Now	Now	Now		Now			Now		1993	Now	Now	Now	End 1992
Ext Concentration, %[h]	4.4[i]	11.6	6.3	8.2	12.4	9[j]	9.4	10.5	5.9[f]	5.5[j]	4.4[k]	8.6[b,l]		~6.5[m]
WEq[n]	1.1	2.4	1.8	2.6	2.0	1.1	2.6	2.5	2.4	3.07	2.8	1.9		1.8
SVEq[o]	1.3	3.0	2.3	2.9	4.6	1.7	3.2	3.1	2.5	3.03	3.1	2.3		2.30
Inertion Conc., %[p]	8.0	18.8		12	19.8	17.5	14.7	13.5	12	9.5	7.2			
WEq[q]	1.6	2.5		2.6	2.2	1.4	2.8	2.2	3.2	3.5	3.8			
SVEq[r]	1.6	3.2		2.8	4.8	2.2	3.4	2.7	3.4	3.5	3.4			
Toxicity, LC_{50}, %[s]	10.8[l]	27-30	3.2[u]	23-36	66.3	>76	70	50	>80		>30[v]	30[b]		~3.2[m]
Primary Application[w]	S	T	S	T	T	T	T	T	T	T	S	T	S	S

[a] Calculated from atmospheric data provided by Dr. A. R.Ravishankara, Aeronomy Laboratory, National Oceanic and Atmospheric Administration, Boulder Colorado.
[b] Provided by North American Fire Guardian, April 16, 1992.
[c] Average values from Reference 8 unless otherwise noted.
[d] Reference 9.
[e] Reference 10
[f] Reference 11.
[g] Reference 12.
[h] Reference 13 unless otherwise noted.
[i] Reference 14 gives an extinguishment concentration of 3.9 percent for same fuel.
[j] Reference 15.
[k] Reference 16.
[l] Specified as the "Minimum Design Concentration" in Reference 17. A higher estimated concentration is expected from data supplied to EPA SNAP program by North American Fire Guardian.
[m] Estimated.

[n] Calculated weight of candidate required for flame extinguishment relative to that required for a given halon. $WEq=(EC_C/EC_R)X(MW_C/MW_R)$; EC=exting. conc., MW=Mole Weight, C=Candidate, R=reference halon. Relative to Halon 1211 for HBFC-22B1, HCFC-123, FC-5-1-14, and Halotron I; relative to Halon 1301 for other agents.
[o] Calculated storage volume of candidate required for flame extinguishment relative to that required for a given halon. $SVEq=WEqX(LD_R/LD_C)$; LD=Liquid Density. Relative to Halon 1211 for HBFC-22B1, HCFC-123, FC-5-1-14, and Halotron I; relative to Halon 1301 for other agents.
[p] Reference 18. The explosion inertion concentration of Halon is 4.3 percent.
[q] Calculated weight of candidate required for explosion inertion relative to that required for Halon 1301. $WEq=(IC_C/IC_R)X(MW_C/MW_R)$.
[r] Calculated storage volume of candidate required for explosion inertion relative to that required for Halon 1301. $SVEq=WEqX(LD_R/LD_C)$
[s] Unless otherwise noted, 4-hour rat values from Reference 15.
[t] Reference 19.
[u] Reference 20.
[v] Reference 21.
[w] S = streaming, T = Total Flood.

TABLE 4. ALTERNATIVE AGENTS			
WATER		COMBINATION	
FOAM		1.	Loaded Stream
1.	Low-Expansion Foam	2.	other
2	High- and Medium-Expansion Foam	INERT GAS	
DRY CHEMICAL		1.	Carbon Dioxide
1.	Monoammonium Phosphate	2.	Nitrogen
2.	Sodium Bicarbonate	3.	Argon
3.	Potassium Bicarbonate	4.	Helium
4.	Proprietary	5.	Inert Gases

HALON USE SECTORS AND SUBSTITUTES

Table 5 contains a list of specific halon applications divided into ten major groups. This table omits fire hazards for which halons have received little use (e.g., aircraft hanger fixed systems). Since for most applications, little performance difference exists between the physically acting replacement candidates (HCFCs, HFCs, and FCs), in many cases, only "streaming halocarbon," "flooding halocarbon," or just "halocarbon" has been noted. A streaming halocarbon is one that has suitable physical properties to allow satisfactory streaming in the application noted. Similarly, a flooding halocarbon is one that is more gaseous and will satisfactorily fill a space. Since the degree of streaming or total-flood capability needed depends on the application, no attempt has been made at this time to determine which candidates could be used. However, Table 3 indicates which replacements have properties making them more suitable for streaming or for total flood. In general, the substitutes are listed in order of decreasing preference based on the assessment as it now stands. ***It must be recognized that substitutes are proposed rather than recommended.*** In many cases, little or no testing has been performed to show the applicability of the suggested substitutes. Combinations of substitutes shown in Table 5 may provide optimal protection for specific applications.

TABLE 5. HALON USE SECTORS AND SUGGESTED SUBSTITUTES		
Application	**Substitutes**	
A. PORTABLE EXTINGUISHERS FOR FIXED FACILITIES		
1. Residential		Dry Chemical Carbon Dioxide Water Foam Combination
2. Commercial	a. Offices:	Carbon Dioxide Dry Chemical Water
	b. Manufacturing:	Dry Chemical Carbon Dioxide Water Streaming Halocarbon
	c. Retail Sales:	Dry Chemical Carbon Dioxide Water
3. Military and Government	a. Offices:	Carbon Dioxide Dry Chemical Water
	b. Special Facilities:	Dry Chemical Carbon Dioxide Water Foam Streaming Halocarbon
B. AEROSPACE APPLICATIONS		
1. Handheld Extinguishers for On-Board Aircraft	a. Passenger Areas	Loaded Stream Streaming Halocarbon
	a. Cockpit	Streaming Halocarbon Carbon Dioxide
2. Ground-Based Aircraft Fire Protection	a. Flightline	Streaming Halocarbon - Perfluorohexane - 123 or Halotron I Carbon Dioxide
	b. Crash/Rescue	Dry Chemical Foam
3. Aircraft Cargo Bays		Carbon Dioxide Inert Gas Flooding Halocarbon
4. Dry Bay Explosion Suppression		Halocarbon Dry Chemical
5. Aircraft Engine Nacelle		Halocarbon Dry Chemical

TABLE 5. HALON USE SECTORS AND SUGGESTED SUBSTITUTES		
Application	**Substitutes**	
6. Spacecraft Fire Protection	Fixed Systems:	Carbon Dioxide Inert Gas FC or HFC
	Portable:	FC or HFC
7. Aircraft Manufacture	Portable Plug-In Halocarbon	Carbon Dioxide
C. MARINE APPLICATIONS		
1. Crew Quarters	Fixed System:	Water
	Portable:	Dry Chemical Carbon Dioxide Water
2. Machinery Spaces	Fixed System:	Carbon Dioxide[a] Foam[a] Water[a] Halocarbon
	Portable:	Dry Chemical Carbon Dioxide Foam Halocarbon
3. Control Rooms	Fixed System:	Flooding Halocarbon
4. Automobile Ferry Boats	Fixed System:	Flooding Halocarbon
D. CIVILIAN GROUND TRANSPORTATION		
1. Rail Transportation		Dry Chemical Carbon Dioxide
2. Vehicle Fixed Systems		Dry Chemical Carbon Dioxide
3. Vehicle Handhelds		Dry Chemical Carbon Dioxide
E. TOTAL-FLOOD ELECTRONICS PROTECTION		
1. Nuclear Power Plant Control Rooms		Flooding Halocarbon Inert Gases
2. Telecommunications		Water Sprinklers Inert Gases
3. Production Control Rooms	Essential:	Flooding Halocarbon Inert Gases
	Nonessential:	Water Sprinklers Flooding Halocarbon Inert Gases

TABLE 5. HALON USE SECTORS AND SUGGESTED SUBSTITUTES

Application	Substitutes	
4. Data Processing	a. Occupied Areas	Water Sprinklers Underfloor CO_2 Inert Gases CO_2 with Prior Evacuation Flooding Halocarbon
	b. Unoccupied Areas	Carbon Dioxide Flood Water Sprinklers Underfloor CO_2 Inert Gases
5. Medical Facilities		Inert Gases Water Sprinklers Flooding Halocarbon
F. OIL PRODUCTION, REFINING, TRANSFER, AND STORAGE		
1. North Slope Facilities	a. Fixed Total-Flood Inert Gases	Flooding Halocarbon
	b. Portable Non-Electronic	Dry Chemical Foam Carbon Dioxide
	c. Portables Control Rooms, Electronic Areas	Carbon Dioxide Halocarbon
2. Pipeline Pumping Stations	Fixed	Carbon Dioxide Inert Gases Flooding Halocarbon
3. Off-Shore Oil Production	Fixed:	Flooding Halocarbon Inert Gases
4. Other Fixed Facilities	Storage Tanks:	Foam
G. PROTECTION OF NON-ELECTRONIC FACILITIES		
1. Flammable Liquid Storage	Fixed, Unoccupied:	Foam System Carbon Dioxide Inert Gas Flooding Halocarbon
	Fixed, Occupied:	Foam System Inert Gases Flooding Halocarbon
2. Explosion Suppression (fiberboard manufacturing, corn starch drying, coal processing, waste gas incineration, grain elevators)	Normally Unoccupied	Dry Chemical Halocarbon Inert Gases
3. Libraries, Museums, Art Galleries		Inert Gases Flooding Halocarbon Water Sprinklers

TABLE 5. HALON USE SECTORS AND SUGGESTED SUBSTITUTES		
Application	**Substitutes**	
4. Records Storage	Unoccupied:	Carbon Dioxide Inert Gas Flooding Halocarbon Water Sprinklers
	Occupied:	Inert Gases Flooding Halocarbon Water Sprinklers
5. Bank Vaults and Depositories	Unoccupied:	Carbon Dioxide Inert Gas Water Sprinklers Flooding Halocarbon
	Occupied:	Inert Gases Water Sprinklers Flooding Halocarbon
6. Warehouses	Unoccupied	Water Sprinklers Carbon Dioxide Inert Gas Flooding Halocarbon
	Occupied:	Water Sprinklers Inert Gases Flooding Halocarbon
7. Cooking and Food Processing		Dry Chemical Carbon Dioxide
H. TOTAL-FLOOD PROTECTION OF SPECIAL FACILITIES		
1. Toll Booths		Flooding Halocarbon
2. Antarctic Research Facilities	Occupied:	Inert Gases Flooding Halocarbon
3. Research Laboratories		Water Sprinklers Flooding Halocarbon
4. Anechoic Chambers		Inert Gases Flooding Halocarbon
I. APPLICATIONS UNIQUE TO THE MILITARY		
1. Fixed Systems for Tactical Vehicles	crew Compartment	Flooding Halocarbon
	Engine Compartment	*Dry* Chemical Carbon Dioxide Halocarbon
2. Aircraft Fuel Cell Inerting		Halocarbon
3. Missile Vector Control		(?)
4. High Security Fixed Facilities		Halocarbon Inert Gases
J. TRAINING AND TESTING		

[a] Work is needed to verify applicability.

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