Montreal Protocol

Halons Technical Options Committe

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1 Fire Protection Alternatives to Halon

1.1 Introduction

The phase-out of halon production has had a dramatic impact on the fire and explosion protection industry. Halons were clean, non-conductive, safe for people, and highly effective. Replacing them in their many applications continues to present challenges for fire protection professionals.

The use of traditional non-halon fire protection materials has been promoted as a means of reducing halon use. The degree to which these traditional not-in-kind alternatives successfully replace halon is driven by the details of the hazard being protected, the characteristics of the alternative method, and the risk management philosophy of the user.

Clean agent replacement chemicals and new "not-in-kind" alternative technologies have been introduced at a rapid pace. The purpose of this chapter is to provide a brief review of the types of alternatives that are available, including information on physical and chemical characteristics, fire protection capabilities, toxicity, and key environmental parameters.

As this report is being published, there are three significant changes being considered by standards making organizations that - if adopted - will affect some of the measures of performance and guidelines for use of the agents described in this chapter. These include:

- The consideration of new testing protocol(s) to measure the performance of gaseous halon alternatives on Class A fires independent of the performance of the agents in the Class B cup burner. Preliminary Class A fire tests indicate that halocarbon agent concentrations lower than the heptane cup burner value plus the 20% factor of safety will likely be found adequate for Class A fires for all the halocarbon agents listed in this report.

- The development of new procedures for determining safe personnel exposure guidelines (the PBPK or physiologically based pharmacokinetic model) where exposure time is considered in addition to the NOAEL and LOAEL values.

- The serious debate, on an international basis, on whether the minimum 20% safety factor mandated for these agents is adequate or should it be increased - perhaps to 30%.

The document, Tech Note #1 at the Halons - Reports section of the TEAP Web Site (http://www.teap.org) provides current information regarding halon alternatives and their characteristics. This document will be updated in the future to continue to provide the most current information regarding new technology halon alternatives.

The types of new technology alternatives currently include the following:

Table 1.1
New Technology Halon Alternatives

Total Flooding Gaseous Alternatives	
Halocarbons	**Composition**
HCFC:	HCFC Blend A, HCFC 124
HFC:	HFC-23, HFC-125, HFC-227ea, HFC-236fa
PFC:	FC-3-1-10, FC-2-1-8
FIC:	FIC-13I1
Inert Gases	
Nitogen:	IG-10
Argon:	IG-01
Nitrogen/argon blend:	IG-55
Nitrogen/argon/CO2 blend:	IG-541
Water Mist Technologies	**Manufacturer**
Single Fluid, Low/Moderate Pressure (3 - < 50 bar)	Grinnell, Kidde, GW Sprinkler, and Total Walther
Single Fluid, High Pressure (> 50 bar)	Marioff, Reliable, Ultra Fog, Semco, and Unifog
Dual Fluid Systems	Securiplex, ADA Technologies, Kidde and Ginge Kerr (BP)
Flashing Liquid Systems	MicroMist Ltd.
Inert Gas Generators	**Manufacturer**
	ICI and Primex
Fine Particulate Aerosols	**Manufacturer**
	Kidde, Powsus, Spectrex, Russian Research Institute for Applied Chemistry, Soyz Association, Intertexnolog Assoc., and Dynamit-Nobel
Streaming Agents	**Composition**
HCFC:	HCFC Blend B, HCFC Blend E, HCFC-124
HFC:	HFC: HFC-227ea, HFC-236fa
PFC:	PFC: FC-5-1-14

1.2 Alternatives for Fixed Systems

1.2.1 Halocarbon Agents

These agents share several common characteristics, with the details varying between chemicals. These common characteristics include the following:

1. All are electrically non-conductive;
2. All are clean agents; they vaporise readily and leave no residue;
3. All are stored as liquefied compressed gases;
4. All can be stored and discharged from fire protection system hardware that is similar to that used for halon 1301;

5. All (except HFC-23) use nitrogen super-pressurisation for discharge purposes;
6. All (except CF3I) are less efficient fire extinguishants than halon 1301 in terms of storage volume and agent weight. The use of most of these agents requires increased storage capacity;
7. All are either permanent gases after discharge or are liquefied compressed gases which vaporise upon discharge (except HCFC Blend A which consists of 3.75% of a non-volatile liquid). Many require additional care relative to nozzle design and mixing;
8. All (except CF3I) produce more decomposition products (primarily HF) than halon 1301 given similar fire type, fire size, and discharge time; and
9. All are more expensive at present than halon 1301 on a weight (mass) basis.

These agents differ widely in the areas of toxicity, environmental impact, storage weight and volume requirements, cost, and availability of approved system hardware. Each of these categories will be discussed for each agent in the following sections.

1.2.1.1 Toxicity

Table 1.2.1(b) summarises the toxicity information available for each chemical. The NOAEL is the No Observed Adverse Effect Level. This is the concentration at which no adverse effect was observed in the test specimen. The LOAEL is the Lowest Observed Adverse Effect Level. This is the lowest concentration at which an adverse effect was observed. For halocarbon agents, these levels are usually driven by the cardio-sensitisation level of the agent. Several compounds including HFC-23 and FC-3-1-10 have little or no cardio-toxicity. Historically, it has been recommended that halon replacement agents should not normally be used at concentrations above the NOAEL in occupied areas. Use of agents up to the LOAEL has been permitted in occupied areas if adequate time delays and pre-discharge alarms were provided and time required for escape was short. New recommendations have been proposed that would allow use at or above the LOAEL based on the use of a physiologically-based pharmocokinetic (PB-PK) model.

1.2.1.2 Environmental Factors

The primary environmental factors to be considered for these agents are ozone-depletion potential (ODP), global-warming potential (GWP), and atmospheric lifetime, and these are summarised in Tables 1.2.1(c). It is important to select the fire protection choice with the lowest environmental impact that will adequately provide the necessary fire protection performance for the specific application. The use of any synthetic compound that accumulates in the atmosphere carries some potential risk with regard to atmospheric equilibrium changes. PFCs, in particular, represent an unusually severe potential environmental impact due to the combination of extremely long atmospheric lifetime and high GWP.

International agreements and individual actions by national governments may affect future availability of these compounds and subsequent support for installed fire protection systems that utilise them. Some examples are presented below:

- HCFCs are scheduled for a production and consumption phase-out under the Montreal Protocol in 2020-2030 in developed countries and 2040 in developing countries.

- Currently the European Union restricts fire protection usage of HCFCs.

- HFCs and PFCs are included in the basket of six gases. The other four gases are; SF_6, carbon dioxide, methane, nitrous oxide. Flexible and binding emission reduction targets were agreed as part of the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC). The Kyoto Protocol requires developed countries to reduce their aggregate emissions of the six gases by an average of 5% below 1990 levels. HFCs and PFCs represent less than 2% of current greenhouse gas emissions on a carbon-equivalency basis.

- The United States allows use of PFCs only when no other agent or engineering approach will meet the fire protection need.

Table 1.2.1 (a)
Halocarbon Gaseous Agents for Fixed Systems
Physical Properties

Generic Name	Trade Name	Chemical Composition		Group	Stored Agent State	Vapour pressure bars @ 20º C	k1, m^3/kg (9)	k2, $m^3/kg/deg$ C (9)	Vapour Density @ 20º C (kg/m^3)	Liquid Density @ 20º C (kg/m^3)
Halon 1301	BTM	CF_3Br		Halon	LCG*	12.90	0.1478	0.00057	6.283	1,572
HCFC Blend A (HCFC-22) (HCFC-124) (HCFC-123) (isopro penyl-1-methyl-cyclohexane)	NAF S-III	Component $CHClF_2$ $CHClFCF_3$ $CHCl_2CF_3$ $C_{10}H_{16}$	Weight % 82% 9.50% 4.75% 3.75%	HCFC	LCG*: 91.5% LIQ**: 8.5%	8.30	0.2413	0.00088	3.862	1,200
HCFC-124	FE-24	$CHClFCF_3$		HCFC	LCG*	3.30	0.1575	0.00066	5.858	1,373
HFC-23	FE-13	CHF_3		HFC	LCG*	41.83	0.3164	0.00122	2.934	807
HFC-125	FE-25	CF_3CHF_2		HFC	LCG*	12.10	0.1825	0.00073	5.074	1,218
HFC-227ea	FM-200	CF_3CHFCF_3		HFC	LCG*	3.91	0.1269	0.00052	7.283	1,407
HFC-236fa	FE-36	$CF_3CH_2CF_3$		HFC	LCG*	2.30	0.1413	0.00057	6.549	1,377
FC-2-1-8	CEA-308	$CF_3CF_2CF_3$		PFC	LCG*	7.92	0.1171	0.00047	7.904	1,320
FC-3-1-10	CEA-410	C_4F_{10}		PFC	LCG*	2.84	0.0941	0.00034	9.911	1,517
FIC-13I1	Triodide	CF_3I		FIC	LCG*	4.65	0.1138	0.00050	8.078	2,096

LCG* = Liquified Compressed Gas
LIQ** = Liquid

Table 1.2.1 (b)
Halocarbon Gaseous Agents for Fixed Systems
Minimum Extinguishing Concentrations and Agent Exposure Limits

Generic Name	Trade Name	Heptane Extinguishing Concentration vol% (1)	Minimum Class B Fire Design Conc. vol% (1)	Inerting Methane/Air Design Conc. vol%	NOAEL vol% (2)	LOAEL vol% (2)
Halon 1301	BTM	3.2	5.0	4.9	5	7.5
HCFC Blend A	NAF S-III	9.9	12.0	20.1	10	>10
HCFC-124	FE-24	6.7	8.0	Not Reported	1	2.5
HFC-23	FE-13	12.5	18.0	22.2	50	<50
HFC-125	FE-25	8.1	9.7	Not Reported	7.5	10
HFC-227ea	FM-200	6.6	7.9	8.8	9	10.5
HFC-236fa	FE-36	6.1	7.3	Not Reported	10	15
FC-2-1-8	CEA-308	7.3	8.8	9.8	30	>30
FC-3-1-10	CEA-410	5.9	7.1	8.6	40	>40
FIC-13I1	Triodide	3.0	3.6	7.15 propane	0.2	0.4

Table 1.2.1 (c)
Halocarbon Gaseous Agents for Fixed Systems
Environmental Factors

Generic Name	Trade Name	Ozone Depletion Potential	Global Warming Potential* 100 yr.	Global Warming Potential* 500 yr.	Atmospheric Lifetime* years
Halon 1301	BTM	10	6,900	2,700	65
HCFC Blend A	NAF S-III	HCFC-22 = 0.05 HCFC-124 = 0.02 HCFC-123 = 0.02	HCFC-22 = 1,900 HCFC-124 = 620 HCFC-123 =120	HCFC-22 = 590 HCFC-124 = 190 HCFC-123 = 36	HCFC-22 = 11.8 HCFC-124 = 6.1 HCFC-123 = 1.4
HCFC-124	FE-24	0.02	620	190	6.1
HFC-23	FE-13	0	14,800	11,900	243
HFC-125	FE-25	0	3,800	1,200	32.6
HFC-227ea	FM-200	0	3,800	1,300	36.5
HFC-236fa	FE-36	0	9,400	7,300	226
FC-2-1-8	CEA-318	0	8,600	12,400	2,600
FC-3-1-10	CEA-410	0	8,600	12,400	2,600
FIC-13I1	Triodide	0.0001	<1	<<1	0.005

* Source of GWP and ALT values "Scientific Assessment of Ozone Depletion: 1998." World Meteorological Organization, Global Ozone Research and Monitoring Project - Report No. 44

Table 1.2.1 (d)
Halocarbon Gaseous Agents for Fixed Systems
System Features

Generic Name	Trade Name	Mass Required Relative to Halon 1301	Cylinder Storage Volume Relative to Halon 1301	Nominal Discharge Time seconds	Cylinder Pressure bar	Maximum Fill Density kg/m3 (7)
Halon 1301	BTM	1	1	10	24 to 42	1,082
HCFC Blend A	NAF S-III	1.6	1.9	10	24 to 42	900
HCFC-124	FE-24	1.5	1.5	10	24	1,140
HFC-23	FE-13	2.0	2.5	10	42	860
HFC-125	FE-25	1.6	2.2	10	24	831
HFC-227ea	FM-200	1.9	1.8	10	24 to 42	1,150
HFC-236fa	FE-36	1.6	1.4	10	24 to 42	1,200
FC-2-1-8	CEA-318	2.3	2.2	10	24 to 42	1,124
FC-3-1-10	CEA-410	2.3	1.9	10	24 to 42	1,280
FIC-13I1	Triodide	0.9	0.6	10	24	1,680

Note: Mass and volume ratios based on "Minimum Class B Fire Design Concentrations" from Table 1.2.1(b)

Notes to Tables 1.2.1 (x)

1. Nominal agent extinguishing and design concentrations are minimum values recommended by manufacturers, where available.
2. Maximum unrestricted agent concentration: NOAEL for halocarbons.
3. Maximum restricted agent concentration: LOAEL for halocarbons.
4. Liquid densities are nominal in 20-25ºC range.
5. NFPA 2001, Sec. A-2-1.4.1
6. k1 and k2 are the constants used in the vapor / gas specific volume correlation. Vapor specific volume: S = k1 + k2*t, m3/kg. Vapor density = 1/S, kg/m3 where the temperature, t, is in ºC.

1.2.2 Inert Gas Systems

There have been at least four inert gases or gas mixtures commercialised as clean total flooding fire suppression agents. Inert gases are used in design concentrations of 35-50% by volume which reduces the ambient oxygen concentration to between 14% to 10% by volume, respectively. It is known that for most typical fuels oxygen concentrations below 12-14% will not support flaming combustion. The inert gas mixtures proposed contain nitrogen and/or argon; one blend contains carbon dioxide (<8%). Although CO_2 is not an inert gas the addition of CO_2 is added by one manufacturer to act as a breathing stimulant. This may increase safety to personnel for cases where accidental (non-fire) release of the agent has occurred, however it may also increase inspiration of fire by-products during a release of the agent on an actual fire. The addition of CO_2 should be considered in relationship to the types of fuels present in the space to be protected and their likelihood of by-product formation during a fire.

Proposed commercialised inert gases/mixtures are summarised in Tables 1.2.2(a) and 1.2.2(b)

These agents are electrically non-conductive, clean fire suppressants. They differ from halocarbon agents in the following ways:

1. They are not liquefied gases. They are stored as high pressure gases and hence require high pressure storage cylinders which may have storage volume and weight impact.
2. These systems use pressure reducing devices at or near the discharge manifold. This reduces the pipe thickness requirements and alleviates concerns regarding high pressure discharges.
3. Discharge times are on the order of one to two minutes. This may limit some applications involving very rapidly developing fires.

4. Inert gas agents are not subject to thermal decomposition and hence form no by-products.

1.2.2.1 Physiological Effects

The primary health concern relative to the use of these agents is the effect of reduced oxygen concentration on the occupants of a space. The use of reduced oxygen environments has been extensively researched and studied. Many countries have granted health and safety approval for use of inert gases in occupied areas in the workplace. One product contains a limited concentration of carbon dioxide to stimulate breathing in a reduced oxygen atmosphere.

1.2.2.2 Environmental Factors

There is no concern regarding the ozone depletion or global warming potential of inert gas systems.

Table 1.2.2 (a)
Inert Gases for Fixed Systems
Physical Properties

Generic Name	IG-541	IG-55	IG-01	IG-100
Trade name	Inergen	Argonite	Argotec	NN100
Chemical composition				
Nitrogen	52%	50%	0%	100%
Argon	40%	50%	100%	0%
Carbon Dioxide	8%	0%	0%	0%
Chemical group	Inert gas blend	Inert gas blend	Inert gas	Inert gas
Agent form, stored	Compressed Gas	Compressed Gas	Compressed Gas	Compressed Gas
k1, m3/kg (9)	0.65799	0.6598	0.5612	0.7998
k2, m3/kg/deg C (9)	0.00239	0.00242	0.00205	0.00293
Specific Volume, m3/kg	0.697	0.708	0.602	0.858
Gas Density@20 C,kg/m3	1.434	1.412	1.661	1.165
Liquid Density, kg/m3 (6)	n/a	n/a	n/a	n/a
Extinguishing (8)				
Heptane extinguishing Conc., vol%	29.1	32.3	37.5	33.6
Minimum Class B fire design conc., vol% (1)	34.9	36.8	45.0	40.3
Minimum Class A fire design conc., vol% (1)	33.8	31.6	35.9	41.0
Inerting:Methane-Air, Design Conc., vol%	47.3	Not Reported	61.4	41.7

Table 1.2.2 (b
Inert Gases for Fixed Systems
Toxicity, Storage and Environmental Factors

Generic Name	IG-541	IG-55	IG-01	IG-100
Trade name	Inergen	Argonite	Argotec	NN100
Agent exposure limits				
Max unrestricted agent concentration, vol% (2)	42.8	42.8	42.8	42.8
Max restricted agent concentration, vol% (3)	52.3	52.3	52.3	52.3
Other				
In Relation to Halon 1301				
Mass Required (Class A)	2.2	2	2.8	2
Cylinder Storage Vol.	~10 (5)	~10 (5)	~10 (5)	~10 (5)
Environmental factors				
Ozone depletion potential	0	0	0	0
Global warming potential, 100 yr.	n/a	n/a	n/a	n/a
Atmospheric Life Time, yrs.	n/a	n/a	n/a	n/a
System Features				
Nominal Discharge Time, seconds	60	60	60	60
Cylinder pressure, bar	150 or 200	150 or 200	180	180 or 240

Notes to Tables 1.2.2(x)

1. Nominal agent extinguishing and design concentrations are minimum values recommended by manufacturers, where available.
2. Maximum unrestricted agent concentration: NOAEL 12% oxygen for inert gases except CO_2
3. Maximum restricted agent concentration: LOAEL 10% oxygen for inert gases except CO_2
4. Inert gas at 150 bar cylinder pressure
5. NFPA 2001, Sec. A-2-1.4.1
6. There are inconsistencies in the inert gas heptane extinguishing concentration values in relation to the heat capacities of the various agents. Heat capacity is the principal figure of merit for agents lacking chemically active extinguishing mechanisms.

1.2.3 Water Mist Technology

One of the non-traditional halon replacements which has been developed and partially commercialised is fine water mist technology. Fine water mist relies on relatively small (less than 200 m) droplet sprays to extinguish fires. The mechanisms of extinguishment include the following:

- gas phase cooling,
- oxygen dilution by steam expansion or by combustion products,
- wetting of surfaces, and
- turbulence effects.

Water mist systems have attracted a great deal of attention and are under very active development due primarily to their low environmental impact, ability to suppress three-dimensional flammable liquid fires, and reduced water application rates relative to automatic sprinklers. The use of relatively small (10-100 m) diameter water droplets as a gas phase extinguishing agent has been established for at least 40 years. Recent advances in nozzle design and improved theoretical understanding of fire suppression processes has led to the development of at least nine water mist fire suppression systems. Several systems have been approved by national authorities for use in relatively narrow application areas. To date, these applications include shipboard accommodation, storage and machinery spaces, combustion turbine enclosures, flammable and combustible liquid machinery areas as well as light and ordinary hazard sprinkler application areas.

Theoretical analysis of water droplet suppression efficiencies has indicated that water liquid volume concentrations on the order of 0.1 L of water per m^3 of air is sufficient to extinguish fires in the gas phase. This represents a potential of two orders of magnitude efficiency improvement over application rates typically used in conventional sprinklers. The most important aspect of water mist technology is the extent to which the mist spray can be mixed and distributed throughout a compartment versus the loss rate by water deposition and gravity dropout. The suppression mechanism of water mist is primarily gas phase cooling of the flame reaction zone below the limiting flame temperature. Other mechanisms are important in certain applications; for example, steam expansion/O_2 dilution has been shown to be important for suppression of enclosed 3-D flammable liquid spray fires.

While water mist offers excellent control of fires, it does not always guarantee extinguishment. Small, obstructed fires may require response team intervention to achieve total extinguishment. Applying water mist for a sufficient time period to allow response by trained fire fighters may be an important design consideration, especially where small, obstructed fires could develop.

The performance of a particular water mist system is strongly dependent on its ability to generate sufficiently small droplet sizes and distribute adequate quantities of water throughout the compartment. This depends on the droplet size, velocity, distribution, and spray pattern geometry, as well as the momentum and mixing characteristics of the spray jet and the geometry and other characteristics of the protected risk. Hence, the required application rate varies by manufacturer for the same hazard. Therefore, water mist must be evaluated in the context of a system not just an extinguishing agent.

There is no current theoretical basis for designing the optimum droplet size and velocity distribution, spray momentum, distribution pattern, and other important system parameters. This is quite analogous to the lack of a theoretical basis for nozzle design for total flooding, gaseous systems, or even conventional sprinkler and water spray systems. Hence, much of the experimental effort conducted to date is full-scale fire testing of particular water mist hardware systems which are designed empirically. This poses special problems for standards making and regulatory authorities.

There are currently two basic types of water mist suppression systems: single and dual fluid systems. Single fluid systems utilise water stored at 40-200 bar pressure and spray nozzles which deliver droplet sizes in the 10 to 100 m diameter range. Dual systems use air, nitrogen, or other gas to atomise water at a nozzle. Both types of systems have been shown to be promising fire suppression systems. It is more difficult to develop single phase systems with the proper droplet size distribution, spray geometry, and momentum characteristics. This difficulty is offset by the advantage of requiring only a high pressure water source versus water and atomiser gas storage.

Water mist systems are reasonably weight efficient. The use of small diameter distribution tubing and the possible use of composite, lightweight, high-pressure storage cylinders would increase this efficiency. It may also be possible to integrate a "central storage" of agent for use in several potential fire locations (for example, cargo and passenger cabin locations). This would further increase the benefit.

The major difficulties with water mist systems are those associated with design and engineering. These problems arise from the need to distribute the mist throughout the space while gravity and agent deposition loss on surfaces deplete the concentration and the need to generate, distribute, and maintain an adequate concentration of the proper size droplets. Engineering analysis and evaluation of droplet loss and fallout as well as optimum droplet size ranges and concentrations can be used effectively to minimise the uncertainty and direct the experimental program. Approval testing and standardisation efforts have begun. Some of these systems have received acceptance from approval authorities for limited applications. Other manufacturers are in the R&D phase with their particular hardware.

1.2.3.1 Physiological Effects

At the request of the United States Environmental Protection Agency, manufacturers of water mist systems and other industry partners convened a medical panel to address questions concerning the potential physiological effects of inhaling very small water droplets in fire and non-fire scenarios. Disciplines represented on the Panel included inhalation toxicology, pulmonary medicine, physiology, aerosol physics, fire toxicity, smoke dynamics, and chemistry, with members coming from commercial, university, and military sectors. The Executive Summary (draft "Water Mist Fire Suppression Systems Health Hazard Evaluation;" HARC, US Army, NFPA; March 1995) states the following: "The overall conclusion of the Health Panel's review is that...water mist systems using pure water do not present a toxicological or physiological hazard and are safe for use in occupied areas. Thus, EPA is listing water mist systems composed of potable water and natural sea water as acceptable without restriction. However, water mist systems comprised of mixtures in solution must be submitted to EPA for review on a case-by-case basis."

1.2.3.2 Environmental Factors

There is no concern regarding the ozone depletion or global warming potential of water mist

Table 1.2.3
Water Mist Technologies

Manufacturer	Country	Atomization Method	Activation Method
ADA Technologies	USA	Gas Atomized	Manual
Fike	USA	Gas Atomized	Smoke or heat detectors/Manual
Kidde Graviner	UK, USA	Gas Atomized	Smoke or heat detector/Manual
Ginge Kerr	UK, Denmark, Norway	Gas Atomized	Smoke or heat detector/Manual
Grinnell	USA	Impingement	Fusible link or glass bulb/Manual
GW Sprinkler	Denmark	Impingement	Fusible link or glass bulb/Manual
Chemetron	USA	Impingement	Smoke or heat detector/Manual
Marioff Hi-fog	Finland	High Pressure	Detectors/glass bulb/Manual
Microguard-Unifog	Germany	High Pressure	Fusible link or glass bulb/Manual
MicroMist	UK	Flashing	Smoke or heat detector/Manual
Reliable Automatic Sprinkler	USA	High Pressure	Smoke or heat detector/Manual
Securiplex	Canada	Gas Atomized	Smoke or heat detector/Manual
Semco	USA, Denmark,	High Pressure	Fusible link or glass bulb/Manual
Total Walther	Germany	Impingement	Smoke or heat detectors
Ultra Fog	Sweden	High Pressure	Unknown

1.2.4 Inert Gas Generators

Inert gas generators utilise a solid material which oxidises rapidly, producing large quantities of CO_2 and/or nitrogen. The use of this technology to date has been limited to specialised applications such as engine nacelles and dry bays on military aircraft. This technology has demonstrated excellent performance in these applications with space and weight requirements equivalent to those of halon 1301 and is currently being utilised in some U.S. Navy aircraft applications.

1.2.4.1 Physiological Effects

Applications to date have included only non-occupied areas. The precise composition of the gas produced will obviously affect the response of exposed persons. Significant work is required to expand application of this technology to occupied areas.

1.2.4.2 Environmental Effects

There is no concern regarding the ozone depletion or global warming potential of inert gas generators.

Table 1.2.4
Inert Gas Generator Technologies

Manufacturers
ICI
Primex

1.2.5 Fine Solid Particulate Technology

Another category of new technologies being developed and introduced are those related to fine solid particulates and aerosols. These take advantage of the well established fire suppression capability of solid particulates, with potentially reduced collateral damage associated with traditional dry powders. This technology is being pursued independently by several groups and is proprietary. To date, a number of aerosol generating extinguishing compositions and aerosol extinguishing means have been developed in several countries. They are in mass production and are used to protect a range of hazards.

One principle of these aerosol extinguishants is in generating solid aerosol particles and inert gases in the concentration required and distributing them uniformly in the protected volume. Aerosol and inert gases are formed through a burning reaction of the pyrotechnic charge having a specially proportioned composition. An insight into an extinguishing effect of aerosol compositions has shown that extinguishment is achieved by combined action of two factors such as flame cooling due to aerosol particles heating and vaporising in the flame front as well as a chemical action on the radical level. Solid aerosols must act directly upon the flame. Gases serve as a mechanism for delivering aerosol towards the seat of a fire.

A number of Russian enterprises have commercialised the production of aerosol generators for extinguishing systems which are installed at stationary and mobile industrial applications such as nuclear power station control rooms, automotive engine compartments, defence premises, engine compartments of ships, telecommunications/electronics cabinets, and aircraft nacelles.

Fine particulate aerosols have also been delivered in HFC/HCFC carrier gases. The compositions are low in cost and use relatively simple hardware. A wide range of research into aerosol generating compositions has been carried out to define their extinguishing properties, corrosion activity, toxicity, and effect upon the ozone layer as well as electronics equipment.

Solid particulates and chemicals have very high effectiveness/weight ratios. They also have the advantage of reduced wall and surface losses relative to water mist, and the particle size distribution is easier to control and optimise. However, there is concern of potential collateral damage to electronics, engines, and other sensitive equipment. They are unsuitable for explosion suppression or inerting since pyrotechnic/combustion ignited aerosols can be re-ignition sources. These agents also have low extinguishing efficiency on smouldering materials. Technical problems including high temperature, high energy output of combustion generated aerosols and the inability to produce a uniform mixture of aerosol throughout a complex geometry remain to be solved.

1.2.5.1 Physiological Effects

There are several potential problems associated with the use of these agents. While none of these problems has been proven, they remain potential concerns. These effects include inhalation of particulate, blockage of airways, elevated pH, visibility, and the products of combustion from combustion generated aerosols, such as HCl, CO, and NOx.

1.2.5.2 Environmental Factors

There are no environmental concerns with respect to ODP or GWP for solid particulates beyond those of carrier gases (if any) that may be used.

Table 1.2.5
Fine Particulate Aerosol Technologies

Manufacturers
Kidde
Powsus
Spectrex
Russian Research Institute for Applied Chemistry
Soyz Association
Intertexnolog Assoc
Dynamit-Nobel

1.3 System Design Considerations for Fixed Systems

The new gaseous fire extinguishing agents are less forgiving in total flooding applications than halon 1301. Care must be taken throughout the design process to assure satisfactory system performance. Halon 1301 typically employed safety factors of 60% to over 100%. This extra margin did not require the very high degree of attention required to apply the new technology agents in a reliable manner. Hazard definition, nozzle location and design concentration must be specified within carefully defined limits. Further, a high degree of enclosure integrity is required. Design requirements are provided by national and international standards such as NFPA 2001 and ISO 14520. An outline of factors to be taken into consideration is given below.

1.3.1 Definition of the Hazard

- Fuel type(s)
- Fuel loading
- Room integrity (openings, ventilation, false ceilings, sub-floors)
- Dimensions and Net Volume of the room
- Temperature extremes

1.3.2 Agent Selection

- Statutory approvals
- Personnel safety (occupied, not occupied?)
- Minimum concentration required (cup burner / full scale tests)
- Design concentration required with factor of safety
- NOAEL / LOAEL okay at minimum volume, max temperature and design

concentration

- Decomposition characteristics
- Replenishment availability

1.3.3 System Selection

- System intended for use with the agent selected

  Pressures, elastomers, gauges, labels

- System has appropriate approvals as the result of third party testing

  Strength tests (containers, valves, gauges, hoses, etc.)
  Leakage tests
  Cycle testing of all actuating components
  Corrosion tests
  Cylinder mounting device tests
  Ageing tests for elastomers
  Flow tests (software verification, balance limitations)
  Fire tests (nozzle area coverage, nozzle height limitations

- System has documented design, installation, maintenance procedures

1.3.4 System Design

- Automatic detection and control

  Type of detection (smoke, heat, flame, etc.).
  Logic (cross zoned, priority designated)
  Control system features
  Local and remote annunciation
  Start up and shut down of auxiliary systems
  Primary and back-up power supply
  Manual backup and discharge abort controls

- Central agent storage, distributed or modular
- Electrical, pneumatic or electrical/pneumatic actuation
- Detector location
- Alarm and control devices location
- Class A (control loop) or Class B electrical wiring

- Electrical signal and power cable specifications
- Nozzle selection and location
- Piping distribution network with control devices
- Piping and other component hangers and supports
- Agent hold time and leakage
- Selection of an appropriate design concentration
- Agent quantity calculations
- Flow calculations
- Pipe size and nozzle orifice determination

1.3.5 System Installation

- Installed per design
- System recalculated to confirm "as built" installation
- Correct piping

  Size
  Routing
  Number and placement of fittings
  Pipe supports
  Correct type, style, orifice size nozzle in each location

- Fan test to confirm tightness of protected volume
- Acceptance functional test of full system without discharge

  Test each detector's operation
  Test system logic with detection operation
  Test operation of auxiliary controls
  Test local and remote annunciation
  Test signal received at system valve actuators
  Test system manual operators
  Test system abort discharge abilities

1.3.6 Follow Up

- Integrity of the protected space does not change

  Walls, ceiling and floor intact
  Any new openings sealed properly

- Net volume and temperature range of the space does not change

- Regular maintenance for detection, control, alarm and actuation system
- Regular verification of the agent containers' charged weight
- Regular cleaning of the detection devices
- Confirmation of back-up battery condition

1.4 Alternatives for Portable Extinguishers

1.4.1 Traditional Streaming Agents

1.4.1.2 Straight Stream Water

Straight stream water is suitable for use on fires of ordinary combustibles such as wood, paper and fabrics only. This type of extinguisher is unsuitable for use in extinguishing fires involving liquids or gases and in fact could spread a flammable liquid fuel. Straight stream water extinguishers are unsafe for use on fires where electrical circuits are present.

1.4.1.2 Water Fog (Spray)

Water spray extinguishers are most suitable for use on fires of ordinary combustibles such as wood, paper and fabrics. This type of extinguisher may be less effective on deep-seated fires. The spray stream is generally more effective on burning embers and may provide a very limited capability for fires involving combustible liquid fuels. Some water spray extinguishers can be used on fires where live electrical circuits are present. Users should ensure that the extinguisher has been tested and certified before use on live electrical circuits.

1.4.1.3 Aqueous Film Forming Foam (AFFF)

AFFF extinguishers generally may increase the effectiveness of water on fires of ordinary combustibles such as wood, paper and fabrics and provide a limited capability to extinguish fires involving flammable or combustible liquids. As well, this agent has the ability to reduce the likelihood of ignition when applied to the liquid surface of an unignited spill. The aqueous film forming foam reduces vapor propagation from the flammable liquid.

Depending upon the stream pattern, this type of extinguisher may not be safe for use on fires where live electrical circuits are present.

1.4.1.4 Carbon Dioxide (CO2)

Carbon dioxide extinguishers use CO2 as a liquefied compressed gas. Carbon dioxide is most suitable for use on fires involving flammable liquids. Carbon dioxide does not conduct electricity and can be used safely on fires involving live electrical circuits. In general, carbon dioxide extinguishers are not capable of extinguishing fires of ordinary combustibles such as wood, paper and fabrics.

1.4.1.5 Dry Powder

Dry chemical extinguishers are of two types. Ordinary dry chemicals, usually formulations based on sodium bicarbonate, are suitable for fires involving flammable liquids and gases. Multipurpose dry chemicals, usually formulations of ammonium dihydrogenphosphate, are suitable for use on fires of ordinary combustibles such as wood, paper and fabrics and fires involving flammable liquids and gases. Both ordinary and multipurpose dry chemicals may be safely used on fires where electrical circuits are present; however, after application dry chemical residue should be removed because in the presence of moisture it could provide an electrical path that would reduce insulation effectiveness.

1.4.2 Halocarbon Agents

Information on halocarbon streaming agents is contained in Table 1.4.2. These agents come closest to matching all the desirable properties of halon 1211. For example they are effective on both solid and liquid fuel fires and they permeate well avoiding secondary damage. However, in general, they are more expensive than traditional fire protection agents.

1.4.2.1 Toxicity

The toxicity of streaming agents is assessed based on the likely exposure of the person using the extinguisher. This is sometimes measured using breathing zone samples. All of the streaming agents discussed above are considered safe for normal use. Use of some of these agents in confined spaces may be a cause for concern.

1.4.2.2 Environmental Factors

The environmental factors for halocarbon streaming agent alternatives are the same as those discussed for halocarbon total flooding agents. Information on ODP, GWP and atmospheric lifetime are presented in Table 1.4.2. Traditional streaming agents do not present environmental concerns in the areas of ODP, GWP, or atmospheric lifetime.

Table 1.4.2
New Technology Streaming Agents

Physical Characteristics						**Environmental Factors**			
Generic Name	Trade Name	Group	Storage State	Chemical Composition: Weight %	Chemical Composition: Species	ODP	GWP 100 yrs	GWP 500 yrs	Atmospheric Lifetime (yrs)
Halon 1211	BCF	Halon	LCG*	CF_2ClBr		3	1300	390	11
HCFC Blend B	Halotron I	HCFC/ PFC Blend	LCG*	>96%	HCFC-123	0.02	120	36	1.4
				<4%	CF_4	0	5700	8900	50000
				<4%	Argon	0	n/a	n/a	n/a
HCFC Blend E	NAF P-IV	HCFC Blend	LCG*/ Liquid	90%	HCFC-123	0.02	120	36	1.4
				8%	HFC-125	0	3800	1200	32.6
				2%	isopro-penyl-1-methyl-cyclohexene	0	n/a	n/a	n/a
HCFC-124	FE-24	HCFC	LCG*	$CHClFCF_3$		0.022	620	190	6.1
HFC-236fa	FE-36	HFC	LCG*	$CF_3CH_2CF_3$		0	9400	7300	226
HFC-227ea	FM-200	HFC	LCG*	CF_3CHFCF_3		0	3800	1300	36.5
FC-5-1-14		PFC	LCG*	C_6F_{14}		0	9000	13200	3200

*LCG - Liquified Compressed Gas
**ODP - Ozone Depletion Potential
***GWP - Global Warming Potential

1.5 Selecting an Alternative Streaming Agent

1.5.1 Assessment of Alternative Streaming Agents

The important features of alternative, manually applied fire extinguishing agents are described below. In general portable extinguishers are only used on actual fires and can be readily directed at the burning material.

1.5.1.1 Effectiveness on Ordinary Combustibles

This parameter considers the ability of the agent to extinguish fires in ordinary solid combustibles, including cellulosics. These are called Class A fires and the extinguisher should carry a rating categorising its Class A performance.

1.5.1.2 Effectiveness on Liquid Fuel Fires

This parameter considers the ability of the agent to extinguish liquid fuel fires (Class B). The extinguisher should carry a Class B rating.

1.5.1.3 Electrical Conductivity

Minimal conductivity is important in fighting fires where electricity is involved.

1.5.1.4 Ability to Permeate

This parameter reflects the ability of the agent to extinguish fires in locations where direct application to the fuel surface or flame reaction zone is not possible, for example, in the floor void of a commercial airliner.

1.5.1.5 Range

This parameter reflects the ability of the agent to maintain a coherent effective stream over a modest distance.

1.5.1.6 Effectiveness to Weight Ratio

This parameter considers the relative fire suppression capability across all fuels per unit weight of agent.

1.5.1.7 Secondary Damage

This category refers to the “clean agent” aspects of the agents, i.e. secondary damage caused by the suppressant agent itself.

1.5.2 Match the performance of the Alternative Streaming Agent to the Hazard

The performance of each alternative is summarised in the table below. The relative importance of each parameter has not been rigorously derived and final selection depends on detailed knowledge of the risk to be protected.

Table 1.5.2
Streaming Agents for Portable Fire Extinguishers

Type	Ordinary Combustibles	Flammable Liquids	Electrically Non Conductive	Ability to Permeate Concealed Spaces	Stream Range	Effective Weight	Secondary Damage
CO_2	Poor	Fair	Yes	Good	Fair	Poor	Good
Multi-purpose Dry Powder	Good	Good	Yes	Fair	Very Good	Good	Poor
AFFF	Good	Fair	No	Poor	Good	Poor	Poor
Water Stream	Good	Ineffective	No	Poor	Good	Poor	Poor
Water Fog	Good	Fair	Yes	Fair	Fair	Fair	Fair
Halocarbons	Good	Good	Yes	Good	Good	Good	Good
Halon 1211	Good	Good	Yes	Good	Good	Good	Good

1.6 Ongoing Research.

Developing new agents and approaches entails far more than identifying potential substitutes. Manufacturing and economic feasibility are important considerations. Proper implementation also requires a major effort to be done properly.

The early focused program for identifying efficient fire suppressants was conducted for the United States Army following needs documented during WWII. The 'Purdue' laboratory study identified halon 1301, 1211, 2402, and CF_3I, among other chemicals, as potential effective agents. Halon 1301, with high efficiency and low toxicity, became a near universal total flooding agent until the realisation of the stratospheric ozone layer depletion phenomenon.

The gaseous agents listed in the Tables presented in this chapter provide commercialised solutions for halon replacement. However, no gaseous replacement has been identified to date that adequately matches halon 1301 characteristics in terms of space, weight, discharged gas volume, and toxicity. In some applications the minimisation of these characteristics in a replacement agent or extinguishing system is critical. The number of potential applications is thus somewhat limited. In a number of cases, the original halon discharge and dissemination systems were never fully optimised. Halon was so efficient and cheap that over designed systems were satisfactory approaches. System optimisation may now allow less efficient agents to provide the required performance. An improved discharge system is being investigated for enabling a less efficient HFC agent for use as a 'drop-in' halon replacement in a US Navy aircraft engine nacelle fire protection system.

In other cases, a re-evaluation of requirements, changing from what is desired to what is required, may enable halon alternative usage. Water mist systems have difficulty extinguishing small, obstructed fires, but should extinguish larger fires and adequately control the smaller fires. This allows minimising damage and directly addressing the remaining fires by response personnel.

Optimum system selection is very application dependent. Minor differences may lead to entirely different solutions. Care must be taken against transfer of a solution from one case to another without a thorough understanding of the underlying considerations and ramifications. The bottom line is: in most cases, solutions currently exist for most halon applications, provided intelligent fire protection engineering design is conducted.

There remains to be addressed a minority of halon uses for which agent physical and performance properties essentially identical to those of halon 1301 are required. These applications constitute very difficult problems and include many of the remaining critical uses. Many of these needs are in military applications and the bulk of research is driven by those needs. The largest programs on halon replacement are by the United States (Department of Defense, Coast Guard and Federal Aviation Administration), and by Russia, the United Kingdom (Ministry of Defence), and Canada (Department of National Defence).

The US Air Force is investigating engine nacelle dynamics including computer modelling. The US Army program has identified a solution for existing armoured vehicle engine compartments, and is currently conducting trials of vendor proposals for crew compartments. The Army is implementing a US Navy developed hybrid gaseous agent/water spray system for water craft. The US Navy has evaluated both water mist and HFC based systems for new ship class construction. Current Navy research is to provide gaseous agent implementation specification guidance including nozzle placement, and to continue to seek more optimum replacement solutions for future construction and retrofit. The platform specific efforts will likely end within two years, transitioning into implementation.

A more general effort was initiated in 1997 in the United States funded by the Strategic Environmental Research and Development Program (SERDP) focused specifically on halon retrofits for existing weapon platforms. This is the Next-Generation Fire Suppression Technology Program (NGP). The goal of this joint Department of Defense - SERDP effort is to develop and demonstrate, by 2004, retrofitable, economically feasible, environmentally acceptable and user-safe processes, techniques, and fluids that meet the operational requirements currently satisfied by halon 1301 systems in aircraft, ships, land combat vehicles, and critical mission support facilities.

As well, there are other research programs being undertaken, including those of the Advanced Agent Working Group, European JAA and several major fire equipment manufacturers.

1.7 Conclusion

New and existing alternatives exist for most halon applications. Where replacement of halon 1301 is especially difficult (for example, ground combat vehicle crew bays, certain aviation applications, and inertion of flammable liquids) substantial research and development is underway.