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Fire Protection

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EXECUTIVE SUMMARY

Halons are gaseous fire- and explosion-suppression agents that leave no damaging residue and are safe for human exposure. They are inexpensive to make, forgiving to use and applicable across a wide range of conditions. Despite these challenging benchmarks halons are no longer needed for over 95% of the applications that used halons before the Montreal Protocol. This transformation came about through a combination of national regulations, research, commercial product development and the approval of alternatives under fire protection regulations.

The ozone layer

The environmental goal of ozone protection is being achieved with a growing base of newly installed systems which now use halon alternatives. Seventy-five percent of the applications that originally used halons have shifted to agents with no climate impact. Four percent of the original halon applications continue to employ halons. The remaining 21% have shifted to HFCs and a small number of applications have shifted to PFCs and HCFCs. While this is a significant achievement, it is tempered by the reality that there remains a large base of installed halon systems and the eventual choice of alternatives for these systems remains unknown at this time.

Past practice (1987–2002)

Before the Montreal Protocol, HFCs, PFCs and HCFCs were not used in fire protection. Their current, and growing, usage is a direct result of their adoption as halon alternatives, despite being inferior to halons both in terms of cost and performance. Because fire protection is regulated in most countries, only those agents meeting minimum acceptable fire extinguishment and life-safety performance levels have been certified. About half of former halon users are now choosing to protect new installations with zero-ODP gaseous (in-kind) clean agents. Some have no significant effect on the climate system, while others have substantial GWPs. The other half are choosing non-gaseous (not-in-kind) agents, such as water, water mist, dry chemical, foam and aerosols, all of which produce no direct greenhouse-gas emissions. There are a small number of users that have adopted HCFC-123, HCFC-22 and HCFC-124 agent blends.

Emissions of gaseous halon alternatives are very small compared with those estimated for halon. This is the result of cooperation between industry and governments to implement standards for system maintenance, training and certification programmes, and equipment that minimizes or eliminates escape during transfer and detects leaks from storage. Emissions are estimated to range from 1 to 3% of the fixed-system bank and 2 to 6% of the portable extinguisher bank per year.

With the exception of civil aviation applications, where the added weight of halon alternatives produces indirect emissions through additional fuel use over the aircraft's life, the indirect greenhouse-gas emissions are negligible compared with the direct effects. Total equivalent warming impact (TEWI) and life cycle climate performance (LCCP) are therefore not particularly relevant to fire protection.

Recent modelling suggests the global fixed-system bank for HFCs, PFCs and HCFCs at the end of 2002 was 22,000 tonnes, with 1.1 $MtCO_2$-eq of emissions at a 2% emission rate. For portable extinguishers, the global bank of HFCs, PFCs and HCFCs was approximately 1,500 tonnes at the end of 2002, with 0.12 $MtCO_2$-eq of emissions at a 4% emission rate.

The most recent estimate from the Halons Technical Options Committee (HTOC) of the size of the existing halon bank and annual emission rates (2002) is 42,000 tonnes with 2,100 tonnes of emissions for halon 1301, and 125,000 tonnes with 17,000 tonnes of emissions for halon 1211 (HTOC, 2003). Atmospheric measurements in 2002 for halon 1301 suggest emissions of 1000–2000 tonnes and emissions of 7,000–8,000 tonnes for halon 1211. Halon 2402 was used mainly in the former Soviet Union and no information on banks or emissions was found in the literature.

Present practice (2003–2004)

In fixed systems where a clean agent is necessary, the alternatives currently available are carbon dioxide (lethal at concentrations that extinguish fires) and inert gases, HFCs, PFCs, HCFCs and more recently, a fluoroketone[1] (FK). Carbon-dioxide and inert-gas systems account for approximately half of the new clean-agent systems, with HFCs, PFCs, HCFCs and FK accounting for the other half. HFCs are playing an important role in the transition away from halon where the unique properties of this type of agent are required to achieve safe, fast fire extinguishing without causing residual damage. PFCs played an early role but current use is limited to the replenishment of previously installed systems. The current fixed system bank of HFCs, PFCs, HCFCs and FK was estimated to be 27,000 tonnes at the end of 2004 with 1.4 $MtCO_2$-eq of emissions at a 2% emission rate.

Compared to halon 1211, portable extinguishers using HFCs, PFCs and HCFCs have achieved very limited market acceptance, primarily because of their high cost. PFCs are limited to use as a propellant in one manufacturer's portable extinguisher agent blend. The portable extinguisher bank based on information from a producer is approximately 1,850 tonnes, with 0.16 $MtCO_2$-eq of emissions at a 4% emission rate at the end of 2004.

In the case of fixed clean-agent systems, four main factors contribute to the choice of replacement agents: performance, life safety, cost and environmental concerns. In addition, two other factors may be important in some instances: demonstrated special capabilities and multiple supply sources. For portable extinguishers, cost is the main factor. Table 9.1 compares the performance of the available alternatives for gaseous fire extinguishing systems and Table 9.2 does the same for portable fire extinguishers.

[1] Fluoroketone (FK) - An organic compound in which two fully fluorinated alkyl groups are attached to a carbonyl group (C=O).

The future (2005–2015)

During this period, the use of HFCs and FK for fire protection is expected to increase due to general economic expansion and improvements in technologies that allow these materials to displace current halon applications. The halon alternatives most likely to be employed through 2015 are identified in Tables 9-1 and 9-2.

HTOC (2003) estimates that significant quantities of halon will remain in the global bank in 2015. The figures for halon 1301 are as follows: in 2005, there will be a bank of 39,000 tonnes with 1,900 tonnes of emissions; in 2010, there will be a bank of 31,000 tonnes with 1,500 tonnes of emissions and, in 2015, there will be a bank of 24,000 tonnes with 1,300 tonnes of emissions. The figures for halon 1211 are: a bank of 83,000 tonnes with 16,000 tonnes of emissions in 2005, a bank of 33,000 tonnes with 6,000 tonnes of emissions in 2010 and a bank of 19,000 tonnes with 1,600 tonnes of emissions in 2015.

Modelling suggests an HFC/HCFC/PFC/FK fixed-system bank of 67,000 tonnes with annual emissions of 4 $MtCO_2$-eq in 2015 at an emission rate of 2%. In the absence of a change in emission rate, total annual emissions will change in proportion to changes in the installed base. For the portable extinguisher bank, projections of information provided by a producer are 4,000 tonnes in 2015 with 0.34 $MtCO_2$-eq of emissions at a 4% emission rate.

Clean-agent demand will be influenced by economic growth and decisions by regulators and halon owners regarding the disposition of agent from decommissioned systems. If decommissioned halon is destroyed, the demand for new clean agents will increase, probably in the same proportion as for new systems. In addition, clean-agent demand will be influenced by existing and future regulation. As research into new fire protection technologies continues, additional options will likely emerge. However, due to the lengthy process of testing, approval and market acceptance of new fire protection equipment types and agents, no additional options are likely to be available in time to have appreciable impact by 2015.

Since the Montreal Protocol, the fire protection community has become much more active in managing emissions. Industry practices of capturing, recycling and reusing halons have carried over to all high-value gaseous agents, including HFCs, HCFCs and PFCs. There is no reason to believe they will not also apply to any additional agents entering the market. Because of their more complex chemistries, halon replacements are unlikely to ever be as inexpensive as halons. As a result, there is both a market incentive as well as an industry culture that encourage the capture, recycling and reuse of fire-fighting agents. Adhering to these practices, including certification programmes, has been shown to minimize emissions and to limit the use of these agents to applications where their cleanliness is needed. In countries where high levels of regulation exist, the emission rates have been estimated at 1% or less; the figure is 2% where levels of regulation are average and approaches 3% where there is less regulation. Portable extinguishers have an emission rate of approximately 4%.

Table 9.1. Comparison table – clean-agent systems suitable for occupied spaces.

Fixed systems	Halon 1301 (reference)	HFC-23	HFC-227ea	HFC-125[1]	FK- 5-1-12	Inert Gas
Substance characteristics						
Radiative efficiency (W m^{-2} ppb^{-1})	0.32	0.19	0.26	0.23	0.3	N/A
Atmospheric lifetime (yr)	65	270	34.2	29	0.038	N/A
Direct GWP (100-yr time horizon)						
- This report	7030	14,310	3140	3450	not	N/A
- IPCC (1996)	5400	11,700	2900	2800	available[2]	
Ozone depletion potential	12	~0	-	~0	-	N/A
Technical data						
Demonstrated special capabilities	yes	yes[3]	yes[4]	yes[4]	note[6]	no
Weight (kg m^{-3}) [a]	0.8	2.3	1.1	1.1	1.2	4.3
Area (10^4 m^2/m^3) [b]	5.8	12.0	6.8	7.4	7.3	28.2
Volume (10^4 m^3/m^3) [c]	8.6	18.0	13.1	14.4	13.8	56.6
Emission rate [d]	2 ± 1%	2 ± 1%	2 ± 1%	2 ± 1%	2 ± 1%	2 ± 1%
Costs						
Investment cost (relative to halon 1301)	100%	535%	377%	355%	484%	458%
Additional service costs (US$ kg^{-1}) [e]	0.15	0.43	0.60	0.53	0.72	0.31
Additional recovery costs at end-of-life	(3.85)	(10.75)	(15.07)	(13.20)	(18.00)	0.00
(US$ kg-1) [f] ( ) indicates income						
HFC abatement costs (US$ per tCO_2-eq) [g]	-	-	-	-	21–22	14–27
Commercial considerations						
Multiple agent manufacturers	-	yes	yes	yes	no[7]	yes

Notes:

[a] Average weight of the agent storage containers and contents in kilogrammes per cubic metre of space protected.

[b] Average area of a square or rectangle circumscribing the agent cylinder bank expressed in square metres x 10^4 per cubic metre of volume protected.

[c] Average volume is the area multiplied by the height of the cylinders measured to the top of the valves expressed in cubic metres x 104 per cubic metre of volume protected.

[d] Total average in-service-life annual emissions rate including system discharges for fire and inadvertent discharges.

[e] Additional annual service costs are based on the replacement of 2% of the agent charge emitted per year.

[f] For the halocarbon agents, the end-of-life agent value is positive and represents a cost recovery equivalent to 50% of the initial cost of the agent as the agent is recovered, recycled and resold for use in either new systems or for the replenishment of existing systems.

[g] HFC abatement costs for FK-5-1-12 and inert gas are based on HFC-227ea, the predominant HFC, as the reference. The lower value reflects the cost in US$ per tonne of CO_2-equivalent at a discount rate of 4% and tax rate of 0%. The range includes both the lowest and highest of costs for the USA, non-USA Annex 1 and non-Annex 1 countries.

Explanation of special capabilities:

1. In some jurisdictions HFC-125 is not allowed for use in occupied spaces while in other jurisdictions that use is permitted under certain conditions.
2. Due to the short atmospheric lifetime, no GWP can be given. It is expected to be negligible for all practical purposes (Taniguchi *et al*., 2003). See Section 2.5.3.3 'Very short-lived hydrocarbons' for additional information.
3. HFC-23 is effective at low temperatures (cold climates) and in large volumes due to its high vapour pressure.
4. HFC-227ea is effective in shipboard and vehicle applications due to extensive large-scale testing that has established the use parameters and demonstrated its specialized capabilities in these applications.
5. HFC-125 is effective in vehicle and aircraft engine applications as a result of extensive large-scale testing that has established the use parameters and demonstrated its specialized capabilities in these applications.
6. FK-5-1-12 is in the early stages of its product life cycle and has yet to be tested for special applications beyond those achieved through the conventional approval testing of the requirements in ISO and NFPA type standards.
7. While the agent FK-5-1-12 is a proprietary product of a single agent-manufacturer, the agent is available from multiple systems manufacturers.

Table 9.2. Comparison table – extinguishing agents for portable fire extinguishers.

Portable systems	Halon 1211 (reference)	HCFC Blend B	HFC-236fa	Carbon Dioxide	Dry Chemical	Water
Substance characteristics						
Radiative efficiency (W m^{-2} ppb^{-1})	0.3	Note [a]	0.28	See Ch. 2	-	-
Atmospheric lifetime (yr)	16	Note [a]	240	See Ch. 2	-	-
Direct GWP (100-yr time horizon)						
- This report	1860	<650 [a]	9500	1	-	-
- IPCC (1996)	not given	<730 [a]	6300	1	-	-
Ozone depletion potential	5.3	<0.02 a	-	-	-	-
Technical data						
Agent residue after discharge	no	no	no	no	yes	yes
Suitable for Class A fires	yes	yes	yes	no	yes	yes
Suitable for Class B fires	yes	yes	yes	yes	yes	no
Suitable for energized electrical	yes	yes	yes	yes	yes	no
Extinguisher fire rating [b]	2-A:40-B:C	2-A:10-B:C	2-A:10-B:C	10-B:C	3-A:40-B:C	2-A
Agent charge (kg)	6.4	7.0	6.0	4.5	2.3	9.5
Extinguisher charged weight (kg)	9.9	12.5	11.6	15.4	4.15	13.1
Extinguisher height (mm)	489	546	572	591	432	629
Extinguisher width (mm)	229	241	241	276	216	229
Emission rate [c]	4 ± 2%	4 ± 2%	4 ± 2%	4 ± 2%	4 ± 2%	4 ± 2%
Costs						
Investment costs (relative to halon 1211)	100%	186%	221%	78%	14%	28%
Additional service costs (US$ kg^{-1})	- [d]	- [d]	- [d]	- [d]	- [d]	- [d]
Additional recovery costs at end-of-life (US$ kg^{-1})	- [d]	- [d]	- [d]	0.00	0.00	0.00

Notes:

[a] HCFC Blend B is a mixture of HCFC-123, CF_4 and argon. While the ratio of the components is considered proprietary by the manufacturer, two sources report that HCFC-123 represents over 90% of the blend on a weight basis, with CF_4 and argon accounting for the remainder. The atmospheric lifetime of HCFC-123 is 1.3 years; this figure is 50,000 years for CF_4.

[b] Fire extinguisher rating in accordance with the requirements of Underwriters Laboratories, Inc. The higher the number, the more effective the extinguisher.

[c] This value is the total average in-service-life annual emissions rate, including both intentional discharges for fire and inadvertent discharges.

[d] This information is neither in the literature nor available from other sources, as it is considered confidential.

9.1 Introduction

Halons are halogenated hydrocarbons that contain bromine and exhibit exceptional fire-fighting effectiveness. They are known as "clean agents" because they are volatile liquids or gases, electrically non-conductive and leave no residue. As gases, when dispensed in air, they can extinguish hidden fires and those with complex geometries (three-dimensional fires). At least one halon (1301) is safe for human exposure at concentrations that will extinguish fires. In short, they are easy to use, versatile and inexpensive.

After their introduction in the early 1960s, the use of halons grew steadily worldwide until the Montreal Protocol required an end to their production by 1/1/94 in developed countries. Global production of halon 1211 and 1301 peaked in 1988 at 43,000 and 13,000 tonnes respectively (HTOC, 1991). In developing countries halon 1211 production began in the 1980s, and showed a growth curve similar to developed countries until Multilateral Fund projects began to reverse that trend in the 1990s (HTOC, 2003). A third halon, 2402, was mainly used in the former Soviet Union. No information on emissions or bank size was found in the literature.

The most recent estimate of the Halons Technical Options Committee (HTOC) of the existing halon bank (their 2002 assessment report (HTOC, 2003)) is as follows. For halon 1301: a bank of 39,000 tonnes with 1,900 tonnes of emissions in 2005, a bank of 31,000 tonnes with 1,500 tonnes of emissions in 2010 and a bank of 24,000 tonnes with 1,300 tonnes of emissions in 2015. For halon 1211: a bank of 83,000 tonnes with 16,000 tonnes of emissions in 2005, a bank of 33,000 tonnes with 6,000 tonnes of emissions in 2010 and a bank of 19,000 tonnes with 1,600 tonnes of emissions in 2015.

Atmospheric measurements in 2002 place emissions of halon 1301 between 1,000 and 2,000 tonnes. This is close to the HTOC estimates. Atmospheric measurements for halon 1211, however, are between 7,000 and 8,000 tonnes in 2002, considerably lower than estimated by the HTOC. It appears that recent actions by several parties may result in significant future adjustments to the estimated quantities and to the geographical distribution of halons. However, the HTOC estimate of future emissions is currently the best available in the literature.

Halons' unique combination of properties led to their selection for many fire protection situations: computer, communications and electronic equipment facilities; museums; engine spaces on ships and aircraft; ground protection of aircraft; flammable liquid storage and processing facilities, general office fire protection and industrial applications (HTOC, 1989). Wickham (2002), however, finds that the halocarbon alternatives are not in such general use now. In part, their high cost appears to be limiting their use to applications where a clean agent is a necessity. The development and use of halon alternatives are driven entirely by the Montreal Protocol. None of the available alternatives offer performance or cost advantages over halons.

9.1.1 Overview of the halon market before the Montreal Protocol

The market for halons and their alternatives is divided into two distinctly separate sub-sectors: portable extinguishers and fixed systems. Halon 1301 (ODP = 10, Montreal Protocol value) dominated the market for fixed gaseous systems while halon 1211 (ODP = 3) dominated the market for gaseous portable extinguishers. Halon 2402 (ODP = 6) is more toxic than the other halons and was used only in a small number of countries.

9.1.2 Progress since the Montreal Protocol

Research on alternatives to halons has been underway since at least 1988 (HTOC, 1989). In 1994, the HTOC (1994) reported that newly developed replacement products were commercially available for most new applications, but stated that retrofitting of existing systems to use new alternatives needed further evaluation.

As of 1999, it was estimated that only 4% of the former halon market still required halon in new systems. Applications with halon had successfully shifted to new systems with many different alternative agents and approaches, as shown below (IPCC/TEAP, 1999):

• not-in-kind (non-gaseous) agents	50%
• clean agents	50%
- *carbon dioxide and inert gases*	*25%*
- *halons*	*4%*
- *PFCs*	*<1%*
- *HFCs*	*20%*

In 2002, the HTOC (2003) concluded that halon was no longer necessary in virtually any new installations, with the possible exceptions of engine nacelles, passenger spaces and cargo compartments of commercial aircraft, and crew compartments of military combat vehicles. A new fluorinated agent, fluoroketone FK-5-1-12, was also introduced in 2002.

For all practical purposes, PFC use has ceased and been replaced by HFCs. PFC use is currently limited to the replenishment of existing systems and as a minor component in a streaming agent identified as HCFC Blend B.

9.1.3 Emission characteristics of fire protection applications

Any fire protection system or extinguisher must be available for discharge at the moment a fire event occurs. Fixed systems and extinguishers should therefore be designed, produced and maintained in a manner that eliminates loss of agent through leakage and, in the case of fixed systems, inadvertent or unwanted discharges. As a result, fire protection codes and standards establish minimum levels of design, require periodic maintenance, and require regulatory authorities to adhere to these minimum levels (NFPA, 2000, 2004).

Since the Montreal Protocol, the fire protection community has become much more active in managing emissions. For example, the highly emissive equipment testing and personnel training practices were eliminated (HTOC, 1991, 1994) and as a result emissions have decreased significantly. Until 2003, the only estimates of emission rates for halons and their alternatives were based on expert opinion. The 1996 IPCC Revised Guidelines for National Greenhouse Gas Inventories recommended using the estimates for halons developed by McCulloch (1992) to estimate HFC and PFC emissions (IPCC, 1997). In Volume 3, however, it is also noted that the emissions of HFCs and PFCs could be reduced by more than 50% in recognition of the changes being implemented by the fire protection community. The HTOC (1997) also estimated that these new procedures reduced the non-fire emissions of halons by up to 90%. Ball (1999) reported that many of the procedures originally developed for halons are now being applied to alternatives, reducing emissions far below pre-Montreal Protocol levels. Ball opined that emissions for HFCs and PFCs could be as low as 1% of in-use quantities. On the basis of consultation with industry, a study prepared for the United Kingdom Department of Environment, Food and Rural Affairs (UK DEFRA) estimated current annual HFC emissions at approximately 5% of the installed base per annum (AEAT, 2003).

Recent data from the Halon Recycling and Banking Support Committee in Japan indicate a 0.12% emission rate for halon 1301 systems, with the exception of ships, aircraft and military systems (Verdonik and Robin, 2004). Verdonik and Robin (2004) evaluated the publicly available data relating to the production and emissions of HFCs and PFCs from fire suppression applications and developed three independent approaches to determine emission rates. The study derived an average emission rate of 2% of the installed base, with an uncertainty range of 1 to 3% (i.e. 2% ±1%).

9.1.4 Estimates of direct greenhouse-gas emissions

The actual global production or consumption of halon alternatives in fire protection applications is not known. This is because each is produced by a limited number of companies and each company regards their sales-related data as proprietary. Actual emissions are therefore reported as an aggregated value using the GWPs in the IPCC Second Assessment Report (SAR) (IPCC, 1996). All bank and emission estimates presented in this report are based on the SAR 100-yr GWP values. It is anticipated that the new 100-yr GWPs for fire protection agents provided in this report would change these estimates by less than 10%, which is well within the range of results presented and significantly less than the uncertainty of these estimates. As such, no adjustments to the SAR 100-yr GWP values have been included in the estimates in this chapter.

The UK fire industry collected and reported aggregate emissions of HFCs and PFCs from fire protection applications for the years 1997–1999 as part of their voluntary agreement with the government (FIC, 1997–1999). The results were: 1997 – 0.010 $MtCO_2$-eq; 1998 – 0.012 $MtCO_2$-eq; and 1999 – 0.014 $MtCO_2$-eq. The US fire protection industry collected and reported aggregate emissions of HFCs and PFCs for 2002 under their voluntary agreement with the government (Cortina, 2004). The result was 0.56 $MtCO_2$-eq. These methodologies estimate emissions on the basis of the amount of agent sold to recharge systems. The data may therefore slightly understate emissions where a system that has been discharged has, for any reason, not been recharged.

Verdonik (2004) used these UK and US emissions data and other publicly available data to update the Fire Protection Emissions Model developed under the Greenhouse Gases Emission Estimating Consortium. Estimates of emissions of HFCs and PFCs from fire protection applications and the fixed-system bank of HFCs and PFCs were developed using the 1 to 3% emission rate range developed by Verdonik and Robin (2004). The results are provided in Table 9.3 where the composite gas is defined as consisting of 97.5% HFC-227ea and 2.5% HFC-23. As fixed PFC systems are no longer installed, only a small difference results when PFC is included in the calculation. Information provided by a producer of HCFCs for fixed systems places the bank in 2002 at 3,400 and in 2004–2015 at 3,600 tonnes with annual emissions of 0.09 $MtCO_2$-eq. The fixed-system bank of HCFCs is assumed to be 85% HCFC-22, 10% HCFC-124 and 5% HCFC-123.

Additional modelling using the methodology of Verdonik (2004) suggests the global fixed system bank for HFCs, PFCs and HCFCs at the end of 2002 was 22,000 tonnes with 1.1 $MtCO_2$-eq of emissions at a 2% emission rate assuming (1) that the fixed system bank of HFCs/PFCs is approximated in 2002 by 95.1% HFC-227ea and 2.45% each of HFC-23 and PFC-3-1-10, and (2) that the fixed-system bank of HCFCs is comprised of 85% HCFC-22, 10% HCFC-124 and 5% HCFC-123 (henceforth all referred to as the fixed-system composite bank). PFCs played an early role but current use is limited to the replenishment of previously installed systems. The annual addition to the fixed-system composite bank consists of 97.5% HFC-227ea and 2.5% HFC-23. The current fixed-system composite bank is estimated at 27,000 tonnes at the end of 2004 with 1.4 $MtCO_2$-eq of emissions at a 2% emission rate.

Looking to the future, modelling suggests a fixed-system bank (including 3,600 tonnes of HCFCs and some use of FK) of 67,000 tonnes with annual emissions of 4 $MtCO_2$-eq in 2015 at an emission rate of 2%. In the absence of a change in emission rate, total annual emissions will change in proportion to changes in the installed base.

In countries where high levels of regulation exist, the emission rates have been approximated as 1% or less. The estimated emission rate is 2% where there are average levels of regulation, approaching 3% at lower levels of regulation. On the basis of the 2000 estimate from HTOC (2003a), portable extinguishers are thought to have an emission rate of approximately twice that of fixed systems. Applying that factor provides an uncertainty range of 2 to 6% (i.e. 4% ±2%). Looking forward, one might expect that the continuation of efforts to minimize emissions

Table 9.3. Estimation of global emissions and bank of HFC/PFCs in fixed-system fire protection.

		1995	2000	2005	2010	2015
1% Emission Rate						
Fixed-system emissions	$MtCO_2$-eq	0.06	0.60	1.20	1.99	2.87
	MtC-eq	0.02	0.16	0.33	0.54	0.78
Fixed-system bank	tonnes composite gas	1,805	19,325	38,599	63,685	92,052
2% Emission Rate						
Fixed-system emissions	$MtCO_2$-eq	0.11	0.85	1.64	2.74	3.95
	MtC-eq	0.03	0.23	0.45	0.75	1.08
Fixed-system bank	tonnes composite gas	1,684	13,576	26,360	43,968	63,315
3% Emission Rate						
Fixed-system emissions	$MtCO_2$-eq	0.11	1.10	2.13	3.46	4.91
	MtC-eq	0.03	0.30	0.58	0.94	1.34
Fixed-system bank	tonnes composite gas	1,127	11,726	22,711	37,003	52,415

further would drive the emission rates toward the 1% level for fixed systems and 2% for portable extinguishers; conversely, a relaxation of this goal would likely increase those emissions to the 3% level for fixed systems and 6% for portable extinguishers.

Products have been available for portable extinguisher applications since the early 1990s. No information was found in the literature about the quantities of HCFCs, PFCs or HFCs used for portable extinguisher applications. Information provided by a producer, combined with modelling, results in an estimate for the portable extinguisher composite bank of HCFCs, HFCs, and PFCs of approximately 1,500 tonnes at the end of 2002 with 0. 12 $MtCO_2$-eq of emissions and approximately 1,900 tonnes at the end of 2004 with emissions of 0.16 $MtCO_2$-eq at a 4% emission rate. The portable extinguisher composite bank is assumed to be comprised of 68% HCFC-123, 30% HFC-236fa and 2% PFC-14. Assuming an annual 3% growth rate, the estimated size of the portable extinguisher composite bank in 2015 will be 4,000 tonnes with 0.34 $MtCO_2$-eq of emissions at a 4% emission rate.

9.1.5 Regulatory and approval processes – hurdles to introducing new technologies

Most countries regulate the requirements for fire protection and the type provided. These controls can take the form of requiring fire protection in specific situations, such as sprinklers in hotels and offices. They can also take the form of required approval for the design and installation of specific fire protection systems. For example, organizations such as the National Fire Protection Association (NFPA), the Comité Européen de Normalisation (CEN) and the International Organization for Standardization (ISO) publish standards for specific types of fire protection systems, such as fixed systems using gaseous agents (NFPA, 2000; ISO, 2000). Some countries simply adopt NFPA or ISO standards, while others have their own standard-making bodies. For example, the Brazilian Association for Technical Standards (ABNT) includes a committee for Fire Protection (CB24) (UNEP-TEAP, 1999) and there are some 12 Indian standards for halon alternatives. Furthermore, testing organizations such as Underwriters Laboratories (UL) or Factory Mutual Research Corporation (FM) test specific manufacturers' products to validate their performance against the standards written by the standard-setting organizations.

Such regulatory and approval processes can limit the introduction of new agents and techniques to those that have demonstrated acceptable levels of performance in two, and sometimes three, key areas: fire extinguishing effectiveness, safety for personnel/life safety and possible environmental considerations. The United Nations Environment Programme (UNEP) has prepared two documents that compile examples of such environmental regulations (UNEP 2000, 2001). The reader is encouraged to review these documents for further information. Only alternative fire protection agents and techniques that have satisfied or are undergoing nationally or internationally recognized regulatory approval processes are discussed in this section.

9.2 Reducing emissions through the choice of agents in fixed systems

9.2.1 Agents and systems with the potential to replace halons

With the halt in production of halon total flooding agents, fire protection professionals had two choices: (1) to begin using not-in-kind alternatives, accepting their deficiencies or (2) to wait for the development of new alternatives and techniques as they come available. Different market sectors were able to accept different choices based on the particular fire threat and risk acceptance.

9.2.1.1 Agents existing at the time of the Montreal Protocol

In its 1989 report, HTOC discussed a technique called the selection matrix. Basically, it places a value on performance parameters for several fire extinguishing system types, helping end users and authorities select the most appropriate alternative for a given application. The parameters in the matrix are: (1) low space and weight (of the agent storage containers), (2) damage limiting (speed of extinguishment and no agent residue), (3) ability to permeate (works around obstructions), (4) occupant risk (safe at concentrations used), (5) flammable liquid extinguishing capability, (6) system efficacy, (7) energized electrical equipment capability (electrically non-conductive) and (8) installed cost.

None of the new halon alternatives (HCFCs, HFCs, PFCs, FK, inert gases, water mist, etc.) had been developed at the time of the 1989 report. The types of systems directly considered in the matrix at that time were: automatic water sprinklers, fast response water sprinklers, pre-action water sprinklers, total flooding dry-chemical systems, total flooding carbon-dioxide systems, deluge water-spray systems, low-expansion foam and high-expansion foam.

The HTOC matrix effectively illustrates the individual strengths and weaknesses of the various systems, and reveals that all of the alternatives available at that time had one or more shortcomings that would prevent them from fully replacing halon in every application.

9.2.1.2 Agents developed since the Montreal Protocol

The conclusion drawn from the HTOC 1989 matrix – that no single suitable alternative for halon 1301 existed at that time – served as the incentive for the development of fire extinguishing systems using agents in four broad categories:

- halocarbon gaseous chemical agents including HCFCs, PFCs, HFCs and FK;
- inert gases, such as nitrogen or argon, or blends of those inert gases;
- water mist;
- fine powder aerosol.

Alternatives to halon fall into two broad categories: (1) clean agents similar to halon 1301 and (2) additional not-in-kind agents and systems similar to the other pre-Montreal Protocol alternatives.

9.2.2 Not-in-kind technologies

Not-in-kind technologies include the agents and systems considered in the 1989 HTOC matrix and the more recently developed water-mist and fine-powder-aerosol systems. When compared to halon, all of the not-in-kind alternatives continue to have the same fire protection shortcomings described in 1989. However, each has an appropriate place within fire protection. Not-in-kind alternatives offer the advantage of generating no direct greenhouse-gas emissions and are currently being used in about half of the applications that used halon before the Montreal Protocol (IPCC/TEAP, 1999).

9.2.2.1 Water-based systems

Water-based systems include automatic, fast response and pre-action water sprinklers, deluge water spray and water mist. In some applications, additives protect against freezing. Water-based systems have a limited ability to permeate obstructions, poor flammable liquid extinguishing capability and use limitations around energized electrical equipment (HTOC, 1989). Water itself may damage the items to be protected, i.e. it is not a clean agent. By contrast with gaseous agents, there is also an agent residue after the systems discharge. Water mist technology has achieved limited market acceptance, primarily in turbine and diesel-powered machinery and, somewhat less frequently, machinery spaces aboard ships. Water mist faces two obstacles (Wickham, 2002). First, the systems are not good at extinguishing small fires in large volumes, even to the point of failing to extinguish them. Second, applications are limited (in size and characteristics) to those where fire test protocols have been developed in which system performance has been determined empirically. This drives up costs higher than for other technologies.

9.2.2.2 Total flooding dry-chemical and aerosol systems

These systems use compounds such as sodium bicarbonate, ammonium phosphate and potassium bromide. They have a limited ability to permeate obstructions and leave a residue that normally precludes use for the protection of electronic equipment spaces. With aerosol systems, the technology is so new that suitable standards for approval testing and application requirements are still under development by the major standards organizations, including the NFPA, CEN and ISO.

9.2.2.3 Foam systems

Systems using foam employ water-based formulations containing surfactants to produce semi-stable foams. These systems leave agent residue after discharge and are larger and heavier than other options. They have limited ability to permeate obstructions and are not used around energized electrical equipment. Foams also have other environmental impacts on water quality and aquatic life (Ruppert and Verdonik, 2001). One manufacturer's version of Aqueous Film Forming Foam (AFFF), the best performing foam, is no longer produced in the US due to persistence, bioaccumulation and toxicity concerns (Dominiak, 2000).

Continuing research and development is underway with water mist and aerosol systems, as are efforts to develop and improve test methods and application standards (IMO, 1996, 1999, 2001).

9.2.3 Clean agents

Clean agents include inert gases (nitrogen, argon or blends of these two sometimes incorporating carbon dioxide as a third component), HCFC blends, HFCs, PFCs, FK and in some definitions carbon dioxide also (NFPA, 2000). With the exception of carbon dioxide, all clean-agent alternatives have been de-

Table 9.4. Clean-agent alternatives to halon 1301 (ISO, 2000; NFPA, 2004).

Generic name	Group	Comment
HFC-23	HFC	
HFC-125	HFC	
HFC-227ea	HFC	
HFC-236fa	HFC	Not commercialized in fixed systems
HCFC Blend A	HCFC Blend	Unsuitable for occupied spaces
HCFC-124	*HCFC*	*Being withdrawn from ISO standard. Unsuitable for occupied spaces.*
FC-2-1-8	*PFC*	*Being withdrawn from ISO and withdrawn from NFPA standard(s).*
FC-3-1-10	*PFC*	*Being withdrawn from ISO standard.*
FIC-13I1	FIC	Unsuitable for occupied spaces
FK-5-1-12	FK	New agent in the NFPA and expected in ISO referenced standards
Inert Gases	IG	Argon, nitrogen or blends of the two, sometimes with carbon dioxide

veloped since the Montreal Protocol and are used when not-in-kind technologies do not offer the required level of performance. While carbon dioxide systems have been used for many years and the technology is well developed, its use as a total flooding agent in occupied spaces involves significant life safety considerations. This is because the concentration needed to extinguish a fire is lethal. Numerous incidents of fatalities have been reported (Wickham, 2003). Carbon dioxide systems are therefore not included in the detailed sections below. They may be appropriate for use in some applications but only where personnel cannot be exposed.

PFC systems were initially used to help in the transition away from halons, but because of their impact to the climate system and lack of performance advantage over other alternatives new systems are no longer installed. The original agent manufacturer is supporting existing systems where necessary.

9.2.3.1 Progress with clean-agent systems

Market acceptance of the halocarbon and inert gas systems was generated relatively quickly. This was made possible by the early development of standards and the willingness of end users to accept these agents (NFPA, 2000; ISO, 2000; and IMO, 1998a,b). However, the path to market for new fire extinguishing agents and systems is laborious (Wickham, 2002). In most instances, the suitability of an agent is determined through data submittals, reviews and often testing involving the following: national health authorities to approve safe usage levels, national environmental authorities to assure compliance with laws and treaties, national and international standard-making organizations to write rules for safe use, national testing laboratories to test the chemicals, national testing laboratories to test and approve agent systems, national and international certification bodies for approvals.

This process is lengthy, expensive and often has to be repeated country-by-country to meet different national standards. While it may be onerous, it is important from the points of view of both fire protection and the environment. Countries and regions with high levels of regulatory supervision tend to avoid unapproved products, while those with less regulation have experienced difficulties with agents of questionable safety and effectiveness. Table 9.4 provides a listing of the clean extinguishing agents identified as suitable for use, within limitations, in ISO Standard 14520-1 and NFPA Standard 2001. This list includes all agents that are known to have been subjected to the appropriate approval processes at the time the list was compiled. Using an agent for an application for which it has not been approved can result in significant loss of life and property. From an environmental point of view, any use of unapproved agents that are greenhouse gases may result in emissions that otherwise could have been avoided

9.2.3.2 Refining the list of available gaseous alternatives to halon 1301

While Table 9.4 shows numerous halocarbon alternatives, the TEAP concluded that only three were commercially viable in 1999: HFC-23, HFC-227ea and HFC-236fa (UNEP-TEAP, 1999). A key characteristic of halon is its safety for use in occupied areas, but TEAP concluded that HFC-125, HCFC Blend A, HCFC-124 and FIC-13I1 were unsuitable due to unacceptable toxicity. However, new exposure guidelines are being adopted in some jurisdictions that will allow the use of HFC-125 in occupied spaces under certain conditions (NFPA, 2003).

Since 1999, FK-5-1-12 has become available. It has been listed as an acceptable alternative to halon under the US Environmental Protection Agency's Significant New Alternatives Policy (SNAP) programme (US EPA, 1994, 2002). It has also been included in the latest revision of the NFPA clean-agent standard (NFPA, 2004) and is expected to be in the next revision of the ISO standard (ISO, 2003). Systems have been approved by several testing and approval organizations and are now available. Additional technical information on FK-5-1-12 and the other clean-agent alternatives to halon 1301 is available in the referenced ISO and NFPA documents.

Table 2.6 (see chapter 2) lists the environmental properties of the halocarbon agents deemed acceptable for safe human exposure for use in normally occupied spaces: HFC-23, HFC-125,

Table 9.5. Remaining gaseous alternatives to halon 1301.

Generic name	Group	Comment
HFC-23	HFC	
HFC-125	HFC	
HFC-227ea	HFC	
FK-5-1-12	FK	New agent that went into commercial use in 2002.
Inert Gases	IG	Argon, nitrogen or blends of the two, sometimes with carbon dioxide

HFC-227ea, HFC-236fa, FC-2-1-8, FC-3-1-10 and FK-5-1-12. It is important to note that:

- HFC-23's high vapour pressure and low boiling point make it a unique replacement for halon 1301 in large-volume, low-temperature applications such as those found on the oil and gas industry on the North Slope of Alaska (Catchpole, 1999);
- HFC-236fa has never been commercialized as a fire extinguishing agent in fixed systems;
- FC-2-1-8 and FC-3-1-10 are being withdrawn from the ISO standard and all PFCs are prohibited by the International Maritime Organization (IMO) for shipboard fire extinguishing systems (SOLAS, 2000).

9.2.3.3 *Available clean agents*

After elimination of the agents either found unsuitable for occupied spaces, withdrawn from standards, prohibited by IMO or not commercialized in fire extinguishing systems, the list of potential gaseous total flooding agents is reduced considerably, as shown in Table 9.5.

Comparing the list from Table 9.5 against the performance parameters in the 1989 HTOC report shows that the agents listed in Table 9.5 are quite similar in terms of several parameters. For example, they are all gaseous agents that readily permeate obstructions, they are effective at concentrations safe for human exposure, they are effective for flammable liquids, they are non-conductive and can be used around energized electrical equipment. The real differentiation in system performance is (1) space and weight, (2) cost, (3) greenhouse-gas effect and (4) speed of extinguishing. In addition, two other factors may be important in some instances: (5) demonstrated special capabilities and (6) multiple supply sources.

- Space, weight and cost: A comparison was made of the agent storage container weights, floor area occupied (footprint), volume occupied (cube) and costs of several types of systems to protect volumes of 500, 1,000, 3,000 and 5,000 m^3 under the rules of the IMO for the protection of shipboard machinery spaces (Wickham, 2003). The results are shown in Table 9.6, using a halon 1301 system as the basis for comparison. The following definitions apply to Table 9.6:
  a. Weight includes the storage containers and contents but not the weight of piping, hangers, etc.
  b. Footprint is that area occupied by the agent containers defined by a square or rectangle circumscribing the agent cylinder bank.
  c. Cube is that volume occupied by the agent containers defined as the area multiplied by the height of the agent cylinders measured to the top of the valves.
  d. System cost is the average selling price of the system components charged by a manufacturer to a distributor or installer, and includes agent, agent storage containers, actuators, brackets, discharge and actuation hoses, check valves, stop valves and controls, time delay, manually-operated stations, predischarge alarms, pilot cylinders and controls. Cost does not include agent distribution piping and fittings, pipe supports and hangers, actuation tubing and fittings, electrical cables and junction boxes or labor to install, packing or freight.
- Greenhouse-gas effect: The GWPs of the agents (as listed in Table 2.6) provide a relative comparison of the direct greenhouse-gas emissions of fire protection systems and do not take into account any effects from indirect emissions. For most applications, the indirect effects are negligible compared with the direct effects. By contrast with

Table 9.6. Comparisons of average values in the 500 to 5,000 m^3 range (per cubic metre of protected volume at the concentration indicated).

		Halon 1301	HFC-23	HFC-227ea	HFC-125	FK 5-1-12	Inert gas
Concentration	Vol. %	6.0	19.5	8.7	12.1	5.5	40.0
Weight	kg/m^3	0.8	2.3	1.1	1.1	1.2	4.3
Footprint	$10^4\ m^2/m^3$	5.8	12.0	6.8	7.4	7.3	28.2
Cube	$10^4\ m^3/m^3$	8.6	18.0	13.1	14.4	13.8	56.6
System cost	US$/$m^3$	7.43	39.77	28.05	26.37	35.98	34.07
Agent cost	US$/$m^3$	3.34	18.33	19.08	16.81	26.59	9.62

other sectors, the amount of energy required to operate fire protection systems is trivial and largely unaffected by the agent used. This includes the impact of heating and cooling the systems installed in buildings, as this is quite small compared to the direct effect of an annual emission rate of even 1%. Techniques such as TEWI and LCCP identify only negligible levels of change compared to evaluations based only on the GWPs of the agents. The notable exception is aviation. The added weight of any of the halon alternatives has an indirect emissions effect because of the additional fuel use during the life of an aircraft.

- Speed of suppression: The discharge time for inert gas systems is in the order of 60 seconds or more. This is significantly longer than the discharge time of 10 seconds for halocarbon systems. Inert gas systems are therefore not recommended for areas where a rapidly developing fire can be expected (Kucnerowicz-Polak, 2002).
- Demonstrated special capabilities: There can be other performance requirements that apply to specific applications for which alternatives may not have been tested. For example, Catchpole (1999) described the unique capabilities of HFC-23 for deployment in high bay areas and in low ambient temperature conditions. Wickham (2002) described multiple special applications for HFC-227ea in military shipboard and vehicle applications and the choice of HFC-125 for both military vehicle and high-performance aircraft engine protection. The comprehensive testing and evaluation of HFC-23, HFC-227ea and HFC-125 for these applications and others are well documented in the publications of the US National Institute of Standards and Technology (NIST, 2003). FK-5-1-12 became commercially available in 2002 but has not yet been tested for some special applications. It has satisfied regulatory review under US EPA SNAP, NFPA and VdS, (VdS Schadenverhütung GmbH) and is pending at ISO. Market acceptance will depend on the comparative cost of the competing options. No estimates are available about how further restrictions on ozone-depleting substances and greenhouse-gases would affect agent choice in the future.
- Multiple supply sources: HFC-23, HFC-125 and HFC-227ea are manufactured by several companies in the US, Europe and Asia, and inert gas agents and systems are available worldwide from several competitive sources. FK-5-1-12 is available from one manufacturer in the US. Fixed systems utilizing these agents are available from several manufacturers.

9.2.3.4 Abatement costs

The abatement costs for assessing fire protection alternatives vary greatly depending upon specific assumptions that may or may not be applicable for any given situation. Harnish *et al*. (2001) assessed abatement costs for leakage reduction and recovery assuming a cost structure comparable to commercial refrigeration. The abatement cost was US$ 158,000 per ton of abated substance based on a projected 30% reduction of these emissions in 2010 and a 60% reduction in 2020. Harnish and Schwartz (2003) calculated an abatement cost to retrofit PFC 3-1-8 fixed systems with HFC-227ea in the EU assuming a 7% emission rate. The results were approximately 26 US$/t$CO_2$-eq abated (27.53 /t$CO_2$-eq). With a 2% emission rate, their result changes to approximately 130 US$/t CO_2-eq abated. Godwin (2004) proposed three abatement options for future systems: (1) replacing up to 30% of HFC-227ea with inert gases by 2020; (2) replacing all HFC-227ea in Class B (flammable liquids) applications with water mist by 2020; and (3) replacing up to 50% of HFC-227ea with FK 5-1-12 by 2020. The specific abatement costs range from approximately 14 to 57 US$/t$CO_2$-eq (4% discount rate) per year over the twenty-year lifetime. A fifteen-year lifetime leads to a range of 17–70 US$/t$CO_2$-eq per year.

While Godwin (2004) provides these possible scenarios, they must be viewed as hypothetical. HFCs and inert gases have evolved as the most commonly used agents, having achieved a degree of equilibrium in terms of market applications and share. FK-5-1-12 has been commercialized and is now available but there is no basis for predicting the rate of its market acceptance or its effect on the already established equilibrium. Under these circumstances, it is impossible to quantify the reduction in the use or emissions of HFCs in fire protection through 2015.

9.3 Reducing emissions through the choice of portable extinguisher agents

9.3.1 Regulatory requirements for portable extinguishers

Users almost always purchase hand portable fire extinguishers to comply with fire codes. In general, depending on the type of occupancy, fire codes and regulations describe the hand portable fire extinguisher requirements in terms of (1) either the charged weight or fire test rating of the extinguisher and (2) the number of extinguishers required based on the floor area of the facility and the maximum travel distance to an extinguisher. Furthermore, most codes require extinguishers capable of extinguishing fires in Class A and B fuels, often with the additional requirement that the extinguisher can be used safely around energized electrical equipment (NFPA, 1998 and UL, 2000). Extinguishers suitable for Class A fuels are tested by approval laboratories on wood cribs, wood panels and excelsior material. Extinguishers suitable for Class B fuels are tested by approval laboratories on flammable liquids in metal pans. The code requirements can be met either by employing an extinguisher capable of both Class A and Class B fires or separate extinguishers, one for each type of fire (Wickham, 2002).

9.3.2 Agents existing at the time of the Montreal Protocol

The HTOC (1989) also developed an agent selection matrix for portable fire extinguishers as follows: (1) effectiveness on ordinary combustibles, (2) effectiveness on flammable/combustible liquid fires, (3) electrical conductivity, (4) ability to permeate, (5) range, (6) effectiveness to weight ratio, (7) secondary damage (by extinguishing agent residue) and (8) cost.

Since none of the new halon alternatives were developed at the time of the 1989 report, the types of portable extinguishers considered in the matrix are regarded as not-in-kind technologies: carbon dioxide, multipurpose dry chemical, aqueous film forming foam and water.

The matrix illustrates the strengths and weaknesses of the various types of portables, and reveals that each one has shortcomings that would limit widespread use as halon alternatives.

- Water can be used for Class A fuels (ordinary combustibles) but has limited ability to permeate obstructions, poor flammable liquid extinguishing capability (Class B fuels) and limitations of use around energized electrical equipment (Class C fires). Water leaves a residue but produces no direct greenhouse-gas emissions (HTOC, 1999b).
- Carbon dioxide is effective on Class B and Class C fuels, but has poor effectiveness on ordinary combustibles (Class A fires), (HTOC, 1999a), poor range and high weight to effectiveness ratio. Its direct greenhouse-gas emissions are negligible (HTOC, 1999b).
- Multipurpose dry-chemical extinguishers, such as ammonium phosphate-based powder, are rated for use on Class A, B and C fires. They have a limited ability to permeate obstructions and can produce significant secondary damage from agent residue. They produce no direct greenhouse-gas emissions (HTOC, 1999b).
- Aqueous –film forming foam (AFFF) extinguishers use water-based formulations that contain surfactants to create a semi-stable foam. They are effective on Class A and B fuels, but have a limited ability to permeate and there are limitations on use around energized electrical equipment. In addition, AFFF extinguishers leave a residue after discharge. They produce no direct greenhouse-gas emissions (HTOC, 1999b).

9.3.2.1 Agents developed since the Montreal Protocol

Table 9.7 is an illustration of the clean agents developed for use in portable extinguishers since the Montreal Protocol. According to Wickham (2002), only HCFC Blend B and HFC-236fa have achieved any significant level of commercialization and the manufacture of PFC-5-1-14 has been discontinued. FK 5-1-12 is a newly developed agent capable of extinguishing Class A, B and C fires. Extinguishers using FK-5-1-12 have negligible direct greenhouse-gas emissions (Taniguchi *et al*., 2003). Other blends of HCFCs are in use in portable extinguishers but the literature contains no information about commercial acceptance. All of the agents in Table 9.7 have had use limitations applied to them by the US EPA, which has found the agents “acceptable in non-residential uses only”. In effect, this precludes their use in residential applications (US EPA, 2003). The EPA uses the expression “residential” to differentiate from “commercial” applications.

9.3.2.2 Options for prospective owners of portable extinguishers

An end user is faced with making trade-offs between effectiveness, cleanliness and cost because, given equal size, (1) halocarbons are most expensive and least effective and (2) multipurpose dry chemicals cost least but are most effective.

End users who would have purchased halon 1211 portable extinguishers to protect their facilities or equipment fifteen years ago have three options today. (1) They can use an “in-kind” halon 1211 alternative such as one of the new halocarbon agents. (2) They can use two extinguishers (to do the job of one halon 1211 unit): water for Class A fires and carbon dioxide for Class B fires and those around electrically energized equipment. (3) They can use a multipurpose dry-chemical extinguisher in situations where the agent residue can be tolerated.

9.3.2.3 Progress with halocarbon portable extinguishers

Wickham (2002) compared the agent charge, fire rating and average selling price of several types of extinguishers. This is shown in Table 9.8. The available data for extinguishers with FK-5-1-12 are limited for this comparison, as few portable extinguishers have been developed using this agent to date.

As an example, a commonly specified extinguisher is 2-A:10-B:C rating, where “A” indicates it is suitable for use on Class A fires and the preceding number indicates its degree of effectiveness on those types of fires as determined in testing by approval laboratories; “B” indicates it is suitable for Class B fires and the preceding number indicates its degree of effectiveness on those

Table 9.7. Gaseous alternatives to halon 1211 in portable extinguishers (HTOC, 1999).

Generic name	Group	Comment
HCFC Blend B	HCFC+ PFC + inert gas	Blend of $CHCl_2CF_3$, CF_4 and argon
HCFC Blend E	HCFC+ HFC + hydrocarbon	Blend of $CHCl_2CF_3$, CF_3CHF_2 and $C_{10}H_{16}$
HCFC-124	HCFC	$CHClFCF_3$
HFC-236fa	HFC	$CF_3CH_2CF_3$
HFC-227ea	HFC	CF_3CHFCF_3
FC-5-1-14	PFC	C_6F_{14}
FK-5-1-12	FK	$CF_3CF_2C(O)CF(CF_3)_2$

Table 9.8. Cost comparisons for portable extinguishers.

Type	Agent charge		Fire rating	Average selling price (US$)
Halon 1211*	14.0 pounds	6.35 kg	2-A:40-B:C	223
Multipurpose dry chemical	5.0 pounds	2.27 kg	3-A:40-B:C	30
HFC-236fa	13.3 pounds	6.03 kg	2-A:10-B:C	493
HCFC Blend B	15.5 pounds	7.03 kg	2-A:10-B:C	415
Carbon dioxide	10.0 pounds	4.54 kg	10-B:C	175
Water	2.5 gallons	9.5 litre	2-A	63

*The halon 1211 price information is from 1993 before the halt of production of new halon 1211.

types of fires; and "C" indicates it is safe for use around energized electrical equipment. Table 9.8 shows end users have a choice of using the five-pound multipurpose dry-chemical unit for an average end user cost of US$ 30 each, the 13.3-pound HFC-236fa unit for US$ 493, the 15.5-pound HCFC Blend B unit for US$ 415, or both a ten-pound carbon dioxide unit and a 2.5 US gallon water extinguisher with a combined average end-user cost of US$ 238. This is compared to a cost of US$ 223 for equivalent halon 1211 units prior to 1994 when they were still being manufactured.

History has shown that a large portion of the market place was willing to pay over seven times more to get a clean-agent halon 1211 unit rather a not very clean dry-chemical extinguisher (US$ 223/30=7.43). The current cost multiple of 13 to 16 for the HCFC Blend B and HFC agents appears to be limiting market acceptance to those applications where users consider cleanliness a necessity.

9.4 Additional abatement options for emissions

9.4.1 Responsible agent management

The significantly reduced emission rates were achieved through a variety of actions within the fire protection community. For example, both the United Kingdom and the United States have developed voluntary agreements between the government and the fire protection industry that include specific actions by the fire protection community and also include the specific codes and standards that must be followed (DETR and FIC, 1997; FEMA *et al*., 2002). While the specific form of implementation will differ according to the country or region depending on culture and legal traditions, the technical practices needed to minimize emissions will be the same. An explanation of these kinds of practices may be found in the agreements themselves and in the HTOC Technical Note #2 (1997), which also include important provisions for stored and stockpiled halons.

Another method chosen by some authorities is to use regulation to reduce emissions. For example, the International Convention for the Prevention of Pollution from Ships (Marpol 73/78) prohibits deliberate emissions of ozone-depleting substances and the European Union requires that all halon systems and extinguishers, except those on a critical list, be decommissioned.

9.4.2 Importance of applying and enforcing codes and standards to minimize emissions

The UK and US agreements, and HTOC Technical Note #2, all make reference to the specific codes and standards that need to be followed in carrying out these provisions. Many, but not all, of these codes and standards have been discussed earlier in this chapter and have been an integral part of successful national programmes for reducing non-fire emissions. The specific codes or standards are different in the UK and US agreements, but their use was key to the success of both countries' programmes. The reader is encouraged to review the cited references to gain a better understanding of the types of codes and standards available, how they were applied and how their use produced emissions reductions.

9.4.3 End-of-life considerations for clean-agent systems and extinguishers

There are three distinct end-of-life considerations for clean-agent fixed systems and extinguishers: (1) end of useful life of the fire protection application, (2) end of useful life of the fire protection equipment and (3) end of useful life of the fire protection agent.

Fixed systems protect specific volumes (rooms), often telecommunications suites. Over the typical system life of 15 to 20 years, the protected equipment may change many times, with the fire protection system remaining in place. In specialized applications, such as aircraft and military systems, systems can remain in use for 25 to 35 years or longer (HTOC, 1994). Similarly, portable extinguishers meet a particular fire code or level of safety and are not replaced unless the use of the space changes in a way that requires a different fire protection capability. Portable extinguishers are generally required to undergo periodic pressure testing that involves removing the agent from the cylinder (NFPA 10), which is then recycled and redeployed. Estimates of the useful lifetime of portable extinguishers are between five to 25 years, depending upon regional factors

(HTOC, 1994).

The current availability of halons is the direct result of a strategy to recycle, effectively manage, and allow trade of the existing supplies of halons. The objectives were twofold: to enable a production phase-out in advance of alternatives to important national security and public safety applications, and to preclude the need for any future new production and consumption. The current global trade in halons produced before the phase-out is neither accidental nor a situation arising from oversupply. No exemptions to the halon production and consumption phase-out have been requested, or are expected to be granted by the parties (HTOC, 1994). Halon's positive market value provides a financial incentive to minimize emissions. Alternatively, because halon released to the atmosphere is untraceable, policies that diminish halon's value or make ownership a liability could result in increased emissions (UNEP-TEAP, 1998).

In countries or regions that have also placed export restrictions on the stores of halon, the only solution proposed has been destruction, often through a plasma arc or incineration process. To date, there has been only one known potentially economically feasible process described in the literature to convert either halons or the halocarbon alternatives to other useful products (Uddin *et al*., 2004).

To date, there are no fire-protection-specific proposals in the literature for managing the end of life of halocarbon agents other than halons (HTOC, 2002, page 6). However, the industry practices of capturing, recycling and reusing halons have carried over to all high value gaseous agents, including HFCs, HCFCs and PFCs. There is no reason to believe they will not also be applied to FK agents as they enter the market. In addition, because of their more complex chemistries, it appears unlikely that halon replacements will ever be as inexpensive as halons. As a result, there is both a market incentive as well as an industry culture favouring capture, recycle and reuse. Adherence to these practices, including certification programmes, has been shown to minimize emissions and to limit the use of these agents to applications where their cleanliness is needed.

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