MONTREAL PROTOCOL
ON SUBSTANCES THAT DEPLETE
THE OZONE LAYER

UNEP

2006 REPORT OF THE HALONS TECHNICAL OPTIONS COMMITTEE

2006 ASSESSMENT

Montreal Protocol
On Substances that Deplete the Ozone Layer

United Nations Environment Programme (UNEP)
2006 Assessment Report of the
Halons Technical Options Committee

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The following persons were instrumental in developing this report:

Committee Co-chairs

David Catchpole
PRA
United Kingdom

Dr. Daniel Verdonik
Hughes Associates
U.S.A.

Committee Members

Ahmad Al-Khatib
Ministry of Environment – Ozone Unit
Jordan

Geok Kwang Boo
Singapore Civil Defence Force
Singapore

Fareed Bushehri
UNEP / ROWA
Bahrain

Seunghwan (Charles) Choi
Hanju Chemical Co., Ltd..
South Korea

Dr. Michelle Collins
EECO, Inc.
U.S.A.

Andrew Greig
Protection Projects, Inc.
South Africa

Matsuo Ishiyama
Fire and Environment Protection Network
Japan

Zhou Kaixuan
CAAC-AAD
P.R. China

H.S. Kaprwan
Consultant
India

Dr. Barbara Kucnerowicz-Polak
State Fire Services Headquarters
Poland

Dr. Nikolai Kopylov
All Russian Research Institute for Fire Protection
Russia

Dr. David Liddy
Ministry of Defence
United Kingdom

Bella Maranion
US EPA
U.S.A.

John O’Sullivan, M.B.E.
British Airways
United Kingdom

Erik Pedersen
World Bank
Denmark

Donald Thomson
MOPIA & Manitoba Hydro
Canada

Robert Wickham
Consultant
U.S.A.

Consulting Experts

Tom Cortina
HARC
U.S.A.

Dr. Sergey Kopylov
All Russian Research Institute for Fire Protection
Russia

Steve McCormick
United States Army
U.S.A.

Jawad Rida
Consultant
Jordan

Dr. Mark Robin
DuPont, Inc.
U.S.A.

Dr. Joseph Senecal
Kidde-Fenwal, Inc.
U.S.A.

Dr. Ronald Sheinson
Naval Research Laboratory – Department of the Navy
U.S.A.

Ronald Sibley
Defence Supply Center
U.S.A.

Mitsuru Yagi
Fire and Environment Protection Network
Japan

Hailin Zhu
Tianjin Fire Research Institute
P.R. China

Peer Reviewers

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Robin Bennett – The Boeing Company, USA

Bradford Colton – American Pacific Corporation, USA

Robert Darwin – Hughes Associates Inc., USA

John Demeter – Wesco, USA

Dave Koehler – Prospective Technology, Inc., USA

Richard Marcus – RemTec International, USA

Pete Mullenhard – SAIC, USA

Jayan Pillai – Maritime and Coastguard Agency, UK

Yuko Saso – National Research Institute of Fire and Disaster, Japan

Al Thorton – Chemtura Corporation, USA

Kurt Werner – 3M Corporation, USA

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The following sector summaries show the remarkable progress that has been made to reduce the need for halons, and highlights problem areas where attention needs to be focussed to ensure adequate stocks of halons are available to meet Parties’ future needs.

E.2 Phase-out in Article 5(1) Countries

Only two Article 5(1) countries, The Peoples Republic of China (P.R. China) and The Republic of Korea (South Korea), continue to produce halons for fire protection purposes. The P.R. China stopped production of halon 1211 at the end of 2005 and its current production of halon 1301 is well below the limits agreed with the Executive Committee of the Multilateral Fund of the Montreal Protocol.

Only 26 of more than 120 countries operating under Article 5, paragraph 1, continue to import newly produced halons, primarily for the servicing of existing equipment. The demand for new halons has been reduced in developing countries through the availability of substitute fire extinguishing agents and alternatives, and only to a limited extent through halon recycling programs. Halon recycling remains a challenge as the commercial aspects of the trade in recycled halon are not fully understood and some operational and technical problems need to be resolved.

E.3 Phase-out in Countries that use Halon 2402

During the period 2002-2003 when the average price of halon 2402 was low, its use as a process agent in the Russian chemical industry substantially reduced the Russian inventory of halon 2402. Nevertheless, within Russia and the Ukraine there appears to be a large installed capacity of halon 2402 and sufficient quantities are available on the market from storage and recovery/banking for the servicing of existing applications. There may also be a sufficient amount of recovered halon 2402 to support the current needs of other countries, however export of halon 2402 from Russia and the Ukraine is banned by national regulations. Owing to this, there is growing concern from HTOC local and regional experts about the availability of halon 2402 outside of the Russian Federation and the Ukraine to support the critical servicing needs of Russian produced aircraft, military vehicles, and naval vessels still in operation in some countries, particularly India.

There is little open literature information available on inventories and emissions of halon 2402. Parties may wish to request additional information be collected on existing inventories, historic and current emission factors, and projected needs to support critical or essential halon 2402 fire protection equipment through their end of useful lives.

E.4 Global Halon Banking

Halon banking can play a significant role in ensuring the quality and availability of recycled halon, in managing the consumption down to zero, and in assisting with emission data by providing regional estimates that should be more accurate than global estimates. In Article 5(1) countries, halon banking has been a mix of success and failure, with the establishment of halon recycling facilities and coordination between industry, government, and national militaries being challenges that some have found difficult to overcome.

E.5 Estimated Inventories of Halons

The HTOC has updated the inventory and emission models of halon 1211 and halon 1301 taking into account direct data on destruction, inventories and emissions, where available, and additional expert opinion on past practices.

For halon 1301, the 2006 Assessment indicates an even greater global inventory or bank of halon 1301 as compared with the 2002 assessment. The global bank of halon 1301at the end of 2005 is now estimated to be approximately 50,000 metric tonnes (MT) as compared with the 2002 assessment of 39,000 MT.

For the global halon 1211 bank, the 2006 Assessment provides as estimate of 90,000 MT at the end of 2005 as compared with 106,000 MT from the corrected 2002 assessment, as reported in the TEAP Supplement to the IPCC/TEAP Special Report on Fluorocarbons (TEAP, 2005), and 83,000 MT in the pre-corrected 2002 HTOC assessment report.

From the 2006 Assessment, the HTOC is of the opinion that adequate global stocks of halon 1211 and halon 1301 currently exist to meet the future service and replenishment needs of existing critical or essential halon 1211 and halon 1301 fire equipment until the end of their useful lives. While it appears that adequate supplies of halon 1211 and halon 1301 are expected to be available on a global basis, over 35% of the global supply of halon 1301 is projected to be in Japan, see Figure ES-1. Model projections for halon 1211 based on Article 7 reporting of production and consumption place over 60% of the halon 1211 in Article 5(1) countries, see Figure ES-2, with the clear majority being in handheld extinguishers and unused stocks in China. Similarly, expert opinion places the majority of halon 2402 in the Russian Federation and Ukraine. These regional imbalances, where excess agent supply in some regions cannot be used to meet shortages in other regions because of obstacles presented by national or international regulations, either through complications or the outright prohibition of transfers, are a growing concern for the HTOC. Parties may wish to consider asking HTOC to investigate mechanisms to better predict and mitigate such imbalances in the future.

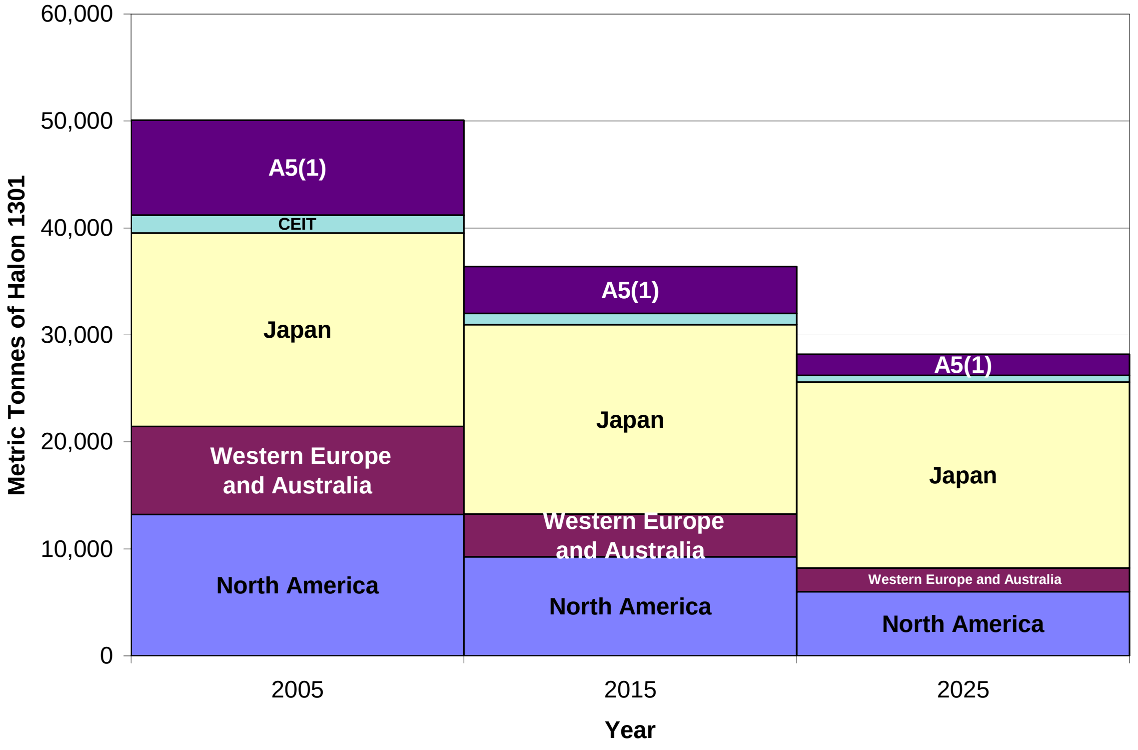

Figure ES-1 Breakout of Global Inventories (Bank) of Halon 1301 by HTOC Model Regions

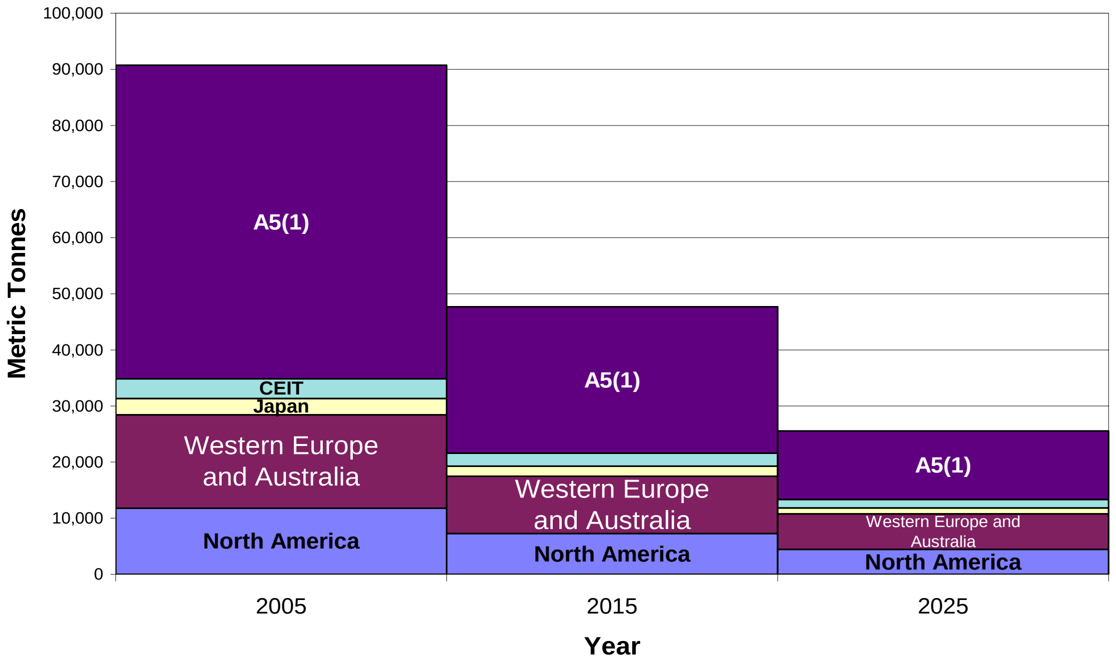

Figure ES-2 Breakout of Global Inventories (Bank) of Halon 1211 by HTOC Model Regions

E.6 Civil Aviation

The status of the transition away from halons in civil aviation reflects progress that has already been made in other sectors of use: minimising emissions of halons from testing and training practices, recycling and recovery of halons, testing of the available alternatives, and changing to alternative methods of fire suppression for ground based situations. However, unlike those other sectors, the civil aircraft sector continues to be dependent on halons, has not demonstrated further progress through the adoption of alternative technologies in new airframe designs, and lacks having an agreed technical design strategy to implement alternative methods of fire suppression. There is an immediate need to produce technical designs to conform with the minimum performance specifications that will in turn enable regulatory authorities to certify the systems to be fitted to new aircraft designs.

The civil aircraft business sector must demonstrate a focused leadership on this transition to deliver new technically certified systems that will meet the necessary regulatory processes and which can be consistently and broadly applied across the industry. Unless and until progress is made in this area, it will represent a significant barrier to the transition away from halons for new aircraft designs. Until supplies of recycled halons become unavailable, or until policy changes push a transition to the alternatives, the situation is unlikely to change in the near-to-mid term.

E.7 Merchant Shipping

Within the marine industry, it is important that stakeholders closely monitor the changes in availability of replenishment halon around the world. This is a dynamic situation and it will only be through pre-planning that owners and authorities are going to be prepared for a halon shortage. It is the recommendation of the HTOC that all Parties to the Montreal Protocol and all Members of the International Maritime Organization continually remind the marine industry of the importance of preparing for this inevitability.

E.8 Halon Usage and Replacement in Military Application

The military sector has shown leadership in the identification and implementation of halon alternatives, with considerable benefit transferring to the civilian and commercial sectors. Many equipment procurements are proceeding with alternative fire extinguishants and fire protection technologies. No new facilities or designs of equipment now require halons.

The conversion of existing equipment is more challenging, but programmes are underway or completed for many important applications. In other cases, especially for existing systems that protect normally occupied spaces in naval vessels, military vehicles, and military aircraft, very significant technical, economic and logistical barriers remain for retrofit. These halon systems may need to continue in service for the remainder of the operational life of the equipment, likely until the middle of the century in many cases. Halon use by the sector is well managed. Many organisations have established dedicated halon storage and recycling facilities to support Critical Use equipment for as long as is necessary.

E.9 Inertion/Explosion Suppression

Halons have been widely used to prevent explosions by suppressing deflagrations in their early stages of development. Explosion suppression and prevention (inertion) were challenging problems to overcome, but as with fire suppression, alternative agents or methods are now available for virtually all new applications. However, in some existing facilities in hostile climates, facilities were designed and constructed with halon 1301 fixed systems as an integral part of the safety system design as well as the physical layout of the facility. After extensive research, it has been determined that the replacement of such systems with currently available alternatives is not technically or economically feasible.

E.10 Destruction

Halons, more than some of the other ozone depleting substances (ODS), are readily accessible for collection, storage, and disposal. Options for disposal of surplus halons include destruction and transformation. One study sponsored by the Multilateral Fund Secretariat estimated that in 2010 no more than approximately 950 MT per year of contaminated halons would need to be disposed of in Article 5(1) countries. The actual amounts of the global halon inventory potentially available for destruction or transformation is highly uncertain due to business planning and economic considerations by users, local and regional imbalances of supply and demand, the availability of destruction or transformation technologies and facilities, inventory management approaches, and applicable disposal regulations.

Compliant ODS destruction technologies and facilities can be found in many countries, and some already have experience destroying some types of ODS. Owing to the relatively high market value and little outflow of halons into the waste stream, there is more limited experience in destroying halons. Continued research into transformation of halons – including feedstock uses - and the viability of producing useful products holds promise as a future option for halon disposal.

E.11 Other Issues

Although production of halon 1301 for fire protection uses has virtually ceased, France has continued to produce halon 1301 as a feedstock for production of an insecticide, and China has also begun to divert some production to feedstock use, and is likely to continue to do so. As the demand for bioactive compounds grows worldwide, it is conceivable that other manufacturing facilities may continue or restart production of halon 1301 to support feedstock needs. The continued routine, annual production of halon 1301 changes the economic considerations of the point at which halon is considered under Decision IV/25 to not be available in sufficient quantity and quality, and may provide an incentive for an essential use production exemption request.

The build up of stocks of contaminated or otherwise unwanted halons continues to be reported as a problem in Article 5(1) countries, particularly in Africa and also now in China. In many cases, this is becoming a storage and space issue as the halon needs to be stored in its pressure cylinder. Disposition options for contaminated halon include reclamation (assuming that one can sell it cost-effectively after reclamation), destruction, or venting. The first two options require monetary investment, which is generally not available in most circumstances. Unless there is a need for significant quantities of halon 1211 in the immediate future, the quantities stored and becoming available in China may also become unwanted with only destruction and, unfortunately, venting as disposition options.

1.0 Phase-out in Article 5(1) Countries

1.1 Introduction

Article 5, paragraph 1 makes provisions for developing countries, with a consumption of less than 0.3 ODP MT per capita, to have a 10 year grace period compared to the originally agreed to schedule for halon phase-out in developed countries. Accordingly, the Montreal Protocol requirements for developing countries are the freeze of production and consumption at the country's baseline level by 2002, a 50% reduction by 2005, and no production and consumption[1] after 2009. More than 120 countries are operating under Article 5(1) of the Montreal Protocol and are eligible for financial and technical support for fulfilling their phase-out obligations. Many of the countries covered under Article 5(1) have received funding and have initiated and/or implemented some form of halon management and banking program. Details of the Article 5(1) countries' banking programs and progress where available are covered in Chapter 3.

Based on the latest Article 7 data for 2004 reported to the ozone Secretariat, halons are only produced for fire protection uses by two countries, and only twenty-six countries are still importing halons (reported as consumption).

1.2 Halon Production

The only two countries still producing halons for fire protections purposes are The People's Republic of China (P.R. China) and The Republic of Korea (South Korea). The P.R. China has entered into an agreement with the Multilateral Fund for annual reductions of halon production and consumption and final closure of halon production by 2005 for halon 1211 and 2009 for halon 1301. Details of the P.R. China production phase-out are provided in Table 1-1.

The total reported amount of halons imported in 2004 by countries still reporting consumption was approximately 1,736 ODP MT, as shown in Table 1–3 below. One of the two producing countries reported an export of 1,185 ODP MT in 2004, and the other reported no export. The difference between reported export and import could be due to transit through free trade zone areas and/or import of recycled halons mistakenly reported as import of newly produced halons. In addition, as the Montreal Protocol only tracks export and import in bulk, and not halons contained in fire equipment (products containing ODS are not controlled), halon fire extinguishers and halon fire extinguishing systems might still have been exported by halon producing countries and others without being recorded.

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[1] Consumption as defined by the Montreal Protocol meaning production plus import minus export minus destruction.

Table 1-1 Halon Production (MT) in the P.R. China as per the Halon Sector Plan

Halon	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
1211	11,644	7,842	5,965	3,978	3,118	2,469	1,884	1,068	1,276	0	0	0	0
1301	1,027	450	484	428	213	0	0	22	150	*150*	*150*	*150*	*150*

Note, Italics indicate allowable production.

The production quantities shown in Table 1-1 are actual production for the period 1997 to 2005 for fire protection uses, while the quantities from 2006-2009 are allowable production under the agreement between The P.R. China and the Executive Committee of the Multilateral Fund of the Montreal Protocol. Production of halon 1211 ceased at the end of December 2005 and only 150 MT per year of halon 1301 can be produced through December 2009. As there are also agreed limits on domestic consumption, the production quota can only be utilized if the export quotas are fully utilized. Owing to very low exports in 2000 and 2001, the actual production of halon 1301 was much lower than allowed under the agreement. Halon 1301 was not produced in 2002 or 2003 due to limited demand and existing stocks and only a small amount was produced for fire protection uses in 2004. Additional halon 1301 was produced in 2004 (163 MT) and 2005 (277 MT) for the new feedstock demand for the production of a pesticide. As production for feedstocks is not controlled by the Montreal Protocol, or the agreement with the MLF, it is not included in this chapter’s discussions.

South Korea does not have a phase-out agreement with the Multilateral Fund but continues to follow the phase-out schedule for Article 5(1) countries. Based on information available, and the general Montreal Protocol phase-out schedule for developing countries, South Korea’s production was limited to the baseline level of 3,678 ODP MT in 2002, with a reduction to a maximum of 1,839 ODP MT by 2005, and a complete end to production by 2009. Table 1-2 shows actual production for the period 1997 to 2005.

Table 1-2 Reported Halon Production (ODP MT) in South Korea

Halon	1997	1998	1999	2000	2001	2002	2003	2004	2005
1211			336	323	399	476	690	354	165
1301	3,950	2,162	1,860	2,537	2,003	1,712	1,568	1,054	691

Note, the quantities in 1997 and 1998 are total halons combined.

1.3 Halon Consumption

The reported consumption of halons in Article 5(1) countries in 2004 was approximately 5,364 ODP MT, of which The P.R. China and South Korea accounted for approximately 3,647 ODP MT for their own consumption, leaving approximately 1,717 ODP MT for the rest of the Article 5(1) countries. Table 1-3 provides information on halon consumption (note, differences in final totals are caused by the rounding of reported data). Unfortunately, the report from the Ozone Secretariat does not provide a breakdown between halon 1211, halon 1301, and halon 2402. Also, the report does not provide information on how much halon is used for manufacturing of new halon fire-fighting equipment or how much for goes for servicing.

Table 1-3 Halon consumption reported by Article 5(1) Parties (P.R. China and South Korea not included)

Country	2003 Consumption in ODP MT	2004 Consumption in ODP MT	2005 Consumption in ODP MT
Afghanistan	0	0.1	N.R.
Algeria	169.0	80.0	80.0
Argentina	0	0	3.0
Bahrain	4.4	0.0	N.R.
Bosnia	4.1	4.1	N.R.
Botswana:	0.6	0.6	0.3
Brazil	2.1	9.0	3.0
Cameroon	2.0	1.2	1.2
Chile	0	0	1.2
Croatia	5.0	0.8	0
Congo, DPR	27.9	22.9	22.8
Egypt	180.0	193.0	145.0
Eritrea	0	0	0.3
Ethiopia	0.9	0.5	0.4
Georgia	37.4	36.2	16.5
Guinea	1.6	0	N.R.
Guyana	0.2	0	0
Jordan	35.0	32.0	47.0
Kyrgystan	0	2.4	0
Libyan Arab	714.5	714.5	714.5
Mexico	103.8	124.6	52.8
Nigeria	191.2	151.0	N.R.
Oman	0.7	0	0
Pakistan	15.0	7.2	0
Qatar	8.3	0	0
Romania	15.0	1.8	N.R.
Serbia	0	0	0.9
Sierra Leone	15.0	18.5	0
Singapore	-21.2	0	0
Somalia	25.2	23.4	N.R.
Syrian Arab	366.2	215.6	79.0
Thailand	0	0	10.9
Tunisia	42.0	42.0	39.0
Turkey	40.9	22.0	30.0
UAE	29.8	26.9	N.R.
Yemen	11.5	5.6	N.R.
Zimbabwe	0	0.1	0
TOTAL	2028.1	1,736.0	1,247.8

N.R. = Not Reported as of 11th September 2006

Based on studies conducted under projects prepared for various countries, it is estimated that currently all halon 1301, and 80% to 90% of halon 1211, are used for the servicing of existing halon fire equipment. It should be noted that national records of imports of halons has not always been able to capture the total amount actual imported. In many cases, halon has been imported as a fire extinguishing agent and not as an ODS substance. In other cases, halon has been considered as fire equipment and the halon contained in the cylinders has not been reported as "fire extinguishing agent."

1.4 Halon Demand and Replacement

The demand for new halons has been reduced in developing countries through the availability of substitute fire extinguishing agents and alternatives, and only to a limited extent through halon recycling programs. Based on a review of the situation in a large number of countries, with the exception of aviation, it has been concluded that generally halons have been replaced by substitutes for all new applications where halons were traditionally used. It is also apparent that existing halon fire extinguishers and fire extinguishing systems have been replaced to some extent by substitutes when a need for refilling is required. For the portable fire extinguisher market, ABC powder, foam, and CO_2 have been the primary choices both for new extinguishers and for the replacement of existing extinguishers. For halon 1301 fixed fire extinguishing systems, HFC-227ea, inert gas systems and CO_2 systems seem to be the preferred substitutes. HCFC blends are also present in many markets, mainly due to the lower cost.

The supply of fire extinguishers in developing countries is to a large extent based on the local production of fire extinguisher cylinders and valves etc. and, in most countries, the import of the fire extinguishing agents. Fire extinguishing systems are usually imported based on licensing agreements between local fire equipment companies and one or more of the global fire equipment companies. Under such license agreements, design manuals, fire equipment and components, specifications and training are provided by the international company. Substitute chemicals are imported in bulk and are available in sufficient quantities.

Most countries rely on internationally recognised standards and codes for fire extinguishers and fire extinguishing systems such as NFPA codes and CEN standards. A few countries have over time adjusted existing national standards and drafted and issued standards for new substitutes based on ISO and CEN standards and NFPA fire codes.

1.5 Challenges

Halon recycling centres in Article 5(1) countries are either operated on a private commercial or a public funded basis. Each implementation has its advantages and disadvantages. However, the commercial aspects of the trade in recycled halon are not fully understood, and some operational and technical problems need to be resolved.

Training must be provided for fire protection engineers in the design of gaseous fire protection systems giving them the capacity to use the alternatives available in a safe manner. Technicians need to be trained in the proper maintenance of alternative systems as well as critical halon systems. Halon users need to be educated in general fire protection and how to make good choices when they are going to replace their existing halon system with substitutes in a cost effective manner. They also need to understand the importance of ensuring that halons are made available for essential applications.

As halon becomes scarce, management of the remaining stock will become critical for ensuring sufficient halons for critical applications.

2.0 Phase out in Countries that use Halon 2402

2.1 Introduction

Halon 2402 had been produced nearly exclusively in the former USSR, and production was continued by the Russian Federation after 1991 until the end of 2000. From 1994 production was continued under the essential use exemption procedure, approved by the Parties to the Montreal Protocol.

The quality control requirements for halon 2402, and for comparison halons 1301 and 1211, are given in Table 2-1.

Table 2-1 Quality Control Requirements for Halon 2402, 1301 and 1211

Property	**Requirements**		
	Halon 2402[2]	**Halon 1301**[1]	**Halon 1211**[1]
Purity, mole percent, minimum	99.5	99.6	99.0
Other halocarbons, mole percent, maximum		0.4	0.8
Acidity, ppm (by weight), maximum		3.0	3.0
Water content, ppm by weight, maximum	30	10	20
Boiling temperature, °C	47.5	-57.7	-4.0
Boiling range, °C to 85 percent distilled		0.3	Not determined
Non volatile residue, % by weight, max		0.01	0.01
Suspended matter or sediment		None visible	None visible
Total impurities, % by weight, max	0.5		

1 – according to ISO 7201-1
2 – according to GOST No: 15899-93 for halon 2402

The properties of halon 2402 allow it to be used in:

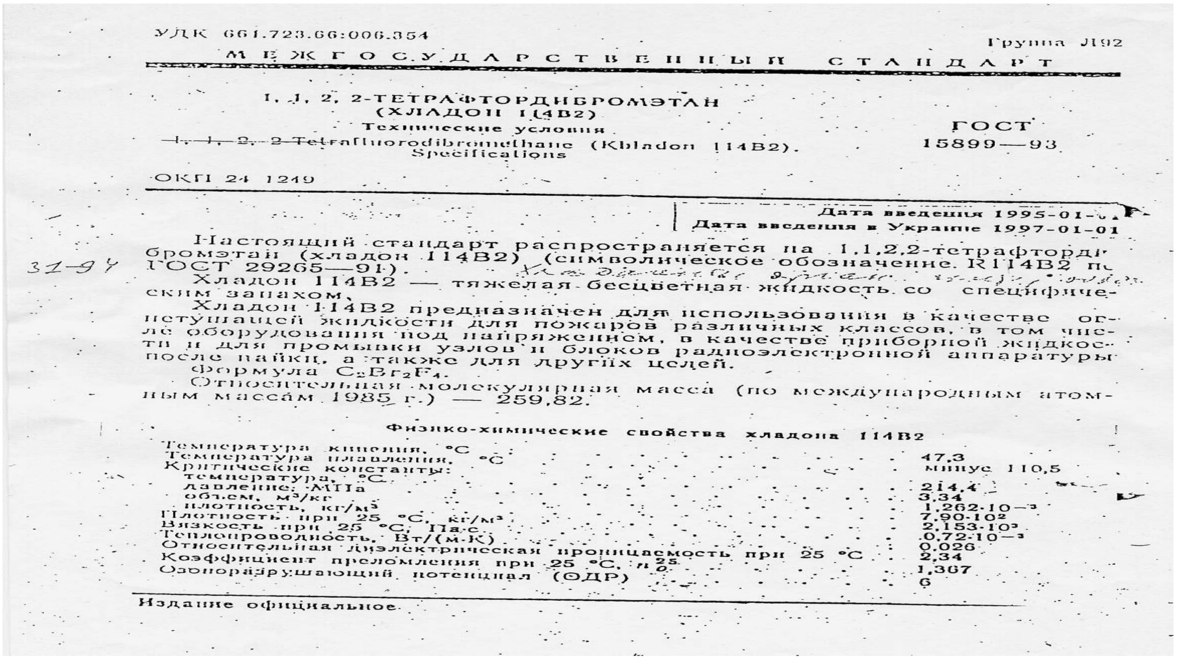
- Fixed systems as a local application agent
- Portable equipment.

Examples of the main applications of halon 2402 include:

- Military uses:
  - combat vehicles,
  - armoured vehicles,
  - naval ships, and
  - aircraft
- Other uses:
  - nuclear power stations,
  - oil platforms, compressing and pumping oil-gas stations,
  - civil aviation,
  - main computer centres in banking facilities, and
  - telecommunication facilities, etc.

In the Russian Federation and the Ukraine, the great majority of halon used has been halon 2402 ($C_2F_4Br_2$, CFC 114B2). Being a low pressure fluid with a boiling temperature of 47.5^{o}C, halon 2402 is particularly easy to handle. Containers are stored at low pressure and pressurized with Nitrogen when installed in applications. Therefore, halon 2402 has been commonly used for civilian applications. Halon 1301 and halon 1211 use in Russia has been largely confined to military and specialist applications, but fire protection in those sectors has been dominated by halon 2402. All equipment associated with halon systems was manufactured in the USSR until its dissolution in 1991, and in the Russian Federation and the Ukraine since. In other countries of the former Eastern Block (e.g., Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Slovakia etc.) use of halon 2402 was associated with the use of Russian military equipment and civilian aircraft. However, now many of these are no longer used. Halon 2402 based fire protection equipment was also exported to some Asian countries together with Russian products, mostly military vehicles, ships and aircrafts.

The only known standard for halon 2402 is the Russian GOST (see picture below).



УДК 661.723.66:006.354

Группа Л92

МЕЖГОСУДАРСТВЕННЫЙ СТАНДАРТ

1, 1, 2, 2-ТЕТРАФТОРДИБРОМЭТАН
(ХЛАДОН 114B2)
Технические условия
1, 1, 2, 2-Tetrafluorodibromethane (Khladon 114B2).
Specifications

ГОСТ
15899—93

ОКП 24 1249

Дата введения 1995-01-
Дата введения в Украине 1997-01-01

Настоящий стандарт распространяется на 1,1,2,2-тетрафтордибромэтан (хладон 114B2) (символическое обозначение R114B2 п
31-94 ГОСТ 29265—91).

Хладон 114B2 — тяжелая бесцветная жидкость со специфическим запахом.

Хладон 114B2 предназначен для использования в качестве огнетушащей жидкости для пожаров различных классов, в том числе оборудования под напряжением, в качестве приборной жидкости и для промывки узлов и блоков радиоэлектронной аппаратуры после пайки, а также для других целей.

Формула $C_2Br_2F_4$.

Относительная молекулярная масса (по международным атомным массам 1985 г.) — 259,82.

Физико-химические свойства хладона 114B2

Температура кипения, °C	47,3
Температура плавления, °C	минус 110,5
Критические константы:	
температура, °C	214,4
давление, МПа	3,34
объем, м³/кг	$1{,}262 \cdot 10^{-3}$
плотность, кг/м³	$7{,}90 \cdot 10^{2}$
Плотность при 25 °C, кг/м³	$2{,}153 \cdot 10^{3}$
Вязкость при 25 °C, Па·с	$0{,}72 \cdot 10^{-3}$
Теплопроводность, Вт/(м·К)	0,026
Относительная диэлектрическая проницаемость при 25 °C	2,34
Коэффициент преломления при 25 °C, n_D^{25}	1,367
Озоноразрушающий потенциал (ОДР)	6

Издание официальное

2.2 Countries That Still Use Halon 2402

Countries that still use halon 2402 as a fire protection agent can be grouped as follows:

- Russian Federation: Ukraine, Belarus;
- Former USSR and other countries of the former Eastern Block:
  - Caucasus: Armenia, Azerbaijan, Georgia;
  - Central Asia: Kazakhstan, Kyrgyzstan, Tadzhikistan, Turkmenistan, Uzbekistan;
  - Non-EU states of East- South Europe: e.g., former Yugoslavia, etc.;

- EU member states: Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Slovakia; and
- South-East Asia: Afghanistan, India, Vietnam.

Some military and aviation equipment employing halon 2402 may still be in use in countries that purchased equipment from the USSR, and later from Russia, e.g., Algeria, China, Cuba, Egypt, Libya, Mongolia and Syria.

India has used substantial amounts of halon 2402 and its blends, e.g., halon 2402 and ethyl bromide, in its military equipment purchased from the former Soviet Union. Examples are armoured fighting vehicles, e.g., T-54, T-60, T-70, T-80 produced in the 1990's. Russia stopped the use of halon 2402 and its blends in their new generation tanks in the mid – 1990's. For example, the T-90 is now equipped with halon 1301 systems for both its crew and engine compartments. Portable extinguishers for armoured fighting vehicles in the former Soviet Union used CO_2, halon 2402, or halon 2402 and its blends in the 1980's and early 1990's. New equipment now uses CO_2 or dry chemical portable extinguishers. A similar situation exists with military aircraft, both fighters as well as transport, and helicopters. New generation tanks, aircraft and ships no longer require halon 2402.

2.3 Halon 2402 Supply and Demand

According to Russian experts – members of the HTOC - the amount of halon 2402 currently available for purchase in the Russian market can be estimated at 100 MT. However, it should be borne in mind that a substantial part of this quantity is held by large organizations such as the military sector or Gazprom, and other large companies. These amounts may or may not be available for other users depending on the owners' current situation. According to VNIIPO estimation, the total amount of halon 2402 installed in the Russian Federation bank is approx. 960 MT. In comparison, in 2000 when production of halon 2402 was stopped, the inventory estimated was more then 3000 MT. This substantial reduction in inventory was mainly due to the use of halon 2402 as a process agent in the chemical industry during the period 2002-2003 when the average price of halon 2402 was low.

At least 3 private companies are involved in the recycling and banking of halon 2402 in Russia. One of them is the GYPH – the National Institute for Applied Chemistry, St. Petersburg, which is equipped with a recycling machine. In addition, the military sector, Gazprom, and some other large companies have banking facilities for supporting their own needs.

Russian national regulations prohibit the export of ozone depleting substances, including halons. The installation of halon 2402 in new fire suppression systems in the Russian Federation is allowed for critical uses only. In such cases an application for special permission from the Ministry of Natural Resources is required.

A similar situation exists in the Ukraine, i.e., a large amount of halon 2402 is available for purchase, the installed base of halon 2402 is large, and Ukraine national regulations prohibit the export of ozone depleting substances, including halons. During the preparation of the draft concept of the National Halon Management Strategy for Ukraine (2002-2003), it was concluded that the installed base of halon 2402 in the Ukraine ranges from 552 to 602 MT.

In Russia and the Ukraine, there appears to be sufficient halon 2402 available for the servicing of existing equipment and supporting critical needs. In addition, the existing stocks of halon 2402 in Russia and the Ukrainian could also support the current critical demands of other countries that use halon 2402. The price of halon 2402 in the Russian market has risen from US$ 5.50 / kg at the end of 2000, to US$18 to US$25 / kg currently. Note, some of this increase in price is due to the change in exchange rates between the US dollar and the ruble, but the significant use of halon 2402 in Russia as a process agent in the chemical industry also contributed to the increased halon 2402 price. Higher prices in other parts of Eastern Europe have also been reported.

Information on the installed capacity and demand for halon 2402 in Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, Tadzhikistan, Turkmenistan and Uzbekistan is not currently available. Similarly, data with regard to halon 2402 demand for Afghanistan, Algeria, Egypt, China, Cuba, Mongolia, Libya and Syria, is not available. However, based on other countries' experiences, it should be assumed that a demand for halon 2402 for the servicing of operating equipment exists and that halon from outside sources will be required.

In general there is only a minor demand for halon 2402 in some Members States of the European Union: Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Slovakia and Slovenia. The majority of former halon 2402 applications have been switched to other agents or technologies, but a small sector of industry continues to employ halon 2402. Currently the installed capacity of halon 2402 in these countries is not sufficient to support critical uses via recovery and recycling, and the purchase of halon 2402 from Russia appears to be virtually impossible.

India is currently seeking 15 MT of halon 2402 for critical uses. It is projected that the Indian Navy's demand for halon 2402 over the next 20 to 30 years will be approximately100 MT. The Indian Army, although slowly switching over fire protection to halon1301, also requires limited amounts of halon 2402 for critical uses in fixed systems.

India is currently implementing a Halon Banking Programme that includes the recovery and recycling of halon 2402. The Military sector will make use of this facility but it is projected that sufficient supplies of halon 2402 will not be available to satisfy all Military requirements. The halon bank of the Baltic States supported India by transferring recycled halon 2402 for critical needs of the Indian Navy. This was done based on a request from India under a licence given by the European Commission, and with support from HTOC experts. However, the amount provided was far below needs, and the halon bank of the Baltic States will not be able to supply halon 2402 in the future.

2.4 Conclusions and Recommendations

During the period 2002-2003 when the average price of halon 2402 was low, its use as a process agent in the Russian chemical industry substantially reduced the Russian inventory of halon 2402. Nevertheless, within Russia and the Ukraine there appears to be a large installed capacity of halon 2402 and sufficient quantities are available on the market from storage and recovery/banking for the servicing of existing applications. There may also be a sufficient amount of recovered halon 2402 to support the current needs of other countries, however export of halon 2402 from Russia and the Ukraine is banned by national regulations.

There is growing concern over the availability of halon 2402 outside of Russia and the Ukraine to support the critical servicing needs of Russian produced aircraft, military vehicles and naval vessels still in operation in some countries. A particularly difficult situation currently exists in India.

As the world's bank of halons becomes smaller through emissions and transformation, the ability to replenish agent for critical uses in some regions will become more difficult. There will be imbalances where excess agent supply in some regions cannot be used to meet shortages in other regions because of obstacles presented by national or international regulations, either through complications or the outright prohibition of the transfer. The HTOC has already seen evidence of this with halon 2402, and would expect the other halons to follow suit as their supplies are reduced. In effect, while there is no apparent shortage of any halons on a global basis, there are regional shortages today that cannot be met with excess agent from other regions.

Parties may wish to consider developing mechanisms that would assist in resolving such regional or local imbalances.

3.0 Global Halon Banking

3.1 Introduction

Halon banking is a critical part of the management of halons. Halon Bank Programs must be accessible to all halon users or we run the risk of accelerated atmospheric emissions and unsafe fire hazards. This chapter is a synopsis of the current state of halon banking globally. Phase-out of halons cannot be accomplished without implementing national and regional halon bank management programs to collect, reclaim/recycle, store, and redistribute the agents. A facility or organization can either perform the banking function physically as an actual "physical" bank with halon actually stored and maintained in specific locations, or they can act as a virtual clearinghouse where halon users can be facilitated in turning-in halon and/or obtaining halon. A physical halon bank is all halons contained in fire extinguishing cylinders and storage cylinders within any organization, country, or region. Likewise the 'global halon bank' normally refers to all halon presently contained in halon fire equipment and halon stored at halon recycling centres, at fire equipment companies, at critical halon users, at halon producers, committed for future uses, etc. The collection, reclamation, storage, and redistribution of halons is referred to as "Halon Banking." Virtual halon banking is a clearinghouse whereby halon transfer is facilitated between users. For the purposes of this Assessment Report, "Banking" is considered all functions both physical and virtual that involve the use, recovery, reclamation, transfer, storage, and disposal of all halons used for fire protection.

3.2 Regional and National Halon Banking Programs

Many countries have developed halon banking programs that are now fully operational. The earlier halon production phase-out schedule imposed on the non-Article 5(1) countries resulted in early establishment of halon banking programs. As a result, their programs have been tested and have matured. Previous HTOC reports have covered the development, implementation, and operation of many successful halon banking programs within non-Article 5(1) countries. The CEIT's and Article 5(1) countries are in many cases just now getting halon banks established or setting up protocols for participation in regional halon banks. There remain many countries that have not yet implemented any regulations, procedures, or programs to facilitate the management of remaining halon inventories. Table 3-1 is a list of country national and regional halon banking operations extracted from the *Final Evaluation Report on Halon Banking Projects for Countries with Low Volumes of Installed Capacities* (UNEP/OzL.Pro/ExCom/44/10). Table 3-1 is not a globally comprehensive list of halon banking programs, but rather a list of those programs that were established or assisted utilizing Multilateral Funds. Where "Recovery & Recycling" is indicated under the "Operations" column, there is not yet a national "Halon Bank."

Table 3-1 Regional and National Halon Banking Programs

Country	Program	Operations	Functionality
Algeria	National	Halon Banking	Unknown
Argentina	National	Halon Banking	Beginning Operations in 2006
Bahamas	Regional	Halon Banking	Unknown
Bahrain	Regional	Halon Banking	Unknown
Barbados	Regional	Halon Banking	Unknown
Benin	Regional	Halon Banking	Unknown
Bosnia and Herzegovina	National	Halon Banking	Unknown
Botswana	Regional	Halon Banking	Not Operational
Brazil	National	Halon Banking	Unknown
Burkina Faso	Regional	Halon Banking	Unknown
Cameroon	Regional	Halon Banking	Unknown
Chile	National	Halon Banking	Getting Established – Not Operational Yet
China	National	Recovery & Recycling	Marginally Operational – Experiencing Difficulties
Congo	Regional	Halon Banking	Unknown
Congo, DR	Regional	Halon Banking	Unknown
Croatia	National	Halon Banking	Unknown
Czech Republic*	National	Halon Banking	Operational beginning 2005
Dominican Republic	National	Halon Banking	Unknown
Ecuador	National	Recovery & Recycling	Unknown
Egypt	National	Halon Banking	Not Operational
Estonia*	Regional	Halon Banking	Operational beginning 2003
Ethiopia	Regional	Halon Banking	Unknown
Grenada	Regional	Halon Banking	Unknown
Guinea	Regional	Halon Banking	Unknown
Guyana	Regional	Halon Banking	Unknown
Hungary*	National	Halon Banking	Operational beginning 1997
India	National	Halon Banking	Operating – some challenges with imports
Indonesia	National	Halon Banking	Operating – Problems with Handling Contaminated Halons
Iran	National	Halon Banking	Unknown
Jamaica	Regional	Halon Banking	Unknown
Jordan	National	Halon Banking	Operating – Halon Owners Not Donating Halons to Bank
Kenya	Regional	Halon Banking	Unknown
Lebanon	Regional	Halon Banking	Unknown

Country	Program	Operations	Functionality
Lesotho	Regional	Halon Banking	Not Operational
Macedonia	National	Technical Assistance	Unknown
Malaysia	National	Halon Banking	Not Operating – Lack of halon availability and demand
Mexico	National	Halon Banking	Operating minimally
Namibia	Regional	Halon Banking	Not Operational
Nigeria	National	Halon Banking	Unknown
Oman	National	Recovery & Recycling	Unknown
Pakistan	National	Halon Banking	Unknown
Qatar	Regional	Halon Banking	Unknown
Serbia and Montenegro	National	Halon Banking	Operational beginning 2003
Syria	National	Halon Banking	Not Operational
Tanzania	Regional	Halon Banking	Unknown
Thailand	Regional	Halon Banking	No activity reported
Trinidad and Tobago	Regional	Halon Banking	Unknown
Turkey	National	Halon Banking	No work started yet on Halon Bank
Uruguay	National	Recovery & Recycling	Unknown
Venezuela	National	Halon Banking	Unknown
Vietnam	National	Halon Banking	Work on establishing recycling centre has just begun
Yemen	Regional	Halon Banking	Unknown
Zimbabwe	Regional	Halon Banking	Not Operational

* These countries did not receive Multilateral Funds.

The International Maritime Organization (IMO) Sub-Committee on Fire Protection has provided information on the availability of halons at various ports of the world for existing maritime halon systems that may need to be recharged with recycled halons in compliance with the relevant requirements of the 1974 SOLAS Convention. Member Governments provided information on available halon banking facilities. Table 3-2 is a list of country facilities and their halon services available, extracted from IMO FP.1/Circ.31 dated 4 January 2006.

Table 3-2 Halon Banking and Reception Facilities at Various Ports Around the World Available for Maritime Halon Needs

Country	Facilities	Type of Bank
Argentina	INTI	Virtual Bank
Australia	Australian National Halon Bank	Full Service Halon Bank
Brazil	Two Facilities	Halon Recycling, Recovery, and Supply
Canada	Numerous	Varies
Croatia	One Facility	Halon Bank
Denmark	Danish Halon Bank	Halon Bank
Egypt	Two Facilities	Halon Bank
Finland	Federation of Finnish Insurance Companies	Virtual Halon bank
France	Numerous Facilities	Halon Recycling, Recovery, and Supply
Norway	Numerous Facilities	Halon Recycling, Recovery, and Supply
Poland*	Savi Technologies	Halon Recycling
Republic of Korea	One Facility	Halon Recycling, Recovery, and Supply
Russian Federation	One Facility	Halon Recycling, Recovery, and Supply
United States	Halon Recycling Corporation	Virtual Halon Bank
Hong Kong, China	Environmental Protection Dept.	Virtual Halon Bank

* Not listed in the IMO Circular

3.2.1 Examples of Halon Banks that are functioning successfully in CEIT and Article 5(1) Countries

Russia: Russia has a national halon banking programme that is reported to be operating successfully (see Chapter 2). Russia does allow new halon installations in critical applications and has extensive military systems that will need maintaining. There are several companies performing halon recycling, reclamation, and banking activities. In addition, the military sector, Gazprom, and some other large companies have banking facilities for supporting their own needs. The export/import of ozone depleting substances, including halons, is banned according to Russian national regulations.

Southern Africa: The halon banking program was initiated by the South African Government; a steering committee commenced working on a halon bank concept in 1994.

The Halon Bank of Southern Africa (SA) was officially started in 1995, under the auspices of the South African Government's Department of National Health. A loan was provided by the Department to start the Bank.

Some of the functions of the Halon Bank, as originally set out, are to manage existing stocks of halon down to zero, facilitate the disposal of halons, and assist in locating halons to keep critical systems running. It acts as a clearing agent for sales of used halon, 'lists and approves' companies that recycle used halons to a recognised specification, and acts as a link between SA users and halon banks in other countries. It also provides advice and investigations on all matters relating to halon and alternative fire protection methods, arranges for assay testing of halon samples, and issues a variety of certificates, for example a certificate of ‘halon deposit’ to end users.

The steering committee originally intended that the Bank would serve South Africa and neighbouring countries, such as Swaziland, Lesotho, Namibia, Botswana and Zimbabwe. Subsequent operational experience has been that these countries have little halon refill needs or stock to return.

The Bank is a non-profit organisation and is run by a management committee consisting of the Managing Director of the Fire Protection Association of SA, and a Consulting Fire Engineer, assisted by both parties’ administration staff as required. Bank expenses are met by funds raised mainly by levies on halon transactions and certification charges. The accounts are audited annually by independent auditors.

From September 1995 to June 2006, the Bank authorised 16 re-use applications, rejected four, and approved 25 refill applications and rejected five. Ten batches of halon were assayed - most of which failed due to contamination. Eighteen critical use refills (for aviation) were facilitated. Most of the transactions are for halon 1301. Halon 1211 is also processed, but mainly in the form of returns (to portable extinguisher vendors). Only one application for a small quantity of halon 2402 has been received. Over six policy documents have been developed and revised by the Bank during this 10 year period. A number of investigations were carried out and reported on. Nearly 500 documents have been issued, over 230 correspondences received, and some 2000 man hours incurred on a part-time basis during this time.

No legislation has been proposed or implemented by the Bank. Control of import or export of halons is however regulated by the Customs Department. The strategy has been to rely on the market to follow the intention of the Montreal Protocol and amendments, with regard to halon consumption. Good practice has in general been followed by most halon vendors. Exceptions do occur occasionally, most notably on the part of vendors serving the shipping industry, whereby halon is imported or exported without authorisation by the Bank. Apart from such activities contravening the customs regulations, the quality of the ‘halon’ so transacted would also be unknown due to lack of assay and certification.

Refills of halon containers are done by approved vendors or by end-users, (such as the SA Air Force or the SA Airways Technical Centre). Refills are mostly from stock of halon saturated with nitrogen, i.e., the nitrogen is generally not fully extracted before refilling. Apart from this, the procedures are generally in accordance with those set out in Section 3.3 of this Report.

A containerised recycling plant from GTZ PROKLIMA was delivered to South Africa in 2005. This has been placed with an industrial gas manufacturer / vendor, who has not yet put the unit to use. This is mainly due to existing stock of halon being sufficient for the refill applications that are received and approved by the Bank from time to time.

The Bank has identified a destruction facility in Johannesburg. Based on the facility’s stated capability and interest in the destruction of halons, the Bank has an informal agreement to be the sole authorising agency for such destruction. No destruction has yet occurred, although some reject halon is envisaged for this purpose in cases where recycling by means of the GTZ plant proves to be unsuccessful.

The business model adopted is mainly one of vendor-operated under authorisation by the Bank, whereby halon is returned to, or refilled by, approved vendors under the authority and monitoring of the Bank. This process is particularly successful where the Bank operates the financial aspects of the transactions. Some halon is also returned directly to the Bank, with the result that the Bank itself has some of its own stock that can be used for recycling. This has a potential benefit in that recycled stock may be an asset, but also is a potential liability in that the stock may not be in demand in the future for recycling, or that it could require destruction.

The cost implications of potential destruction ‘liability’ need to be taken into account by the relevant UN organisation, as an Article 5(1) country’s halon bank may need financial assistance with the destruction costs.

India: The National Halon Management program is implemented by Ozone Cell, India. The program includes a national recycling and reclamation centre. National policy requires that all new fire equipment sold in the Indian market contain alternatives to halons. Existing halon fire equipment can remain in place and be serviced as long as the users want to and can find halons for it. As per condition associated with the MLF funding for the Halon Management Program, import of newly produced halons was stopped by the government through an administrative order issued by the Ozone Cell in December 2004. Recycled halon can be imported; however, procedural delays in their import/export is making it difficult for users. Importing from a regional or national bank involves procedures such as obtaining quotations, quantities, rates, terms of supplies, etc., which causes it to be difficult for recyclers to reserve the quantities needed.

A Halon Bank facility consisting of recovery, recycling and reclamation machines for all three halons (1211, 1301 and 2402) has been set up at the “Center for Environment and Explosive Safety Laboratory” in New Delhi. The facility also provides quality control on halons and has the necessary testing and laboratory equipment. The Center has been operational since August 2004 and has been used by critical users regularly. The recycling is provided as a free service to the critical users (of which many are governmental departments). The halon recycling centre does stockpile halons, but leaves it to the critical users to establish their own halon stocks for their future uses.

The Halon Bank is a bilateral project with Canada and Australia and funded under the MLF.

In addition to this national recycling and reclamation facility, and because of the their specific requirements and functions, the private sector has set up recycling centres in different parts of the country at their own cost and they operate them on a commercial basis. Halon recycling equipment has been funded by the MLF as part of their halon conversion projects for a small number of the larger fire equipment companies allowing them to provide services in general. (Three of the companies are New Age Fire protection Industry, Mumbai, Nitiin Fire Protection Industry, Mumbai, and Minimax Chennai).

Halon users have been educated and trained in the use of the national recycling and reclamation facility for their inventory. The physical inventories are with the owners of the halons, e.g., the military, civil aviation, oil, power/energy sector, merchant shipping companies, private sector industries, fire services, etc. and not with the national centre. The total inventory including the users is approximately 1,000 MT of halon 1301, 2,000 MT of halon 1211, and 100 MT of halon 2402. The halon is for the most part installed in existing fire protection equipment with a smaller amount being stocked for refill and servicing.

It is also understood that the Indian Navy is planning to start up their own halon recycling and reclamation facility in one of their naval bases for their own use, because of specialized applications being different from the civil sector.

The national recycling facility is up and running and halon is recycled and reclaimed for critical users on a regular free of charge basis for the users. No technical problems have been found in running the national recycling facility so far. Also, so far there have been no reported cases of Indian users having problems finding halons for their critical applications. The private sector seems to use the halon recycling centres operating on a commercial basis by the private fire equipment companies.

3.2.2 Examples of Halon Banking Programmes experiencing difficulties in Article 5(1) countries

Egypt: Recovery and recycling equipment was purchased as part of the Halon Banking Project of Egypt, but the equipment has been kept in storage and not operated for various procedural reasons. The National Ozone Unit and UNDP are attempting to find ways to set up the recovery and recycling centre to make it operational.

Syria: The recovery and recycling centre was set up under the control of the Civil Defence. Training of operational staff was carried out. However, the centre has not operated since. Legislation was enacted to control importation of halons. Awareness training for stakeholders was conducted.

West Asia, Eastern Africa, and Western Africa: There are three regional halon banking projects in these three regions. Recycling and recovery equipment were purchased for all three regions, but centres have not been set up for any of the three regions. Implementation has not been successful.

Mexico: A Mexican halon recycling facility has been established. The operation started in early 2006. Up to now a small amount of halons have been recovered and reclaimed by the facility. The implementation was delayed for nearly a year due to a number of technical problems, which have all been overcome. As time has elapsed, and as the equipment has been under-utilized, the contractor reported that the equipment needs maintenance to be put back in full working order. Development of the Mexico halon database has stalled because most halon owners, particularly those that are government owned, are reluctant to provide details of their installed halon due to confidentiality issues. After a significant awareness campaign, momentum was lost due to the delayed installation of the halon banking equipment, thus additional awareness activities and advocacy efforts are needed to stimulate potential users of the halon bank to come forward and to finally make the whole project fully operational. The Halon Management Group/Advisory Forum and the associated Halon Essential Use Panel only met before the commissioning of the equipment and needs to resume its leading/steering role. In order to support the halon banking operation, a number of supporting activities including the aforementioned will need to be carried out during the coming months.

China: China does not have a national Halon Bank. Although there is use of halon 2402 and 1301 in China, halon 1211 is the primary halon in the country. As identified in this report, 60% of the global halon 1211 inventory seems to be contained in handheld fire extinguishers and stocks in China. As halon fire extinguishers in China are mandated to be retired after 10 years of service, effort should be made to recover halon 1211 from retired handheld fire extinguishers in order to avoid emissions. As the production and sale of handheld halon 1211 fire extinguishers were banned at the end of 2005, the domestic demand for halon 1211 is limited to some critical applications (e.g., aviation and military uses).

The members of the HTOC are aware of a number of Parties that are seeking recycled halon 1211 for critical applications and are having difficulties finding it. As part of its halon phase-out program, China has set up a halon 1211 reclamation facility which is now operational. In order to facilitate the global trade in recycled halons, China has been encouraged to provide information on the availability of recycled halon 1211 and Parties are encouraged to contact China if they need recycled halon 1211.

3.3 Path to Halon Management and Banking Plan

Halon Banking comprises but a portion of an overall Montreal Protocol compliance programme. The other features of a comprehensive programme should occur before a halon bank is established. Examples of these features include:

- Establish governmental policy and program
- Choose appropriate replacements or alternatives
- Identify remaining mission critical uses and quantity requirements
- Identify halon sources (recoverable and available for reclaiming)from non-critical uses or acquisitions
- Survey installed capacities & establish database of halon users
- Identify & involve stakeholders.
- Establish National Halon Steering Committee
- Open discussions with the Military, Civil Aviation, Shipping, & Airlines
- Plan for decommissioning of halon systems

A decision can then be made whether to establish or join a Halon Bank to meet mission critical uses.

Important policies that have been shown to help ensure successful implementation of a banking program include:

- Senior leaders acknowledge Montreal Protocol does not allow government exemption for halon production
- Emphasize to stakeholders that supplies are limited with no future production
- Prohibit new halon systems in facilities or new equipment designs
- Prohibit halon emissions in testing and drills – use only on real fires
- Replace discharged halon systems with other forms of fire protection
- Require that all halon removed from retired systems must be sent to the Bank
- Prohibit purchases of halon on the market - all transactions via the Bank – through regulations or voluntary agreements
- Exchange information and expertise regionally
- Develop halon regulations, i.e., importation of halons, a quota system, etc.
- Develop and approve code of conduct/strategy

The Concept of Operation is as follows:

- The Bank acts as a centralized warehousing and repair facility
- The Bank becomes a “one stop shop” for all halon transactions; e.g., turn in, reclamation, storage and reissue
- All used halon is turned in to the Bank
- Deliver the type and quantity of halon bottles where and when needed
- Bank provides clean halon for critical uses, as needed

Recordkeeping and program management are greatly simplified by strict adherence to the banking concept because multiple, dispersed physical storage locations and information systems are eliminated. Bank users should be apprised of the benefits they derive from their participation in a banking program, such as consistent quality and predictable supplies of halon.

Options for setting up a halon Bank include contractor-operated, government-operated or a combination of these. The combination option allows for a contractor to run ‘normal’ operations, but ownership and control of government halon is maintained by government personnel who monitor turn-ins and approve issues, as well as retaining overall program control.

A purely contracted operation would be less expensive to set up initially, but it may be more difficult for a private concern to obtain halon or ensure compliance with national policies than a government or military organization would experience.

A purely government operated bank would ensure stricter control of quantities and availability of halon, but would likely be more expensive to set up and maintain. The expertise required to operate the halon Bank may be difficult to obtain in a government organization.

Halon Bank rules should be clearly established up front and strictly adhered to during operation. The Bank concept is that you can't take out more than you put in. Issues will be limited to those required for authorized uses and not for convenience. Examples include aircraft, tactical vehicles and shipboard uses. Some critical command, control and communications facilities could be included. A list of authorized users must be created and issues to those users should be made in approved quantities.

Halon removed from service must be sent to the Bank for reuse. Owners are not allowed to sell, trade, give away or dispose of halon. The Bank must provide shipping and containers free of charge. It must be easy and cost nothing to encourage field units to turn in used halon. After encouraging and facilitating all possible sources to turn in their halon, the Bank may then turn to commercial sources to obtain recycled halon. This can be expensive, but should be considered to meet critical requirements.

The basic functions of the Bank are to receive, test, recycle and repackage, store and issue halons. In addition, the Bank must either renovate cylinders in-house or contract out this function.

Safety is critical in the operation of a halon Bank. Workers must be fully trained to know and avoid common safety problems when dealing with compressed gas cylinders. Hand held leak detectors should be used at receiving facilities. Each cylinder should be inspected for valve type and integrity to include all safety devices. Workers should always assume a cylinder is fully pressurized regardless of gauge reading.

Cylinders should always be chained down when being evacuated or worked on in any way. Workers need to be trained to know the different types of valves and how they activate, e.g., Burst Disk/Initiator, Mechanical/Cutter Valves and Schrader Valves. Everyone working on halon cylinders needs to be fully trained to avoid fatal accidents.

In addition to Safety training, workers need to be competent to perform the routine functions of the Bank:

- Verify product and possible contaminants
- Remove/recover all halon to specified level of vacuum
- Repackage into larger cylinders
- Clean halon to specification
- Repackage for storage and Issue
- Certify workers
- Use certified equipment

All incoming halon must be tested. Cylinders may not contain what the label states. Halon may be contaminated and unsuitable for use. Always test before repackaging as small impurities can contaminate large amounts of otherwise good halon.

Recycling is a core function of a halon Bank. Commercial recycling machines are available on the market. Halon 1211, halon 1301, and halon 2402 are recyclable. Operator training is required.

Cylinders can be reclaimed for reuse by undertaking the following steps:

- Visual inspection
- Sand blast
- Prime
- Hydrostatic test
- Clean interior
- Pressurize in chamber/check expansion
- Steam dry
- Certify facility and workers

During storage, halon should be colour-tagged to denote new versus recovered, type and quantity, ready for issue or not and owner. Halon should be kept between 20 and 100 degrees F (-7 and 38 degrees C). Cooler is better. Security measures should include fencing, motion sensors and video cameras.

In summary, halon Banking is one part of an overall total compliance program. Efforts to identify equipment using halon, select replacements, identify mission critical uses, and monitor progress all need to be accomplished. Establishing and enforcing the Bank rules is critical to success. Issues must be limited to authorized users for mission critical applications only. Safety is paramount – unsecured halon vessels can kill! Leak detection and physical security protect scarce, valuable halon.

3.4 Current Situation

In reviewing the halon recycling component of a number of Halon Management Programs, there is very often a conflict between the policies introduced and enforced and the objectives the halon recycling activities envisaged. One example has been the introduction of policies and regulations banning or significantly limiting the use of halons (including recycled halons), and at the same time setting up a halon recycling program with the expectation that it be financially self supporting, while at the same time the market for halons for servicing have been more or less eliminated through the policies and regulations.

Halon management and recycling programs differ considerably from country to country. They are very much based on national regulations and business requirements. In some countries the fire protection industry and some of the critical halon users have established a national focal point as a broker function, where halon users and buyers can register their need for or surplus of halons so that those who want to sell can announce their halons and those who want to buy can find halon available and contact the seller. The focal point is not involved in the physical transfer of halon. The focal point is normally financed through a combination of membership fees and a fee for each transaction through the focal point.

A number of recycling companies exist that have evolved over time. From manufacturing halon recycling equipment, or as fire equipment companies, or fire service companies, they have developed into international halon recycling centres on a strictly commercial basis. They buy halons from existing users and owners of halons and from other recycling centres and sell it to users. As they operate on a commercial basis, the operation cost is covered by selling recycled halons. The demand and availability of recycled halon is of course a key factor in the sustainability of the operation.

Below are few examples of fairly successful halon recovery and recycling programs:

- Jordan has managed to setup a fairly successful halon recovery & recycling centre staffed by competent national operators and in cooperation with the armed forces. Jordan has conducted a series of training courses targeting specific stakeholders, such as the civil aviation and various branches of the armed forces. The training expertise developed in Jordan could be utilized to provide training for other countries of the West Asia Region.
- India has set up a well equipped recovery & recycling centre run by competent operators, under the supervision of the Defence Department. Given adequate support by the various branches of the armed forces this centre will have a sustainable recovery & recycling operation.
- A number of Caribbean countries, with the assistance from Environment Canada and the University of West Indies, set up a Regional Halon Clearing House to manage halon inventories of the member countries.

One final note on the current situation in many developed countries is the fact that it is becoming very difficult to find halon 1211. The predication in the EU is that there is only about a three to five years supply available, mainly for hand held portables for aircraft. Halon 1301 seems to more plentiful in availability and supply, and with the present estimates of demand for critical uses there is approximately a 20 year supply left. However, should the EU introduce any more restrictions there may be a reduction in availability similar to what happened when regulation EC 2037-2000 was introduced.

3.5 Challenges

The implementation of some of the projects in Article 5(1) countries faced a number of challenges which limited and/or were the main reasons for failure of these projects. Below are some of these challenges:

- Competition within the fire protection industry in the country resulted in lack of general support from the rest of the fire protection industry. (Used as a platform for promotion of the company and replacement of halon fire equipment).
- Selection of a company with no prior experience within the fire protection industry.
- Selection of a company which only needed the halon for its own use.
- Regional centre serving several countries (one proposed set of mobile equipment to serve a number of countries).
- Not enough business to sustain operation.
- The bulk of the project funding is exhausted in the purchase of halon recovery and recycling equipment.
- The ability of some host countries to operate and maintain halon recovery and recycling equipment centres have been problematic (sustainability of the banks).
- Finding excessive quantities of contaminated halons in some countries, particularly in Africa. As venting would be unacceptable, shipping to and cleaning up at a reclamation

facility would be needed; however, it remains to be determined how to cover such costs.

- Selection of inappropriate recycling and recovery equipment and inadequate operators' training.
- Data on the installed base and stored inventories of halon is poor.
- Coordination with military branches is not being done.
- Exchange of data and information are not adequate.
- Overly restrictive national regulations that prevented the free flow of recycled halon.

There has been an unanticipated lag in the establishment of halon banking and management programs globally. Whereas some countries and organizations were proactive, many are just now beginning implementation or the consideration of legislation and implementation. Nonetheless, despite global turmoil, changing political parties, and lack of infrastructure, the progress of halon phase-out is steady, and with continued support, the Montreal Protocol processes will allow for the utilization of halons in the remaining critical uses while minimizing unnecessary emissions to the atmosphere.

3.6 Conclusions

Halon banking can play a significant role in ensuring the quality and availability of recycled halon, in managing the consumption down to zero, and in assisting with emission data by providing regional estimates that should be more accurate than global estimates. National or regional banking schemes that maintain good records offer the opportunity to minimise the uncertainty in stored inventory and stock availability. Parties may wish to encourage such national halon banking schemes in order to ensure that a country's critical needs are met.

4.0 Estimated Inventories of Halons

As in previous Assessment Reports, the HTOC is providing the most current estimates of inventories for halon 1211 and halon 1301 based on modelling of known production and estimated emissions. As part of the Science Assessment Panel (SAP) efforts for the 2006 ozone assessment, the HTOC and SAP identified an error in the 2002 model that significantly overstated halon 1211 production in Article 5(1) countries. As a result, the 2002 HTOC assessment also over predicted both the inventory and emissions of halon 1211. When the error was corrected the emissions were generally consistent with emissions based on atmospheric concentration measurements reported in the IPCC/TEAP Special Report on Fluorocarbons (IPCC, 2005). In addition to the error in the halon 1211 model, there was also significant difference in the emissions of halon 1301 from the HTOC 2002 assessment compared with the atmospheric measurements under review for inclusion in the 2006 ozone assessment from the SAP. For the 2006 assessment, the HTOC has updated the emission models of halon 1211 and 1301 taking into account direct data on destruction, inventories and emissions, where available, and additional expert opinion on past practices.

For halon 1301, the 2006 assessment indicates an even greater global inventory or bank of halon 1301. At the end of 2005, the global bank of halon 1301 is now estimated at approximately 50,000 MT as compared with the 2002 assessment of 39,000 MT. For the global halon 1211 bank, the 2006 assessment provides as estimate of 91,000 MT as compared with 106,000 MT from the corrected 2002 assessment, as reported in the TEAP Supplement to the IPCC/TEAP Special Report on Fluorocarbons (TEAP, 2005) and 83,000 MT in the pre-corrected 2002 HTOC assessment report. From the 2006 assessment, the HTOC is of the opinion that adequate global stocks of halon 1211 and halon 1301 currently exist to meet the future service needs and replenishment needs of all existing critical or essential halon fire equipment until the end of their useful life.

While it appears that adequate supplies would be expected to be available on a global basis, over 35% of the projected global supply of halon 1301 has been positively identified to be in only one country, see section 4.1. The situation for halon 1211 is not as well documented but it expected to be similar. Model projections based on Article 7 reporting of production and consumption place over 60% of the halon 1211 in Article 5(1) countries with the overwhelming majority of that in just one country, see section 4.2.

There is little open literature information available on inventories and emissions of halon 2402. HTOC experts from the main countries using halon 2402 have provided estimates of their country banks and current needs in Chapter 2. As a result, there is growing concern about the availability of halon 2402 outside of the Russian Federation and the Ukraine to support existing uses in aircraft, military vehicles, and ships. The Parties may wish to request additional information be collected on existing inventories, historic and current emission factors, and projected needs to support critical or essential halon 2402 equipment through their end of useful life.

Owners of existing halon fire equipment that would be considered as meeting the needs of one or more of the preceding categories would be prudent to ensure that their future needs will be met from their own secure stocks. Current and proposed regulatory programs that require the recovery and destruction of halons will obviously eliminate future availability of halons as a source of supply for critical or essential needs. As adequate global supplies presently exist it would be unlikely that inadequate planning would serve as a reasonable basis for a future essential use nomination by a Party on behalf of an owner of a particular essential or critical application for halon 1211 or halon 1301.

4.1 Emissions and Inventories of Halon 1301

In recognition of discrepancies between HTOC emission estimates and atmospheric measurements, the HTOC performed a review of all of the assumptions previously used to develop the emissions estimates, re-queried industry experts about past service practices, and collected direct data on measured inventories and emission rates. The main source of direct data comes from the Fire and Environment Protection Network (FEPN) in Japan. (This was previously performed and provided by the Halon Recycling and Banking Support Committee in Japan). In 2006, the FEPN provided recorded values of installed halon and re-supply quantities in Japan from 1994–2005. Their annual data does not include ships, aircraft, and military. However, they performed a survey of those uses in January 2000 and have statistics on the installed quantities at that time. The FEPN data did not match the projected quantities in Japan from the 2002 HTOC Assessment. For example, in the year 2000, the HTOC 2002 Assessment report projected approximately 10,000 MT of halon 1301 in Japan. The FEPN data including ships, aircraft and military was measured at over 18,000 MT. This discrepancy is consistent with the discrepancy between the HTOC 2002 assessment and the atmospheric measurements under review for inclusion in the 2006 Ozone Assessment from the Science Assessment Panel.

In addition to the direct FEPN data, HTOC began to question the assumptions previously used for equipment lifetimes / end of life, retrofit to alternatives, and use patterns based on recent information. As a result, the 2006 assessment changes the assumption that systems come out of service based only on lifetimes and end-of life considerations. Instead, the estimate for when halon cylinders come out of service is based on when they have leaked below either 90% or 95% of their design charge, depending upon national regulations or requirements. At that point the cylinders are emptied, repaired (or replaced) if necessary and refilled. In order to achieve known quantities in place in Japan and projecting to other regions, the leakage and discharge rates were initially set at between 2.5% - 3.5% of the bank and with the exception of Japan, were subsequently reduced to 2.5% - 3% consistent with the emission rates developed by Verdonik and Robin, 2004. The leakage rate for Japan was set to 0.2% starting in 1993 based on their actual measurements.

Other changes for the 2006 Assessment are as follows:

- Reduce the amount used for system discharge testing. While this initially seemed to be counter to expert opinion on past practices, there is enough uncertainty on how much test gas (typically CFC-12) was used in lieu of halon 1301. Reducing this use in order to keep the leakage and discharge rates higher is more consistent with the experts' consensus of past and current service experience.

- Re-evaluate the percentage of CEFIC reported production provided to each region based on Article 7 production and consumption reporting taking into account trade patterns of equipment containing halon that do not get reported as consumption.
- Remove from the bank the quantities reported as destroyed by Parties.
- Account for documented imports/exports between regions.
- The practice of recovering halon in lieu of venting the cylinder to empty it began with large users in the latter 1970s as a cost cutting measure.

Table 4-1 provides the HTOC 2006 Assessment of current estimates of inventories for halon 1301. These estimates have been provided to the Science Assessment Panel.
Figure 4-1 provides the regional distribution of the global inventory of halon 1301. As shown in Table 4-1 and Figure 4-1, over 35% of the current inventory of halon 1301 is projected to be in Japan. It is anticipated that regional imbalances may result in shortages in one country or region with excesses in other countries and regions. Parties may wish to consider asking HTOC to investigate mechanisms to better predict and mitigate such imbalances.

Table 4-1 HTOC 2006 Assessment of current estimates of inventories for halon 1301

Halon 1301 Summary

(All quantities are provided in metric tonnes)

Year	**1963**	**1964**	**1965**	**1966**	**1967**	**1968**	**1969**	**1970**	**1971**	**1972**	**1973**	**1974**
ANNUAL PRODUCTION												
North America, Western Europe and Japan	10.0	20.0	30.0	40.0	50.0	60.0	100.0	200.0	550.0	839.0	1292.0	1461.0
CEIT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Article 5(1)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL ANNUAL PRODUCTION	10.0	20.0	30.0	40.0	50.0	60.0	100.0	200.0	550.0	839.0	1292.0	1461.0
ANNUAL PRODUCTION ALLOCATION												
North America	3.0	6.0	9.0	12.0	15.0	18.0	30.0	60.0	165.0	251.7	387.6	438.3
Western Europe and Australia	2.5	5.0	7.5	10.0	12.5	15.0	25.0	50.0	137.5	209.8	323.0	365.3
Japan	2.2	4.4	6.6	8.8	11.0	13.2	22.0	44.0	121.0	184.6	284.2	321.4
CEIT	0.3	0.6	0.9	1.2	1.5	1.8	3.0	6.0	16.5	25.2	38.8	43.8
Article 5(1)	2.0	4.0	6.0	8.0	10.0	12.0	20.0	40.0	110.0	167.8	258.4	292.2
TOTAL ANNUAL PRODUCTION ALLOCATION	10.0	20.0	30.0	40.0	50.0	60.0	100.0	200.0	550.0	839.0	1292.0	1461.0
ANNUAL EMISSIONS												
North America	1.4	2.4	3.2	3.7	5.3	7.0	10.7	18.8	43.9	75.4	123.1	165.6
Western Europe and Australia	1.2	2.0	2.6	3.0	4.4	5.9	8.9	15.7	36.5	62.8	102.6	138.0
Japan	0.3	0.8	1.4	2.1	2.9	3.8	5.8	10.2	24.0	40.5	65.9	87.8
CEIT	0.1	0.2	0.3	0.4	0.5	0.7	1.1	1.9	4.4	7.5	12.3	16.6
Article 5(1)	0.9	1.6	2.1	2.5	3.6	4.8	7.2	12.7	29.5	50.8	83.0	111.9
TOTAL ANNUAL EMISSIONS	3.9	7.1	9.6	11.6	16.6	22.2	33.7	59.2	138.2	237.1	386.9	520.0
CUMMULATIVE PRODUCTION												
North America, Western Europe and Japan	10.0	30.0	60.0	100.0	150.0	210.0	310.0	510.0	1060.0	1899.0	3191.0	4652.0
CEIT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Article 5(1)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL CUMMULATIVE PRODUCTION	10.0	30.0	60.0	100.0	150.0	210.0	310.0	510.0	1060.0	1899.0	3191.0	4652.0
CUMMULATIVE PRODUCTION ALLOCATION												
North America	3.0	9.0	18.0	30.0	45.0	63.0	93.0	153.0	318.0	569.7	957.3	1395.6
Western Europe and Australia	2.5	7.5	15.0	25.0	37.5	52.5	77.5	127.5	265.0	474.8	797.8	1163.0
Japan	2.2	6.6	13.2	22.0	33.0	46.2	68.2	112.2	233.2	417.8	702.0	1023.4
CEIT	0.3	0.9	1.8	3.0	4.5	6.3	9.3	15.3	31.8	57.0	95.7	139.6
Article 5(1)	2.0	6.0	12.0	20.0	30.0	42.0	62.0	102.0	212.0	379.8	638.2	930.4
TOTAL CUMMULATIVE PRODUCTION ALLOCATION	10.0	30.0	60.0	100.0	150.0	210.0	310.0	510.0	1060.0	1899.0	3191.0	4652.0
CUMMULATIVE EMISSIONS												
North America	1.4	3.8	6.9	10.6	15.9	22.9	33.6	52.4	96.2	171.6	294.7	460.4
Western Europe and Australia	1.2	3.2	5.8	8.8	13.2	19.1	28.0	43.6	80.2	143.0	245.6	383.6
Japan	0.3	1.1	2.5	4.6	7.5	11.3	17.1	27.4	51.4	91.9	157.7	245.5
CEIT	0.1	0.4	0.7	1.1	1.6	2.3	3.4	5.2	9.6	17.2	29.5	46.0
Article 5(1)	0.9	2.5	4.6	7.1	10.7	15.4	22.6	35.3	64.8	115.5	198.5	310.5
TOTAL CUMMULATIVE EMISSIONS	3.9	11.0	20.5	32.2	48.8	71.0	104.7	163.9	302.1	539.2	926.1	1446.1
INVENTORY (BANK)												
North America	1.6	5.2	11.1	19.4	29.1	40.1	59.4	100.6	221.8	398.1	662.6	935.2
Western Europe and Australia	1.4	4.3	9.2	16.2	24.3	33.4	49.5	83.9	184.8	331.7	552.1	779.4
Japan	1.9	5.5	10.7	17.4	25.5	34.9	51.1	84.8	181.8	325.9	544.3	777.9
CEIT	0.2	0.5	1.1	1.9	2.9	4.0	5.9	10.1	22.2	39.8	66.3	93.5
Article 5(1)	1.1	3.5	7.4	12.9	19.3	26.6	39.4	66.7	147.2	264.3	439.7	619.9
GLOBAL INVENTORY (BANK)	6.1	19.0	39.5	67.8	101.2	139.0	205.3	346.1	757.9	1359.8	2264.9	3205.9

Halon 1301 Summary

(All quantities are provided in metric tonnes)

Year	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
ANNUAL PRODUCTION												
North America, Western Europe and Japan	2019.0	3172.0	3550.0	4015.0	4718.0	4877.0	5694.0	7565.0	7386.0	8692.0	9781.0	11076.0
CEIT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	30.0	30.0	30.0
Article 5(1)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	70.0	94.4	127.5
TOTAL ANNUAL PRODUCTION	2019.0	3172.0	3550.0	4015.0	4718.0	4877.0	5694.0	7565.0	7386.0	8792.0	9905.4	11233.5
ANNUAL PRODUCTION ALLOCATION												
North America	605.7	951.6	1065.0	1204.5	1415.4	1463.1	1708.2	2269.5	2215.8	2607.6	2934.3	3322.8
Western Europe and Australia	504.8	793.0	887.5	1003.8	1179.5	1219.3	1423.5	1891.3	1846.5	2173.0	2445.3	2769.0
Japan	444.2	697.8	781.0	883.3	1038.0	1072.9	1252.7	1664.3	1624.9	1912.2	2151.8	2436.7
CEIT	60.6	95.2	106.5	120.5	141.5	146.3	170.8	227.0	221.6	290.8	323.4	362.3
Article 5(1)	403.8	634.4	710.0	803.0	943.6	975.4	1138.8	1513.0	1477.2	1808.4	2050.6	2342.7
TOTAL ANNUAL PRODUCTION ALLOCATION	2019.0	3172.0	3550.0	4015.0	4718.0	4877.0	5694.0	7565.0	7386.0	8792.0	9905.4	11233.5
ANNUAL EMISSIONS												
North America	231.3	301.0	362.9	418.7	476.3	560.1	667.2	831.1	937.4	1095.6	1262.9	1451.8
Western Europe and Australia	192.8	250.8	302.4	348.9	396.9	466.7	556.0	692.6	781.2	913.0	1052.4	1209.8
Japan	123.3	167.3	203.4	238.6	296.2	321.1	384.4	481.0	539.0	632.0	729.3	839.9
CEIT	23.1	34.4	38.4	44.7	51.2	54.7	59.3	75.1	85.0	104.0	121.6	141.1
Article 5(1)	156.3	231.9	235.7	300.1	372.1	433.4	512.9	634.3	715.0	843.0	976.8	1129.1
TOTAL ANNUAL EMISSIONS	726.8	985.4	1142.8	1351.1	1592.6	1836.0	2179.7	2714.2	3057.7	3587.6	4143.0	4771.6
CUMMULATIVE PRODUCTION												
North America, Western Europe and Japan	6671.0	9843.0	13393.0	17408.0	22126.0	27003.0	32697.0	40262.0	47648.0	56340.0	66121.0	77197.0
CEIT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	30.0	60.0	90.0
Article 5(1)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	70.0	164.4	291.9
TOTAL CUMMULATIVE PRODUCTION	6671.0	9843.0	13393.0	17408.0	22126.0	27003.0	32697.0	40262.0	47648.0	56440.0	66345.4	77578.9
CUMMULATIVE PRODUCTION ALLOCATION												
North America	2001.3	2952.9	4017.9	5222.4	6637.8	8100.9	9809.1	12078.6	14294.4	16902.0	19836.3	23159.1
Western Europe and Australia	1667.8	2460.8	3348.3	4352.0	5531.5	6750.8	8174.3	10065.5	11912.0	14085.0	16530.3	19299.3
Japan	1467.6	2165.5	2946.5	3829.8	4867.7	5940.7	7193.3	8857.6	10482.6	12394.8	14546.6	16983.3
CEIT	200.1	295.3	401.8	522.2	663.8	810.1	980.9	1207.9	1429.4	1720.2	2043.6	2405.9
Article 5(1)	1334.2	1968.6	2678.6	3481.6	4425.2	5400.6	6539.4	8052.4	9529.6	11338.0	13388.6	15731.3
TOTAL CUMMULATIVE PRODUCTION ALLOCATION	6671.0	9843.0	13393.0	17408.0	22126.0	27003.0	32697.0	40262.0	47648.0	56440.0	66345.4	77578.9
CUMMULATIVE EMISSIONS												
North America	691.7	992.7	1355.6	1774.3	2250.6	2810.6	3477.8	4309.0	5246.4	6342.0	7604.9	9056.6
Western Europe and Australia	576.4	827.2	1129.7	1478.6	1875.5	2342.2	2898.2	3590.8	4372.0	5285.0	6337.4	7547.2
Japan	368.8	536.1	739.5	978.1	1274.3	1595.5	1979.9	2460.8	2999.9	3631.8	4361.2	5201.0
CEIT	69.2	103.5	142.0	186.7	237.9	292.6	351.8	426.9	511.9	616.0	737.6	878.7
Article 5(1)	466.8	698.7	934.3	1234.4	1606.5	2039.9	2552.8	3187.1	3902.1	4745.2	5721.9	6851.1
TOTAL CUMMULATIVE EMISSIONS	2172.9	3158.2	4301.0	5652.1	7244.7	9080.7	11260.5	13974.6	17032.4	20620.0	24763.0	29534.6
INVENTORY (BANK)												
North America	1309.6	1960.2	2662.3	3448.1	4387.2	5290.3	6331.3	7769.6	9048.0	10560.0	12231.4	14102.5
Western Europe and Australia	1091.3	1633.5	2218.6	2873.4	3656.0	4408.6	5276.1	6474.7	7540.0	8800.0	10192.8	11752.0
Japan	1098.8	1629.3	2207.0	2851.6	3593.4	4345.2	5213.5	6396.8	7482.7	8763.0	10185.4	11782.3
CEIT	131.0	191.8	259.8	335.6	425.9	517.5	629.1	781.0	917.5	1104.2	1306.0	1527.2
Article 5(1)	867.4	1269.9	1744.3	2247.2	2818.7	3360.7	3986.6	4865.3	5627.5	6592.8	7666.6	8880.2
GLOBAL INVENTORY (BANK)	4498.1	6684.8	9092.0	11755.9	14881.3	17922.3	21436.5	26287.4	30615.6	35820.0	41582.4	48044.2

Halon 1301 Summary

(All quantities are provided in metric tonnes)

Year	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**
ANNUAL PRODUCTION												
North America, Western Europe and Japan	11604.0	12551.0	11152.0	9115.0	7326.0	4884.0	2442.0	0.0	0.0	0.0	0.0	0.0
CEIT	35.0	30.0	30.0	1100.0	50.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0
Article 5(1)	192.8	214.1	227.1	359.8	571.6	511.1	738.4	700.0	750.0	800.0	750.0	535.0
TOTAL ANNUAL PRODUCTION	11831.8	12795.1	11409.1	10574.8	7947.6	5445.1	3180.4	700.0	750.0	800.0	750.0	535.0
ANNUAL PRODUCTION ALLOCATION												
North America	3481.2	3765.3	3345.6	2734.5	2197.8	1465.2	732.6	0.0	0.0	0.0	0.0	66.4
Western Europe and Australia	2901.0	3137.8	2788.0	2278.8	1831.5	1221.0	610.5	0.0	0.0	-0.2	-4.6	-70.8
Japan	2552.9	2761.2	2453.4	2005.3	1611.7	1074.5	537.2	0.0	0.0	0.0	0.0	0.0
CEIT	383.1	406.5	364.6	1373.5	269.8	196.5	73.3	0.0	0.0	0.0	0.0	0.0
Article 5(1)	2513.6	2724.3	2457.5	2182.8	2036.8	1487.9	1226.8	700.0	750.0	800.0	750.0	535.0
TOTAL ANNUAL PRODUCTION ALLOCATION	11831.8	12795.1	11409.1	10574.8	7947.6	5445.1	3180.4	700.0	750.0	799.8	745.4	530.6
ANNUAL EMISSIONS												
North America	1455.1	1645.9	1737.8	1767.7	1762.7	1693.7	1086.2	878.7	841.4	805.6	771.4	739.9
Western Europe and Australia	1352.6	1352.6	1439.7	1465.2	1461.6	1404.6	960.0	726.1	695.2	665.7	637.3	608.7
Japan	939.0	1050.3	1038.9	1053.1	959.0	709.2	387.6	185.7	36.5	36.1	36.0	36.0
CEIT	159.5	178.4	177.5	323.1	247.1	223.6	192.9	147.9	140.1	133.4	127.0	121.0
Article 5(1)	1275.9	1431.4	1515.9	1564.5	1602.0	1488.3	1431.7	1287.1	1235.0	1192.4	1151.9	1099.6
TOTAL ANNUAL EMISSIONS	5182.0	5658.5	5909.8	6173.8	6032.4	5519.4	4058.3	3225.5	2948.1	2833.2	2723.7	2605.1
CUMMULATIVE PRODUCTION												
North America, Western Europe and Japan	88801.0	101352.0	112504.0	121619.0	128945.0	133829.0	136271.0	136271.0	136271.0	136271.0	136271.0	136271.0
CEIT	125.0	155.0	185.0	1285.0	1335.0	1385.0	1385.0	1385.0	1385.0	1385.0	1385.0	1385.0
Article 5(1)	484.6	698.7	925.8	1285.6	1857.3	2368.3	3106.7	3806.7	4556.7	5356.7	6106.7	6641.7
TOTAL CUMMULATIVE PRODUCTION	89410.6	102205.7	113614.8	124189.6	132137.3	137582.3	140762.7	141462.7	142212.7	143012.7	143762.7	144297.7
CUMMULATIVE PRODUCTION ALLOCATION												
North America	26640.3	30405.6	33751.2	36485.7	38683.5	40148.7	40881.3	40881.3	40881.3	40881.3	40881.3	40947.7
Western Europe and Australia	22200.3	25338.0	28126.0	30404.8	32236.3	33457.3	34067.8	34067.8	34067.8	34067.5	34062.9	33992.1
Japan	19536.2	22297.4	24750.9	26756.2	28367.9	29442.4	29979.6	29979.6	29979.6	29979.6	29979.6	29979.6
CEIT	2789.0	3195.6	3560.1	4933.6	5203.4	5399.9	5473.1	5473.1	5473.1	5473.1	5473.1	5473.1
Article 5(1)	18244.8	20969.1	23426.6	25609.4	27646.3	29134.1	30360.9	31060.9	31810.9	32610.9	33360.9	33895.9
TOTAL CUMMULATIVE PRODUCTION ALLOCATION	89410.6	102205.7	113614.8	124189.6	132137.3	137582.3	140762.7	141462.7	142212.7	143012.5	143757.9	144288.5
CUMMULATIVE EMISSIONS												
North America	10511.7	12157.7	13895.5	15663.2	17426.0	19119.6	20205.8	21084.5	21925.9	22731.5	23502.8	24242.8
Western Europe and Australia	8899.8	10252.3	11692.0	13157.2	14618.8	16023.4	16983.4	17709.4	18404.7	19070.4	19707.6	20316.3
Japan	6140.0	7190.3	8229.2	9282.3	10241.3	10950.6	11338.2	11523.9	11560.3	11596.4	11632.5	11668.4
CEIT	1038.2	1216.5	1394.0	1717.1	1964.3	2187.8	2380.7	2528.5	2668.6	2802.0	2929.0	3050.0
Article 5(1)	8126.9	9558.3	11074.2	12638.7	14240.7	15729.1	17160.7	18447.9	19682.8	20875.2	22027.2	23126.8
TOTAL CUMMULATIVE EMISSIONS	34716.6	40375.1	46284.9	52458.7	58491.1	64010.5	68068.8	71294.2	74242.3	77075.5	79799.2	82404.3
INVENTORY (BANK)												
North America	16128.6	18247.9	19855.7	20822.5	21257.5	21029.1	20675.5	19796.8	18955.4	18149.8	17378.5	16704.9
Western Europe and Australia	13300.5	15085.7	16434.0	17247.5	17617.4	17433.9	17084.4	16358.3	15663.1	14997.2	14355.3	13675.8
Japan	13396.2	15107.2	16521.7	17473.9	18126.6	18491.8	18641.4	18455.7	18419.3	18383.2	18347.2	18311.2
CEIT	1750.9	1979.0	2166.1	3216.4	3239.1	3212.0	3092.4	2944.6	2804.5	2671.1	2544.1	2423.1
Article 5(1)	10117.9	11410.8	12352.4	12970.7	13405.5	13405.1	13200.2	12613.1	12128.1	11735.7	11333.8	10769.1
GLOBAL INVENTORY (BANK)	54694.0	61830.6	67329.9	71730.9	73646.2	73571.9	72694.0	70168.5	67970.4	65937.0	63958.7	61884.2

Halon 1301 Summary

(All quantities are provided in metric tonnes)

Year	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
ANNUAL PRODUCTION												
North America, Western Europe and Japan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CEIT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Article 5(1)	475.0	475.0	590.0	650.0	650.0	711.0	650.0	200.0	200.0	200.0	200.0	0.0
TOTAL ANNUAL PRODUCTION	475.0	475.0	590.0	650.0	650.0	711.0	650.0	200.0	200.0	200.0	200.0	0.0
ANNUAL PRODUCTION ALLOCATION												
North America	165.7	266.5	202.4	81.8	99.5	78.4	152.3	1061.6	0.0	0.0	0.0	0.0
Western Europe and Australia	-172.7	-305.8	-213.5	-88.6	-318.0	-283.0	-122.3	-1061.6	0.0	0.0	0.0	0.0
Japan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CEIT	0.0	0.0	0.0	0.0	0.0	0.0	-30.0	0.0	0.0	0.0	0.0	0.0
Article 5(1)	459.7	475.0	583.9	650.0	650.0	711.0	650.0	200.0	200.0	200.0	200.0	0.0
TOTAL ANNUAL PRODUCTION ALLOCATION	452.7	435.6	572.8	643.2	431.6	506.3	650.0	200.0	200.0	200.0	200.0	0.0
ANNUAL EMISSIONS												
North America	713.3	692.0	672.7	650.3	626.4	603.6	582.8	582.7	581.8	557.1	533.4	510.7
Western Europe and Australia	577.8	543.2	509.0	645.8	599.5	548.0	505.8	427.0	380.4	359.7	339.9	321.2
Japan	35.9	35.8	35.7	35.7	35.6	35.5	35.5	35.4	35.3	35.3	35.2	35.1
CEIT	115.2	109.7	104.5	99.5	94.8	90.3	85.2	80.5	76.7	73.0	69.6	66.2
Article 5(1)	1041.4	987.7	946.7	917.0	734.0	726.1	721.8	693.7	655.7	620.5	588.1	548.2
TOTAL ANNUAL EMISSIONS	2483.6	2368.5	2268.6	2348.2	2090.3	2003.5	1931.1	1819.3	1729.9	1645.5	1566.2	1481.5
CUMMULATIVE PRODUCTION												
North America, Western Europe and Japan	136271.0	136271.0	136271.0	136271.0	136271.0	136271.0	136271.0	136271.0	136271.0	136271.0	136271.0	136271.0
CEIT	1385.0	1385.0	1385.0	1385.0	1385.0	1385.0	1385.0	1385.0	1385.0	1385.0	1385.0	1385.0
Article 5(1)	7116.7	7591.7	8181.7	8831.7	9481.7	10192.7	10842.7	11042.7	11242.7	11442.7	11642.7	11642.7
TOTAL CUMMULATIVE PRODUCTION	144772.7	145247.7	145837.7	146487.7	147137.7	147848.7	148498.7	148698.7	148898.7	149098.7	149298.7	149298.7
CUMMULATIVE PRODUCTION ALLOCATION												
North America	41113.4	41379.9	41582.3	41664.1	41763.6	41842.0	41994.3	43055.9	43055.9	43055.9	43055.9	43055.9
Western Europe and Australia	33819.4	33513.6	33300.1	33211.6	32893.6	32610.6	32488.2	31426.6	31426.6	31426.6	31426.6	31426.6
Japan	29979.6	29979.6	29979.6	29979.6	29979.6	29979.6	29979.6	29979.6	29979.6	29979.6	29979.6	29979.6
CEIT	5473.1	5473.1	5473.1	5473.1	5473.1	5473.1	5443.1	5443.1	5443.1	5443.1	5443.1	5443.1
Article 5(1)	34355.7	34830.7	35414.5	36064.5	36714.5	37425.5	38075.5	38275.5	38475.5	38675.5	38875.5	38875.5
TOTAL CUMMULATIVE PRODUCTION ALLOCATION	144741.2	145176.8	145749.7	146392.9	146824.5	147330.8	147980.8	148180.8	148380.8	148580.8	148780.8	148780.8
CUMMULATIVE EMISSIONS												
North America	24956.0	25648.0	26320.7	26970.9	27597.4	28201.0	28783.8	29366.5	29948.3	30505.4	31038.8	31549.5
Western Europe and Australia	20894.1	21437.3	21946.3	22592.1	23191.6	23739.6	24245.4	24672.4	25052.8	25412.4	25752.4	26073.6
Japan	11704.3	11740.1	11775.9	11811.6	11847.2	11882.7	11918.2	11953.6	11988.9	12024.2	12059.4	12094.5
CEIT	3165.2	3274.9	3379.4	3479.0	3573.7	3664.0	3749.2	3829.7	3906.4	3979.4	4049.0	4115.2
Article 5(1)	24168.2	25155.9	26102.6	27019.6	27753.6	28479.7	29201.6	29895.3	30550.9	31171.5	31759.5	32307.7
TOTAL CUMMULATIVE EMISSIONS	84887.9	87256.3	89524.9	91873.2	93963.5	95967.0	97898.1	99717.5	101447.3	103092.9	104659.0	106140.5
INVENTORY (BANK)												
North America	16157.4	15731.8	15261.6	14693.1	14166.2	13640.9	13210.5	13689.4	13107.6	12550.5	12017.1	11506.4
Western Europe and Australia	12925.3	12076.3	11353.8	10619.5	9702.0	8871.0	8242.9	6754.2	6373.8	6014.2	5674.2	5353.0
Japan	18275.3	18239.5	18203.7	18168.1	18132.4	18096.9	18061.4	18026.0	17990.7	17955.4	17920.2	17885.1
CEIT	2307.9	2198.2	2093.7	1994.2	1899.4	1809.1	1693.9	1613.4	1536.7	1463.7	1394.2	1327.9
Article 5(1)	10187.4	9674.7	9311.9	9044.9	8960.9	8945.8	8874.0	8380.2	7924.6	7504.1	7116.0	6567.8
GLOBAL INVENTORY (BANK)	59853.3	57920.5	56224.8	54519.7	52860.9	51363.8	50082.6	48463.3	46933.5	45487.9	44121.8	42640.3

Halon 1301 Summary

(All quantities are provided in metric tonnes)

Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
ANNUAL PRODUCTION												
North America, Western Europe and Japan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CEIT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Article 5(1)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL ANNUAL PRODUCTION	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL PRODUCTION ALLOCATION												
North America	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Western Europe and Australia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Japan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CEIT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Article 5(1)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL ANNUAL PRODUCTION ALLOCATION	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL EMISSIONS												
North America	489.0	468.2	448.3	429.3	411.0	393.6	376.8	360.8	345.5	330.8	316.8	303.3
Western Europe and Australia	303.4	286.6	270.7	255.5	241.2	227.7	214.9	202.8	191.3	180.5	170.3	160.6
Japan	35.1	35.0	34.9	34.8	34.8	34.7	34.6	34.6	34.5	34.4	34.4	34.3
CEIT	63.1	60.1	57.2	54.5	51.9	49.5	47.1	44.9	42.7	40.7	38.8	36.9
Article 5(1)	505.9	466.9	431.0	397.8	367.1	338.8	312.7	288.6	266.4	245.9	226.9	209.5
TOTAL ANNUAL EMISSIONS	1396.5	1316.9	1242.1	1171.9	1106.1	1044.3	986.2	931.7	880.5	832.3	787.1	744.6
CUMMULATIVE PRODUCTION												
North America, Western Europe and Japan	136271.0	136271.0	136271.0	136271.0	136271.0	136271.0	136271.0	136271.0	136271.0	136271.0	136271.0	136271.0
CEIT	1385.0	1385.0	1385.0	1385.0	1385.0	1385.0	1385.0	1385.0	1385.0	1385.0	1385.0	1385.0
Article 5(1)	11642.7	11642.7	11642.7	11642.7	11642.7	11642.7	11642.7	11642.7	11642.7	11642.7	11642.7	11642.7
TOTAL CUMMULATIVE PRODUCTION	149298.7	149298.7	149298.7	149298.7	149298.7	149298.7	149298.7	149298.7	149298.7	149298.7	149298.7	149298.7
CUMMULATIVE PRODUCTION ALLOCATION												
North America	43055.9	43055.9	43055.9	43055.9	43055.9	43055.9	43055.9	43055.9	43055.9	43055.9	43055.9	43055.9
Western Europe and Australia	31426.6	31426.6	31426.6	31426.6	31426.6	31426.6	31426.6	31426.6	31426.6	31426.6	31426.6	31426.6
Japan	29979.6	29979.6	29979.6	29979.6	29979.6	29979.6	29979.6	29979.6	29979.6	29979.6	29979.6	29979.6
CEIT	5443.1	5443.1	5443.1	5443.1	5443.1	5443.1	5443.1	5443.1	5443.1	5443.1	5443.1	5443.1
Article 5(1)	38875.5	38875.5	38875.5	38875.5	38875.5	38875.5	38875.5	38875.5	38875.5	38875.5	38875.5	38875.5
TOTAL CUMMULATIVE PRODUCTION ALLOCATION	148780.8	148780.8	148780.8	148780.8	148780.8	148780.8	148780.8	148780.8	148780.8	148780.8	148780.8	148780.8
CUMMULATIVE EMISSIONS												
North America	32038.5	32506.8	32955.1	33384.4	33795.4	34189.0	34565.8	34926.7	35272.1	35603.0	35919.7	36223.0
Western Europe and Australia	26377.0	26663.6	26934.3	27189.8	27431.1	27658.8	27873.7	28076.4	28267.8	28448.3	28618.6	28779.2
Japan	12129.6	12164.5	12199.5	12234.3	12269.1	12303.8	12338.4	12373.0	12407.5	12442.0	12476.3	12510.6
CEIT	4178.3	4238.4	4295.6	4350.2	4402.1	4451.5	4498.7	4543.5	4586.3	4627.0	4665.7	4702.7
Article 5(1)	32813.6	33280.6	33711.5	34109.3	34476.4	34815.2	35128.0	35416.6	35683.0	35928.9	36155.8	36365.3
TOTAL CUMMULATIVE EMISSIONS	107537.0	108853.9	110096.0	111268.0	112374.1	113418.3	114404.5	115336.2	116216.7	117049.0	117836.2	118580.8
INVENTORY (BANK)												
North America	11017.4	10549.2	10100.8	9671.5	9260.5	8866.9	8490.1	8129.2	7783.8	7452.9	7136.2	6832.9
Western Europe and Australia	5049.6	4763.0	4492.3	4236.8	3995.5	3767.9	3553.0	3350.2	3158.8	2978.3	2808.0	2647.4
Japan	17850.1	17815.1	17780.2	17745.3	17710.5	17675.8	17641.2	17606.6	17572.1	17537.7	17503.3	17469.0
CEIT	1264.8	1204.7	1147.5	1093.0	1041.0	991.6	944.5	899.6	856.9	816.2	777.4	740.5
Article 5(1)	6061.9	5595.0	5164.0	4766.2	4399.1	4060.3	3747.6	3458.9	3192.5	2946.7	2719.7	2510.3
GLOBAL INVENTORY (BANK)	41243.8	39926.9	38684.8	37512.8	36406.7	35362.5	34376.3	33444.6	32564.1	31731.8	30944.6	30200.0

Halon 1301 Summary

(All quantities are provided in metric tonnes)

Year	2023	2024	2025	2026	2027	2028	2029	2030
ANNUAL PRODUCTION								
North America, Western Europe and Japan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CEIT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Article 5(1)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL ANNUAL PRODUCTION	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL PRODUCTION ALLOCATION								
North America	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Western Europe and Australia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Japan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CEIT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Article 5(1)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL ANNUAL PRODUCTION ALLOCATION	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL EMISSIONS								
North America	290.4	278.1	266.2	254.9	244.1	233.7	223.8	214.3
Western Europe and Australia	151.5	142.9	134.8	127.1	119.9	113.0	106.6	100.5
Japan	34.2	34.2	34.1	34.0	34.0	33.9	33.8	33.8
CEIT	35.2	33.5	31.9	30.4	29.0	27.6	26.3	25.0
Article 5(1)	193.3	178.4	164.7	152.0	140.3	129.5	119.5	110.3
TOTAL ANNUAL EMISSIONS	704.6	667.1	631.7	598.5	567.2	537.7	510.0	483.9
CUMMULATIVE PRODUCTION								
North America, Western Europe and Japan	136271.0	136271.0	136271.0	136271.0	136271.0	136271.0	136271.0	136271.0
CEIT	1385.0	1385.0	1385.0	1385.0	1385.0	1385.0	1385.0	1385.0
Article 5(1)	11642.7	11642.7	11642.7	11642.7	11642.7	11642.7	11642.7	11642.7
TOTAL CUMMULATIVE PRODUCTION	149298.7	149298.7	149298.7	149298.7	149298.7	149298.7	149298.7	149298.7
CUMMULATIVE PRODUCTION ALLOCATION								
North America	43055.9	43055.9	43055.9	43055.9	43055.9	43055.9	43055.9	43055.9
Western Europe and Australia	31426.6	31426.6	31426.6	31426.6	31426.6	31426.6	31426.6	31426.6
Japan	29979.6	29979.6	29979.6	29979.6	29979.6	29979.6	29979.6	29979.6
CEIT	5443.1	5443.1	5443.1	5443.1	5443.1	5443.1	5443.1	5443.1
Article 5(1)	38875.5	38875.5	38875.5	38875.5	38875.5	38875.5	38875.5	38875.5
TOTAL CUMMULATIVE PRODUCTION ALLOCATION	148780.8	148780.8	148780.8	148780.8	148780.8	148780.8	148780.8	148780.8
CUMMULATIVE EMISSIONS								
North America	36513.4	36791.5	37057.7	37312.6	37556.7	37790.4	38014.2	38228.5
Western Europe and Australia	28930.7	29073.6	29208.4	29335.5	29455.3	29568.3	29674.9	29775.4
Japan	12544.9	12579.1	12613.2	12647.2	12681.2	12715.1	12748.9	12782.7
CEIT	4737.8	4771.3	4803.3	4833.7	4862.6	4890.2	4916.4	4941.5
Article 5(1)	36558.6	36737.0	36901.7	37053.7	37194.0	37323.5	37443.0	37553.3
TOTAL CUMMULATIVE EMISSIONS	119285.4	119952.5	120584.2	121182.7	121749.8	122287.5	122797.5	123281.4
INVENTORY (BANK)								
North America	6542.5	6264.4	5998.2	5743.3	5499.2	5265.5	5041.7	4827.4
Western Europe and Australia	2495.9	2353.0	2218.2	2091.1	1971.3	1858.3	1751.7	1651.2
Japan	17434.7	17400.6	17366.5	17332.4	17298.4	17264.5	17230.7	17196.9
CEIT	705.3	671.8	639.9	609.5	580.5	552.9	526.7	501.7
Article 5(1)	2316.9	2138.5	1973.8	1821.8	1681.5	1552.0	1432.5	1322.2
GLOBAL INVENTORY (BANK)	29495.4	28828.3	28196.6	27598.1	27031.0	26493.3	25983.3	25499.4

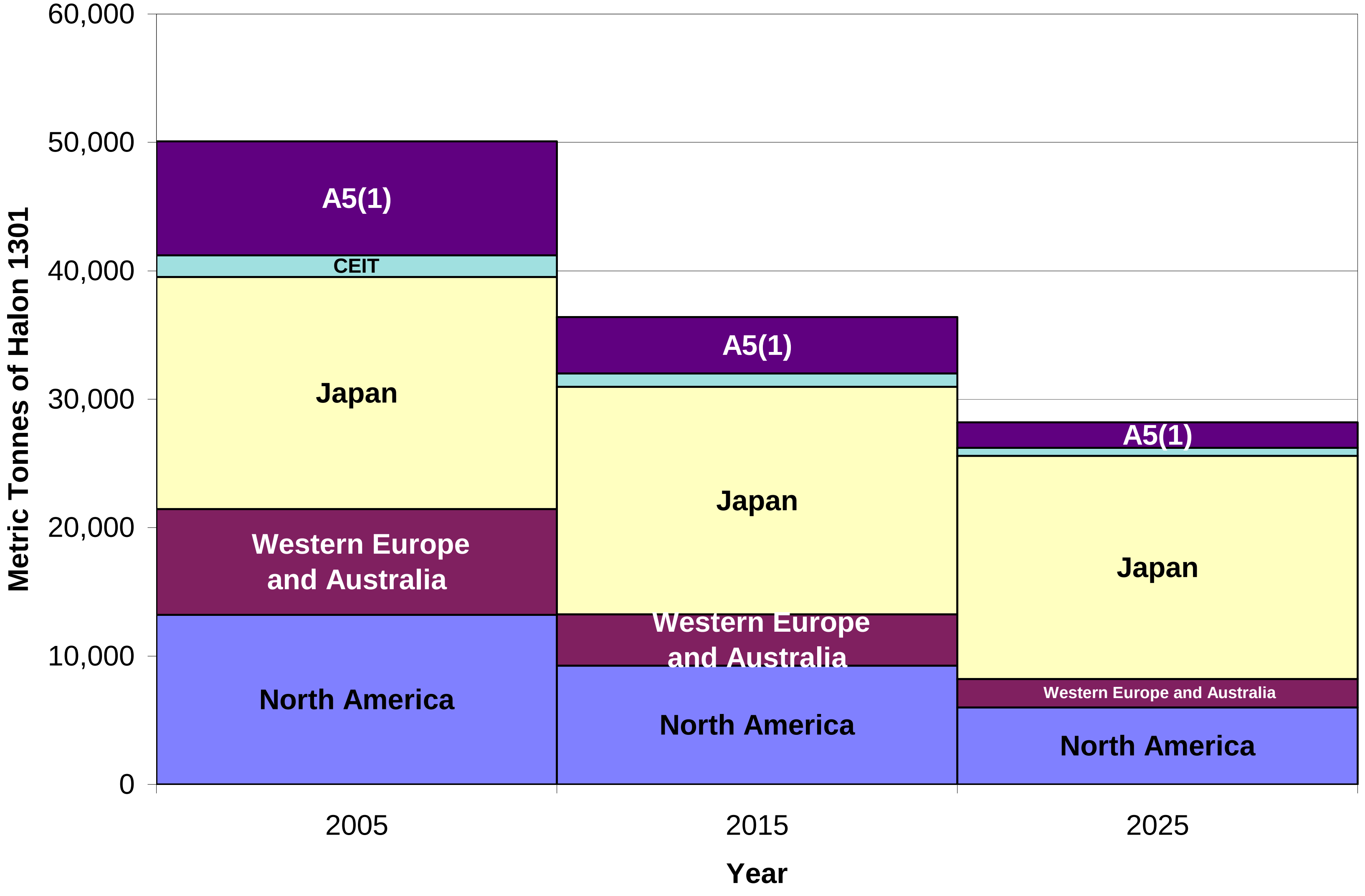


Figure 4-1 Breakout of Global Inventories (Bank) of Halon 1301 by HTOC Model Regions

4.2 Emissions and Inventories of Halon 1211

Similar to the assessment for halon 1301, a major change was made to the assumption on when cylinders need to be emptied. Instead of basing it solely on its ultimate useful lifetime, it is now also based on the premise that halon extinguishers need to be serviced on five or six year cycles depending upon national regulations and requirements. Currently, this is estimated at a quarter of the total inventory of halon 1211.

Other changes in the 2006 assessment for halon 1211 are as follows.

- Re-evaluate the percentage of CEFIC reported production provided to each region based on Article 7 production and consumption reporting taking into account trade patterns of equipment containing halon that do not get reported as consumption.
- Remove from the bank the quantities reported as destroyed by Parties.
- Account for documented imports/exports between regions.
- Increased recovery rates as halon 1211 is easier to recover than is halon 1301.

Table 4-2 provides the HTOC 2006 Assessment of current estimates of inventories for halon 1211. These estimates have been provided to the Science Assessment Panel.
Figure 4-2 provides the regional distribution of the global inventory of halon 1211. As shown in Table 4-1 and Figure 4-1, over 60% of the current inventory of halon 1211 is projected to be in Article 5(1) countries with the clear majority being in handheld extinguishers and unused stocks in China. As halon 1211 handheld fire extinguishers can no longer be produced or sold in China as of the end of 2005, and it is mandatory to retire in-service halon fire extinguishers after 10 years of service, unwanted halon 1211 stocks are beginning to build-up in China. Efforts should be made to recover the halon 1211 from these retired handheld fire extinguishers in order to avoid unnecessary emissions.

The HTOC is aware that a number of Parties are seeking recycled halon 1211 for critical applications and are having difficulties in finding it. China has set up a halon 1211 reclamation facility as part of its halon phase-out program and it is now operational. In order to facilitate the global trade in recycled halons, China is encouraged to provide information on the availability of recycled halon 1211 and Parties seeking recycled halon 1211 are encouraged to contact China. Note that in some countries there are regulations that encompass the import of foreign halons and there may also be taxes and restrictions that apply. Parties may wish to consider asking HTOC to investigate mechanisms to better predict and mitigate such imbalances in the future.

Table 4-2 HTOC 2006 Assessment of current estimates of inventories for halon 1211

Halon 1211 Summary

(All quantities are metric tonnes)

Year	**1963**	**1964**	**1965**	**1966**	**1967**	**1968**	**1969**	**1970**	**1971**	**1972**	**1973**	**1974**
ANNUAL PRODUCTION												
North America, Western Europe and Japan Production	50.0	100.0	200.0	300.0	500.0	700.0	900.0	1260.0	1700.0	2200.0	2750.0	3300.0
CEIT Production	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Article 5(1) Production	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Production	50.0	100.0	200.0	300.0	500.0	700.0	900.0	1260.0	1700.0	2200.0	2750.0	3300.0
ANNUAL PRODUCTION ALLOCATION												
North America	10.0	20.0	40.0	60.0	100.0	140.0	180.0	252.0	340.0	440.0	550.0	660.0
Western Europe and Australia	15.0	30.0	60.0	90.0	150.0	210.0	270.0	378.0	510.0	660.0	825.0	990.0
Japan	2.5	5.0	10.0	15.0	25.0	35.0	45.0	63.0	85.0	110.0	137.5	165.0
CEIT	2.5	5.0	10.0	15.0	25.0	35.0	45.0	63.0	85.0	110.0	137.5	165.0
Article 5(1)	20.0	40.0	80.0	120.0	200.0	280.0	360.0	504.0	680.0	880.0	1100.0	1320.0
TOTAL ANNUAL PRODUCTION ALLOCATION	50.0	100.0	200.0	300.0	500.0	700.0	900.0	1260.0	1700.0	2200.0	2750.0	3300.0
ANNUAL EMISSIONS												
North America	0.8	2.4	5.5	9.9	17.3	27.3	39.8	57.1	80.2	109.6	145.5	187.6
Western Europe and Australia	1.2	3.5	8.0	14.5	25.3	40.0	58.4	83.8	117.8	161.0	213.9	275.8
Japan	0.1	0.5	1.1	2.1	3.8	6.1	9.1	13.2	18.6	25.7	34.4	44.8
CEIT	0.2	0.6	1.4	2.5	4.3	6.8	9.9	14.3	20.0	27.4	36.4	46.9
Article 5(1)	1.7	5.2	12.2	22.5	39.2	62.4	91.5	131.1	184.2	251.9	334.9	431.9
TOTAL ANNUAL EMISSIONS	4.0	12.2	28.1	51.5	89.9	142.7	208.7	299.5	420.9	575.6	765.2	987.0
CUMMULATIVE PRODUCTION												
North America, Western Europe and Japan	50.0	150.0	350.0	650.0	1150.0	1850.0	2750.0	4010.0	5710.0	7910.0	10660.0	13960.0
CEIT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Article 5(1)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL CUMMULATIVE PRODUCTION	50.0	150.0	350.0	650.0	1150.0	1850.0	2750.0	4010.0	5710.0	7910.0	10660.0	13960.0
CUMMULATIVE PRODUCTION ALLOCATIONS												
North America	10.0	30.0	70.0	130.0	230.0	370.0	550.0	802.0	1142.0	1582.0	2132.0	2792.0
Western Europe and Australia	15.0	45.0	105.0	195.0	345.0	555.0	825.0	1203.0	1713.0	2373.0	3198.0	4188.0
Japan	2.5	7.5	17.5	32.5	57.5	92.5	137.5	200.5	285.5	395.5	533.0	698.0
CEIT	2.5	7.5	17.5	32.5	57.5	92.5	137.5	200.5	285.5	395.5	533.0	698.0
Article 5(1)	20.0	60.0	140.0	260.0	460.0	740.0	1100.0	1604.0	2284.0	3164.0	4264.0	5584.0
TOTAL CUMMULATIVE PRODUCTION ALLOCATIONS	50.0	150.0	350.0	650.0	1150.0	1850.0	2750.0	4010.0	5710.0	7910.0	10660.0	13960.0
CUMMULATIVE EMISSIONS												
North America	0.8	3.2	8.7	18.6	35.8	63.1	102.9	160.0	240.2	349.8	495.3	682.9
Western Europe and Australia	1.2	4.7	12.7	27.2	52.5	92.6	150.9	234.8	352.6	513.6	727.5	1003.2
Japan	0.1	0.6	1.7	3.8	7.6	13.7	22.8	36.0	54.6	80.3	114.7	159.6
CEIT	0.2	0.8	2.2	4.6	9.0	15.8	25.7	40.0	60.0	87.4	123.8	170.7
Article 5(1)	1.7	6.9	19.1	41.5	80.7	143.1	234.6	365.7	549.9	801.8	1136.7	1568.6
TOTAL CUMMULATIVE EMISSIONS	4.0	16.2	44.2	95.8	185.6	328.3	537.0	836.5	1257.3	1832.9	2598.0	3585.0
INVENTORY												
North America	9.2	26.8	61.3	111.4	194.2	306.9	447.1	642.0	901.8	1232.2	1636.7	2109.1
Western Europe and Australia	13.8	40.3	92.3	167.8	292.5	462.4	674.1	968.2	1360.4	1859.4	2470.5	3184.8
Japan	2.4	6.9	15.8	28.7	49.9	78.8	114.7	164.5	230.9	315.2	418.3	538.4
CEIT	2.3	6.7	15.3	27.9	48.5	76.7	111.8	160.5	225.5	308.1	409.2	527.3
Article 5(1)	18.3	53.1	120.9	218.5	379.3	596.9	865.4	1238.3	1734.1	2362.2	3127.3	4015.4
TOTAL INVENTORY	46.0	133.8	305.8	554.2	964.4	1521.7	2213.0	3173.5	4452.7	6077.1	8062.0	10375.0

Halon 1211 Summary

(All quantities are metric tonnes)

Year	**1975**	**1976**	**1977**	**1978**	**1979**	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**
ANNUAL PRODUCTION												
North America, Western Europe and Japan Production	3800.0	4356.0	5000.0	5650.0	6280.0	6910.0	6689.0	7485.0	8259.0	10408.0	12491.0	13731.0
CEIT Production	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	30.0	30.0	30.0
Article 5(1) Production	0.0	0.0	0.0	210.1	265.7	336.2	425.2	537.9	680.4	1060.7	1341.8	1658.3
Total Production	3800.0	4356.0	5000.0	5860.1	6545.7	7246.2	7114.2	8022.9	8939.4	11498.7	13862.8	15419.3
ANNUAL PRODUCTION ALLOCATION												
North America	760.0	871.2	1000.0	1130.0	1256.0	1382.0	1337.8	1497.0	1651.8	2081.6	2498.2	2746.2
Western Europe and Australia	1140.0	1306.8	1500.0	1695.0	1884.0	2073.0	2006.7	2245.5	2477.7	3122.4	3747.3	4119.3
Japan	190.0	217.8	250.0	282.5	314.0	345.5	334.5	374.3	413.0	520.4	624.6	686.6
CEIT	190.0	217.8	250.0	282.5	314.0	345.5	334.5	374.3	413.0	550.4	654.6	716.6
Article 5(1)	1520.0	1742.4	2000.0	2470.1	2777.7	3100.2	3100.8	3531.9	3984.0	5223.9	6338.2	7150.7
TOTAL ANNUAL PRODUCTION ALLOCATION	3800.0	4356.0	5000.0	5860.1	6545.7	7246.2	7114.2	8022.9	8939.4	11498.7	13862.8	15419.3
ANNUAL EMISSIONS												
North America	234.3	286.3	344.6	408.7	477.9	551.8	616.0	687.9	766.6	874.0	1006.7	1148.7
Western Europe and Australia	344.6	421.3	507.3	601.9	704.1	833.4	929.2	1036.7	1154.4	1315.1	1513.7	1726.5
Japan	56.6	69.7	84.2	100.4	117.9	136.6	154.4	172.1	191.7	216.5	248.2	284.3
CEIT	58.6	71.6	86.2	102.2	119.5	137.9	154.0	172.0	191.7	221.0	249.8	287.3
Article 5(1)	540.0	659.3	792.2	955.7	1137.2	1332.8	1514.6	1713.7	1938.5	2252.5	2651.2	3098.2
TOTAL ANNUAL EMISSIONS	1234.1	1508.2	1814.5	2168.9	2556.5	2992.5	3368.1	3782.4	4242.9	4879.0	5669.6	6545.1
CUMMULATIVE PRODUCTION												
North America, Western Europe and Japan	17760.0	22116.0	27116.0	32766.0	39046.0	45956.0	52645.0	60130.0	68389.0	78797.0	91288.0	105019.0
CEIT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	30.0	60.0	90.0
Article 5(1)	0.0	0.0	0.0	210.1	475.8	812.0	1237.2	1775.1	2455.5	3516.3	4858.1	6516.4
TOTAL CUMMULATIVE PRODUCTION	17760.0	22116.0	27116.0	32976.1	39521.8	46768.0	53882.2	61905.1	70844.5	82343.3	96206.1	111625.4
CUMMULATIVE PRODUCTION ALLOCATIONS												
North America	3552.0	4423.2	5423.2	6553.2	7809.2	9191.2	10529.0	12026.0	13677.8	15759.4	18257.6	21003.8
Western Europe and Australia	5328.0	6634.8	8134.8	9829.8	11713.8	13786.8	15793.5	18039.0	20516.7	23639.1	27386.4	31505.7
Japan	888.0	1105.8	1355.8	1638.3	1952.3	2297.8	2632.3	3006.5	3419.5	3939.9	4564.4	5251.0
CEIT	888.0	1105.8	1355.8	1638.3	1952.3	2297.8	2632.3	3006.5	3419.5	3969.9	4624.4	5341.0
Article 5(1)	7104.0	8846.4	10846.4	13316.5	16094.2	19194.4	22295.2	25827.1	29811.1	35035.1	41373.3	48524.0
TOTAL CUMMULATIVE PRODUCTION ALLOCATIONS	17760.0	22116.0	27116.0	32976.1	39521.8	46768.0	53882.2	61905.1	70844.5	82343.3	96206.1	111625.4
CUMMULATIVE EMISSIONS												
North America	917.2	1203.5	1548.1	1956.9	2434.8	2986.6	3602.5	4290.5	5057.1	5931.1	6937.8	8086.5
Western Europe and Australia	1347.9	1769.2	2276.4	2878.3	3582.4	4415.8	5345.0	6381.6	7536.0	8851.1	10364.8	12091.3
Japan	216.1	285.8	370.0	470.4	588.3	724.9	879.3	1051.4	1243.2	1459.6	1707.9	1992.1
CEIT	229.3	300.9	387.0	489.2	608.7	746.6	900.6	1072.6	1264.3	1485.2	1735.1	2022.4
Article 5(1)	2108.6	2767.9	3560.2	4515.9	5653.1	6985.8	8500.4	10214.1	12152.6	14405.1	17056.2	20154.5
TOTAL CUMMULATIVE EMISSIONS	4819.1	6327.3	8141.8	10310.7	12867.3	15859.8	19227.8	23010.2	27253.1	32132.1	37801.7	44346.8
INVENTORY												
North America	2634.8	3219.7	3875.1	4596.3	5374.4	6204.6	6926.5	7735.5	8620.7	9828.3	11319.8	12917.3
Western Europe and Australia	3980.1	4865.6	5858.4	6951.5	8131.4	9371.0	10448.5	11657.4	12980.7	14788.0	17021.6	19414.4
Japan	671.9	820.0	985.8	1167.9	1364.0	1572.9	1753.0	1955.1	2176.3	2480.2	2856.5	3258.8
CEIT	658.7	804.9	968.8	1149.1	1343.6	1551.2	1731.6	1933.9	2155.2	2484.6	2889.3	3318.6
Article 5(1)	4995.4	6078.5	7286.2	8800.6	10441.2	12208.5	13794.8	15613.0	17658.6	20630.0	24317.1	28369.6
TOTAL INVENTORY	12940.9	15788.7	18974.2	22665.3	26654.5	30908.2	34654.4	38894.9	43591.4	50211.2	58404.4	67278.6

Halon 1211 Summary

(All quantities are metric tonnes)

Year	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**
ANNUAL PRODUCTION												
North America, Western Europe and Japan Production	17058.0	20181.0	16182.0	14852.0	11882.0	7921.0	3960.0	0.0	0.0	0.0	0.0	0.0
CEIT Production	35.0	35.0	80.0	700.0	50.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0
Article 5(1) Production	2049.3	2545.0	3074.0	3716.5	4646.0	7002.0	8713.0	10447.5	11250.0	14180.0	12124.0	8175.0
Total Production	19142.3	22761.0	19336.0	19268.5	16578.0	14973.0	12673.0	10447.5	11250.0	14180.0	12124.0	8175.0
ANNUAL PRODUCTION ALLOCATION												
North America	3411.6	4036.2	3236.4	2970.4	2376.4	1584.2	792.0	0.0	0.0	0.0	0.0	0.0
Western Europe and Australia	5117.4	6054.3	4854.6	4455.6	3564.6	2376.3	1188.0	0.0	0.0	-1.0	0.0	-6.5
Japan	852.9	1009.1	809.1	742.6	594.1	396.1	198.0	0.0	0.0	0.0	0.0	0.0
CEIT	887.9	1044.1	889.1	1442.6	644.1	446.1	198.0	0.0	0.0	0.0	0.0	0.0
Article 5(1)	8872.5	10617.4	9546.8	9657.3	9398.8	10170.4	10297.0	10447.5	11250.0	14180.0	12124.0	8175.0
TOTAL ANNUAL PRODUCTION ALLOCATION	19142.3	22761.0	19336.0	19268.5	16578.0	14973.0	12673.0	10447.5	11250.0	14179.0	12124.0	8168.5
ANNUAL EMISSIONS												
North America	1333.5	1554.2	1691.6	1796.1	1396.0	1384.3	1042.5	1001.7	954.2	909.0	865.9	824.8
Western Europe and Australia	2003.4	2334.3	2540.1	2696.5	2723.0	2675.2	1519.5	1447.8	1379.1	1313.7	1251.4	1192.0
Japan	327.8	381.5	470.1	483.4	485.7	474.5	262.1	248.3	235.9	224.1	212.9	202.3
CEIT	334.7	391.0	453.8	522.9	524.7	514.3	291.2	277.3	265.7	254.7	244.0	233.9
Article 5(1)	3658.9	4340.9	4830.4	5256.5	5624.8	5990.2	6364.7	5144.4	5224.3	8525.8	9096.6	9315.0
TOTAL ANNUAL EMISSIONS	7658.3	9001.9	9986.0	10755.3	10754.2	11038.5	9479.9	8119.4	8059.3	11227.3	11670.9	11768.0
CUMMULATIVE PRODUCTION												
North America, Western Europe and Japan	122077.0	142258.0	158440.0	173292.0	185174.0	193095.0	197055.0	197055.0	197055.0	197055.0	197055.0	197055.0
CEIT	125.0	160.0	240.0	940.0	990.0	1040.0	1040.0	1040.0	1040.0	1040.0	1040.0	1040.0
Article 5(1)	8565.7	11110.7	14184.7	17901.2	22547.2	29549.2	38262.2	48709.7	59959.7	74139.7	86263.7	94438.7
TOTAL CUMMULATIVE PRODUCTION	130767.7	153528.7	172864.7	192133.2	208711.2	223684.2	236357.2	246804.7	258054.7	272234.7	284358.7	292533.7
CUMMULATIVE PRODUCTION ALLOCATIONS												
North America	24415.4	28451.6	31688.0	34658.4	37034.8	38619.0	39411.0	39411.0	39411.0	39411.0	39411.0	39411.0
Western Europe and Australia	36623.1	42677.4	47532.0	51987.6	55552.2	57928.5	59116.5	59116.5	59116.5	59115.5	59115.5	59109.0
Japan	6103.9	7112.9	7922.0	8664.6	9258.7	9654.8	9852.8	9852.8	9852.8	9852.8	9852.8	9852.8
CEIT	6228.9	7272.9	8162.0	9604.6	10248.7	10694.8	10892.8	10892.8	10892.8	10892.8	10892.8	10892.8
Article 5(1)	57396.5	68013.9	77560.7	87218.0	96616.8	106787.2	117084.2	127531.7	138781.7	152961.7	165085.7	173260.7
TOTAL CUMMULATIVE PRODUCTION ALLOCATIONS	130767.7	153528.7	172864.7	192133.2	208711.2	223684.2	236357.2	246804.7	258054.7	272233.7	284357.7	292526.2
CUMMULATIVE EMISSIONS												
North America	9420.0	10974.3	12665.9	14461.9	15857.9	17242.3	18284.7	19286.5	20240.7	21149.7	22015.6	22840.4
Western Europe and Australia	14094.7	16429.0	18969.1	21665.6	24388.6	27063.8	28583.2	30031.0	31410.2	32723.9	33975.3	35167.3
Japan	2319.9	2701.4	3171.5	3654.9	4140.6	4615.1	4877.1	5125.4	5361.3	5585.4	5798.4	6000.7
CEIT	2357.0	2748.1	3201.9	3724.8	4249.5	4763.8	5055.0	5332.3	5598.0	5852.7	6096.7	6330.6
Article 5(1)	23813.4	28154.2	32984.7	38241.1	43865.9	49856.2	56220.9	61365.2	66589.6	75115.4	84211.9	93526.9
TOTAL CUMMULATIVE EMISSIONS	52005.1	61007.0	70993.0	81748.3	92502.6	103541.1	113021.0	121140.4	129199.7	140427.0	152097.9	163865.8
INVENTORY												
North America	14995.4	17477.3	19022.1	20196.5	21176.9	21376.7	21126.3	20124.5	19170.3	18261.3	17395.4	16570.6
Western Europe and Australia	22528.4	26248.4	28562.9	30322.0	31163.6	30864.7	30533.3	29085.5	27706.3	26391.6	25140.2	23941.7
Japan	3783.9	4411.5	4750.5	5009.7	5118.1	5039.7	4975.6	4727.4	4491.5	4267.3	4054.4	3852.1
CEIT	3871.8	4524.8	4960.1	5879.8	5999.2	5930.9	5837.7	5560.5	5294.7	5040.1	4796.0	4562.2
Article 5(1)	33583.2	39859.7	44576.1	48976.9	52750.9	56931.1	60863.3	66166.5	72192.2	77846.4	80873.8	79733.8
TOTAL INVENTORY	78762.7	92521.7	101871.7	110384.9	116208.7	120143.1	123336.2	125664.3	128855.0	131806.7	132259.8	128660.4

Halon 1211 Summary

(All quantities are metric tonnes)

Year	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
ANNUAL PRODUCTION												
North America, Western Europe and Japan Production	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CEIT Production	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Article 5(1) Production	6265.0	4278.0	3599.0	2954.0	2384.0	1568.0	165.0	165.0	0.0	0.0	0.0	0.0
Total Production	6265.0	4278.0	3599.0	2954.0	2384.0	1568.0	165.0	165.0	0.0	0.0	0.0	0.0
ANNUAL PRODUCTION ALLOCATION												
North America	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Western Europe and Australia	0.0	-3.9	-1.1	-1.3	-259.8	-180.9	0.0	0.0	0.0	0.0	0.0	0.0
Japan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CEIT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Article 5(1)	6265.0	4278.0	3599.0	2954.0	2384.0	1568.0	165.0	165.0	0.0	0.0	0.0	0.0
TOTAL ANNUAL PRODUCTION ALLOCATION	6265.0	4274.1	3597.9	2952.7	2124.2	1387.2	165.0	165.0	0.0	0.0	0.0	0.0
ANNUAL EMISSIONS												
North America	785.7	748.5	713.0	679.2	647.0	616.3	587.1	559.2	532.7	507.5	483.4	460.5
Western Europe and Australia	1135.2	1081.4	1029.9	981.0	930.9	875.5	827.9	788.7	751.3	715.7	681.7	649.4
Japan	192.2	182.6	173.5	164.9	156.6	148.8	141.4	134.3	127.6	121.3	115.2	109.5
CEIT	224.1	214.8	205.8	197.3	189.0	181.2	173.6	166.4	159.5	152.8	146.4	140.3
Article 5(1)	9128.7	8689.0	8181.3	5053.3	4887.1	4686.0	4427.4	4114.0	3820.1	3539.2	3278.9	3037.8
TOTAL ANNUAL EMISSIONS	11466.0	10916.2	10303.6	7075.6	6810.6	6507.8	6157.5	5762.6	5391.2	5036.4	4705.7	4397.4
CUMMULATIVE PRODUCTION												
North America, Western Europe and Japan	197055.0	197055.0	197055.0	197055.0	197055.0	197055.0	197055.0	197055.0	197055.0	197055.0	197055.0	197055.0
CEIT	1040.0	1040.0	1040.0	1040.0	1040.0	1040.0	1040.0	1040.0	1040.0	1040.0	1040.0	1040.0
Article 5(1)	100703.7	104981.7	108580.7	111534.7	113918.7	115486.7	115651.7	115816.7	115816.7	115816.7	115816.7	115816.7
TOTAL CUMMULATIVE PRODUCTION	298798.7	303076.7	306675.7	309629.7	312013.7	313581.7	313746.7	313911.7	313911.7	313911.7	313911.7	313911.7
CUMMULATIVE PRODUCTION ALLOCATIONS												
North America	39411.0	39411.0	39411.0	39411.0	39411.0	39411.0	39411.0	39411.0	39411.0	39411.0	39411.0	39411.0
Western Europe and Australia	59109.0	59105.1	59104.0	59102.7	58842.9	58662.0	58662.0	58662.0	58662.0	58662.0	58662.0	58662.0
Japan	9852.8	9852.8	9852.8	9852.8	9852.8	9852.8	9852.8	9852.8	9852.8	9852.8	9852.8	9852.8
CEIT	10892.8	10892.8	10892.8	10892.8	10892.8	10892.8	10892.8	10892.8	10892.8	10892.8	10892.8	10892.8
Article 5(1)	179525.7	183803.7	187402.7	190356.7	192740.7	194308.7	194473.7	194638.7	194638.7	194638.7	194638.7	194638.7
TOTAL CUMMULATIVE PRODUCTION ALLOCATIONS	298791.2	303065.3	306663.2	309615.9	311740.1	313127.2	313292.2	313457.2	313457.2	313457.2	313457.2	313457.2
CUMMULATIVE EMISSIONS												
North America	23626.1	24374.6	25087.6	25766.8	26413.7	27030.0	27617.1	28176.3	28709.0	29216.5	29699.9	30160.3
Western Europe and Australia	36302.5	37383.9	38413.8	39394.8	40325.7	41201.2	42029.2	42817.8	43569.1	44284.8	44966.5	45615.9
Japan	6192.9	6375.5	6549.0	6713.9	6870.5	7019.3	7160.7	7295.0	7422.7	7543.9	7659.1	7768.6
CEIT	6554.7	6769.5	6975.3	7172.6	7361.7	7542.8	7716.4	7882.8	8042.3	8195.1	8341.5	8481.9
Article 5(1)	102655.6	111344.6	119525.9	124579.2	129466.3	134152.3	138579.7	142693.7	146513.8	150053.0	153331.9	156369.7
TOTAL CUMMULATIVE EMISSIONS	175331.8	186248.1	196551.7	203627.3	210437.9	216945.6	223103.1	228865.7	234256.9	239293.3	243998.9	248396.4
INVENTORY												
North America	15784.9	15036.4	14323.4	13644.2	12997.3	12381.0	11793.9	11234.7	10702.0	10194.5	9711.1	9250.7
Western Europe and Australia	22806.5	21721.2	20690.2	19707.9	18517.2	17460.8	16632.9	15844.2	15092.9	14377.3	13695.5	13046.1
Japan	3659.9	3477.2	3303.7	3138.9	2982.2	2833.4	2692.0	2557.7	2430.1	2308.8	2193.6	2084.1
CEIT	4338.0	4123.2	3917.4	3720.1	3531.1	3349.9	3176.3	3009.9	2850.5	2697.7	2551.2	2410.9
Article 5(1)	76870.1	72459.2	67876.8	65777.5	63274.4	60156.5	55894.0	51945.0	48124.9	44585.7	41306.8	38269.1
TOTAL INVENTORY	123459.4	116817.3	110111.6	105988.6	101302.2	96181.6	90189.2	84591.6	79200.4	74164.0	69458.3	65060.9

Halon 1211 Summary

(All quantities are metric tonnes)

Year	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
ANNUAL PRODUCTION												
North America, Western Europe and Japan Production	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CEIT Production	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Article 5(1) Production	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Production	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL PRODUCTION ALLOCATION												
North America	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Western Europe and Australia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Japan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CEIT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Article 5(1)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL ANNUAL PRODUCTION ALLOCATION	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL EMISSIONS												
North America	438.6	417.8	398.0	379.2	361.2	344.0	327.7	312.2	297.4	283.3	269.9	257.1
Western Europe and Australia	618.6	589.3	561.3	534.7	509.4	485.2	462.2	440.3	419.4	399.5	380.6	362.5
Japan	104.0	98.8	93.9	89.2	84.7	80.5	76.5	72.7	69.1	65.6	62.3	59.2
CEIT	134.5	128.9	123.5	118.4	113.4	108.7	104.2	99.8	95.7	91.7	87.9	84.2
Article 5(1)	2814.4	2607.4	2415.6	2238.0	2073.4	1920.9	1779.7	1648.8	1527.5	1415.2	1311.1	1214.7
TOTAL ANNUAL EMISSIONS	4110.1	3842.2	3592.4	3359.4	3142.1	2939.4	2750.3	2573.8	2409.1	2255.3	2111.8	1977.7
CUMMULATIVE PRODUCTION												
North America, Western Europe and Japan	197055.0	197055.0	197055.0	197055.0	197055.0	197055.0	197055.0	197055.0	197055.0	197055.0	197055.0	197055.0
CEIT	1040.0	1040.0	1040.0	1040.0	1040.0	1040.0	1040.0	1040.0	1040.0	1040.0	1040.0	1040.0
Article 5(1)	115816.7	115816.7	115816.7	115816.7	115816.7	115816.7	115816.7	115816.7	115816.7	115816.7	115816.7	115816.7
TOTAL CUMMULATIVE PRODUCTION	313911.7	313911.7	313911.7	313911.7	313911.7	313911.7	313911.7	313911.7	313911.7	313911.7	313911.7	313911.7
CUMMULATIVE PRODUCTION ALLOCATIONS												
North America	39411.0	39411.0	39411.0	39411.0	39411.0	39411.0	39411.0	39411.0	39411.0	39411.0	39411.0	39411.0
Western Europe and Australia	58662.0	58662.0	58662.0	58662.0	58662.0	58662.0	58662.0	58662.0	58662.0	58662.0	58662.0	58662.0
Japan	9852.8	9852.8	9852.8	9852.8	9852.8	9852.8	9852.8	9852.8	9852.8	9852.8	9852.8	9852.8
CEIT	10892.8	10892.8	10892.8	10892.8	10892.8	10892.8	10892.8	10892.8	10892.8	10892.8	10892.8	10892.8
Article 5(1)	194638.7	194638.7	194638.7	194638.7	194638.7	194638.7	194638.7	194638.7	194638.7	194638.7	194638.7	194638.7
TOTAL CUMMULATIVE PRODUCTION ALLOCATIONS	313457.2	313457.2	313457.2	313457.2	313457.2	313457.2	313457.2	313457.2	313457.2	313457.2	313457.2	313457.2
CUMMULATIVE EMISSIONS												
North America	30599.0	31016.8	31414.8	31794.0	32155.1	32499.2	32826.9	33139.1	33436.5	33719.8	33989.7	34246.7
Western Europe and Australia	46234.5	46823.8	47385.1	47919.8	48429.2	48914.4	49376.6	49816.9	50236.3	50635.8	51016.4	51378.9
Japan	7872.6	7971.4	8065.3	8154.5	8239.2	8319.7	8396.2	8468.9	8538.0	8603.6	8665.9	8725.1
CEIT	8616.4	8745.3	8868.8	8987.1	9100.6	9209.3	9313.5	9413.3	9509.0	9600.7	9688.6	9772.8
Article 5(1)	159184.0	161791.4	164207.1	166445.1	168518.5	170439.4	172219.1	173867.9	175395.4	176810.6	178121.7	179336.4
TOTAL CUMMULATIVE EMISSIONS	252506.5	256348.7	259941.1	263300.5	266442.6	269382.0	272132.3	274706.1	277115.1	279370.4	281482.2	283459.9
INVENTORY												
North America	8812.0	8394.2	7996.2	7617.0	7255.9	6911.8	6584.1	6271.9	5974.5	5691.2	5421.3	5164.3
Western Europe and Australia	12427.5	11838.3	11276.9	10742.2	10232.9	9747.6	9285.4	8845.2	8425.8	8026.2	7645.7	7283.1
Japan	1980.1	1881.3	1787.5	1698.3	1613.5	1533.0	1456.5	1383.8	1314.8	1249.2	1186.8	1127.6
CEIT	2276.4	2147.5	2024.0	1905.6	1792.2	1683.5	1579.3	1479.4	1383.7	1292.1	1204.2	1120.0
Article 5(1)	35454.7	32847.3	30431.6	28193.6	26120.2	24199.3	22419.7	20770.9	19243.4	17828.2	16517.1	15302.4
TOTAL INVENTORY	60950.8	57108.6	53516.2	50156.8	47014.6	44075.2	41324.9	38751.2	36342.1	34086.8	31975.0	29997.3

Halon 1211 Summary

(All quantities are metric tonnes)

Year	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
ANNUAL PRODUCTION								
North America, Western Europe and Japan Production	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CEIT Production	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Article 5(1) Production	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Production	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL PRODUCTION ALLOCATION								
North America	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Western Europe and Australia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Japan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CEIT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Article 5(1)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL ANNUAL PRODUCTION ALLOCATION	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL EMISSIONS								
North America	244.9	233.3	222.2	211.7	201.6	192.1	183.0	174.3
Western Europe and Australia	345.3	329.0	313.4	298.5	284.4	270.9	258.0	245.8
Japan	56.3	53.5	50.8	48.3	45.8	43.6	41.4	39.3
CEIT	80.7	77.3	74.1	71.0	68.1	65.2	62.5	59.9
Article 5(1)	1125.4	1042.6	965.9	894.9	829.1	768.1	711.6	659.3
TOTAL ANNUAL EMISSIONS	1852.5	1735.6	1626.4	1524.4	1429.0	1339.8	1256.5	1178.6
CUMMULATIVE PRODUCTION								
North America, Western Europe and Japan	197055.0	197055.0	197055.0	197055.0	197055.0	197055.0	197055.0	197055.0
CEIT	1040.0	1040.0	1040.0	1040.0	1040.0	1040.0	1040.0	1040.0
Article 5(1)	115816.7	115816.7	115816.7	115816.7	115816.7	115816.7	115816.7	115816.7
TOTAL CUMMULATIVE PRODUCTION	313911.7	313911.7	313911.7	313911.7	313911.7	313911.7	313911.7	313911.7
CUMMULATIVE PRODUCTION ALLOCATIONS								
North America	39411.0	39411.0	39411.0	39411.0	39411.0	39411.0	39411.0	39411.0
Western Europe and Australia	58662.0	58662.0	58662.0	58662.0	58662.0	58662.0	58662.0	58662.0
Japan	9852.8	9852.8	9852.8	9852.8	9852.8	9852.8	9852.8	9852.8
CEIT	10892.8	10892.8	10892.8	10892.8	10892.8	10892.8	10892.8	10892.8
Article 5(1)	194638.7	194638.7	194638.7	194638.7	194638.7	194638.7	194638.7	194638.7
TOTAL CUMMULATIVE PRODUCTION ALLOCATIONS	313457.2	313457.2	313457.2	313457.2	313457.2	313457.2	313457.2	313457.2
CUMMULATIVE EMISSIONS								
North America	34491.6	34724.9	34947.1	35158.7	35360.4	35552.4	35735.4	35909.7
Western Europe and Australia	51724.2	52053.2	52366.6	52665.1	52949.4	53220.3	53478.3	53724.1
Japan	8781.4	8834.9	8885.7	8933.9	8979.8	9023.3	9064.7	9104.0
CEIT	9853.5	9930.8	10005.0	10076.0	10144.1	10209.3	10271.8	10331.7
Article 5(1)	180461.7	181504.3	182470.3	183365.1	184194.2	184962.3	185673.9	186333.2
TOTAL CUMMULATIVE EMISSIONS	285312.5	287048.1	288674.5	290198.9	291627.8	292967.7	294224.2	295402.8
INVENTORY								
North America	4919.4	4686.1	4463.9	4252.3	4050.6	3858.6	3675.6	3501.3
Western Europe and Australia	6937.8	6608.8	6295.4	5996.9	5712.6	5441.7	5183.7	4937.9
Japan	1071.3	1017.9	967.1	918.8	873.0	829.4	788.0	748.7
CEIT	1039.3	961.9	887.8	816.8	748.7	683.5	620.9	561.0
Article 5(1)	14177.0	13134.4	12168.5	11273.6	10444.5	9676.4	8964.8	8305.5
TOTAL INVENTORY	28144.8	26409.2	24782.7	23258.4	21829.4	20489.6	19233.1	18054.5

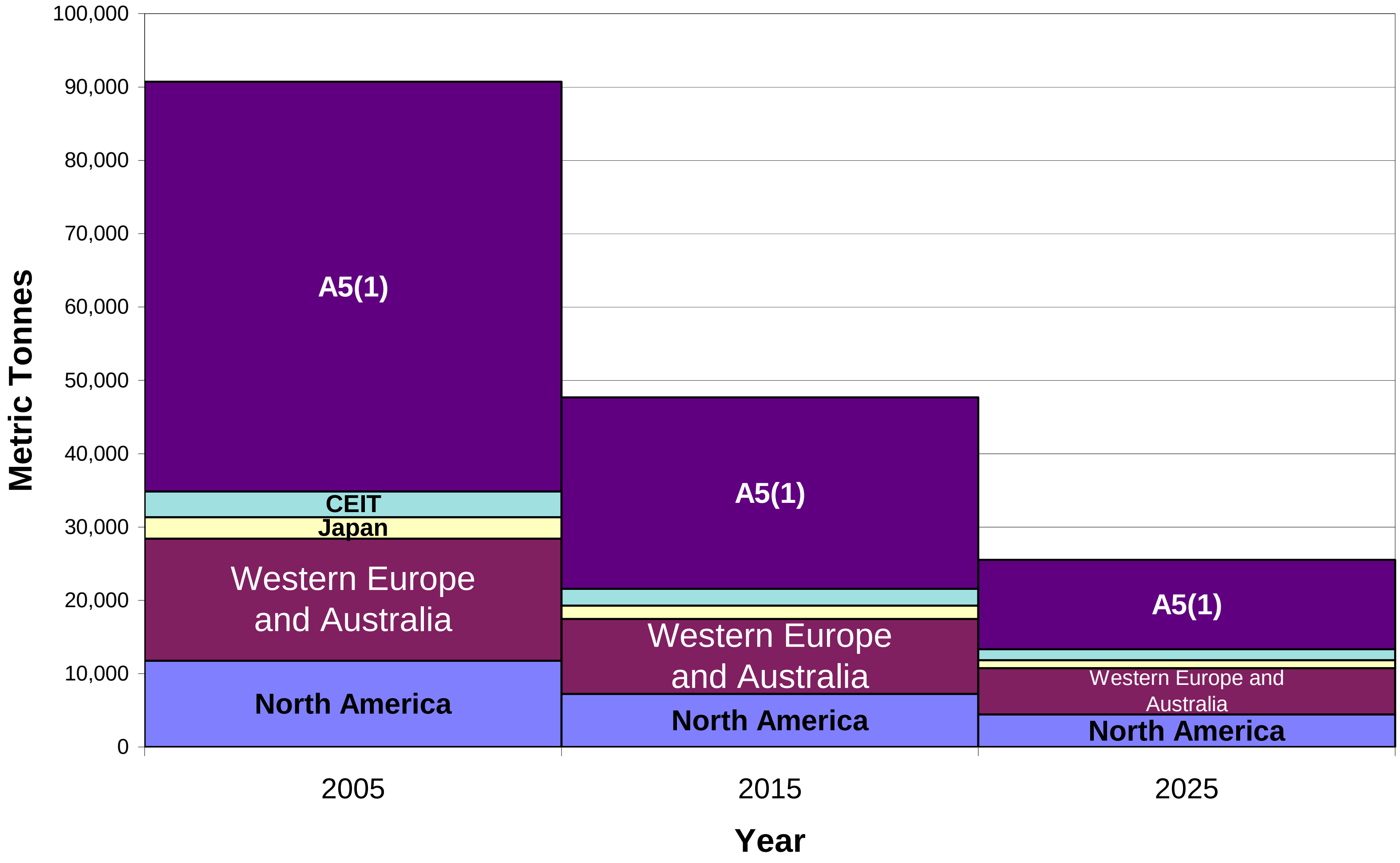


Figure 4-2 Breakout of Global Inventories (Bank) of Halon 1211 by HTOC Model Regions

4.3 Conclusions

The HTOC has updated the inventory and emission models of halon 1211 and 1301 taking into account direct data on destruction, inventories and emissions, where available, and additional expert opinion on past practices.

For halon 1301, the 2006 assessment indicates an even greater global inventory or bank of halon 1301 as compared with the 2002 assessment. The global bank of halon 1301 at the end of 2005 is now estimated to be approximately 50,000 MT as compared with the 2002 assessment of 39,000 MT.

For the global halon 1211 bank, the 2006 assessment provides as estimate of 90,000 MT at the end of 2005 as compared with 106,000 MT from the corrected 2002 assessment, as reported in the TEAP Supplement to the IPCC/TEAP Special Report on Fluorocarbons (TEAP, 2005), and 83,000 MT in the pre-corrected 2002 HTOC assessment report.

There is little open literature information available on inventories and emissions of halon 2402. However, from the 2006 assessment there is growing concern from HTOC local and regional experts about the availability of halon 2402 outside of the Russian Federation and the Ukraine to support existing uses in aircraft, military vehicles, and ships (see Chapter 2). Parties may wish to request additional information be collected on existing inventories, historic and current emission factors, and projected needs to support critical or essential halon 2402 equipment through their end of useful life.

From the 2006 assessment, the HTOC is of the opinion that adequate global stocks of halon 1211 and halon 1301 currently exist to meet the future service and replenishment needs of existing critical or essential halon 1211 and halon 1301 fire equipment until the end of their useful lives. While it appears that adequate supplies of halon 1211 and 1301 would be expected to be available on a global basis, over 35% of the global supply of halon 1301 is projected to be in Japan. Model projections for halon 1211 based on Article 7 reporting of production and consumption place over 60% of the halon 1211 in Article 5(1) countries with the clear majority being in handheld extinguishers and unused stocks in China. Similarly, expert opinion places the majority of halon 2402 in the Russian Federation and Ukraine. Parties may wish to consider asking HTOC to investigate mechanisms to better predict and mitigate such imbalances in the future.

5.0 Civil Aviation

5.1 Introduction

Although the incidence of in-flight fires is low, the consequences in terms of loss of life are potentially devastating, and the use of halon to help guard against such events has been extensive. Aviation applications of halons are amongst the most demanding uses of the agents, and require every one of their beneficial characteristics. Particularly important are dispersion and suppression effectiveness, which must be maintained even at the low temperatures encountered at high altitude to exercise duty of care with minimal toxic hazard to the health and safety of ground maintenance staff and also of passengers and flight crew, who could be exposed to the agent and any decomposition products for periods as long as several hours; and the weight and space requirements of the agent and associated hardware.

Also significant are short and long term damage to structure or contents resulting from the agent or from its potential decomposition products in a fire; avoidance of clean-up problems; suitability for use on live electrical equipment; effectiveness on the hidden fire; and the installed cost of the system and its maintenance over its life. It is no surprise, therefore, that it is in an area which is proving technically difficult to satisfy - it is for these reasons many aviation applications are generally accepted as “critical” in accordance with the terms of Decision VII/12 by reference to the criteria set out in Decision IV/25 and European Union Regulation EC2037/2000 – Annex VII.

While alternative methods of fire suppression for ground based situations have been implemented, the status of halons in the civil aircraft sector must be viewed in two different contexts: existing aircraft and new aircraft. Existing civil aircraft and new designs continue to depend on halons for the majority of their fire protection applications. Given the anticipated 25–30 year lifespan of civil aircraft, this dependency is likely to continue well beyond the time when existing recycled halon stocks expire. The civil aviation industry must look either to their own stockpiles of halons or to the limited amounts of recycled halons available on the open market to avoid grounding aircraft because of a lack of appropriate fire protection.

5.2 Status of Halon Replacement Options

Halon is used for fire suppression on civil aircraft in:

1) lavatory trash receptacle extinguishing systems,
2) handheld extinguishers,
3) engine nacelle/auxiliary power unit (APU) protection systems, and
4) cargo compartment extinguishing systems.

With the exception of lavatory trash receptacles on some new Airbus and Boeing aircraft, all new installations of fire extinguishing systems for lavatory trash receptacles, engines and cargo compartments use halon 1301, and all new installations of handheld extinguishers use halon 1211. There has been no retrofit of halon systems or portable extinguishers with available alternatives in the existing worldwide fleet of aircraft.

Key to the acceptance of one or more of the approved substitutes has been their ability to demonstrate a fire extinguishing performance equivalent to halon in specific applications. As such, substitutes for halons in civil aviation fire extinguishing systems are evaluated and approved according to the relevant Minimum Performance Standards (MPS) and testing scenarios developed by the International Aircraft Systems Fire Protection Working Group (IASFPWG), originally established in 1993 by the Federal Aviation Administration and cooperating agencies and known then as the International Halon Replacement Working Group. The status of the development of these MPS for the above applications and the alternatives tested to these MPS is discussed below.

5.3 Lavatory Trash Receptacle

Halon 1301 is used in lavatory extinguishing (lavex) systems, which are designed to extinguish trash receptacle fires in the lavatories of pressurized cabins. Trash receptacles are required to be installed with a lavex system that automatically discharges into the container in the event of a Class A fire (i.e., involving paper materials). All lavex systems must meet the standards established by the Minimum Performance Standard, which include the ability to extinguish a Class A fire and in the case of discharge, not create an environment that exceeds the chemical agent’s no observable adverse effect level (NOAEL).

A finalized MPS for lavex systems was completed in February 1997. Research and testing has shown that there is suitable alternative suppression systems available for this application that meet the criteria for space and weight, the toxicological factors, and cost the same as the halon systems being replaced. As of 2001, HFC-227ea and HFC-236fa passed the MPS requirements. In 2005, Lufthansa Airlines rolled out new Airbus 340-600 aircraft using the new HFC-236fa lavex systems, and in 2006 Boeing began installing new HFC-227ea lavex systems on new production aircraft. In addition, Lufthansa is replacing existing halon 1301 lavex systems during scheduled maintenance operations.

5.4 Handheld Extinguishers

All handheld extinguishers intended to replace halon 1211 extinguishers must meet the specific standards required in the Minimum Performance Standard to ensure their performance and safety. These standards require that any handheld extinguisher for final use be listed by UL or equivalent listing organization. To be listed, the extinguisher must be able to disperse in a manner that allows for a hidden fire to be suppressed and does not cause any unacceptable visual obscuration, passenger discomfort, and toxic effects where people are present.

The finalized handheld MPS was published in August 2002. As of 2003, three halon alternatives, HFC-227ea, HFC-236fa and HCFC Blend B, were commercially available and had successfully completed all of the required handheld UL and MPS tests. These units have different volume and weight characteristics compared to existing halon 1211 extinguishers and the development of new brackets and supports may be required for new airframes and/or retrofit. Qualification and installation certification by airframe manufacturers and regional authorities is needed prior to airline use, however to date this has not happened despite the extinguishers being available since 2003. The change to an alternative suppression agent will also require that a new training programme be developed for flight crew/attendants. Currently, no alternative agents have replaced halon 1211 in handheld fire extinguishers in passenger compartments on current aircraft models or new airframe designs.

5.5 Engine and APU Compartment

Halon 1301 is typically used in engine nacelles and APUs to protect against Class B fires. The requirements of fire suppression systems for engine nacelle and APUs are particularly demanding, since these compartments contain fuels and other volatile fluids in close proximity to high-temperature surfaces. The surrounding environment also typically has complex airflows at low temperature and pressure, making most non-halon agents ineffective.

A finalized MPS for engine nacelle/APU protection is not yet available. Agents included in the testing program are HFC-125, FIC-13I1, and FK-5-1-12. Although alternatives have been implemented in military aircraft, to date, there have been no examples of the replacement of halon 1301 in the engine nacelles or APUs of civil aircraft.

5.6 Cargo Compartments

Cargo compartments are typically located below the passenger compartment and the main deck on freighter aircraft. In the case of a fire, a quick discharge of halon is deployed into the protected space to suppress the fire, which is followed by a discharge that is released slowly to maintain a concentration of halon to prevent re-flame. The slow discharge is maintained until the plane is landed to protect against any reduction in the concentration of halon caused by ventilation or leakage. Cargo compartment fire suppression systems must be able to meet the requirements of four fire tests required in the Cargo Compartment Minimum Performance Standard. The system must be able to suppress a Class A deep-seated fire for at least 30 minutes and a Class A fire inside a cargo container for at least 30 minutes. The system must be able to extinguish Class B fire (Jet-A fuel) within 5 minutes, and prevent the explosion of a hydrocarbon mixture, such as found in aerosol cans. In addition, the system must have sufficient agent/suppression capability to be able to provide continued safe flight and landing from the time a fire warning occurs, which could be in excess of 200 minutes, depending on the aircraft type and route planned.

In April 2003, the current Cargo Compartment MPS was published. In this most recent version of the MPS, the aerosol explosion protocol has been modified to allow the inclusion of a non-gaseous system such as water spray. A "long" and a "short" version of the aerosol can explosion test now exist. Table 5-1 presents the characterization of both of these tests.

Table 5-1 Characterization of "Long" and "Short" Tests of the Aerosol Can Explosion Test

Parameter	"Long" Version	"Short" (Original) Version
Fire Load	0.2 lb propane, 0.6 lb denatured alcohol, 0.2 lb water in simulator, 59 cardboard boxes in cargo bay	0.2 lb propane, 0.6 lb denatured alcohol, 0.2 lb water; Empty standard compartment
Ignition Source	Nichrome wire/paper towel and electrodes	Electrode arc by electrodes 2 ft from floor, 3 ft from simulator
Activation of Suppression System	1 minute after ceiling T reaches 200oF	Discharge agent and allow 2 minutes for dispersion
Aerosol Can Simulator	Activated 5 minutes after T attached to pipes reaches 400oF	Activated when agent, at 2 ft from floor, is at minimum protection concentration
Test Duration	At least 180 minutes or until simulator is activated	At least 180 minutes or until simulator activated

Source: Reinhardt, J., Minimum Performance Standard for Aircraft Cargo Compartment Built-in Fire Suppression Systems, Draft, DOT/FAA/AR-TN02/XX, July 2002.

The shorter version of the aerosol can test is the original procedure developed for gaseous extinguishing agents. Although the Cargo Compartment MPS has been finalized, the adoption of the "long" version of the aerosol can test is viewed by some as a radical departure from the original objective of providing equivalent levels of safety to halons. This issue could delay the replacement of halon 1301 in this application if airframe manufacturers do not accept the final MPS and, therefore, continue to seek a replacement agent that meets the original ("short") version of the exploding aerosol can test.

While the debate over the final MPS has caused some to question whether or not water mist/nitrogen systems require sacrificing extinguishing effectiveness relative to halon 1301, another technical barrier to the introduction of these systems may be their dependence on Onboard Inert Gas Generating Systems (OBIGGS) to produce the required nitrogen. Although OBIGGS technology has been used for decades on military cargo planes, this technology has not been proven for use in cargo compartments in civil aircraft. Research is ongoing to look at the effectiveness of the OBIGGS technology for use on civil aircraft as these systems offer the potential of weight effectiveness equivalent to that of halon 1301.

To date, there have been no cases of halon 1301 replacement with an alternative agent in cargo compartments of civil aircraft, and only a water mist/nitrogen system has been tested to and met the requirements of the current MPS. Other agents, HFC-125, bromotrifluoropropene, and FK-5-1-12, tested against the shorter version of the aerosol can test have proven to be not technically or economically feasible based on testing of these agents below their inerting concentrations. The HTOC is not currently aware of the reasons why this testing was not conducted at the agents' inerting concentrations.

5.7 Estimated Usage and Emissions

A study reviewed data on the number of aircraft produced worldwide by the major airframe manufacturers (including Russian-built aircraft), projected sales, and quantity of halon installed per aircraft for each application in order to estimate the quantity of halon installed in and emitted from mainline and regional passenger and freighter aircraft for each year from 2005 to 2020. Table 5-2 presents a summary of the total number of each type of aircraft in 2005, 2010, 2015, and 2020. The global fleet is projected to grow over 60% in the period 2005 to 2020.

Table 5-2 Estimated (2005) and Projected (to 2020) Number of In-Service Passenger and Freighter Aircraft

	2005	2010	2015	2020
Mainline Passenger Aircraft	14,800	17,900	21,500	24,400
Regional Passenger Aircraft	5,100	5,500	7,000	8,600
Mainline Freighter Aircraft	1,600	1,300	1,600	1,900
Regional Freighter Aircraft	1,000	1,200	1,300	1,400
Total Passenger and Freighter Aircraft	22,500	25,800	31,400	36,300

The quantity of halon 1301 and 1211 installed in and emitted from civil aircraft is expected to increase over the same time period as presented in Table 5-3. The total quantity of halon 1301 installed in civil aircraft is estimated to increase from about 1800 MT in 2005 to over 3200 MT in 2020, or a greater than 80 percent increase. Halon 1211 usage is estimated to increase from more than 170 MT to about 310 MT, also more than an 80 percent increase. It is projected that an increasing quantity of halon 1301 and 1211 will also be emitted into the atmosphere from civil aircraft over the modelling period. Emissions of halon 1301 from civil aircraft are estimated to increase from approximately 35 MT in 2005 to almost 65 MT by 2020. Emissions of halon 1211 are projected to grow from 10 MT to almost 19 MT by 2020.

Table 5-3 Estimated Quantity and Emissions of Halon 1301 and Halon 1211 Associated with Civil Aviation during 2005 to 2020

Year	**2005**	**2010**	**2015**	**2020**
HALON 1301				
Quantity of Halon 1301 Installed in Civil Aviation (MT)	1,800	2,300	2,800	3,200
Quantity of Global Halon 1301 Inventory (MT)	50,000	42,600	36,300	31,700
Percentage of Global Inventory of Halon 1301	*3.6%*	*5.4%*	*7.7%*	*10.1%*
Quantity of Halon 1301 Emitted (MT) per Year	35	45	56	65
Quantity of Global Halon 1301 Emissions (MT) per Year	1,900	1,500	1,100	800
Percentage of Total Halon 1301 Emissions	*1.8%*	*3.0%*	*5.1%*	*8.1%*
HALON 1211				
Quantity of Halon 1211 Installed in Civil Aviation (MT)	170	220	270	310
Quantity of Global Halon 1211 Inventory (MT)	90,400	65,300	47,200	34,200
Percentage of Global Inventory of Halon 1211	*0.2%*	*0.3%*	*0.6%*	*0.9%*
Quantity of Halon 1211 Emitted (MT) per Year	10	13	16	19
Quantity of Global Halon 1211 Emissions (MT) per Year	6,200	4,400	3,100	2,300
Percentage of Total Halon 1211 Emissions	*0.2%*	*0.3%*	*0.5%*	*0.8%*

Table 5-3 also compares the estimated quantities of halon 1301 and 1211 installed in and emitted from civil aircraft to the projected worldwide inventories and emissions of halon 1301 and 1211 (see Chapter 4). In general, the proportion of worldwide inventories and emissions associated with civil aircraft is expected to increase over the time period modelled, even as these inventories are expected to decrease over time with the end of global halon production. Global inventories of halon 1301 and 1211 are projected to decrease by approximately 40 percent and 60 percent, respectively, over the period 2005 to 2020. It is estimated that the percentage of halon 1301 installed in civil aircraft will increase from about four percent to ten percent of the total inventory of halon from 2005 to 2020. As a result of increased use and decreasing halon inventories, emissions of halon 1301 will increase from two percent to eight percent of total halon 1301 emissions from 2005 to 2020. The total quantity of halon 1211 installed in handheld extinguishers on civil aircraft is expected to increase from approximately 0.2 percent to 1 percent of the worldwide halon 1211 inventory from 2005 to 2020. Resulting emissions of halon 1211 are projected to increase from 0.2 percent to approximately one percent of all halon 1211 emissions worldwide.

5.8 Halon Banks

At present, the halon demands of aviation are readily met by recycling agent being withdrawn from applications in other industries. This source of supply will be dramatically reduced long before the aircraft now being built and fitted with halon systems are retired. Civil aviation operators who have not already done so are strongly advised to:

- consider whether the installed stocks of halon they own are sufficient to meet their long-term needs,
- ascertain whether these stocks are being properly managed to ensure they are available for critical needs,
- determine whether it is necessary to procure and store additional agent now, while it is relatively easy to do so, to meet long-term critical demands, and
- continue to implement policies which eliminate or minimise discharge in testing, training and maintenance.

5.9 New Generation Aircraft

New airframe designs should take into account the availability of the alternative fire suppression agents that have been tested and approved by regulatory authorities. In particular, halon alternatives for lavex systems and handheld extinguishers have passed tests based on the relevant minimum performance standards. The civil aviation industry and regulatory authorities should closely monitor and ensure that the testing and approval of alternatives for engine nacelle and cargo compartment applications is also completed in the near-term for new airframe designs. The timing of the inclusion of the available halon alternatives in new aircraft designs remains uncertain, and unless the processes of designing, conforming, qualifying and certifying new extinguishing systems on civil aircraft are made a priority by the airframe manufacturers and approval authorities – and expedited accordingly – these will represent significant barriers to the transition away from halons. The fact that alternatives are used only in the lavatory fire extinguishing systems of new Airbus and Boeing aircraft is a disappointing result given the extensive research and testing efforts that have been expended on aviation applications to date.

5.10 Action Plan

The current understanding of the status of halon supplies indicates that the time available for making the transition to halon alternatives may be much less than many in the civil aviation industry realize. Thus, to avert a situation where aircraft are grounded because halons are unavailable, a plan of action by regulatory authorities is necessary to ensure that the industry can maintain a safe environment for the flying public. To this end, the Parties to the Montreal Protocol have requested that HTOC cooperate with the International Civil Aviation Organization (ICAO) on developing an action plan for the aviation sector. The following course of action has been recommended and agreed to by the HTOC and ICAO:

- HTOC will use its expertise to make a best estimate of the available halon supply, costs, and current emissions rate. These data will be given to ICAO for distribution to its member States;
- ICAO will issue a State Letter to member States in 2006, inviting them to require the use of proven alternatives in new aircraft designs to the extent practicable;
- The ICAO Secretariat will introduce an ICAO/HTOC working paper on the subject of phasing out halons at the 36th Session of the ICAO Assembly in 2007; and
- If the ICAO Assembly endorses the working paper’s recommendation to use halon alternatives in new aircraft designs where practicable, States will then be required to use alternatives for identified applications in new airframe designs first certificated on or after 1 January 2009.

Since alternatives for lavex systems and handheld extinguishers have been tested and met the requirements of the relevant MPS, these can be adopted into new aircraft designs now. The timing of 2009 for ICAO States to use halon alternatives in new aircraft designs is the earliest date that such a requirement can be processed within ICAO’s regulatory process.

As part of this cooperative effort with ICAO, an article covering the issue of the transition away from halons in civil aircraft and incorporating the updated estimates of emissions and use was published in the ICAO Journal, December 2005. A follow-on second article for the ICAO Journal will be developed for planned publication in 2007.

5.11 Conclusions

The status of the transition away from halons in civil aviation reflects progress that has already been made in other sectors of use: minimising emissions of halons from testing and training practices, recycling and recovery of halons, testing of the available alternatives, and changing to alternative methods of fire suppression for ground based situations. However, unlike those other sectors, the civil aircraft sector continues to be dependent on halons, has not demonstrated further progress through the adoption of alternative technologies in new airframe designs, and lacks having an agreed technical design strategy to implement alternative methods of fire suppression. There is an immediate need to produce technical designs to conform with the minimum performance specifications that will in turn enable regulatory authorities to certify the systems to be fitted to new aircraft designs.

The civil aircraft business sector must demonstrate a focused leadership on this transition to deliver new technically certified systems that will meet the necessary regulatory processes and which can be consistently and broadly applied across the industry. Unless and until progress is made in this area, it will represent a significant barrier to the transition away from halons for new aircraft designs. Until supplies of recycled halons become unavailable, or until policy changes push a transition to the alternatives, the situation is unlikely to change in the near-to-mid term.

5.12 References

ICF International, Inc., “Estimated Usage and Emissions of Halon 1301, 1211, 2402 in Civil Aircraft Worldwide (DRAFT),” June 2006.

Marker, T., “Development of a Minimum Performance Standard for Lavatory Trash Receptacle Automatic Fire Extinguishers,” DOT/FAA/AR-96/122, Final Report, February 1997.

Reinhardt, J., “Minimum Performance Standard for Aircraft Cargo Compartment Built-in Fire Suppression Systems,” *International Aircraft Systems Fire Protection Working Group Meeting*, October 30–31, 2002.

Reinhardt, J., “Minimum Performance Standard for Aircraft Cargo Compartment Halon Replacement Fire Suppression Systems,” DOT/FAA/AR-TN03/6, April 2003.

Reinhardt, J., “Water Mist Systems: MPS for Aircraft Cargo Compartment Test Results,” *International Aircraft Systems Fire Protection Working Group Meeting*, Wilson, NC, July 17–18, 2001.

Webster, H., “Development of a Minimum Performance Standard for Hand-held Fire Extinguishers as a Replacement for Halon 1211 on Civilian Transport Category Aircraft,” DOT/FAA/AR-01/37, Final Report, August 2002.

6.0 Merchant Shipping

6.1 Introduction

The status of halons in merchant shipping must be viewed in two different contexts: existing ships already equipped with halons and new ships that are not permitted to employ halons.

At the centre of this halon subject is the International Maritime Organization (IMO) which has been the cohesive force to address the halon status in both contexts. In that regard, IMO has…

- enacted an international ban on the use of halons aboard new ships on international voyages, nearly two years before the halt of production of halons in non-Article 5(1) countries.
- developed and published the approval guidelines and test methods for the systems using halon alternatives on shipboard applications.
- developed recommended procedures for ships with discharged / depleted halon systems to safely move from one port to another where system replenishment is possible.
- established, distributed and has maintained an international listing of halon agent replenishment sources for ships needing a system recharged.

6.2 New Ships

In general, since the 1992 IMO ban on the use of halons on new ships, the industry has found ways to incorporate systems using halon alternatives, both new and old, into the design and construction of new ships. While there have been some difficulties integrating those systems using halon alternatives, as – when compared to halon systems – they take up more space and add more weight to the vessel, the marine industry has found ways to work around these differences. In addition to other well established agents that had been found acceptable for the protection of shipboard machinery spaces, namely carbon dioxide, high expansion foam or water spray, IMO has developed approval guidelines and test methods for three new types of systems for machinery space protection: water mist, other gaseous agents, and aerosol systems. With the development of these guidelines and methods, there have been many halocarbon, inert gas, water mist and aerosol extinguishing systems installed on both new ships and existing ships.

However, a recent survey has illustrated that nine out of ten new ships use carbon dioxide systems for the protection of the machinery space. The reasons for this new popularity are primarily economics – carbon dioxide systems are generally the cheapest – but also to a lesser extent a) historical – the industry traditionally used carbon dioxide prior to the widespread acceptance of halon – b) the worldwide availability of carbon dioxide at major ports, and c) legislative – some countries have banned the use of HFC alternatives for fire fighting. However, systems using the new gaseous alternatives to halon or fine water mist are safer than carbon dioxide in terms of personnel exposure to the agents. Irrespective of the safety devices and measures employed with total flooding carbon dioxide systems, the history of deaths and injuries caused by these systems is ample evidence that their wholesale employment will likely produce higher rates of deaths and injuries than we are currently experiencing. On the basis of the growing life safety concerns, it is likely there will be efforts by some countries to legislate a ban on the use of carbon dioxide total flooding systems in normally occupied spaces – including shipboard machinery spaces.

6.3 Mandatory Halon Decommissioning Regulations

The most visible mandatory decommissioning program at this time is the European Union EC Regulation 2037/2000 which required the removal of all halon systems by December 31, 2003. Anecdotal information suggests that although the actual decommissioning of the halon systems affected by this regulation has not been completed, this decommissioning program is well underway and will lead to halon free merchant ships in the EU fleet within a matter of a few years.

6.4 Existing Ships Equipped With Halon Systems

The existing ships presently equipped with halon systems can be further defined either as those subject to the requirements of a flag state that has a mandatory halon decommissioning program or those not subject to a decommissioning program. For ships that are subject to the decommissioning regulations, it would seem that few options exist other than removing the halon systems and installing an acceptable alternate type fire extinguishing system. See items 3 and 4 below. For ships not subject to mandatory decommissioning regulations, the options are broader but still somewhat problematical as they all involve risks, costs or both. These include:

1) Continue operating with the halon systems, hoping they will not discharge and - if they do - it will happen somewhere where replenishment halon is available.
2) Develop a program within the framework of the maritime industry to establish inventories of recharge halon in key locations around the world, the cost and management of which would be shared by a coalition of ship-owners and other parties with a financial stake in the fire protection of the ships involved.
3) Make a significant investment by removing the halon systems and replacing them with a new halocarbon or inert gas alternative or a water mist system, any of which will certainly be challenging from an engineering standpoint due to space and weight considerations.
4) Incur a slightly lower cost by removing the halon systems and replacing them with carbon dioxide systems, facing the same engineering challenges (weight and space) as with the other systems with the addition of incurring the life safety risks inherent with carbon dioxide.

It appears that most owners are taking a wait and see position (1 above) on this matter. Not necessarily in the order of importance, there are several reasons for making this choice:

- History has shown us that the discharge of a shipboard fire extinguishing system is indeed a rare occurrence, thus making this option in the eyes of many ship-owners a risk worth taking.
- Any of the other three alternatives (2, 3 or 4 above) represents a certain, pre-planned but immediate cost outlay whereas the first option (1 above) represents a low probability but high consequences (cost) scenario.

- While this may change, replenishment halon is readily available worldwide. IMO has published a circular identifying international sources for replenishment halon with the following note on Australia where the world saw its first problems with recharging a marine halon system some years ago:

> "In view of the stock of recycled halon 1301 now held by the Australian National Halon Bank, the supply of halon to a foreign flag ship in an Australian port can be guaranteed on request. Nevertheless, such a supply will be limited to a "one off" provision essential for the safe operation of the ship.
>
> The supply of halon from the Australian National Halon Bank will be subject to approvals from Environmental Australia and the Australian Maritime Safety Authority. The Australian National Halon Bank will acquire these approvals on behalf of the foreign flag ship prior to supply.
>
> The Australian National Halon Bank is committed to ensuring that a supply of recycled halon 1301 over and above that required for Australia's domestic needs will be retained for the purpose of meeting the emergency needs of foreign flag ships."

IMO has developed and published recommended procedures for marine authorities to employ to facilitate the movement of a ship with discharged halon systems to another port where replenishment halon is available. Thus the likelihood of having one's ship tied up for an extended period due to the unavailability of replenishment halon is remote. The complete text of that circular instructs:

1) The Maritime Safety Committee, at its sixty-sixth session (21 May to 5 June 1996), agreed that any ship with a shortage of halon quantities required for the satisfactory operation of its fixed fire-extinguishing system, in ports where halon is not available, should be dealt with under the current established procedures for ships with any major defect or deficiency.
2) The Committee, at its sixty-seventh session (2 to 6 December 1996), having been advised by the Sub-Committee on Fire Protection at its forty-first session, recommended that flag Administrations should, in consultation with the ship's master and owners, and in cooperation with the port State and the authorities of any specified ports of call and the port for rectification of the defect or deficiency, establish a procedure to enable the ship to safely depart the port, call at specified ports for discharge or loading of cargo, and arrive at the port for rectification of the deficiency.
3) Such a procedure should specify the "port and date of departure," the "port of rectification of the deficiency," the "maximum duration of the voyage" and the "ports of call and operations approved en route."
4) Member Governments are advised to consider establishing a procedure along the lines prescribed in paragraphs 2 and 3, when considering invoking flag State equivalent provisions when a ship is found to have a less than fully charged fixed halon fire-extinguishing system for machinery spaces or cargo pump-rooms.

In light of this, the industry appears to have concluded this problem, if not solved, is certainly manageable for the near future.

6.5 Prognosis for Existing Ships Equipped With Halon Systems

It is clear that the world's supply of replenishment (recharge) halon will ultimately shrink to a point that the agent becomes prohibitively expensive or not available at all. This is due both to normal consumption and to the determined efforts of some governments to accelerate the process by mandatory decommissioning of halon systems.

It is also clear that the industry has had many years of experience of equipping both new and – to a lesser degree - existing ships with the systems using various alternatives to halons. The rule making process for accepting new alternatives has been very open, at least to the 166 member Administrations of IMO, as have been the discussions and decisions about dealing with halon shortages when they occur.

For owners who are subject to the decommissioning regulations, the decision has been made for them. They will likely be removing their halon systems and replacing them with acceptable alternatives.

For those owners not bound by decommissioning regulations, some have or will take actions to assure access to a continuing supply of agent to replenish any halon systems that are discharged. Others will pre-plan the conversion of their halon fire extinguishing systems to an alternate type system. Still others will actually make the conversions. All of the owners who take one or more of these actions will be well prepared for the ultimate halon shortage.

6.6 Conclusions

It is important that the marine industry closely monitors the changes in availability of replenishment halon around the world. This is a dynamic situation and it will only be through pre-planning that owners and authorities are going to be prepared for a halon shortage. It is the recommendation of the HTOC that all Parties to the Montreal Protocol and all Members of the International Maritime Organization continually remind the marine industry of the importance of preparing for this inevitability.

6.7 References

International Convention for the Safety of Life at Sea (SOLAS), "Fire extinguishing systems using Halon 1211, 1301 and 2402 and perfluorocarbons shall be prohibited," Regulation 10, Paragraph 4.1.3, Chapter II-2.

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7.0 Halon Usage and Replacement in Military Applications

7.1 Current Uses of Halons in the Military Sector

Prior to the agreement of the Montreal Protocol, the halons found widespread use by military organisations throughout the world, because of their effectiveness against the wide range of fire hazards that existed in military equipment and facilities and on operations.

As in the civilian sectors, the halons were used in defence department offices, military headquarters and command centres, in other buildings such as computer and communications facilities, and at research and equipment test facilities. In non-Article 5(1) countries, the majority of these facility halon systems have now been converted to water sprinkler, HFC, inert gas or carbon dioxide alternatives, though some remain in facilities such as flight or weapon simulators, underground command and control centres and hardened aircraft shelters. In a significant number of cases, improved procedures, changing requirements and alternative fire protection strategies have allowed the removal of the halon systems without their replacement by an in-kind alternative. Nearly all building halon portable extinguishers have now been replaced with conventional alternatives such as dry chemical, foam, carbon dioxide or water extinguishers. In some Article 5(1) countries, several factors, including the relatively higher cost of conversion work and competing demands for scarce resources, have combined to hinder progress in these areas, but there are not considered to be significant technical barriers to the eventual complete conversion of such systems. In countries where the armed forces have yet to make significant progress in halon replacement, priority could usefully be focussed on the remaining building systems, for which the majority of alternative technologies have been optimised.

However, the most important military uses of halon systems and, to a smaller extent, portable extinguishers, have been to protect personnel and the operational capability of front-line weapons platforms (military aircraft and helicopters, naval vessels and armoured fighting vehicles) from fires caused by mechanical or electrical failures or by hostile actions. Some of these hazards, and some of the difficulties that must be overcome in order to replace the halons, are unique to the military sector.

The need for effective fire protection for military personnel and their front-line equipment is universal. However, the hazards involved, and the methods used to counter them, vary with each type of equipment. Where the halons have been used, the choice of halon and the design of the agent delivery system will also vary. Whilst halons 1301 and 1211 are the most common choice, halon 2402 is frequently found in military equipment in eastern European countries and some others where Soviet Union-manufactured equipment is used[2]. The difficulties of finding and implementing acceptable alternatives have proven to be formidable

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[2] Halon 2402 was sometimes blended with ethyl bromide in a 75%/25% mixture with carbon dioxide propellant. The halon 2402 and its blends are no longer being used in new equipment of Russian origin. Some examples of older equipment in Europe and USA may remain in service with halon 1011, 1202 or 2402 and methyl bromide fire protection systems. These are normally replaced with halon 1211 or 1301 upon discharge or during planned system maintenance programmes.

in many cases, and the defence forces of virtually all nations[3] therefore continue to use the halons in many front-line fire protection applications. Although the number and types of different halon applications in front-line equipment vary from nation to nation, some or all of the following Critical Uses may be found in any current combat or peacekeeping force.

> In military armoured fighting vehicles, engine compartments are protected by fixed, total flooding, halon 1301, halon 1211 or halon 2402 systems designed to extinguish any fires caused by the ignition of leaked fuel, lubricant or hydraulic fluids. The crew compartments of some vehicle types are also fitted with halon 1301 or 2402 systems intended to prevent explosions and fires that may be caused by hostile action. These crew compartment systems are designed to discharge the halon in a few tens of milliseconds to prevent or suppress the ignition of any fuel or hydraulic fluid that is vaporised by an incoming round that has penetrated the vehicle. Vehicles may also be equipped with portable halon 1211, 1301 or 2402 extinguishers for crew use on interior or exterior electrical or other equipment fires. There are a few other examples of halon systems in communication and control vehicles or other mobile facilities.
>
> On multi-engine military aircraft, the halons are used to protect the engine nacelles and, on larger aircraft, auxiliary power units, from fires caused by fuel leaks or other engine failures or damage. Many aircraft and helicopters with more than one occupant are also fitted with portable halon 1211 or (to a much lesser extent) 1301 extinguishers. On some transport aircraft, especially those based upon civilian airliners, cargo bays are protected by halon 1301 systems designed to contain any fire for up to several hours. As in the civilian sector, aircraft lavatories may have small fixed systems to extinguish fires in waste receptacles. On a few aircraft and helicopters designed for missions facing a high probability of attack by opposing forces, dry bays (the compartments surrounding fuel tanks) are protected by rapid response automatic explosion suppression halon 1301 systems. These are intended to suppress any explosion caused by the ignition of fuel ejected from a fuel tank by an incoming round. On a couple of US-designed aircraft types, halon 1301 systems are installed to prevent explosions from whatever cause by the pre-emptive inerting of the empty space (ullage) in their fuel tanks. These latter are emissive systems where the halon cannot be recovered once the systems are active. However normal policy in the countries that use the aircraft is that the systems are activated by the pilot only prior to combat operations. On airfields, some forces continue to use halon 1211 in portable extinguishers in flight line applications and on crash rescue vehicles.
>
> Naval vessels, whether surface ship or submarine, and auxiliary (support) vessels, have a number of fixed halon systems designed to extinguish fires caused by equipment faults or hostile action. These systems protect engine rooms, main and auxiliary machinery spaces, gas turbine and diesel engine enclosures, fuel pump rooms and flammable liquid storerooms primarily from flammable liquid fires. On some vessels, operations rooms, command centres and compartments containing electrical equipment also have dedicated halon systems. Some aircraft carriers and smaller vessels carrying

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[3] Several European Union Member States with relatively small armed or civilian defence forces have reported that halons are no longer used. This may also apply in other nations with small standing armed forces.

aircraft or helicopters also have available for their crew halon 1211 units or portable extinguishers to fight fires on flight decks and in hangar bays (flight line extinguishers). The machinery space systems on larger warships and auxiliary vessels can be amongst the largest of all military halon systems, in some cases containing installed charges of several tonnes.

7.2 Alternative Fire Extinguishants and Fire Protection Methods

The military organisations of many Parties to the Montreal Protocol have committed themselves to reducing and eventually eliminating the use of the halons in military equipment and facilities, wherever this is technically and economically feasible. These efforts have included:

> The design of new weapons platforms such that halon systems are no longer required;
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> The removal of halon systems where an active fire suppression system is no longer considered necessary;
>
> The replacement of the halons in existing equipment with alternative means of fire protection; and
>
> The introduction of policies, measures and procedures to reduce halon emissions from the maintenance, testing and support of applications that remain in service.

The military community in many non-Article 5(1) countries has devoted considerable effort and resources towards the assessment and implementation of alternative extinguishants and fire protection technologies.

The task is often complex and challenging. Effective fire protection in front-line military equipment is essential to protect personnel and to maintain and enhance the operational capability and survivability of the weapons platform. In all cases, front-line equipment is characterised by use that demands performance at the limits of capability, in potentially extreme or hostile environments. A variety of fuels and potential explosives will likely be present in a compact design where weight and space are critical. Ensuring the safety of personnel who occupy this equipment is particularly challenging. Maintaining continuity of operations is paramount, especially under combat conditions, and the evacuation of personnel from equipment that is on fire is often not possible or desirable.

7.2.1 New Designs of Equipment

The long lead-times in military equipment development and procurement programmes mean that some equipment, being built to an established design, is still being procured with halon systems on board. This is especially true for aircraft. However, extensive research and development work and laboratory-scale to full-scale performance testing have all but eliminated the need for the halons in new designs of military equipment.

In a few cases, such as the UK variant of the Typhoon aircraft, weapons platforms are being developed and introduced with enhanced passive fire protection and fire control features such that an active fire suppression system is no longer considered to be necessary. Elsewhere, acceptable solutions for new equipment include traditional extinguishants such as foams, dry chemical powders and carbon dioxide, the newer halocarbon alternatives, and new technologies such as water mist/fine water spray, fine particulate aerosols and inert gas generators. Specific examples that have been, or are being, implemented include:

> In armoured fighting vehicles, HFC-125, HFC-227ea, an inert gas (nitrogen) or dry chemical powder are being used for the engine compartments of: Challenger 2, Warrior and other vehicles being manufactured in the UK; Leopard 2 vehicles in Germany; and Expeditionary Fighting Vehicles (EFV, formerly AAAV), Stryker Armoured Vehicles, Bradley Fighting Vehicles, Marine Corps Light Armoured Vehicles (LAV), Multiple Launch Rocket System (MRLS) and assorted other vehicles in the US. A hybrid HFC-227ea/dry chemical system has been introduced for crew compartment explosion suppression on the Stryker, EFV and LAV. The US Army has adopted carbon dioxide extinguishers to replace the halon 1301 portables installed in all its vehicles except the M1 Abrams Main Battle Tank, where a water/potassium acetate extinguisher is now being fitted.
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> In military aircraft, HFC-125 protects the engine nacelles of the Nimrod maritime patrol aircraft in the UK. In the US, the F/A-18E/F Super Hornet, the F-22 Raptor fighter, the V-22 Osprey tilt-rotor aircraft, and the UH-1Y and AH-1Z upgraded helicopters also employ HFC-125 to protect their engine nacelles. Pyrotechnic inert gas generators now protect dry bays on the V-22 and the F/A-18E/F. Further, onboard inert gas generating systems or explosion suppression foams are being used for the inerting of fuel tank ullage spaces in the V-22 and F/A-18E/F, and they are also expected to be used on the newest DoD aircraft design, the F/A-35 Lightning II Joint Strike Fighter.
>
> In naval vessels, HFC-227ea, fine water spray, hybrid HFC-227ea/water spray, foam or carbon dioxide systems are being used for the main machinery and other spaces of new EU and US vessels.

In many cases, particularly where the scope for fundamental changes in equipment design has so far been limited, the acceptance of these alternatives has not been without some trade-off. This can include a weight or space (and hence platform performance) penalty, a reduced level of fire extinguishant performance, or an additional toxicity hazard that must be managed. If foams or powders have been selected, there are implications for the decontamination of protected areas and the return of equipment to service after a system has been discharged. In all cases, operational and maintenance procedures and associated documentation must be changed and personnel suitably trained.

There is an increasing tendency, especially in non-Article 5(1) countries, for the procurement of commercial, off-the-shelf, equipment, or variants of such equipment, for military use. There are a number of apparent benefits to doing this, which include lower development and procurement costs, quicker delivery of the equipment and access to a larger and better equipped supporting infrastructure. These designs in large part use commercial or civil standards where specific military standards applied previously. The approach is particularly noticeable in the procurement of military (non-armoured) vehicles, auxiliary vessels, and transport aircraft and helicopters. In these areas, civilian standards and regulations relating to halon use and replacement may be adopted or specified by the contractor, which might be problematic where defence requirements are more demanding. The implications of this approach for fire protection and safety must be considered very carefully and civilian standards may need to be adapted to ensure adequate safety and performance in combat conditions.

Multilateral procurement collaborations are now commonplace. Each collaborating nation will likely have different performance objectives and requirements, and the choice of fire protection systems is not normally high on the list of priorities to be addressed.

A third procurement option that is finding favour in some countries, primarily for support services such as training, is for the armed services to procure an agreed level of service rather than a particular number of pieces of equipment. The provider of the service procures and maintains the necessary equipment, which can sometimes be used for other purposes when not required for the primary military task.

The consequence of these procurement trends is often for a new design to incorporate the “easiest” fire protection solution. For aircraft especially, the easiest solution continues to be the halons. An example of a current project that has followed the “commercial standards” route is the procurement of the new A400M transport aircraft by a number of Member States of the European Union. For this project, halon systems have recently been specified for a new airframe design. Additional examples include the US Joint Cargo Aircraft and Light Utility Helicopter.

Any selection of a halon in new military equipment or facilities should and can be avoided by a clear policy commitment and up-front investment in alternatives. The additional cost of doing this should be balanced against the need for an assured supply of the halon in the long term, and the potential need for conversion or retrofit before the end of the equipment’s service life should halon supplies become threatened or regulations on continued use be implemented. Those responsible for procuring equipment, whether from manufacturers in their own country or elsewhere, should stipulate that the equipment is halon-free to avoid longer-term liabilities.

7.2.2 Existing, In-service Equipment

Conversion of halon systems in existing military equipment is almost always more difficult than accommodating alternative fire protection solutions in new weapons platforms. This is primarily because the scope for any post-construction alterations to the platform is more limited, and because the conversion programmes must be accommodated without adversely affecting the operational availability of the equipment. Not infrequently, the original design of the weapons platform was predicated on the use of halon and its high level of effectiveness. In some cases, it is not technically feasible to replace the halons with any of the current range of alternatives whilst retaining an acceptable level of safety, fire protection, or platform performance. Even where it might be technically feasible, the complexity and interdependence of equipment components will mean that conversion costs can be very high.

The extent to which conversion programmes for existing equipment have been started or completed varies from country to country. Important factors are the unique characteristics of each nation's forces, the wide range in the technical difficulty of possible solutions, the strength of political will to finance the conversion programmes when there are always competing priorities, and the prevailing legislative position. In some cases, in Europe and Australia for example, legislation has driven changes to certain halon systems that would not be considered acceptable to military organisations elsewhere.

The technical and economic constraints on conversion of existing front-line equipment can be formidable. The alternatives identified as suitable for new equipment may not be technically and economically feasible for use in existing equipment. The properties of the commercially available alternatives may include an inferior intrinsic performance (as measured by the cup-burner test, for example), toxicity or other potential hazards to personnel, and potential adverse environmental impacts. Whilst the disadvantages presented by the alternatives may be overcome or managed by the careful design of new equipment to ensure that the fire protection *system* is effective and safe, there is more limited opportunity within the constraints of existing equipment.

The toxicity of halon alternatives is especially important to the military sector because there is a significant risk that personnel will be exposed to extinguishing concentrations of the agents or high levels of their breakdown products in operational situations. On the latter point, the type and level of halocarbon agent acid-gas decomposition products and their effect on compartment recoverability, equipment, and the associated risks to personnel, are key considerations that must be addressed carefully. For these reasons, conversion of halon systems that protect normally-occupied spaces is significantly more challenging than those protecting normally unoccupied spaces such as engine compartments.

The feasibility of conversion of in-service systems will depend significantly on whether the work can be accomplished during routine maintenance periods or whether a separate programme, entailing the withdrawal of equipment from service, is necessary. If conversion requires major modifications to a protected enclosure, the work will probably be technically and economically feasible only at times of major equipment refit or upgrade, such as mid-life updates. Deployment of equipment and associated maintenance, refit and upgrade schedules are often planned many years ahead and cannot readily be changed, even in peacetime. Thus, even if it is technically feasible to convert a particular type of equipment, it may not be economically justifiable, or practically acceptable, in the short term. Conversion programmes can therefore often be lengthy and any unforeseen operational commitments will potentially delay their completion.

Despite all these difficulties, good progress has been made in some areas and by some countries, especially in applications protecting normally unoccupied spaces:

> The use of halons in protecting the engine compartments of existing armoured fighting vehicles is diminishing as many nations implement conversion programmes. The UK identified HFC-227ea and a dry chemical as the preferred alternative extinguishants and is nearing the completion of a fleet-wide conversion programme scheduled for the end of 2006. The US Army has converted its Bradley and MLRS (Multiple Launch

Rocket System) vehicle engine systems to HFC-227ea. A potassium carbonate system has been selected for the Abrams vehicles, which are being converted during scheduled maintenance programmes. The engine compartments of Germany’s Leopard armoured fighting vehicles are now protected by an inert gas and the armed forces of Denmark and the Netherlands are adopting the same solution. Sweden, in collaboration with a number of countries, is evaluating HFC-236fa for both crew and engine compartments in its variants of the Leopard and Canada is evaluating HFC-125 for the engine compartment of its vehicles. The armies of the US, the Netherlands and Australia have replaced most of their vehicle portable extinguishers with carbon dioxide. The UK has replaced portable extinguishers mounted on the outside of its vehicles with dry chemical alternatives but retains halon 1211 portable extinguishers for the crew compartment interiors. A manually-operated fixed system on the US Marine Corps LAV has been replaced with an automatic HFC-227ea/sodium bicarbonate system. Retrofit of crew-compartment automatic fixed explosion suppression systems has so far proved prohibitively costly.

On existing naval vessels, a number of conversion programmes are being considered or are underway for the smaller, normally unoccupied, spaces such as engine rooms or diesel or turbine modules. In these applications, carbon dioxide or HFC extinguishants have been found acceptable. The US Army has converted machinery spaces in over 60 of its watercraft to use an HFC-227ea/water spray hybrid system. Australia and Germany began conversion programmes to replace main machinery space halon systems with HFC-227ea and carbon dioxide respectively. However, in both cases, difficulties were experienced with ensuring adequate fire extinguishing performance without adverse consequences for platform capability and crew safety and the design process for further conversions is on-going. In Denmark, where HFCs are not acceptable as fire extinguishants because of national halocarbon legislation, nitrogen systems are being installed to protect the engine compartments of surface ships.

The opportunity for conversion of existing aircraft halon systems, whether military or civilian, remains very limited, though a number of studies are underway and considerable investment in potential alternatives continues. In some circumstances, slight changes to a fire protection system design can result in significant improvement in the performance of an extinguishant, such that a less effective agent (as measured by the cup-burner test) might be acceptable with little or no weight penalty. Several aircraft engine nacelle conversions are being evaluated in the US and UK. In the lavatory waste receptacle application, current halon systems have been found to be an over-engineered solution; an HFC alternative probably represents one of the very few examples of a potential “drop-in” solution. However, no such conversions have yet taken place on military aircraft. An opportunity for modification of these systems would certainly present itself when the halon systems were discharged. Similarly, HFC-based and HCFC-based portable extinguishers that meet civilian minimum performance standards are now available. A number of countries are evaluating, or have evaluated, the available extinguishers for suitability but, again, there have been no actual installations on military aircraft[4]. The best time to consider any conversion programme would be during periods of major equipment upgrade or modification.

The US Army and many European MODs have replaced halon 1211 wheeled extinguishers on their flight lines with carbon dioxide, dry chemical, or aqueous film-forming foam (AFFF) units. However, these are not considered to be acceptable by some military authorities because of concerns about compatibility with jet fighter aircraft engine designs.

Table 7-1 summarises where halons are still being used in military applications. It also lists the alternatives that have been implemented in various nations for the conversion of existing equipment and facilities, and in new designs or major modifications of equipment and facilities.

Generally, with the exception of the examples described above, very significant technical, economic and logistical barriers to conversion remain. To maintain Parties' levels of national security, and the safety of military personnel, halon systems may need to continue in service for the remainder of the operational life of the equipment concerned. In some circumstances this could be until the mid-21st Century.

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[4] CO_2 has been adopted as a short term replacement for halon 1301 portable extinguishers on some US aircraft. However these have presented some difficulties during their service life and a programme has been proposed to evaluate and qualify other available alternatives for DOD use as a longer term solution.

Table 7-1 Continuing Uses of Halons and Examples of Implemented Alternatives in the Military Sector

Application	Protected Space	Primary Protected Risk	Halon	Implemented Alternatives	
				In Conversions of Existing Equipment	In New Designs and Major Modifications of Equipment
Military (Armoured Fighting) Vehicle	Engine Compartment	Class B	1301 1211 2402	HFC-227ea Dry Chemical Inert Gas	HFC-227ea HFC-125 Dry Chemical
	Crew Compartment	Class B (explosion)	1301 2402	None	HFC-227ea+Dry Chemical (hybrid system)
	Portable Extinguisher	Class A, B, electrical	1211 1301 2402	CO_2 Dry Chemical Water/Potassium Acetate	CO_2 Dry Chemical Water/Potassium Acetate
Military Aircraft	Engine Nacelle	Class B	1301 1211 2402	None	HFC-125
	APU	Class B	1301 1211 2402	None	HFC-125
	Dry Bay	Class B (explosion)	1301 2402	None	IGG
	Cargo Bay	Class A (deep-seated)	1301	None	None
	Fuel Tank Inerting	Class B	1301	None	OBIGGS Fire Suppression Foam[5]
	Cabin portable extinguisher	Class A, B, electrical	1211 1301	None[6]	None
	Lavatory (waste bin)	Class A	1301	None	None
Naval Vessel (Surface Ship)	Main Machinery Space (normally occupied)	Class B	1301 2402	HFC-227ea CO_2 HFC-227ea/Water Spray	HFC-227ea CO_2 HFC-227ea/Water Spray Water Mist Foam
	Engine space/Module (normally unoccupied)	Class B	1301 1211	HFC-227ea CO_2 Dry Chemical	HFC-227ea CO_2 PGA
	Flammable Liquid Storeroom	Class B	1301 2402	Dry Chemical	HFC-227ea HFC-227ea/Water Spray
	Electrical Compartment	Class A, Electrical	1301 2402	Inert Gas	HFC-227ea Inert Gas
	Fuel Pump Room	Class B	1301	None	Foam HFC-227ea
	Command Centre	Class A, Electrical	1301 2402	None	None
	Flight Line/Hangar	Class B	1211 2402	Foam	Foam
Naval Vessel (Submarine)	Machinery Space	Class B	1301 2402	None	Foam Water Mist
	Diesel Generator Space	Class B	1301 2402	None	Foam Water Mist
	Electrical Compartment	Class A, Electrical	1301 2402	None	None
	Command Centre	Class A, Electrical	1301	None	None

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[5] The fuel tanks are filled with an open-cell polymer foam that prevents flame propagation.

[6] CO_2 has replaced halon 1301 portables in several US aircraft types, for both existing and new designs.

Application	Protected Space	Primary Protected Risk	Halon	Implemented Alternatives	
				In Conversions of Existing Equipment	In New Designs and Major Modifications of Equipment
Military Facilities (Buildings)	Command Centre	Class A, Electrical	1301	HFC-227ea CO_2	Water Sprinkler CO_2 Inert Gas HFC-227ea
	Research Facility	Class A, B, electrical	1301	Water Sprinkler CO_2 Inert Gas HFC-227ea	Water Sprinkler CO_2 Inert Gas HFC-227ea
	Computer Centre	Class A	1301 1211	Water Sprinkler CO_2 Inert Gas HFC-227ea	Water Sprinkler CO_2 Inert Gas HFC-227ea
Military Airfield	Hardened Aircraft Shelter	Class B	1301	Foam	Foam
	Crash Rescue Vehicle	Class B	1211	Dry Chemical Foam	Dry Chemical Foam
	Flight Line (Portable) Extinguisher	Class B	1211	CO_2 Dry Chemical Foam HCFC Blend B	Dry Chemical Foam HCFC Blend B

7.3 Responsible Management – Assurance of Supplies and Minimisation of Halon Use and Emissions

For the applications where an acceptable alternative for in-service equipment has not yet been implemented, operational and maintenance procedures and training can and have been improved to minimise emissions to atmosphere and to conserve the limited supplies of recycled and recyclable materials that are available.

In non-Article 5(1) countries, discharge testing to certify systems as fit for use has been virtually eliminated – acceptable alternative methods of testing are now routinely available. Training procedures for military fire-fighters no longer stipulate use of halons. Recovery equipment and procedures have been introduced to minimise losses during maintenance procedures. Analysis of discharge patterns and a requirement to report reasons for non-fire discharges has been used to identify “weak points” on equipment, such as connections, valves, switches, or bad practice in the field. These weaknesses can then be addressed.

Changes such as these have had a significant impact on usage and emissions. Thus emissions from most non-Article 5(1) country military uses are now small relative to the size of the installed base. In countries where these measures have not yet been implemented, they represent a relatively simple, very cost-effective, means to reduce usage and emissions.

Supplies of halons available from converted and decommissioned systems and extinguishers, both from within military organisations and from the open market, have been banked by many non-Article 5(1) countries to support their critical military uses for which alternatives are not available or have not yet been implemented. This approach has helped, so far, to ensure adequate availability of stocks and also facilitates good management and effective control of usage. The reliance of defence departments on access to stocks of the halons will probably continue for at least the next thirty years to support some equipment which has a long anticipated service life. Of course, the quantities and range of equipment involved in the longer term will steadily reduce in magnitude. Military users must continually review their stocks and usage rates to ensure that they have adequate supplies for as long as they expect to need them.

In Article 5(1) countries, supplies of the halons can be obtained from sources of new production until 2010. These are very limited in number, so most defence departments would need to buy such supplies from overseas. However, in some Article 5(1) countries, where a halon management programme is funded by the UN GEF/Multilateral Fund, production or importation of new supplies of halon is not permitted. Importation of recycled halons is allowed. Alternatively, regional storage and recycling facilities, established with UN (GEF) funds, may be suitable, and more convenient, longer term, sources.

7.4 Military-sponsored Research Into Novel Halon Alternatives

Because of the need for additional solutions to enable the conversion of in-service Critical Uses where current alternatives are not feasible, military organisations continue to sponsor short, medium and longer-term studies of novel fire extinguishants.

One example is the US Department of Defense’s Next Generation Fire Suppression Technology Programme (NGP). This programme has delivered an increased understanding of flame suppression processes and chemistry and evaluations of novel fire suppressants and agent delivery techniques. Originally envisaged as developing and demonstrating feasible, retrofitable, fire protection solutions to replace halon 1301 in aircraft, ships, land combat vehicles and support facilities by 2005, its scope narrowed to concentrate on fire protection technologies for both new and existing aircraft. The current status of the programme and a summary of its outputs so far can be viewed on the NGP website at:

http://www.bfrl.nist.gov/866/NGP.

The programme will conclude this year and a final report is being prepared.

The Advanced Agent Working Group (AAWG), a US/UK industry and government collaboration, aimed to find and characterise a total-flooding alternative to halon 1301 for use with existing halon system hardware. This work focussed primarily on bromine-containing tropodegradable[7] halocarbons which laboratory testing showed are effective extinguishants with minimal ozone depletion and global warming potentials. The UK Ministry of Defence funded participation in the AAWG by QinetiQ with a study of phosphorus-containing compounds. However, the chemicals’ high toxicities and high boiling points have led to the completion of this work without a promising candidate agent. The AAWG program is now complete, and culminated in the characterisation of bromotrifluoropropene (BTP) as a potential total flooding agent for non-occupied areas, or streaming agent for applications such

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[7] The substances degrade rapidly in the lower atmosphere or troposphere. Consequently, the substances do not survive long enough to reach the stratospheric ozone layer under normal weather conditions and their ODPs are therefore very small.

as aircraft portable extinguishers or military flight line wheeled units. This has not yet been put into commercial production and further development work will be necessary by those with specific applications in mind before it could be marketed.

Military organisations are also working closely with airframe manufacturers and regulatory authorities to identify and certify halon alternatives for many of the military aircraft applications. Much of this collaboration builds upon earlier work on halon alternatives for military aircraft engine nacelles that were undertaken by the US DOD from 1992 to 1997.

In 2006, the US Navy and Air Force launched a joint program to replace halon 1211 flight line units. The testing will evaluate spilled fuel fires, hidden fires, and running fuel fires. The objective of the program is to find a suitable existing agent, or one that will require little research and development to commercialise. The selection of a replacement agent is anticipated by the end of 2007.

The UK MOD has investigated the feasibility of using pyrotechnically generated aerosols (PGA) for fire protection of naval vessel main machinery spaces, high voltage electrical spaces and engine enclosures. Real scale tests have given a much better understanding of the design and performance criteria for these systems. However, due to engineering issues associated with the implementation of such systems, the project concluded that the technology was not yet sufficiently developed for implementation on UK naval vessels. Further development of the technology awaits manufacturers' solutions to these issues.

The effort and resources being devoted to fundamental research aimed at identifying novel halon alternatives are now reducing appreciably. The most promising substances and technologies have largely been identified and evaluated, with generally disappointing results. There is no "universal solution" on the horizon but a considerable amount of knowledge has been gained. Research effort is being refocused on improving the performance and characteristics of the options that have already been identified and evaluating the performance of the most promising options in specific applications and platforms.

7.5 Summary

The military sector has shown leadership in, and devoted considerable effort to, the identification, development, testing and implementation of suitable halon alternatives, with considerable benefit transferring to the civilian and commercial sectors. As a result of this effort, much progress has been made with many equipment procurement projects proceeding with alternative fire extinguishants and fire protection technologies. No new facilities or new designs of military equipment now require the use of the halons. The conversion of systems in existing, in-service equipment is more challenging, but conversion programmes are underway or completed for many important applications. In other cases, especially relating to the conversion of existing systems that protect normally occupied spaces in naval vessels and military vehicles, and for most military aircraft applications, very significant technical, economic and logistical barriers to conversion remain for retrofit. To maintain Parties' levels of national security, and the safety of military personnel, halon systems may need to continue in service for the remainder of the operational life of the equipment concerned, likely until the middle of the century in many cases. Halon use by the sector is well managed. Many organisations have established dedicated halon storage and recycling facilities to support Critical Use equipment for as long as is necessary. The demand on such facilities will reduce in future years as equipment that uses halons is replaced or converted.

8.0 Inertion/Explosion Suppression

8.1 Pipelines/Oil and Gas Industry

The use of halon 1301 systems in this industry for explosion prevention (inertion) has been focused on inhospitable locations such as the Alaskan North Slope in the United States and the North Sea in Europe where facilities have had to be enclosed due to the harsh climatic conditions. The process areas in the production modules and the pumping stations live under constant threat of methane gas and crude oil leaks that can lead to potential explosive atmospheres. Halon 1301 has been the agent of choice for mitigating this threat. When reviewing protection measures brought about by the phase out of halon, there are two distinct cases to consider, existing facilities and new facilities. Halon supplies are only a consideration for existing facilities, as new facilities are not being designed to use halon.

8.1.1 Existing Facilities

In most cases, existing facilities were designed and constructed with halon 1301 fixed systems as an integral part of the safety system design as well as the physical layout of the facility. After extensive research, it has been determined that the replacement of such systems with currently available alternatives is economically impossible, and that current research is unlikely to lead to an economic solution. Thus the approach to the phase out of halon has been one of reducing emissions through either of two methodologies, which can be summarized as follows:

1) Reassess the hazards and evaluate whether an inerting system is still required.
   In some aging offshore platforms, process pressures have declined such that an accidental gas or crude oil release could not result in an explosive cloud. In others, advantage can be taken of the high winds that prevail in the area to assist in the exhausting of any gas accumulation from a hydrocarbon release. In both cases, the result may be a fire hazard but not an explosion hazard and so the original fixed halon system can often be replaced with an alternative fire suppression system.

2) Contain the halon and avoid spurious releases.
   Typically, if an inerting system has been required then it is also used for fire suppression in the same facility. Thus, in looking at methods to avoid spurious emissions, focus has been on upgrading both fire and gas detection systems. For fire detection, Triple Infrared detectors or, more recently, Close Circuit Television (CCTV) flame detectors, have been employed because of their reliability in response to fire and also their ability to tune out non-fire conditions. In particular, CCTV flame detectors can be programmed with a range of algorithms to determine whether the changes within its field of view are a fire or not. Such systems are immune to common false alarms such as hot CO_2 emissions, reflections from flare radiation, black body radiation, and hot work such as welding. An added benefit is that an operator can see the hazard in real time and can intervene and prevent a halon discharge if the situation warrants it. For flammable gas detection, open path gas detectors use the latest infrared laser beam technology. These devices produce an infrared beam that is directed across the area to be monitored. The received light is analysed at two or more frequencies, some of which

is absorbed by the target gas or gases; the reference frequency is not. Given the initial and final intensities, the average concentration of gas in the path is calculated and transmitted to the control panel. Different path length options are available, from short-range (about two feet) versions for monitoring ventilation ducts, up to instruments capable of traversing 300 feet or more. Such devices are simple to maintain and are immune to the common problems that affect catalytic bead detectors.

8.1.2 New Facilities

For new facilities, companies are now adopting an inherently safe design approach to facility protection. The basis behind this is the identification of the hazards associated with the process and the elimination (if possible) or reduction of the risk associated with them to a level which is as low as practicable.

The primary tool of inherent safe design is the avoidance of hazards to the extent possible. This means preventing the release of hydrocarbons (loss of containment), eliminating the availability of flammable or explosive materials, and minimising electrical and instrument cables. Only when all such measures have been considered, and a residual risk of the hazard still remains, are other risk reducing measures considered. These include those which control incidents, e.g., limit the extent and duration of a hazardous event, and those that mitigate the effects, e.g., active explosion prevention (inerting). In most cases, the new technology detection systems described above are employed to shutdown and blow-down processes, and turn on high rate ventilation systems rather than closing up the space and trying to inert it with an extinguishing agent. Advantage is also being taken of new materials that can withstand the affects of harsh climatic conditions and allow the construction of open facilities to avoid the accumulation of potentially explosive gases. Where an inerting agent is still required in occupied spaces, halon 1301 has been replaced by HFC-23 as part of the facility protection design. FK-5-1-12 is also being looked at for this application.

8.2 Commercial/Industrial Explosion Protection

Outside of the oil and gas industry, halon has been used to suppress explosions in applications such as aerosol fill rooms, grain silos, paper production and milk powder processing plants. Halons are no longer necessary to meet explosion protection requirements in industrial applications and are not sold into new explosion suppression systems. Legacy explosion suppression units originally containing halons remain in service.

8.2.1 Aerosol Fill Rooms

In the past, halon 1301 was the standard suppression agent used in North America, whereas aqueous systems were employed in Europe. Since approximately 1996, the standard agent for new systems in North America has been water. Retrofit activity from halon 1301 to water in North America has occurred but only to a limited extent, and significant conversion is not likely in the absence of a regulatory mandate.

8.2.2 Industrial Sector

In North America, although halon 1011 systems were used in the past, dry chemical is now used for 95% of explosion suppression applications. The balance of applications is served with water or an aqueous salt solution. A significant fraction of older halon 1011 systems have been changed over to dry chemical. In the United States, decommissioning is not required, but halon 1011 systems cannot be recharged.

In Europe the default suppressant for industrial explosion protection has been dry chemical since the mid eighties, prior to the ozone depleting substances issue, and therefore halon systems were the exception. Most European customers that had legacy halon systems were contacted and advised that these systems are no longer supported - in most cases this has resulted in system replacement with powder or water suppressants.

8.2.3 Agricultural Sector

One manufacturer supplied halon 1301 systems designed specifically for protection of bucket elevators in grain silo applications until about 1997. The product was subsequently redesigned to employ HFC-125. The use of a gaseous agent having a low boiling point is important owing to the fact that the application requires agent penetration into obstructed spaces often at very low ambient temperatures. Owners of systems using halon 1301 have been slow to retrofit serviceable units with alternative products. The result is that many of the original halon 1301 suppression units remain in service.

9.0 Destruction

9.1 Introduction

Since the end of halon production in 1994 in non-Article 5(1) countries, many Parties have allowed recycled halons to maintain and service existing equipment. This has allowed users to retain their initial equipment investment, allowed halons to retain a comparably higher market value to other ODSs, and has resulted in very little halon being destroyed compared to other ODSs. As remaining halon production is scheduled for phase out in Article 5(1) countries by 2010, global inventory management and responsible disposal practices become important considerations to prevent emissions during a critical period of ozone layer recovery. The options for avoided emissions of surplus stockpiles of halons include destruction and transformation, also referred to as conversion, to useful chemical products. This chapter considers the issues related to these final options for halon disposal.

9.2 Destruction Technologies

9.2.1 UNEP Task Force for Destruction Technologies (TFDT) Criteria for Technology Screening

The following screening criteria were developed by the UNEP TFDT in their 2002 report. Technologies for use by Parties to the Protocol to dispose of surplus inventories of ODS were assessed on the basis of:

1) Destruction and Removal Efficiency (DRE)[8]
2) Emissions of dioxins/furans
3) Emissions of other pollutants (acid gases, particulate matter, and carbon monoxide)
4) Technical capability

The technical performance criteria are summarized in Table 9-1. These represent the minimum destruction and removal efficiencies and maximum emission of pollutants to the atmosphere permitted by technologies that qualify for consideration by the TFDT in their recommendation to the Parties for approval as ODS destruction technologies.

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[8] Two commonly used but different ways of measuring the extent of destruction are Destruction Efficiency (DE) and Destruction and Removal Efficiency (DRE).
DE is determined by subtracting from the mass of a chemical fed into a destruction system during a specific period of time the mass of that chemical that is released in stack gases, fly ash, scrubber water, bottom ash, and any other system residues and expressing that difference as a percentage of the mass of the chemical fed into the system.
DRE has traditionally been determined by subtracting from the mass of a chemical fed into a destruction system during a specified period of time the mass of that chemical alone that is released in stack gases, and expressing that difference as a percentage of the mass of that chemical fed into the system.
DE is a more comprehensive measure of destruction than DRE since it considers the amount of targeted chemical that escapes destruction by being removed from the process in the stack gases and in all other residue streams. Most references citing performance of ODS destruction processes only provide data for stack emissions and thus, generally, data is only available for DRE and not DE.

Table 9-1 Summary of Technical Performance Qualifications[9]

Performance Qualification	Units	Concentrated Sources (CFCs, HCFCs, and halons)
DRE	%	99.99
PCDDs/PCDFs[10]	mg-ITEQ*/Nm^3 **	0.2
HCl/Cl$_2$	mg/Nm^3	100
HF	mg/Nm^3	5
HBr/Br$_2$	mg/Nm^3	5
Particulates (TSP)[11]	mg/Nm^3	50
CO	mg/Nm^3	100

* ITEQ – international toxic equivalency
** Normal cubic metre

As well as meeting the above performance criteria, the destruction technologies had to demonstrate technical capability meaning that the technology achieved the required DRE while satisfying the emissions criteria. Demonstration of destruction of ODS is preferred but not necessarily required. Destruction of halogenated compounds that are refractory, i.e., resistant to destruction, is acceptable. For example, demonstrated destruction of polychlorinated byphenyls (PCBs) was often accepted as an adequate surrogate for demonstrated ODS destruction.

The TFDT developed the following minimum criteria for an ODS destruction technology to be considered technically capable:

- It has been demonstrated to have destroyed ODS to the technical performance standards, on at least a pilot scale or demonstration scale
- It has been demonstrated to have destroyed a refractory chlorinated organic compound other than an ODS, to the technical performance standards, on at least a pilot scale or demonstration scale
- The processing capacity of an acceptable pilot plant or demonstration plant must be no less than 1.0 kg/hr of the substance to be destroyed, whether ODS or suitable surrogate.

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[9] All concentrations of pollutants in stack gases and stack gas flow rates are expressed on the basis of dry gas at normal conditions of 0°C and 101.3 kPa, and with the stack gas corrected to 11% O_2.

[10] Polychlorinated Dibenzodioxins (PCDDs), commonly referred to as dioxins, and Polychlorinated Dibenzofurans (PCDFs), commonly referred to as furans, are produced from the combustion of chlorinated ODS including CFCs, HCFCs, and halons. These products of incomplete combustion (PICs) are of greatest concern for potentially adverse effects on public health and the environment. The recognized measure of their toxicity is the international toxic equivalency factor (ITEQ), which is a weighted measure of the toxicity for all members of the families of these toxic compounds that are determined to be present. The internationally accepted protocol for determining ITEQ was established by NATO in 1988.

[11] TSP – total suspended particles

9.2.2 TFDT Recommended Technologies for Destruction of Halons

Of the 45 technologies evaluated, 16 passed the screen and out of these, 5 were approved by the Parties to the Protocol for destruction of halons:

- Liquid injection incineration
- Gaseous/fume oxidation
- Rotary kiln incineration
- Argon plasma arc
- Inductively coupled radio frequency plasma

More information on these approved technologies may be found in Chapter 3 of the TFDT report.

Destruction of halons presents some unique considerations. A number of the screened in technologies satisfied the criteria for the destruction of CFCs and HCFCs, but had not been tested for halon destruction. The TFDT, therefore, could not recommend such technologies for halon destruction, since the presence of bromine in halons can significantly alter the process parameters. In particular, molecular bromine tends to be formed rather than HBr, except under reducing conditions. Molecular bromine is very difficult to remove from the exhaust gases. Technologies that are recommended for CFC and HCFC destruction, but have not been tested for halon destruction, are described as potential technologies for halon destruction.

9.3 Status of Regulations on ODS Disposal

According to the TFDT report, many Article 2 and a few Article 5(1) Parties to the Protocol have developed regulatory programs to address the proper use and disposal of ODS and ODS-containing equipment. Regulations include: (1) proper recycling methods for ODS and ODS-containing equipment; (2) banning the release of ODS; (3) placing controls on the production and consumption of ODS, including placing restrictions on the quantity of ODS imported for destruction purposes; (4) creating hazardous waste regulations that control the destruction of ODS.

With regard to halons and other ODS contained in fire protection systems, many Parties require these agents be recovered during maintenance or prior to dismantling or disposing of the fire protection equipment. The amount of halon that may ultimately be available for destruction depends on inventory management strategies including regulatory measures. The approach adopted by many Parties has been a market-based one that allows continued use of recycled halons and, as alternatives replace halons in many applications, allows remaining halons to meet critical use needs. This approach likely will not yield significant destruction quantities of halons, particularly for halon 1301, which has historically retained a high monetary value relative to other ODS. For example, The Multilateral Fund Secretariat (MFS) sponsored a meeting of experts to estimate the potential requirement for the collection and disposition (emissions, export, reclamation, and destruction) of non-reusable and unwanted ODS in Article 5(1) countries on 13-15 March, 2006 (MFS, 2006). Given the need to continue to support critical uses through recovered/recycled halon in the future, the experts estimated that in 2010 no more than approximately 950 MT of combined halons per year would need to be destroyed because it was contaminated beyond local/regional capabilities to reclaim. Regulatory measures that eliminate the market for recovered and recycled halons can result in creation of additional waste halons that could potentially be destroyed or, worst case, inappropriately vented.

European regulation EC 2037/2000 provided a different regulatory approach to reducing halon emissions by requiring the decommissioning of halon systems at the end of 2003 with exceptions made for defined critical uses, largely military, aviation, and marine applications. The regulation raised concern by both Article 5(1) and non-Article 5(1) countries that had developed halon management strategies that depended on a shared global supply of halons to meet critical needs. The impact of the EC regulation in reducing ODS emissions is still being determined although the amount of halons made potentially available for destruction as a result of the regulation turned out to be significantly below estimates and insufficient to maintain new destruction operations set up in the EU in response to the new regulation.

9.4 Issues Related to Halon Destruction

9.4.1 DRE

The TFDT only recommended technologies for halon destruction based on actual trials of ODS destruction units using halons—i.e., a technology deemed acceptable to destroy CFCs was not necessarily also deemed acceptable to destroy halons if that technology was not actually tested using halons. Thus, the only way to be completely certain that the DRE is being met for halon destruction in hazardous waste combustors (HWCs) would be for facilities to conduct performance testing using halons as principal organic hazardous constituents (POHCs) to directly determine the DRE achieved for each of these compounds.

Based on available performance data and the chemical properties of halons, one can establish to some *degree of confidence that the 99.99% DRE is in fact being met for halons*, which would suggest that testing of each non-hazardous waste ODS is not needed. In particular:

- *Findings based on existing trial burn data:* While performance data for halon destruction in HWCs could not be found, performance data for other ODS – including carbon tetrachloride, CFC-11, and CFC-113 – demonstrate that conventional incineration technologies (e.g., rotary kilns) have in practice achieved DREs far greater than the 99.99%. The fact that HWCs have demonstrated performance greater than the minimum DRE standard provides a substantial margin of operation with respect to the incineration of halons. Unless the thermal stability of halons is far greater than that of monochlorobenzene and other difficult to incinerate compounds, it would be expected that HWCs that could incinerate these other compounds to a DRE of 99.9999% could also incinerate halons to a DRE of at least 99.99%. Furthermore, similar international technologies analyzed in the TFDT report were shown to meet the minimum DRE when destroying both CFCs and halons.
- *Findings based on halon chemistry:* The incinerability of halons can be estimated based on their chemical composition, and it is expected that halons would react

relatively easily at the very high temperatures at which HWCs operate. Indeed, the Material Safety Data Sheets (MSDS) for halons indicate that halon 1301 decomposes at fire temperatures above 850°C, and that halon 1211 can decompose at fire temperatures above 482°C. As these temperatures are lower than the combustion temperatures at which HWCs generally operate (i.e., above 982°C),[12] it is expected that halons will be easily destroyed to the minimum DRE of permitted HWCs in many countries.

9.4.2 Air Emissions

Carbon monoxide, hydrocarbons, organic acids, and other products of incomplete combustion (PICs) and PCDDs and PCDFs are produced from the combustion of chlorinated ODS including CFCs, HCFCs, and halons. The incineration of halons would also result in the release of hydrogen bromide (HBr) and/or bromine (Br_2). The production of toxic PCDD/PCDF is a serious problem which can be minimized in well-designed incinerators, i.e., a combustion process that results in lower concentrations of CO has been shown to produce lower concentrations of dioxins and furans.

Another serious technical problem is the formation of the above-mentioned acid gases during destruction. These are generally removed from the stack gases before the gases are released to the atmosphere. They are removed using gas scrubbing systems such as Venturi scrubbers, packed bed scrubbers, or plate scrubbers.[13] To address the potentially significant emissions of HBr, destruction facilities must establish site-specific feed rate limits for total bromine and site-specific emissions limits for HBr, and ensure that the air emissions control systems in place are designed and operated to control HBr emissions.

The production of acid gases requires specific equipment – which is not necessarily standard at incineration facilities – to prevent damage to the unit caused by corrosion. This equipment includes upgraded bag material in the bag house; acid gas-resistant refractory lining and binder in the combustion chambers through the quench area; and specially-lined, corrosion-resistant, fibreglass-reinforced plastic (FRP) in the scrubbing system. Cost factors would have to be taken into consideration before operators of such incineration facilities could justify the investment in such modifications.

9.5 Reported Destruction of Halons

Under Article 7 of the Montreal Protocol, Parties are required to report annual destruction of halons. Historically, very little halon has been reported as destroyed supporting the findings in Chapter 11 of this report showing significant global inventory of both halon 1301 and halon 1211. Table 9-2 below lists the amounts of halons reported under Article 7.

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[12] According to the U.S. performance test data available, the lowest afterburner (secondary combustion chamber) operating temperature is 877°C, which is higher than the threshold temperatures needed to decompose both halon 1211 and 1301.

[13] Similarly, it is expected that measures will be taken to prevent the formation of Br_2 instead of HBr.

Table 9-2 Article 7 Reporting for Halon Destruction[14] (ODP-weighted MT)

	1996	1997	1998	1999	2000	2001	2002	2003	2004
Halon 1301	0	1	4	22	39	17	7	218	208
Halon 1211	1	0	7	0	4	1	1	260	181
Total	**1**	**1**	**11**	**22**	**43**	**18**	**18**	**478**	**389**

9.6 Transformation of Halons

9.6.1 Halon 1301

The term "transformation" refers to the conversion of halon 1301 into useful, commercially viable products. Ideally this transformation would produce environmentally friendly products that could be sold for profit.

Halon 1301 (CF_3Br, bromotrifluoromethane) is in general a very thermally and chemically stable compound. Halon 1301 fails to undergo S_N2 type reactions with nucleophiles. This alteration in chemical reactivity is due to the extreme electron-withdrawing nature of the fluorine atom. As a result of the strong electron-attracting properties of the fluorine atom, the polarization in the halon 1301 molecule is such that the bromine atom in halon 1301 can be regarded as having a slightly positive nature. Nucleophilic attack on the carbon in halon 1301 and in other polyfluorohaloalkanes is highly disfavoured, but attack on *halogen* by one or two electron transfer processes is possible, and often involves difluorocarbene-mediated processes.

Despite its lessened reactivity, halon 1301 undergoes numerous chemical reactions. The chemical reactions of halon 1301 can be divided into three basic types, which involve three separate mechanisms:

1) Reactions in Zn/aprotic solvent systems
2) Reactions in SO_2 media
3) Reactions with powerful nucleophiles

Reactions involving metals (Zn, Cd) in aprotic solvents such as pyridine or dimethylformamide have been explained by radical or carbanionic intermediates. Reactions in SO_2 media proceed via a radical process. Reaction of halon 1301 with disulfides in the presence of SO_2 has been employed in the production of trifluoromethyl thioether precursors to insecticides such as Fipronil. Finally, reaction with strong nucleophiles such as thiophenoxides is believed to proceed via an SNR1 mechanism.

Owing to the decreased reactivity of halon 1301, several of the reactions depicted in Figure 9-1 proceed with low yields, due to the vigorous reaction conditions required, and as result

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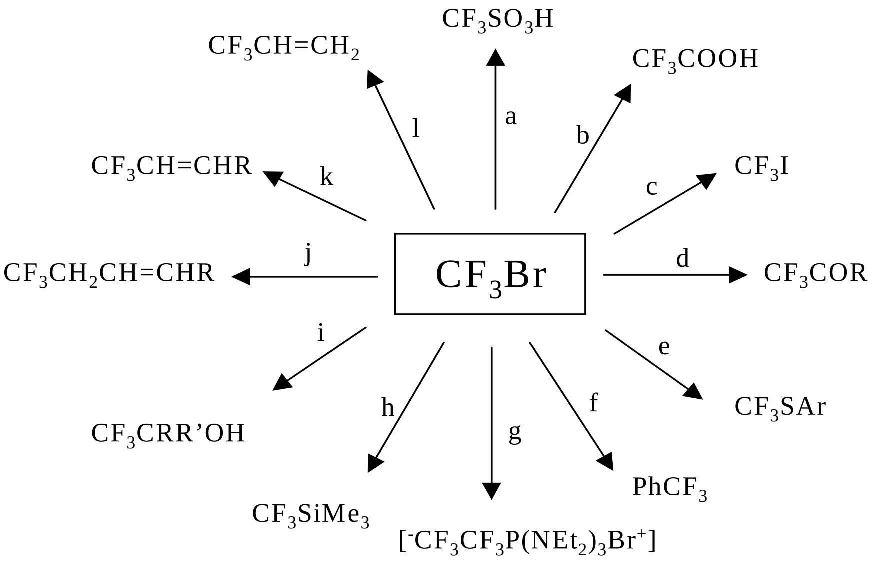
[14] Numbers reported are aggregated by region. Only the region defined as Western Europe and Australia have reported any destruction of halons under Article 7 of the Montreal Protocol.

these processes are not commercially attractive. A successful halon 1301 transformation process must not only produce a commercially useful product, but must also be characterized by high enough yields and conversions to render the process economical compared to simple destruction of halon 1301.

Numerous fluorine-containing products of potential use as monomers, pharmaceutical intermediates and agricultural intermediates can be envisioned as candidates for synthesis from halon 1301. Given recent advances in synthetic techniques, catalysis and other areas, it is believed that the development of a halon 1301 transformation process capable of producing a commercially viable product is an attainable goal.



Reagents: (a) Zn/DMF, SO_2 ; (b) Zn/DMF, CO_2; (c) Zn/DMF, I_2; (d) Zn/pyridine, RCOOR'; (e) ArSK/pyridine; (f) benzene, Zn, SO_2, DMF; (g) $P(NEt_2)_3$; (h) $P(NEt_2)_3$, $SiMe_3Cl$; (i) Zn/pyridine, RCOR'; (j) $RCH=CHCH_2R$, Zn; (k) RCCH, Zn, CuI, THF; (l) $CH_2=CH_2$, Δ

Figure 9-1 Portion of Known Chemistry of Halon 1301

9.6.2 Halon 1211

Halon 1211 is somewhat more reactive than halon 1301, and a number of reactions of halon 1211 have been reported in the open literature. The reaction chemistry of halon 1211 includes:

1) Non-oxidative gas phase reactions
2) Oxidative gas phase reactions
3) Additions to olefins
4) Reactions with nucleophiles

Non-oxidative reactions include reaction with hydrogen to produce the hydro-dechlorination products CF_2HCl and CH_2F_2 and the reaction with methane to produce CF_2HCl, CH_3Br, and CH_2F_2 as the major products. Oxidative gas phase reactions result in the ultimate production of carbonyl fluoride (COF_2), bromine and chlorine. Catalytic pyrolysis of halon 1211 over alumina and aluminium trifluoride has been employed to produce CF_3Br and CF_3Cl.

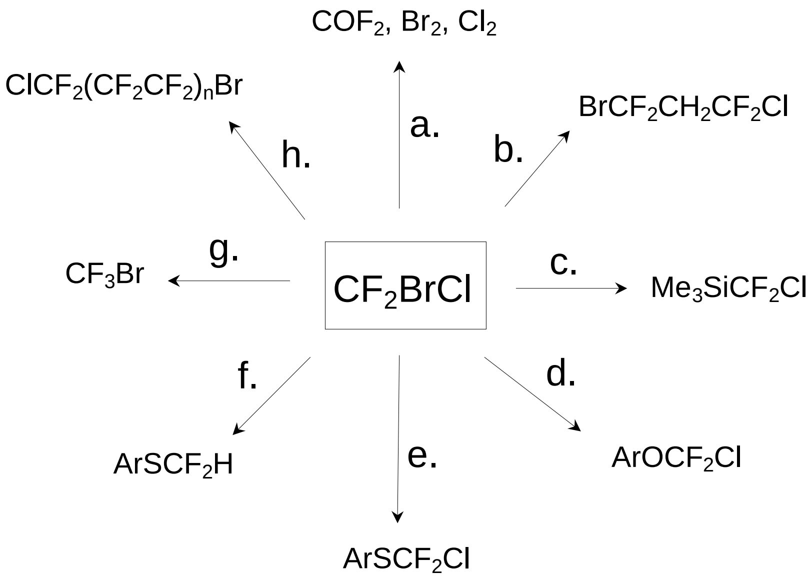
Additions to olefins include additions to partially fluorinated olefins, e.g., addition to $CF_2{=}CH_2$ to produce $BrCF_2CH_2CF_2Cl$, which can be further fluorinated and dehydrofluorinated to produce $CF_3CH{=}CFCl$. Telomerization with tetrafluoroethylene, $CF_2{=}CF_2$, produces the telomers $ClCF_2(CF_2CF_2)_nBr$.

Similar to the reaction chemistry of halon 1301, halon 1211 undergoes reaction with nucleophiles. Reactions with nucleophiles proceed via both carbene and radical processes. For example, treatment of PhSNa with halon 1211 in DMF produces $PhSCF_2Br$ and $PhSCF_2H$, via the difluorocarbene intermediate. Reaction under radical conditions affords $PhSCF_2Br$ and $(PhS)_2CF_2$.

Reaction of alkali phenoxides with halon 1211 provides a route to bromodifluoro-methoxy compounds $ArOCF_2Br$, useful as insecticides and agricultural intermediates.

Reaction of halon 1211 with chlorotrimethylsilane affords chlorodifluoromethyl-trimethylsilane, a useful chlorodifluoromethylation agent.

Like halon 1301, halon 1211 undergoes reactions in Zn/aprotic solvent systems and in SO_2 media, but products are often mixtures due to reactions involving both the C-Br and C-Cl bonds.



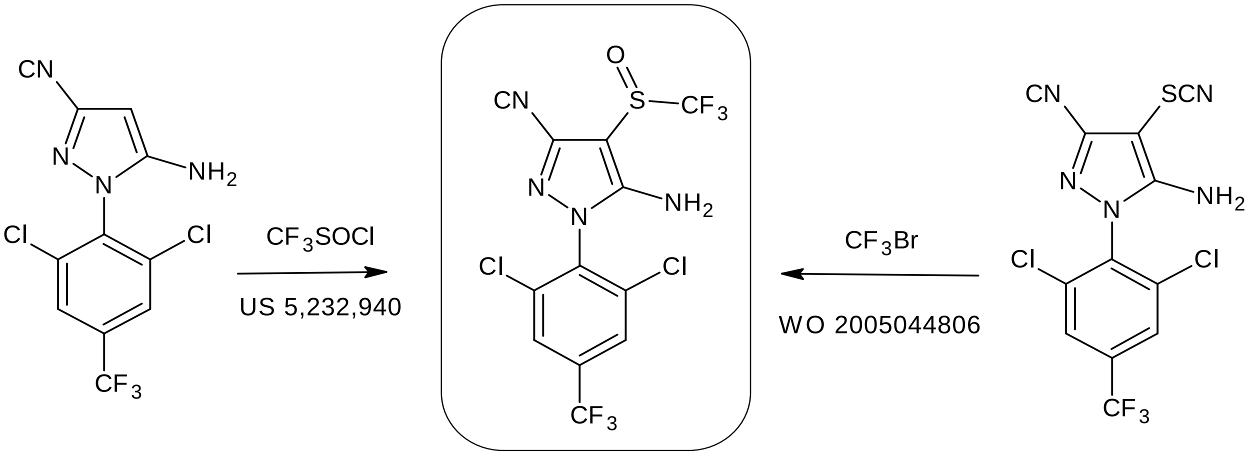
Reagents: (a) O_2 or hv/O_3 ; (b) $CF_2{=}CH_2$; (c) Me_3SiCl, Al, NMP; (d) ArOK; (e) ArSK ; (f) ArSK, DMF; (g) HF; Cr_2O_3; (h) $CF_2{=}CF_2$

Figure 9-2 Summary of the Reaction Chemistry of Halon 1211

Numerous fluorine-containing products of potential use as monomers, pharmaceutical intermediates and agricultural intermediates can be envisioned as candidates for synthesis from halon 1211. Given recent advances in synthetic techniques, catalysis and other areas, it is believed that the development of a halon 1211 transformation process capable of producing a commercially viable product is an attainable goal.

9.6.3 Known Transformations of Halons

The Chemicals Technical Options Committee (CTOC) has determined that halon 1301 is a very useful feedstock for the preparation of bioactive compounds. In particular, halon 1301 has been used for many years in the preparation of Fipronil, a broad-spectrum insecticide used to control multiple species of thrips, which is produced by treatment of 5-amino-3-cyano-1-(2,6-dichloro-4-trifluoro-methylphenyl) pyrazole with trifluoro-methyl sulfenyl chloride or by 5-Amino-3-cyano-1-(2,6-dichloro-4-trifluoro-methylphenyl)-4-thiocyanato-1-H-pyrazolecyano- 1-pyrazole with bromotrifluoromethane.



Fipronil

Figure 9-3 Portion of Chemistry of Fipronil

In order to support Fipronil production, halon 1301 feedstock production in France has averaged approximately 400 tonnes per annum since the mid-1990s and more recently approximately 160 tonnes in China. As the demand for Fipronil (or other bioactive compounds) grows worldwide, it is conceivable that other manufacturing facilities may restart production of halon 1301 to support the feedstock needs.

In Russia, recycled halon 2402 ($C_2F_4Br_2$, dibromotetrafluoroethane) is used as a process agent in the chemical pharmaceutical industry. At this time, very little is known by the HTOC or CTOC about this transformation process. Currently, halon 2402 is not newly produced to support this process agent use.

9.7 Conclusions

Halons, more than some of the other ODS, are readily accessible for collection, storage, and disposal. Options for disposal of surplus halons include destruction and transformation. The actual amounts of the global halon inventory potentially available for destruction or transformation is highly uncertain due to business planning and economic considerations by users, local and regional imbalances of supply and demand, the availability of destruction or transformation technologies and facilities, inventory management approaches, and applicable disposal regulations. Compliant ODS destruction technologies and facilities can be found in many countries, and some already have experience destroying some types of ODS. Owing to the relatively high market value and little outflow of halons into the waste stream, there is more limited experience in destroying halons.

The Parties adopted a "Code of Good Housekeeping" for the destruction of ODS that provides best environmental practices that facilities and entities destroying ODS should adopt in order to minimize emissions. Continued research into transformation of halons – including feedstock uses - and the viability of producing useful products holds promise as a future option for halon disposal.

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U.S. Environmental Protection Agency (EPA), “ODS Destruction in the United States and Abroad (DRAFT),” draft report prepared by ICF International Inc. (formerly ICF Consulting Inc.), U.S. Environmental Protection Agency, 2006.

10.0 Other Issues

10.1 Feedstock Use of Halon 1301 (CF_3Br, Bromotrifluoromethane)

Until this Assessment was started, the HTOC believed that the only uses for halon 1301 were in fire protection and as a very low temperature refrigerant, and that once production ceased in non-Article 5(1) countries, the only source of halon 1301 in those countries would come from the halon bank, through recovery and recycling, and that routine, annual production of new halon 1301 would be unlikely to restart. The HTOC and TEAP have never recommended an essential use production request for halon 1301 because of the availability of material from the bank (global inventory). Thus, eventually, a finite halon resource would become difficult to obtain, encouraging users to move to alternatives. The unavailability of facilities to routinely produce halon 1301, even if an essential use production exemption were granted, has been used to great effect to encourage the aviation, military, and other sectors with important long-term uses to heavily invest in research and development to solve some of their difficult problems. However, it appears that, although production of halon 1301 for fire protection uses ceased January 1, 1994 in non-Article 5(1) countries, actual production did not cease in France, and has continued for feedstock uses. In addition, more recently, production of halon 1301 in China has been diverted to feedstock use, and is likely to continue, despite efforts to close production facilities there.

Under the Montreal Protocol, the feedstock use of halon 1301 (CF_3Br, bromotrifluoromethane) is exempt from control measures. Each Party defines its own feedstock uses and exercises a range of stringency in reducing and eliminating unnecessary emissions. The total emissions from this feedstock use are unknown, but are likely to be small, e.g., the plant in France indicated emissions of 0.6 MT from their approximate 400 MT of production. However, the production of halon 1301 for feedstock uses has implications that Parties where production takes place may wish to consider in order to reduce future emissions.

The Chemicals Technical Options Committee (CTOC) has determined that halon 1301 is a very useful feedstock for the preparation of bioactive compounds. In particular, halon 1301 has been used for many years in the preparation of Fipronil, a broad-spectrum insecticide used to control multiple species of thrips. In order to support Fipronil production, halon 1301 production in France has averaged approximately 400 MT per annum since 1994 and more recently approximately 160 MT in China. As the demand for Fipronil (or other bioactive compounds) grows worldwide, it is conceivable that other manufacturing facilities may continue or restart production of halon 1301 to support the feedstock needs.

The continued production of halon 1301 for feedstock use negates the assertion that there would be no facilities to routinely produce low-cost halon 1301 should an essential use exemption be requested and approved for fire protection uses. Thus the risk of putting off research and development and/or implementing alternatives for long-term critical uses (20 to 30 year lifetimes) that currently have none is greatly reduced. As the global bank diminishes through support of existing and limited new uses, the cost of recycled halon 1301 will rapidly eclipse the cost of new production. In addition, while adequate supplies may exist on a global level, local and regional shortages that are already being shown to occur could cause the local price for halon to become significant compared with newly produced halon. Thus by either cause, the point at which halon is considered under Decision IV/25 to not be available in sufficient quantity and quality can now occur at a much lower cost of recycled halon that was previously believed.

10.2 Contaminated Halon

Article 5(1) members of the HTOC continue to raise issues of locally contaminated and unwanted halons in many countries, particularly in Africa and China (see Section 3.5 and Section 4.2). The out-of-specification or contaminated halon must be stored in cylinders until it can be disposed of. The options for disposition are finding an available reclamation facility, destruction or venting. The first two options require monetary investment, which generally is not available in these countries. With respect to China, their own ban on use is causing the need to store significant quantities of halon 1211. Unless there is a need for significant quantities of halon 1211 in the immediate future, the quantities stored and becoming available in China may also become unwanted with only destruction and venting as disposition options.

10.3 Conclusions

Although production of halon 1301 for fire protection uses has virtually ceased, France has continued to produce Halon 1301 as a feedstock for Fipronil since 1994, averaging 400 MT per annum. China has also begun to divert some production (160 MT in 2004) to feedstock use for Fipronil production, and is likely to continue, despite efforts to close production facilities there. Fipronil is a broad-spectrum insecticide used to control multiple species of thrips. As the demand for Fipronil (or other bioactive compounds) grows worldwide, it is conceivable that other manufacturing facilities may continue or restart production of halon 1301 to support the feedstock needs.

The continued routine, annual production of halon 1301 changes the economic considerations and reduces the risk of delaying research and development and/or implementing alternatives for long-term critical uses (20 to 30 year lifetimes) that currently have none. The point at which halon is considered under Decision IV/25 to not be available in sufficient quantity and quality can now occur at a much lower cost of recycled halon that was previously believed and may provide an incentive for an essential use production exemption request.

The build up of stocks of contaminated or otherwise unwanted halons continues to be reported as a problem in Article 5(1) countries, particularly in Africa and also now in China. With respect to China, their own regulation banning use is causing the need to store significant quantities of halon 1211. In many cases, this is becoming a storage and space issue as the halon needs to be stored in its pressure cylinder. Disposition options for contaminated halon include reclamation (assuming that one can sell it cost-effectively after reclamation), destruction or venting. The first two options require monetary investment, which is generally not available in most circumstances. Unless there is a need for significant quantities of halon 1211 in the immediate future, the quantities stored and becoming available in China may also become unwanted with only destruction and, unfortunately, venting as disposition options.

11.0 Fire Protection Alternatives to Halon

The following information can also be found in the Halon Technical Options Committee's Technical Note 1.

11.1 Introduction

Halons are a class of halogenated chemicals containing bromine that have been and continue to be used as gaseous extinguishing agents in a wide range of fire and explosion protection applications. Halons are very potent stratospheric ozone depleting chemicals when released to the atmosphere. Halons were phased out of production under the Montreal Protocol countries in 1994 except in Article 5(1) countries where continued production of halons is permitted through 2009. The phase-out of halon production has had a dramatic impact on the fire and explosion protection industry. Halons are clean, non-conductive, and highly effective. Halon 1301 in particular is safe for people when used at concentrations typically employed for "total flooding" fire extinguishing systems and explosion prevention (inerting) applications. Halon 1211 was widely employed in portable fire extinguishing units for use in what are called "streaming agent" applications. Fire extinguishing agent alternatives to halons, in the form of non-ozone depleting gases, gas-powder blends, powders and other not-in-kind technologies (i.e., non-gaseous agents) are now available for virtually every fire and explosion protection application once served by halons. Halon 2402 has been used in both total flooding and streaming agent applications.

Selection of the best fire protection method in the absence of halons is often a complex process. Either alternative gaseous fire extinguishing agents, so called in-kind alternatives, or not-in-kind alternatives may successfully replace halon but the decision is driven by the details of the hazard being protected, the characteristics of the gaseous agent or alternative method, and the risk management philosophy of the user.

Gaseous extinguishing agents that are electrically non-conductive and which leave no residue are referred to as "clean" agents. Several clean agents and new "not-in-kind" alternative technologies have been introduced to the market. 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.

Since publication of the 2003 version of Technical Note 1, there have been some changes made to national and international fire protection standards that affect some of the measures of performance and guidelines for use of the agents described in this note.

- International standards recognize Class A fire hazards involving specific arrangements of electrified equipment may pose additional extinguishing challenges and re-ignition risks. In such cases higher minimum agent design concentrations are recommended.
- New procedures have been developed for determining safe personnel exposure guidelines where halocarbon agents are employed in occupied spaces. These procedures are based on what is referred to as the PBPK (physiologically-based pharmacokinetic) model where exposure time is considered in addition to the NOAEL and LOAEL values of an agent.

- Both national and international standards are now in harmony with respect to requiring a 30% minimum safety factor where the fire hazard is due to Class B flammable and combustible liquids. The minimum safety factor for Class A surface fire hazards is 20% in some standards and 30% in others. This means that the minimum design concentration (MDC) of a gaseous fire extinguishing agent must be at least 1.2 or 1.3 times the minimum extinguishing concentration (MEC), as determined by test, for a particular fire hazard and depending on which standard governs the application.

Total Flooding Applications. A number of gaseous fire extinguishing agent technologies have been commercialized as alternatives to halon 1301 for use in total flooding applications. These are summarized in Table 11-1.

Several agents listed in Table 11-1 have been approved for use in normally occupied spaces. These agents include the named inert gas agents, HFC agents, perfluoroketone agent, gaseous agents containing particulate solids and HCFC Blend A. These agents may be used for total flooding fire protection in normally occupied spaces provided that the design concentration is below the safe exposure threshold limits presented in Table 11-4 for gaseous halocarbon agents without powder additives or Table 11-9 for inert gas agents, below. The United States Environmental Protection Agency, under the Significant New Alternatives Policy (SNAP) program, has reviewed a number of materials as substitutes for halons as fire extinguishing agents. The approval status of a number of such alternatives for use in total flooding systems and as streaming agents may be found at the EPA website:

http://www.epa.gov/spdpublc/snap/fire/lists/index.html.

Agents listed in Table 11-1 that are not suitable for use in occupied spaces include carbon dioxide, FIC-13I1, FIC-217I1, HCFC-124, and the aerosol powders.

In addition to gaseous agents, powders, and mixtures of these, a number of other technologies have been evaluated for fire extinguishing applications where halon 1301 might have formerly been used. These include water-foam technologies and several types of water mist systems.

Water mist system technologies strive to generate and distribute within a protected space very small mist droplets which serve to extinguish flames by the combined effects of cooling and oxygen dilution by steam generated upon water evaporation. Technologies used to generate fine water mists include:

- Low-pressure single fluid atomization
- High-pressure single fluid atomization
- Dual-fluid atomization
- Hot water steam generation

Table 11-1 Gaseous Fire Extinguishing Agent Alternatives to Halons for Use in Total Flooding Applications

Agent	Composition
Inert Gases	
• IG-01	Argon, Ar
• IG-100	Nitrogen, N_2
• IG-541	Nitrogen, 52 vol. %; Argon, 40 vol. %; Carbon dioxide, 8 vol.%
• IG-55	Nitrogen, 50 vol. %; Argon, 50 vol. %
Carbon dioxide	Carbon dioxide, CO_2
Hydrofluorocarbons	
• HFC-125	C_2HF_5 – Pentafluoroethane
• HFC-23	CHF_3 - Trifluoromethane
• HFC-227ea	CF_3CHFCF_3 - 1,1,1,2,3,3,3-heptafluoropropane
• HFC-236fa	$CF_3CH_2CF_3$ - 1,1,1,3,3,3-hexafluoropropane
• HFC Blend B	HFC-134a, CH_2FCF_3, 1,1,1,2-tetrafluoroethane, 86 wt% HFC-125, C_2HF_5, pentafluroethane, 9 wt% Carbon dioxide, CO_2, 5 wt%
Perfluoroketone	
• FK-5-1-12	$CF_3CF_2(O)CF(CF_3)_2$ – Dodecafluoro-2-methylpentan-3-one
Iodofluorocarbon	
• FIC-13**I**1	CF_3I – Iodotrifluoromethane
• FIC-217**I**1	C3IF7 – Iodoheptafluoropropane
Hydrochlorofluorocarbons	
• HCFC-124	$CHFClCF_3$, 1-Chloro-1,2,2,2-tetrafluoroethane
• HCFC Blend A	HCFC-22, $CHClF_2$ - Chlorodifluoromethane, 82 wt % HCFC-124, $CHClF\text{-}CF_3$,1-Chloro-tetrafluoroethane, 9.5 wt% HCFC-123, $CHCl2\text{-}CF_3$, 1,1-dichloro-trifluoroethane, 4.75 wt% isopropenyl-1-methylcyclohexane, 3.75 wt%
Gaseous Agents Containing Particulate Solids	
• HFC227-BC	• HFC-227ea with 5 wt% sodium bicarbonate added.
• Gelled mixture of HFC plus dry chemical additive.	• HFC-125 plus ammonium polyphosphate or sodium bicarbonate • HFC-227ea plus ammonium polyphosphate or sodium bicarbonate • HFC-236fa plus ammonium polyphosphate or sodium bicarbonate
Aerosol Powders	
• Powdered Aerosol A	• Proprietary formulation
• Powdered Aerosol C	• Proprietary formulation

Each approach to generating fine water mists has its own advantages and drawbacks. Additional comments on water mist systems are given in Section 11.2.4.

Local Application. Extinguishing agents suitable for use as alternatives for halon 1211 are listed in Table 11-2.

Table 11-2 Fire Extinguishing Agent Alternatives to Halon 1211 for Use in Local Application Fire Protection

Agent	Comment
• HCFC Blend B	Blend of HCFC-123 and two additives
• HCFC Blend C	55% HCFC-123, 31% HFC-124, 10% HFC-134a, 4% d-Limonene
• HCFC Blend D	HCFC-123 plus proprietary additive
• HFC-236fa	$CF_3CH_2CF_3$ - 1,1,1,3,3,3-hexafluoropropane
• HFC-227ea	CF_3CHFCF_3 - 1,1,1,2,3,3,3-heptafluoropropane
• HCFC-123	$CHCl_2CF_3$, 1,1-Dichloro-2,2,2-trifluoroethane
• HCFC-124	$CHFClCF_3$, 1-Chloro-1,2,2,2-tetrafluoroethane
• Gelled Halocarbon / Dry Chemical Suspension	Halocarbon plus dry chemical plus gelling agent
• Surfactant Blend A	Mixture of organic surfactants and water
• Carbon Dioxide	Carbon dioxide, CO_2
• Dry chemical	Several product types based on different base chemistries including • BC powder - Sodium bicarbonate • ABC powder - Monoammoniumphosphate • Purple K - Potassium bicarbonate • Others
• Foam	Numerous aqueous foam chemistries and variations
• Water	Hand-held portable water fire extinguisher

11.2 Alternatives to Halon 1301 for Total Flooding Fire Protection using Fixed Systems

11.2.1 Halocarbon Agents (without powder additives)

Halocarbon agents share several common characteristics, with the details varying among products. Common characteristics include the following:

1.) All are electrically non-conductive;
2.) All are clean agents, meaning that they vaporize readily and leave no residue;
3.) All are stored as liquids or as liquefied compressed gases either as single component agents or as multi-component mixtures;
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-pressurization for discharge purposes;
6.) All (except CF_3I) are less efficient fire extinguishants than halon 1301;
7.) All, upon discharge, vaporize when mixed with air (except HCFC Blend A which contains 3.75% of a non-volatile liquid). Many require additional care relative to nozzle design; and

8.) All (except CF_3I) produce more decomposition products, primarily hydrogen fluoride (HF), than halon 1301 given similar fire type, size, and discharge time.

These agents differ widely in 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.

11.2.1.1 Agent Toxicity

In general, personnel should not be exposed unnecessarily to atmospheres into which gaseous fire extinguishing agents have been discharged. Mixtures of air and halon 1301 have low toxicity at fire extinguishing concentrations and there is little risk posed to personnel that might be exposed in the event of an unexpected discharge of agent into an occupied space. The acceptance of new agents for use in total flooding fire protection in normally occupied spaces has been based on criteria which have evolved over the period of introduction of new technologies into the marketplace. In the case of inert gas agents the usual concern is the residual oxygen concentration in the protected space after discharge. For chemical agents the primary health issue is cardiac effects as a consequence of absorption of the agent into the blood stream. The highest agent concentration for which no adverse effect is observed is designated the “NOAEL” for “no observed adverse effect level.” The lowest agent concentration for which an adverse effect is observed is designated the “LOAEL” for “lowest observed adverse effect level.” This means of assessing chemical agents has been further enhanced by application of physiologically based pharmico-kinetic modelling, or “PBPK” modelling, which accounts for exposure times. Some agents have their use concentration limits based on PBPK analysis. The approach is described in more detail in ISO 14520-1, Annex G, 2nd edition (2006).

Table 11-4 summarizes the toxicity information[15] available for each chemical.

11.2.1.2 Environmental Factors

The primary environmental factors to be considered for halocarbon agents are ozone-depletion potential (ODP), global-warming potential (GWP)~~,~~ and atmospheric lifetime. These factors are summarized in Table 11-5. It is important to select the fire protection choice with the lowest environmental impact that will 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 utilize them. Some examples are presented below:

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[15] The principal basis for assessing the safety of gaseous halocarbon agents is cardiac sensitivity. A more complete discussion on the PBPK model may found at http://www.harc.org/pbpkharc.pdf.

- 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.
- The Kyoto Protocol has identified carbon dioxide, methane, nitrous oxide and the fluorochemicals HFCs, PFCs and SF6 as the basket of six gases primarily responsible atmospheric greenhouse effects and potentially subject to emission controls. All uses of fluorochemicals represent less than 2% of current worldwide greenhouse gas emissions on a carbon-equivalency basis.

Table 11-3 Physical Properties of Gaseous Fire Extinguishing Agent Alternatives to Halons Used in Total Flooding Applications

Generic Name	Vapour Pressure @ 20º C, bar	k1 m^3/kg (1)	k2 $m^3/kg/ºC$ (1)	Vapour Density, @ 20ºC & 1 atm, kg/m^3	Liquid Density @ 20º C, kg/m^3
Halon 1301	12.90	0.1478	0.00057	6.283	1,572
HCFC Blend A	8.30	0.2413	0.00088	3.862	1,200
HCFC-124	3.30	0.1575	0.00066	5.858	1,373
HFC-23	41.83	0.3164	0.00122	2.934	807
HFC-125	12.10	0.1825	0.00073	5.074	1,218
HFC-227ea	3.91	0.1269	0.00052	7.283	1,407
HFC-236fa	2.30	0.1413	0.00057	6.549	1,377
FIC-13I1	4.65	0.1138	0.00050	8.078	2,096
FK-5-1-12	0.33	0.0664	0.000274	13.912	1,616
HFC Blend B	13.03	0.2172	0.0009	4.252	1.190

Note 1: Agent vapour specific volume $s = k1 + k2 \bullet t$, m^3/kg at an atmospheric pressure of 1.03 bar where t is the vapour temp. in ºC. Vapour density = 1/s.

Table 11-4 Gaseous Fire Extinguishing Agent Alternatives to Halons Used in Total Flooding Applications Minimum Extinguishing Concentrations and Agent Exposure Limits

Generic Name **ISO standard reference**	**Minimum Design Conc., Class A Fire Vol. % (1)**	**Minimum Design Conc., Class B Fire Vol. % (1)**	**Inerting Conc. Methane/Air, Vol. %**	**NOAEL Vol. % (2)**	**LOAEL Vol. % (2)**
Halon 1301	5.0 (3)	5.0 (3)	4.9	5	7.5
HCFC Blend A ISO 14520-6	7.8	13.0	20.1	10	>10
HCFC-124 (5, 6)	-	8.7 (4)	-	1	2.5
HFC-23 ISO 14520-10	16.2	16.4	22.2	30	>50
HFC-125 ISO 14520-8	11.2	12.1	-	7.5	10
HFC-227ea ISO 14520-9	7.9	9.0	8.8	9	10.5
HFC-236fa ISO 14520-11	8.8	9.8	-	10	15
FIC-13I1 (5) ISO 14520-2	4.6	4.6	7.15 propane	0.2	0.4
FK-5-1-12 ISO 14520-5	5.3	5.9	-	10	>10
HFC Blend B (5, 7)	14.7	14.7	-	5	7.5

Note 1: Design concentration = Extinguishing concentration x 1.3, the minimum permitted by ISO 14520.

Note 2: A halocarbon agent may be used at a concentration up to its NOAEL value in normally occupied enclosures provided the maximum expected exposure time of personnel is not more than five minutes. A halocarbon agent may be used at a concentration up to the LOAEL value in normally occupied and normally unoccupied enclosures provided certain criteria are met that depend on agent toxicity and egress time. The reader is referred to NFPA 2001-1.5 (2004) and ISO 14520-G.4.3 (2006) for details of the recommended safe exposure guidelines for halocarbon agents.

Note 3: Exceptions, halon 1301 design concentration is taken as the historical employed value of 5%.

Note 4: HCFC-124 data from 1999 revision of this report.

Note 5: Not approved for use in occupied spaces.

Note 6: These agents are not generally supplied in new suppression systems but may be found in legacy systems.

Note 7: Agent manufacturer did not provide Class A extinguishing concentration data. Class A design concentration in this case was taken as Class B design concentration.

Table 11-5 Gaseous Fire Extinguishing Agent Alternatives to Halons Used in Total Flooding Applications Environmental Factors

Generic Name	Ozone Depletion Potential	Global Warming Potential, 100 yr. (1)	Atmospheric Life Time, yr. (1)
Halon 1301	10	6,900	65
HCFC Blend A	HCFC-22 – 0.055 HCFC-124 – 0.022 HCFC-123 – 0.02	HCFC-22 – 1,700 HCFC-124 – 620 HCFC-123 - 120	HCFC-22 – 11.9 HCFC-124 – 6.1 HCFC-123 – 1.4
HCFC-124	0.022	620	6.1
HFC-23	0	12,000	260
HFC-125	0	3,400	29
HFC-227ea	0	3,500	33
HFC-236fa	0	9,400	220
FIC-13I1	0.0001	1	0.005
FK-5-1-12	0	1	0.01
HFC Blend B	HFC-134a – 0 HFC-125 - 0	HFC-134a – 1,300 HFC-125 – 3,400	HFC-134a – 13.8 HFC-125 - 29

Note 1: Source: IPCC Third Assessment Report (2001) except for FK-5-1-12 for which data was supplied by the manufacturer.

Table 11-6 Gaseous Fire Extinguishing Agent Alternatives to Halons Used in Total Flooding Applications Halocarbon Agent Quantity Requirements for Class A Combustible Hazard Applications (1, 2)

Generic Name	Agent Mass, kg/m^3 of Protected Volume	Mass Relative to Halon 1301	Agent Liquid Volume litre/m^3 of Protected Volume	Maximum Cylinder Fill Density, kg/m^3 (3)	Cylinder Storage Volume Relative to Halon 1301 (4)	Cylinder Pressure @ 20 °C, bar
Halon 1301	0.331	1.000	0.210	1,082	1.00	25 or 42
HCFC Blend A	0.327	0.988	0.272	900	1.19	25 or 42
HCFC-124	0.558	1.689	0.407	1,140	1.60	25
HFC-23	0.567	1.716	0.703	860	2.16	42
HFC-125	0.640	1.936	0.525	831	2.52	25
HFC-227ea	0.625	1.890	0.444	1,150	1.78	25 or 42
HFC-236fa	0.632	1.911	0.459	1,200	1.72	25 or 42
FIC-13I1	0.389	1.178	0.186	1,680	0.76	25
FK-5-1-12	0.779	2.355	0.482	1,680	1.52	25
HFC Blend B	0.733	2.216	0.616	930	2.58	25 or 42

Note 1: Halon alternative agent quantities based on 1.3 safety factor.
Note 2: Mass and volume ratios based on "Minimum Class A Fire Design Concentrations" from Table 11-4.
Note 3: Fill density based on 25 bar pressurization except for HFC-23.
Note 4: Agent cylinder volume per m^3 protected volume = (Agent Mass, kg/m^3 protected volume)/ (Maximum Fill Density, kg/m^3 cylinder) = ($V_{CYL}/V_{ProtVol}$). For halon 1301 cylinder volume per m^3 hazard = (0.331 kg/m^3 hazard)/ (1082 kg/m^3 cylinder) = 0.0003059 m^3 cylinder /m^3 protected volume.

Table 11-7 Gaseous Fire Extinguishing Agent Alternatives to Halons Used in Total Flooding Applications Halocarbon Agent Requirements for Class B Fuel Applications (1, 2)

Generic Name	Agent Mass, kg/m^3 of Protected Volume	Mass Relative to Halon 1301	Agent Liquid Volume litre/m^3 of Protected Volume	Maximum Cylinder Fill Density, kg/m^3 (3)	Cylinder Storage Volume Relative to Halon 1301 (4)	Cylinder Pressure @ 20 °C, bar
Halon 1301	0.331	1.000	0.210	1,082	1.00	25 or 42
HCFC Blend A	0.577	1.746	0.481	900	2.10	25 or 42
HCFC-124	0.558	1.689	0.407	1,140	1.60	25
HFC-23	0.576	1.741	0.713	860	2.19	42
HFC-125	0.698	2.113	0.573	831	2.75	25
HFC-227ea	0.720	2.179	0.512	1,150	2.05	25 or 42
HFC-236fa	0.712	2.152	0.517	1,200	1.94	25 or 42
FIC-13I1	0.389	1.178	0.186	1,680	0.76	25
FK-5-1-12	0.872	2.638	0.540	1,680	1.70	25
HFC Blend B	0.733	2.216	0.616	930	2.58	25 or 42

Note 1: Nominal maximum discharge time is 10 seconds in all cases.

Note 2: Mass and volume ratios based on "Minimum Class B Fire Design Concentrations" from Table 11-4.

Note 3: Fill density based on 25 bar pressurization except for HFC-23.

Note 4: Agent cylinder volume per m^3 of protected volume = (Agent Mass, kg/m^3 of protected volume)/(Maximum Fill Density, kg/m^3 cylinder) = ($V_{CYL}/V_{ProtVol}$). For halon 1301 cylinder volume per m^3 of protected volume = (0.331 kg/m^3 hazard)/ (1082 kg/m^3 cylinder) = 0.0003059 m^3 cylinder/m^3 of protected volume.

11.2.2 Carbon Dioxide

Carbon dioxide, used widely for fire protection prior to the introduction of halons, has seen a resurgence in use subsequent to the halon production phase out, particularly in new commercial ship construction where halon 1301 once had a significant role. Minimum design concentrations for carbon dioxide are specified in national and international standards such as NFPA 12 and ISO 6183. The minimum design concentration for carbon dioxide systems is, typically, 35 vol. % for Class B fuels and 34 vol. % for Class A applications.

11.2.2.1 Toxicity effects

Carbon dioxide is essentially chemically inert as a fire extinguishing gas. Carbon dioxide does, however, have significant adverse physiologically effects when inhaled at concentrations above 4 vol. %. The severity of physiological effects increases as the concentration of carbon dioxide in air increases. Exposure to carbon dioxide at concentrations exceeding 10 vol. % poses severe health risks including risk of death. As such, atmospheres containing carbon dioxide at fire extinguishing concentrations are always lethal to humans. Precautions must always be taken to assure that occupied spaces are not put at risk by ingress of carbon dioxide from a space into which the agent has been discharged. A more complete discussion of the health and safety risks of carbon dioxide can be found in "Carbon Dioxide as a Fire Suppressant: Examining the Risks" and "Review of the Use of Carbon Dioxide Total Flooding Fire Extinguishing Systems," which can be found at the EPA website:

http://www.epa.gov/spdpublc/snap/fire/index.html.

11.2.3 Inert Gas Agents

There have been at least four inert gases or gas mixtures commercialized as clean total flooding fire suppression agents. Inert gas agents are typically used at design concentrations of 35-50 vol. % which reduces the ambient oxygen concentration to between 14% to 10% by volume, respectively. Reduced oxygen concentration (hypoxia) is the principal human safety risk for inert gases except for carbon dioxide which has serious human health effects at progressive severity as its concentration increases above 4 vol. %. Inert gas agents mixed with air lead to flame extinguishment by physical mechanisms only. The inert gas agents commercialized since 1990 consist of nitrogen, argon, blends of nitrogen and argon. One blend contains 8% carbon dioxide.

The features of the commercialized inert gas agents are summarized in Tables 11-8 and 11-9. These agents are electrically non-conductive, clean fire suppressants. The inert gas agents containing nitrogen or argon 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.

Table 11-8 Inert Gas Agents for Fixed Systems
Agent Properties & System Features

Generic name	IG-541 ISO 14520-15	IG-55 ISO 14520-14	IG-01 ISO 14520-12	IG-100 ISO 14520-13
Agent composition				
Nitrogen	52%	50%		100%
Argon	40%	50%	100%	
Carbon Dioxide	8%			
Environmental factors				
Ozone depletion potential	0	0	0	0
Global warming potential, 100 yr.	0	0	0	0
Properties				
k1, m^3/kg (1)	0.65799	0.6598	0.5612	0.7998
k2, m^3/kg/deg C (1)	0.00239	0.00242	0.00205	0.00293
Specific Volume, m^3/kg	0.697	0.708	0.602	0.858
Gas Density @ 20^{o}C, 1 atm, kg/m^3	1.434	1.412	1.661	1.165
Extinguishing (2)				
Min. Class A fire design conc., vol. %	39.9	40.3	41.9	40.3
Oxygen conc. at min. Class A design conc., vol. %	12.6	12.5	12.2	12.5
Min. Class B fire design conc., vol. %	41.2	47.5	51	43.7
Oxygen conc. at min. Class B design conc., vol. %	12.3	11.0	10.3	11.8
Inerting design conc., Methane/Air, vol. %	47.3	-	61.4	-
Oxygen conc. at min. inerting design conc., vol. %	11.0	-	8.1	-

Note 1: Agent vapour specific volume s = k1 + k2 x t, m3/kg at an atmospheric pressure of 1.03 bar where t is the vapour temperature in deg C. Vapour density = 1/s.
Note 2: Extinguishing and design concentration values from ISO 14520 2nd Edition (2006)

11.2.3.1 Physiological Effects

The primary health concern relative to the use of the inert gas agents containing nitrogen or argon 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 8% carbon dioxide[16], which is intended to increase blood oxygenation and cerebral blood flow in low oxygen atmospheres.

11.2.3.2 Environmental Factors

Inert gas agents are neither ozone depleting substances nor greenhouse gases and, as such, pose no risk to the environment.

Table 11-9 Inert Gas Agents Fixed System Features

Generic name	IG-541	IG-55	IG-01	IG-100
Agent exposure limits				
Max unrestricted agent conc., vol. % (1)	43	43	43	43
Max restricted agent conc., vol. % (2)	52	52	52.	52
System requirements per m^3 of protected volume				
Class A hazard				
Agent gas volume, m^3	0.457	0.529	0.509	0.494
Cylinder storage volume, litre (3)	3.04	3.53	2.83	2.75
Cylinder volume relative to halon 1301 (4)	10.0	11.5	9.3	9.0
Class B hazard				
Agent gas volume, m^3	0.531	0.643	0.715	0.574
Cylinder storage volume, litre (3)	3.54	4.29	3.97	3.19
Cylinder volume relative to halon 1301 (4)	11.6	14.0	13.0	10.4
System Features				
Nominal Discharge Time, seconds	60	60	60	60
Cylinder pressure, bar	150 or 200	150 or 200	180	180 or 240

Note 1: Corresponds to a residual oxygen concentration of 12 Vol. %.
Note 2: Corresponds to a residual oxygen concentration of 10 Vol. %.
Note 3: Approximate, for the minimum indicated cylinder pressure.
Note 4: Halon 1301 cylinder volume per m3 hazard. See Note 4 of Table 11-6.

11.2.4 Water Mist Technology

One of the non-traditional halon replacements which has been developed and commercialized is fine water mist technology. Water mist fire suppression technologies are described in national and international standards such as NFPA 750 *Standard on Water Mist Fire Protection Systems* and the FM Approvals Standard No. 5560 *Water Mist Systems*. The latter 249 page document is available at no charge from the following website:

http://www.fmglobal.com/approvals/resources/approvalstandards/5560.pdf.

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[16] Inert gas agent IG-541 contains 8% carbon dioxide and is approved by the U.S. EPA SNAP rules as a safe alternative to halon 1301 in total flooding fire protection systems. At elevated concentrations, however, carbon dioxide is not safe for human exposure and is lethal at fire extinguishing concentrations.

Briefly, fine water mist relies on sprays of relatively small diameter droplets (less than 200 μm) to extinguish fires. The mechanisms of extinguishment include the following:

- gas phase cooling
- oxygen dilution by steam formation
- wetting and cooling of surfaces, and
- turbulence effects

Water mist systems have attracted a great deal of attention and are under 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 μ) 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 machinery spaces, combustion turbine enclosures, flammable and combustible liquid storage spaces 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 cubic meter of protected space is sufficient to extinguish fires. 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 coalescence, surface deposition, and gravity dropout. The suppression mechanism of water mist is primarily cooling of the flame reaction zone below the limiting flame temperature. Other mechanisms are important in certain applications; for example, oxygen dilution by steam has been shown to be important for suppression of enclosed 3-D flammable liquid spray fires.

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 test enclosure effects. Hence, the required application rate varies by manufacturer for the same hazard. Therefore, water mist must be evaluated in the combined context of a suppression system and the risk it protects and 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 utilize water delivered at 40-200 bar pressure and spray nozzles which deliver droplet sizes in the 10 to 100 μ diameter range. Dual systems use air, nitrogen, or other gas to atomize water at a nozzle. Both types 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 atomizer gas storage.

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 minimize the uncertainty and direct the experimental program.

11.2.4.1 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.”

11.2.4.2 Environmental Factors

Water mist does not contribute to stratospheric ozone depletion or to greenhouse warming of the atmosphere. Water containing additives may, however, offer other environmental contamination risks, e.g., foams, antifreeze and other additives.

11.2.5 Inert Gas Generators

Inert gas generators utilize a solid material which oxidizes rapidly, producing large quantities of CO_2 and/or nitrogen. The use of this technology to date has been limited to specialized applications such as 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 utilized in some U.S. Navy aircraft applications.

11.2.5.1 Physiological Effects

Applications to date have included normally unoccupied areas only. 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.

11.2.5.2 Environmental Effects

Gases emitted by these products do not contribute to stratospheric ozone depletion or to greenhouse warming of the atmosphere except to the extent that they emit carbon dioxide.

11.2.6 Fine Solid Particulate Technology

Another category of 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 chemicals. 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 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 vaporizing 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 enterprises have commercialized 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 optimize. However, there is concern of potential collateral damage to electronics, engines, and other sensitive equipment. Condensed aerosol generators, which produce solid particulates through combustion of a pyrotechnic material, 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.

Additional information on fine solid particulate technologies may be found in NFPA 2010 *Standard for Fixed Aerosol Fire Extinguishing Systems*.

11.2.6.1 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 particularly in the protection of occupied spaces. These effects include inhalation of particulate, blockage of airways, elevated pH, reduced visibility, and the products of combustion from combustion generated aerosols, such as HCl, CO, and NO_X.

11.2.6.2 Environmental Factors

Fine particulate aerosols themselves and associated inert gases from generators do not contribute to stratospheric ozone depletion or to greenhouse warming of the atmosphere. There may be environmental ozone depletion or greenhouse gas effects, however, where aerosols are delivered with halocarbon carrier gases.

11.3 System Design Considerations for Fixed Systems

Care must be taken throughout the design process to assure satisfactory system performance. 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:

11.3.1 Definition of the Hazard

- Fuel type(s)
- Fuel loading
- Room integrity (openings, ventilation, false ceilings, subfloors)
- Dimensions and Net Volume of the room
- Temperature extremes
- Barometric pressure (altitude above sea level for gas systems)

11.3.2 Agent Selection

- Statutory approvals
- Personnel safety
- Minimum concentration required (cup burner/full scale tests)
- Design concentration required with factor of safety
- NOAEL/LOAEL or limiting oxygen concentration. Is the agent design concentration within safe exposure limits over the range of feasible hazard temperatures and net volumes?
- Decomposition characteristics
- Replenishment availability

11.3.3 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
  - Aging tests for elastomers
  - Flow tests (software verification, balance limitations)
  - Fire tests (nozzle area coverage, nozzle height limitations
- System has documented design, installation, maintenance procedures

11.3.4 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

11.3.5 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 and adequacy of pressure relief venting
- 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

11.3.6 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

11.4 Alternatives for Portable Extinguishers

11.4.1 Traditional Streaming Agents

11.4.1.1 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 energized electrical circuits are present.

11.4.1.2 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.

11.4.1.3 Aqueous Film Forming Foam (AFFF)

Extinguishers using water and AFFF additives may be more effective than those using clean water only on fires of ordinary combustibles such as wood, paper and fabrics. Additionally, water with AFF additives will have improved ability, over water alone, to extinguish fires involving flammable or combustible liquids. Also, 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 vapour 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.

11.4.1.4 Carbon Dioxide (CO_2)

Carbon dioxide extinguishers use CO_2 stored 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 less effective for extinguishing fires of ordinary combustibles such as wood, paper and fabrics.

11.4.1.5 Dry Chemical

Dry chemical extinguishers are of two types. Ordinary dry chemicals, usually formulations based on sodium or potassium bicarbonate, are suitable for fires involving flammable liquids and gases. Multipurpose dry chemicals, usually formulations of monoammonium phosphate (MAP), 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.

11.4.2 Halocarbon Agents

Information on halocarbon streaming agents is contained in Table 11-10. These agents come closest to matching all the desirable properties of halon. 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.

11.4.2.1 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.

11.4.2.2 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 11-10. Traditional streaming agents do not present environmental concerns in the areas of ODP, GWP, or atmospheric lifetime but may offer other environmental risks associated with the use of additives, e.g., fluorosurfactants.

Table 11-10 Halocarbon Streaming Agents for Portable Fire Extinguishers

	Physical Characteristics				**Environmental Factors**		
Generic Name	**Group**	**Storage State**	**Chemical Composition**		**ODP****	**GWP*** 100 yr. (1)**	**Atmospheric Lifetime yr. (1)**
			Weight %	**Species**			
Halon 1211	Halon	LCG*	CF_2ClBr		3	1,300	11
HCFC Blend B	HCFC &	CGS****	>96%	HCFC-123	0.02	120	1.4
	PFC Blend		<4%	CF_4	0	5,700	50,000
			<4%	Argon	0	n/a	n/a
HCFC Blend E	HCFC	LCG*	90%	HCFC-123	0.02	120	1.4
	Blend	Liquid	8%	HFC-125	0	3,400	29
			2%	isopropenyl-1-methylcyclohexene	0	n/a	n/a
HCFC-124	HCFC	LCG*	$CHClF\text{-}CF_3$		0.022	620	6.1
HCFC-123	HCFC	Liquid	$CHCl_2\text{-}CF_3$		0.02	120	1.4
HFC-236fa	HFC	LCG*	$CF_3CH_2CF_3$		0	9,400	220
HFC-227ea	HFC	LCG*	CF_3CHFCF_3		0	3,500	33

*LCG - Liquefied Compressed Gas
**ODP - Ozone Depletion Potential
***GWP - Global Warming Potential
****CGS – Compressed Gas In Solution
Note 1: Source: IPCC Third Assessment Report (2001)

11.5 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.

11.5.1 Effectiveness on Ordinary Combustibles

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

11.5.2 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.

11.5.3 Electrical Conductivity

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

11.5.4 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 hidden void space in a commercial airliner.

11.5.5 Range

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

11.5.6 Effectiveness to Weight Ratio

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

11.5.7 Secondary Damage

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

11.6 Selection of an Alternative Streaming Agent

The performance of each alternative is summarized in Table 11-11. 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 11-11 Portable Fire Extinguisher Capability Comparison

Type	Ordinary Combustibles	Flammable Liquids	Suitable on Energized Electrical Hazards	Ability to Permeate	Stream Range	Effective Weight	Secondary Damage
CO_2	Poor	Fair	Yes	Good	Fair	Poor	Good
Multi-purpose Dry Chemical	Good	Good	Yes	Fair	Good	Good	Poor
AFFF	Good	Fair	No	Poor	Good	Poor	Poor
Water Stream	Good	Poor	No	Poor	Good	Poor	Poor
Water Fog	Good	Fair	Yes	Fair	Fair	Fair	Fair
Halocarbon	Good	Good	Yes	Good	Good	Good	Good
Halon 1211	Good	Good	Yes	Good	Good	Good	Good
Sodium Bicarbonate Dry Chemical	Poor	Good	Yes	Fair	Good	Good	Poor
Potassium Bicarbonate Dry Chemical	Poor	Good	Yes	Fair	Good	Good	Poor

11.7 Conclusions

Alternative extinguishing agents and technologies are available for nearly all new fire protection applications that previously employed halons. Exceptions are found in certain civil aviation fire protection applications.

11.8 References

Halon Alternatives Research Corp., PBPK Model, ISO 14520-1, Annex G, 2nd Edition, 2006, http://www.harc.org/pbpkharc.pdf.

U.S. Environmental Protection Agency (EPA), “Carbon Dioxide as a Fire Suppressant: Examining the Risks,” EPA430-R-00-002, http://www.epa.gov/Ozone/snap/fire/co2/co2report.pdf.

12.0 Halon Emission Reduction Strategies

12.1 Introduction

Releasing halon into the atmosphere is fundamental to the process of flame extinction and enclosed space inertion. However, these necessary emissions only use a small proportion of the available supply of halon in any year. Most countries have discontinued system discharge testing and discharge of extinguishers for training purposes resulting in emission reductions in some cases of up to 90%. Additional and significant reductions of halon emissions can be realized by improving maintenance procedures, detection and control devices, etc. as outlined in this Technical Note.

Emission reduction strategies are discussed in detail in the eight following areas:

- Alternative Fire Protection Strategies
- Halon Use Minimisation
- Maintenance Program
- Detection Systems
- Hazard and Enclosure Review
- Personnel Training And Documentation
- Halon Transfers And Storage
- Halon Discharging

12.2 Alternative Fire Protection Strategies

Do not use halons in new fire protection applications or new designs of equipment. Alternatives are available for virtually all applications with very few exceptions, e.g., some aircraft applications. Clearly halon emissions can be reduced if halon is not employed as the fire protection agent in the first place. In all cases, in determining whether or not a halon protection system is required or should be removed, a risk assessment should be performed.

Good engineering practice dictates that, where possible, hazards should be designed out of facilities rather than simply providing protection against them. Active fire extinguishing systems which perform the same function as halon systems should not be considered as the only alternative to halon systems. A combination of prevention, inherently safe design, minimisation of personnel exposure, passive protection, equipment duplication, detection, and manual intervention should be considered as follows:

1) Prevention

   Where there is a low probability of fire and that probability can be reduced to acceptable proportions by procedures and diligence, the need for protection can be minimised. Where it is not possible to reduce the chance of fire/explosions sufficiently, then a combination of prevention and other measures such as sensitive fire/gas detection and manual intervention may be considered as acceptable protection.

2) Inherently Safe Design

It may be possible to eliminate the need for protection by ensuring that either all the equipment in the area is not combustible, or that inventories are sufficiently small such that there is no immediate threat to life or critical equipment before evacuation of the area and manual intervention can take place.

3) Minimisation Of Personnel Exposure

Where the only threat to life is within the protected area, the need to man the area may be minimised by the segregation of the hazardous equipment from the areas requiring access. Similarly, evacuation strategies and routes may be arranged to ensure that personnel can evacuate before a fire reaches a scale which can threaten life.

4) Passive Protection

Critical equipment may be protected by direct protection with passive fire protection materials to ensure its survivability, or by location in a protective enclosure. This may not be possible where the inherent risks are within the equipment itself.

5) Equipment Duplication

Critical equipment may be duplicated so that the loss of one item does not affect the system availability. However, since secondary equipment may also be exposed to hazards, duplication may not protect the total system from all hazards.

6) Detection

Early detection could allow isolation and manual intervention before a fire reaches a size which can cause major damage or threaten life.

7) Manual Intervention

Critical examination of the fire hazards may show that, where codes permit, a manual response using agents other than halons is acceptable when trained fire teams can react within a short time.

Performing an overall Risk Assessment, taking into consideration fire protection strategies, allowable down time, backup equipment & documentation, backup services, etc., will help in determining the optimum fire protection strategy. A thorough analysis may also provide documentation necessary for obtaining insurance.

12.3 Halon Use Minimisation

When protection against fire or explosion hazards with halon is considered critical, the following practices should be observed to minimise the use of halon systems, and thus reduce emissions potential:

1) Local Application

Local application systems should be used where the primary fire hazards within an area can be identified and effective protection achieved with less agent than a total flood design would require.

2) Reserve Systems

Reserve systems should only be installed when:

- There is a confirmed immediate need to restore fire protection.
- Recharge supplies are an unacceptable transport time away.

If it is feasible to do so, consideration should be given to leaving reserve supplies unconnected, which can help avoid unwarranted release of the reserve supply. If possible, keep reserve agent in a single large storage tank to reduce the risk of accidental release and minimize the chance of leaking. Note, if the reserve halon is on site in a system of cylinders rather than a single large storage tank, then the chances of leaking and accidental discharge is increased by approximately the number of cylinders. Where there are no on-site capabilities for the storage and transfer of halon agent nor a contractor nearby with the capabilities, then consideration should be given to placing all reserve cylinders in an enclosure and installing an automatic halogen leak detector with remote and/or local alarms.

3) Extended Discharge

All possible means to maintain extinguishing concentration from an initial discharge, such as stopping air movement, closing openings, installing system-actuated dampers or shutters, etc., should be explored before considering an extended discharge. Extended discharge systems should be avoided as they normally require more halon than the initial discharge.

4) Zoned Systems

Where it is technically feasible, protection of several separate zones by a single halon bank using total or partial discharge should be considered.

12.4 Maintenance Program

Attention to maintenance programs can add years to a halon bank by reduced emissions. This represents money saved in two ways. It minimises the need to produce or purchase halon, and it prolongs the useful life of the existing fire protection system. Once emissions are minimised, funding for system replacement can be planned over longer periods, for example over the life of the program/equipment. Cost payback from maintenance, manufacturer improvements, and more frequent servicing can be realised almost immediately. A maintenance program includes; upgrading equipment to utilize improvements and new technology, scheduling equipment replacement, proper design, regular maintenance, and regular system checks.

1) Upgrade Equipment

Upgrade halon equipment to minimise leaks, prevent accidental discharges, and minimise false alarms/discharges. In some cases, the same equipment (with minor modifications) can be used for the halon replacements. In most cases, the alarm/detection system can be reused after halon system removal regardless of the method of fire protection. Thus upgrades to equipment represent a natural progression in an operation and maintenance program.

2) Scheduled Equipment Replacement

A well developed maintenance program will include scheduled equipment replacement, based on the expected life of the equipment. The equipment life may be based on manufacturer's recommendations, local or national regulations, or previous history. Planning for replacement provides a basis for forecasting long term funding requirements.

3) Design and Regular Maintenance

In some cases, inadvertent discharges represent the largest source of halon emissions, and they can often be eliminated through improved maintenance and/or system redesign.

Inadvertent discharges are mostly attributed to:

- Automatic detectors responding to transient changes in environmental conditions (i.e., humidity, airborne dust, etc.).
- Electronic unreliability or poor circuit protection from outside interference, e.g. lightening.
- Design not conforming to manufacturer’s recommendations or Listing.
- Irregular and/or inadequate personnel training.
- Inadequate maintenance procedures and documentation.
- Accidents during system servicing or testing (see note below).

Note: Reductions in false releases during maintenance of detection systems have been observed when electrical isolation switches are incorporated in protection system designs. Such devices prevent equipment from being returned to service while still in an alarm condition.

4) Regular System Checks

System checks and maintenance should be done on a frequent and regular basis. System cylinders should be visually inspected on a monthly basis for obvious damage to the cylinders, valves, leak detectors, etc. The contents of cylinders should be checked every six months to monitor losses. (Note: There are a number of methods for checking the quantity of halon in a cylinder. Check with the manufacturer for the optimum method.) Valves, hoses, manifolds, and fittings should be inspected at the same time using a local halon sensor such as those used to check refrigeration systems for leaks. Cylinders should only be replaced if more than 5% by weight of the initial contents has been lost or will be lost by the next service. Minor losses within this 5% can often be tolerated and will minimise unnecessary losses incurred in the process of rectifying such leaks. Bar coding methods have been successfully employed to record and track halon quantities and equipment condition.

It is imperative in cases where halon is still being used that considerable effort is given to developing better maintenance methods for the equipment. Improved discharge system reliability is achieved through enhanced maintenance procedures and/or replacement with new technology. Development of a maintenance program should be done in parallel with performing a risk assessment of the facility and operations. Once a risk assessment has been performed on an operation, the fire protection needs are then determined. In cases where automatic fire detection or suppression is determined necessary, maintenance becomes a significant and integral part of the risk management.

12.5 Detection Systems

Automatic halon systems go hand in hand with sensitive detection systems. Poor design and improper maintenance of sensitive detection systems will almost always result in unwanted halon releases. It is therefore essential that:

1) Systems components not be mixed.

Systems assembled from a mixture of components from different manufacturers should be avoided unless the fire and/or gas control panel manufacturer takes responsibility for the overall system.

2) Halon is released only after positive confirmation of fire.

Automatic release circuits should be designed to operate only after at least two detectors on independent circuits have confirmed a serious incident.

Where the Authority Having Jurisdiction permits, in facilities that are occupied continuously by trained personnel, the use of CCTV flame detectors will allow trained personnel to remotely, visually confirm the existence of a fire within a predetermined time when alerted by pop-up video. If no fire exists, then release of halon can be inhibited.

Where the Authority Having Jurisdiction permits, in protected areas that are occupied continuously by trained personnel, consideration should be given to manually activated systems rather than automatic.

3) Equipment chosen conforms to internationally or nationally accepted specifications.

Equipment chosen should conform to internationally or nationally accepted specifications incorporating suppression of airborne and electrical interference. For example, BS7273 2000 covers the electrical actuation of total flooding extinguishing systems, and was introduced to improve the reliability of control systems to reduce the likelihood of accidental discharges [1]. One of the major requirements is that the circuit design and equipment construction should be such that the system should not discharge because of the failure of a single component or the short circuiting of two current paths. In addition the equipment must be protected from EMI (cellular phones, etc.), e.g., EC Directive 2004/108/EC [2].

4) Existing detection systems are upgraded to take advantage of the latest technology.

Experts in the field have determined that fires produce different types of stimulation that can be detected by sensors, e.g., molecular gases, condensed-phase aerosols, heat conduction, electromagnetic radiation, and acoustic waves. As a result there are a number of ways the fire can be detected. An example of upgraded technology in this area would be the use of early warning air sampling smoke detection systems. These types of systems employ a laser based light source [3]. Owing to particle size discrimination, a laser based light source requires no air intake filter which can clog over time and desensitize the system. In addition, a laser based light source requires no maintenance and no replacement on a periodic basis. Other examples are infrared optical sensors which have an advantage over sensors that depend on sunlight or operate in the ultraviolet range because they cannot be blinded by smoke or obscured by oil or other substances. Consequently, they are less likely to produce false alarms. Sensors using optical signal processing also achieve very rapid response times.

Wherever possible addressable detectors and control panels should be employed. Such systems enable exact location of the fire event to be made resulting in faster attendance with first aid fire fighting. Addressable systems are now no more expensive than earlier conventional systems. More sophisticated systems are also available where a combination of analogue detectors and control equipment can, in addition to identifying event location, compensate for detector deterioration and advise when sensor maintenance is required or the system is tending towards a false alarm. This can be either automatically corrected or manually through the service company [4].

5) Trained service personnel are employed.

User and service company engineers should be fully familiar with the system operation and the equipment fitted and have undergone product/system training with the supplier.

12.6 Hazard and Enclosure Review

Monitor and control the hazard. Check for enclosure modifications or changes to the configuration of the protected space. Halon system removal or redesign will likely be required where walls have been repartitioned, moved, the contents of the enclosure have been changed significantly, etc. During these types of changes it is also important to review impacts to the protection system which may include changes in the environmental control system. It is usually necessary to modify the halon system when heating, ventilation and/or air conditioning systems (HVAC) are added to the protected zone. Check with local/national fire regulations and manufacturers recommendations for specific requirements, which will include requirements to connect controls of the halon system into the HVAC system for automatic shutdown where the HVAC is not dedicated to the protected enclosure.

12.7 Personnel Training and Documentation

Where on-site maintenance will be performed, it is essential that the personnel performing the service be properly trained. It is equally important that the system user be informed of the proper operation of the system and cautioned on activities that could result in an unwanted discharge. Both groups should be educated on ozone depletion issues and the impact of halon releases, as well as the restrictions on future supplies. Encourage participation rather than demand compliance.

Where on-site maintenance personnel are not available, the user should take out a maintenance contract. Whether on-site personnel are utilized or a maintenance servicing contract, always insist on trained and licensed service engineers.

Risk Management includes establishing good system documentation and maintenance procedures. Ensure there is documentation to follow in performing system maintenance and system checks. Review it thoroughly and periodically to see that it correctly addresses the specific equipment on-site and is not a generic copy. Install proper warnings, labels, and instructions on-site, for example post signs on the walls of areas protected by halon systems stating "This area is protected by Halon, Contact xxx prior to performing modifications to this enclosure". Track quantities of halon in service, storage, and emitted to determine areas where emissions can be reduced, as well as, to identify halon needs. Where large quantities of halon are in service, utilize a computer database for tracking quantities and component failures.

12.8 Halon Transfers and Storage

The component of halon emissions related to halon transfers can be substantially reduced by the use of approved filling rigs. Any operation relating to a high pressure gas must conform to the appropriate safety standards in line with all relevant local, national, and international regulations. The equipment used must be certified by a recognized standards organization and be compatible for halon use.

Environmental and operator safety dictates that all filling procedures should be conducted by trained, and preferably licensed, personnel. Filling operations should be carried out in a well ventilated area with all safety relief valves from the rig connected to a containment/recovery system. All equipment, particularly flexible connections, should be checked at monthly intervals for signs of deterioration. To avoid corrosion problems, it is essential that the halon not be allowed to come into contact with water. The filling rig must be leak tested to twice its normal pressure prior to its initial use, and constantly monitored for leaks during the filling operation. During filling and recovery operations, overall loss of halon should be minimised and under no circumstances should it exceed 5%.

It is recommended that all new portable fire extinguishers or system cylinders be leak tested at all welds, valves, fill points, fittings, burst discs and other cylinder closures before and after being filled with halon. Any units that show signs of leaking should be connected immediately to a recovery rig and the contents transferred into the recovery container. The cylinder/valve should be rebuilt and the leak located and eliminated. Newly filled cylinders should not be accepted unless they are certified as having total leak rates below 0.5% by weight per annum of the initial halon fill.

Most safety standards require that portable halon extinguishers be emptied and refilled at regular intervals. This permits the operation of the appliance to be checked, and allows the cylinder to be inspected for signs of corrosion and to be subjected to pressure testing. In the past, frequently the halon was released to the atmosphere. Clearly such practices must be banned, and all discharging accomplished using approved recovery rigs.

Recovery rigs should be operated so as to avoid contaminating halon supplies. Cylinders containing halon should be emptied by pressurising with dry nitrogen or by use of positive displacement pumps. Vapours should be recovered if possible. Halons should never be mixed thereby enhancing recycling possibilities. Halon 1211 recovery systems with an efficiency of 98% and halon 1301 recovery systems with efficiencies >96% are readily available today [5]. The following tables list examples of types of halon recovery equipment and manufacturers known to the HTOC:

Table 12-1 Halon 1211 Recycling, Recovery, and Reclamation Equipment Manufacturers

Type	Product Name	Manufacturer	Country
Halon 1211	Recovery and Conditioning for Halon (REACH)	Kidde Aerospace Inc. 4200 Airport Drive, N.W. Wilson NC 27896 USA Tel: + 1 252 237 7004 Fax: +1 252 246 7185 **or** Kidde Graviner Ltd, Mathisen Way, Colnbrook Slough Berkshire, SL3 0HB United Kingdom Tel: +44 (0)1753 683245 Fax: +44 (0)1753 685126 Web Site: www.kiddegraviner.com	USA United Kingdom
Halon 1211	Defender M-1 Defender C-1	RemTec International 1100 Haskins Rd. Bowling Green Ohio 43402 USA Tel: 800-372-1301 Fax: 419-867-3279 Web Site: www.remtec.net	USA
Halon 1211	Halon 1211 Recovery System	Getz Manufacturing 540 S Main Street North Pekin IL 61554, USA Tel: (309) 382-4389 Fax: (309) 382-6088 Web Site: www.getzmfg.com	USA
Halon 1211	H1301 with Halon 1211 upgrade kit.	Neutronics, Inc. 456 Creamery Way Exton PA 19341 Tel: (610) 524-8800 Fax: (610) 524-8807 Web Site: www.neutronicsinc.com	USA

Table 12-2 Halon 1301 Recycling, Recovery, and Reclamation Equipment Manufacturers

Type	Product Name	Manufacturer	Country
Halon 1301 And Halon 1211	Defender CM700M1 Defender C700	RemTec International 1100 Haskins Rd. Bowling Green Ohio 43402 USA Tel: 800-372-1301 Fax: 419-867-3279 Web Site: www.remtec.net	USA
Halon 1301	Recovery and Conditioning for Halon (REACH)	Kidde Aerospace Inc. 4200 Airport Drive, N.W. Wilson NC 27896 USA Tel: + 1 252 237 7004 Fax: +1 252 246 7185 **or** Kidde Graviner Ltd, Mathisen Way, Colnbrook Slough Berkshire, SL3 0HB United Kingdom Tel: +44 (0)1753 683245 Fax: +44 (0)1753 685126 Web Site: www.kiddegraviner.com	USA United Kingdom
Halon 1301	Halon 1301 Recovery System	Getz Manufacturing 540 S Main Street North Pekin IL 61554, USA Tel: (309) 382-4389 Fax: (309) 382-6088 Web Site: www.getzmfg.com	USA
Halon 1301	H1301	Neutronics, Inc. 456 Creamery Way Exton PA 19341 Tel: (610) 524-8800 Fax: (610) 524-8807 Web Site: www.neutronicsinc.com	USA

Table 12-3 Halon 2402 Recycling, Recovery, and Reclamation Equipment Manufacturers

Type	Product Name	Manufacturer	Country
Halon 2402	Recovery and Conditioning for Halon (REACH)	Kidde Aerospace Inc. 4200 Airport Drive, N.W. Wilson NC 27896 USA Tel: + 1 252 237 7004 Fax: +1 252 246 7185 **or** Kidde Graviner Ltd, Mathisen Way, Colnbrook Slough Berkshire, SL3 0HB United Kingdom Tel: +44 (0)1753 683245 Fax: +44 (0)1753 685126 Web Site: www.kiddegraviner.com	United Kingdom
Halon 2402	Defender C2402	RemTec International 1100 Haskins Rd. Bowling Green Ohio 43402 USA Tel: 800-372-1301 Fax: 419-867-3279 Web Site: www.remtec.net	USA
Halon 2402	Custom made to special order	Neutronics, Inc. 456 Creamery Way Exton PA 19341 Tel: (610) 524-8800 Fax: (610) 524-8807 Web Site: www.neutronicsinc.com	USA

In the past it has been common practice to install redundant or backup halon systems on-site for providing immediate protection once the primary system has discharged. This is no longer an encouraged practice. Where backup systems are not critical, they should be removed from service and the halon recovered. The proliferation of relatively inexpensive, high efficiency halon recovery systems makes it easier to increase the longevity of an individual's halon bank. By recovering all on-site halon that is not used in critical, primary systems, the risk of accidental discharge or agent leakage is minimized. The halon can be recovered into large storage tanks and the tanks monitored for leaks.

The following practices should be observed:

- Store halon reserves in bulk storage where possible rather than in individual cylinders.
- Recover surplus halon from systems and appliances.
- Provide good storage conditions for both in service systems/cylinders and backup systems or bulk agent, and install leak detection for storage atmospheres.

12.9 Halon Discharging

The discharging of halon systems and extinguishers for testing and other non-fire related procedures is a cause of unnecessary emissions that can easily be avoided.

1) Systems

Do not perform discharge tests using halon under any circumstances. The Committee recommends that any existing regulations which mandate such tests should be amended. A principal emission control measure adopted by the fire protection community has been the reduction of halon 1301 full discharge tests by utilising several alternative procedures to ensure operational readiness of a system. These procedures are incorporated in the most recent edition of NFPA 12A, Halon 1301 Fire Extinguishing Systems [6]. The reasons for discharge tests using halon 1301 were to check enclosure integrity, distribution and concentration of agent, movement of piping supports and piping, and detector/control device functions.

To address enclosure integrity a test, known as a "door fan" test, is conducted. The test uses air pressure, developed with a fan and measured with calibrated gauges, to determine the ability of an enclosure to hold the halon 1301 concentration. The calculations to interpret the gauge readings into halon 1301 hold time are usually performed with a small computer.

To address the other items, fire protection equipment standards play an important role. For example, UL 1058, Standard For Halogenated Agent Extinguishing System Units [7], provides an indication of the level of reliability for the proper operation of detector/control devices, guidelines for the proper installation of nozzles to achieve sufficient agent distribution, and a test for verifying a manufacturer's flow calculation methodology. Only systems with complex piping arrangements should require additional agent distribution testing. If you must test, use a surrogate gas. HFC-125 has been proposed as a candidate alternative to halon 1301 for such tests, but it should be noted that this gas has a fairly high Global Warming Potential, which may restrict its use in some countries.

Although the exact decrease in emissions, caused by the reduction in discharge testing using halon 1211, halon 2402, or halon 1301, is not known, it is estimated through the modelling of emissions and inventories to exceed 3500 metric tonnes per annum. The Committee therefore believes that eliminating discharge testing on a global basis should be effected immediately and could be effected without major impact on protection system integrity.

2) Portable Fire Extinguishers

Do not discharge manually operated halon fire extinguishers for training purposes.

The Committee believes that it is now possible to virtually eliminate this source of halon emissions. Discussions within the industry suggest that fire training organisations are now only demonstrating the use of portable halon extinguishers and have stopped using them during training. Thus, where three or four extinguishers may have been discharged in the past, now none are discharged during training sessions. With the increase in awareness of the environmental problems associated with halon, many users are switching to CO_2, dry chemical, AFFF, Water Mist, or other acceptable non or low ODS clean agent extinguishers. Thus, the demand for training and the reliance on the use of portable halon extinguishers is rapidly declining. A pressurised water extinguisher system has been developed for the U.S. military for fire fighter training. The handling behaviour is similar to a halon 1211 system [8].

Video demonstrations of halon 1211 appliances in use compared to alternatives would assist in building user confidence without the actual use of halon 1211 in every training session. Interactive video training has also been developed for US military applications and can be developed for most other needs [8]. The U.K. military in conjunction with the Civil Aviation Authority has also developed and utilises interactive video training [9]. Therefore, it is reasonable to assume that the use of halon 1211 for training purposes can be virtually eliminated.

Similar to the halon system cylinders, UL 1093, Standard For Halogenated Agent Fire Extinguishers provides requirements for the construction and performance of portable halon type fire extinguishers [10].

12.10 Conclusions

Avoidable halon releases account for greater halon emissions than those needed for fire protection and explosion prevention. Clearly such releases can be minimised. In reviewing reduction strategies, the UNEP Halons Technical Options Committee recommends the following:

- Reduce halon usage to existing critical applications only.
- Do not use halon in new fire protection applications unless absolutely necessary.
- Encourage the application of risk management strategies and good engineering design to take advantage of alternative protection schemes.
- Implement a regular maintenance program.
- In protected areas that are occupied continuously by trained personnel, consideration should be given to manually activated systems or automatic systems that are activated via CCTV flame detectors.
- Encourage users of automatic detection/release equipment to take advantage of the latest technology.
- Maintain enclosure integrity.
- Verify system design and requirements when changes in hazard have occurred.

- Improve maintenance and system configuration documentation.
- Educate and train personnel on system characteristics.
- Introduce the use of halon recycling equipment to recover all surplus or reusable material.
- Utilize well-managed central storage for halon reserves and install automatic leak detection.
- Discontinue protection system discharge testing using halon as the test gas, and amend any existing regulations which mandate such testing.
- Discontinue the discharging to the atmosphere of portable halon extinguishers and system cylinders during equipment servicing.
- Discontinue the discharge of portable halon fire extinguishers for training purposes.

12.11 References

1. British Standards Institute (BSI), "Electrical Actuation of Gaseous Total Flooding Extinguishing Systems," BS7273 / Part 1 / 2000, British Standards Institute, London, UK, 2000.

2. *European Community Directive 2004/108/EC*, Office for Official Publications for European Communities, Luxembourg, Germany, 2004.

3. Fenwal, "Analaser II," Fenwal Protection Systems, Ashland, MA.

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6. NFPA 12A-2004, *Halon 1301 Fire Extinguishing Systems*, National Fire Protection Association, Quincy, MA, 2004.

7. Underwriters Laboratories Inc., UL 1058, "Standard for Halogenated Agent Extinguishing System Units," Third Edition, Underwriters Laboratories Inc., Northbrook, IL, 31 August 1995.

8. Hughes Associates, Inc., 3610 Commerce Drive, Suite 817, Baltimore, MD.

9. Civil Aviation Authority Fire Service Branch, Aviation House, South Area, Gatwick Airport, Gatwick, West Sussex, UK.

10. Underwriters Laboratories Inc., UL 1093, "Standard for Halogenated Agent Fire Extinguishers," Fifth Edition, Underwriters Laboratories Inc., Northbrook, IL, 30 November 1995.

13.0 Explosion Protection – Halon Use and Alternatives

The following information can also be found in the Halon Technical Options Committee’s Technical Note 3.

13.1 Introduction

Working spaces, whether manned or not, which may contain dispersed mixtures of fuel and air are at risk of severe loss of property or life should ignition occur. The propagation of flames through such spaces occurs so rapidly that evacuation of personnel is generally not possible. Enclosed spaces are subject to extremely rapid rates of pressure increase leading possibly to explosion of the enclosure. Explosions may lead to fatalities in the immediate area or in areas adjacent to the risk areas. Explosions may cause catastrophic failure of plant components leading to major fires, toxic releases, or environmental damage. The subject of this section is the protection of life and property from such explosive events.

13.2 Definitions

Deflagration:	A combustion process propagated at sub-sonic velocity through a fuel-oxidizer mixture usually consisting of air and a dispersed fuel component, which may be a flammable vapour, mist, or dust. Energy release rates are usually limited by the fundamental burning velocity (thermal and reaction kinetic feedback mechanisms) of the mixture and the extent of the surface area of the flame sheet. Deflagration flame velocities begin at about 0.5 m/s and will rapidly accelerate in the presence of turbulence. Transition to detonation is possible under some conditions. Rates of energy release are typically several orders of magnitude higher than for diffusion flame processes.
Detonation:	A combustion process propagated at sonic or super-sonic velocity through a fuel-oxidizer mixture. The speed of the combustion wave then becomes supersonic relative to the unreacted medium. Flame velocities in excess of 1000m/s prevail.
Explosion:	The damage or injury-producing event which may result from a deflagration or detonation or other pressure-elevating process.
Fire:	A combustion process most often characterized by diffusion flame behaviour where the rate of energy release is limited by the molecular scale mixing of fuel and oxidant species.
Inertion:	The prevention of the initiation of combustion of an otherwise flammable atmosphere by means of the addition of an inhibiting or diluting agent.

Suppression:	The termination of combustion processes through inerting, chemical inhibition, or thermal quenching effects of extinguishing agents.

13.3 Explosion Protection Methods

Spaces at risk of a potential explosion may be protected in the following ways:

13.3.1 Prevention

1) Through application of appropriate principles of safe engineering design construction, operation, and maintenance of process systems such that explosion conditions do not occur as a consequence of normal or abnormal processing conditions
2) Through application of inerting agents to atmospheres which are, or may become flammable.
3) Through high-rate mechanical ventilation of atmospheres that are, or may become flammable to eliminate combustible conditions.

13.3.2 Mitigation, which may be achieved by designing spaces at risk for:

1) Containment of the pressure developed.
2) Pressure relief venting, i.e., release of gas through relieving panels to avoid attainment of pressures which would cause the process to fail.
3) Combustion isolation, i.e., prevention of the transmission of the combustion Process to associated equipment spaces.
4) Explosion suppression, i.e., detection and extinguishment of a deflagration event in its early stages of development prior to attainment of pressure within equipment that can result in damage or personal injury.

The principal extinguishing agents used in new explosion suppression systems are dry chemicals and water. Dry chemicals and hydrofluorocarbons are also particularly useful in applications where an important component of the protection strategy is isolation of pipes and ducts using an inert chemical barrier.

13.4 Fundamentals of Explosion Suppression

Explosion suppression is a special case of fire suppression characterized by very early detection of the onset of combustion followed by the rapid delivery of an appropriate extinguishing agent. Explosion suppression methods are generally appropriate in two types of applications:

Type A	Presents the risk of development of high pressure within a confining space (e.g., process equipment) sufficient to cause catastrophic failure.
Type B	Poses a direct threat to people in the vicinity of a flame front produced by a deflagrating cloud of combustible gases, mists, dusts, or mixtures thereof.

The mechanisms of deflagration suppression include chemical effects (“inhibition” or interference in flame chemistry by free radical mechanisms) and physical effects (thermal quenching of the advancing flame front and dilution of fuel and air by agent vapours, e.g., steam dilution upon evaporation of water droplets.) The relative importance of chemical inhibition in addition to thermal effects to achieve flame extinction depends on the nature of the agent employed. When water is employed as an agent the extinguishing mechanism is entirely thermal. Significant chemical inhibition comes into play in addition to thermal effects when the agents employed are halons or dry chemicals.

An important feature of a deflagration suppression agent is its ability to prevent re-ignition of the combustible atmosphere due to the continued presence of an ignition source such as heated surfaces, flying sparks, embers, electrical shorts, or electrostatic hazards. Water has little or no effectiveness in this regard when the combustible is a gas. Dry chemical agents offer significant short-term re-ignition protection when the hazard is a flammable gas. This protection is lost when the agent dust settles out. Halons, and other gaseous agents, offer sustained re-ignition protection due to the persistence of agent vapours in the protected space. When the hazard is a mist or dust, dry chemical agents offer effective long term re-ignition protection since the powders come out of suspension only when the dust or mist comes out of suspension.

In order to extinguish a deflagration in progress, deflagration suppression systems deliver much larger amounts of agent in much shorter times than do fire extinguishing systems. In fire protection applications the quantity of halon 1301 delivered is generally sufficient to achieve an agent vapour concentration in the vicinity of 5 to 6 vol. %, which includes a significant safety margin. In contrast with fire suppression, deflagration suppression requires much higher effective concentrations of agent in order to achieve successful extinguishment of a growing fireball. These systems, therefore, generally deliver much larger amounts of agent, often to achieve halon 1301 concentrations of up to 15 vol. %.

The elapsed time for agent delivery in fire protection is quite varied depending on the application. Halon total flooding systems were designed to discharge in 10 seconds or less. Total flooding fire extinguishing systems using “clean agents,” as described in ISO 14520, have nominal discharge times of 60 seconds for inert gas agents and 10 seconds for halogenated agents. Water sprinkler systems can be designed to operate in very short time scales, tens of seconds, to long time scales, tens of minutes. In contrast, deflagration suppression must be accomplished in extremely short time frames and total agent discharge is typically achieved in 100 milliseconds or less. Deflagration suppression systems are always operated by automatic sensing and actuation due to the short time scales in which these systems must function in order to achieve successful suppression.

13.5 Applications of Deflagration Suppression

Examples of Type A situations (property damage) include protection of industrial process spaces such as dust collectors, silos, grinding and milling equipment, solvent storage rooms, crude oil pump rooms, solvent vapour headers and pneumatic dust transfer ducts, and municipal waste shredders.

Examples of Type B situations (personal injury) include commercial aerosol filling operations, solvent storage or pump rooms, oil and gas processing facilities, aircraft dry bays, crew bays of military vehicles, naval machinery spaces and any application in which personnel may be reasonably expected to be present at the time of a catastrophic system failure with a subsequent risk of initiation of a deflagration. Material or structural damage in Type A incidents may also lead to personal injury.

Prevention of flame propagation in pipes and ducts is often achieved by chemical isolation, i.e., by dispersing an agent into a pipe system. Protection in pipes and ducts and in many other Type A situations (above) may be achieved by halons or other agents which may be delivered rapidly to achieve extinguishing concentrations. The toxicity of the agent at its extinguishing concentration is not usually an important factor in these applications. Toxic agents, or agents which decompose in a flame to form toxic compounds, may, in some Type A situation, pose significant health risks to personnel involved in necessary service, maintenance, or post-fire activities.

Agent toxicity is generally a major consideration in Type B situation. Such applications are routinely manned or may be manned at the time of actuation of the suppression system. Halon 1301 is a particularly attractive choice in these applications due to its low toxicity, extinguishing effectiveness, and protection against re-ignition. High-speed (delivery in tens of milliseconds) water mist deluge has been used in some applications with the goal of prevention burn injury to personnel. Water mist, however, has only limited explosion suppression capability and is useful in very limited and well defined applications. There is at present no proven general purpose alternative to halon 1301 for explosion protection in occupied spaces.

The processing of hydrocarbons in areas where extreme low temperature climatic conditions occur has led to the enclosing of hydrocarbon process facilities. The early detection of hydrocarbon leaks allows the deployment of an inerting agent in to the enclosure prior to the attainment of combustible conditions. The flame-inhibiting and low toxicity properties of halon 1301 allow creation of an inert, yet habitable, atmosphere in the enclosure which prevents combustion from occurring should an ignition source be present. Systems using HFC-23 have also been installed where development of a flame-inhibiting atmosphere in an occupied enclosure was the basis of explosion prevention. Inert gases, such as nitrogen, can also be used to create a breathable yet combustion inhibited atmosphere. The discharge time of an inert gas systems is nominally 60 s and the gas volume delivered is approximately 50% that of the protected space. Both of these features make use of use of inert gas for explosion inerting applications unattractive.

13.6 Recent Activities in Replacing Halons in Deflagration Suppression Systems

13.6.1 Industrial Applications

Subsequent to passage of the Copenhagen Amendments to the Montreal Protocol actions have been taken by providers of halon industrial deflagration suppression systems to both offer non-halon based systems in new sales and to also urge owners of halon suppression systems to retrofit them with extinguishers using environmentally acceptable agents. Either dry chemical or water, with or without additives, can serve as a satisfactory, or even superior, agent to halon 1301 or halon 2402 in many dust explosion or hydrocarbon vapour explosion protection applications. There remain certain applications where a "clean" extinguishing agent (evaporates leaving no residue) is important. Halon 1011 (chlorobromomethane) was once widely used in explosion suppression systems in non-occupied areas. However, halon 1011 has an ODP of ~0.4. As such, its use in new explosion protection systems is no longer permitted in the United States or European Union. Further, halon 1011 may not be used to recharge older installations originally fitted with this agent. In such cases a suppression system using a zero ODP agent or an alternative technology should be employed. Studies [1] have shown that suppression of vapour cloud (propane) deflagrations can be achieved using high concentrations of fluorocarbon agents with results related closely to the heat absorbing capability of the agent (specific heat and latent heat of vaporization). The same study showed that relatively poor suppression was obtained, in comparison to results obtained using halon 1011, against dust cloud deflagrations using the same agents. HFCs have been shown to be very effective in creating inert flame barriers in duct systems and are specified in one type of explosion isolation system used in protecting commercial bucket elevators.

13.6.2 Commercial Applications

The principal application of deflagration suppression systems using halon 1301 is in protection of aerosol can filling rooms and hydrocarbon pump and transfer stations of moderate size, i.e., of the order of 100 m^3 volume. Protection of aerosol fill operations constitutes an important use of halon 1301 among Type B situations. This special protection need arose due to the abandonment of the use of non-flammable CFCs as propellants in aerosol products. This transition in propellant technology took place in 1975 as an early outgrowth of the discovery of the catalytic role of chlorine in ozone depletion. Most CFC based propellants were replaced by hydrocarbon formulations which were typically mixtures of propane and isobutane. The advent of combustible propellants coupled with, in many cases, the combustible products being delivered presented an extreme potential hazard in the manufacturing environment. This new hazard gave rise to the use of halon 1301 based suppression systems. Some recent research has shown that in some applications water (without additives) appears to offer effective personnel protection against localized hydrocarbon vapour deflagration involving less than 0.5 kg of propane in air. One provider of deflagration suppression systems does offer water as an alternative to halon 1301 in these applications.

13.6.3 Military Vehicles

The crew bays of military vehicles, such as armoured personnel carriers and tanks, face a potential threat due to deflagration of fuel mist should a vehicle's fuel tank or hydraulic system be penetrated by armour piercing rounds. Research conducted on alternatives has yielded at least two alternative agents for protection of crew compartments:

1) HFC-227BC (HFC-227 plus 5 wt. % sodium bicarbonate powder), and
2) Water containing non-toxic additives.

Water, with non-toxic additives that depress the freezing point, has been shown by one supplier of military vehicle systems to offer suppression effectiveness nearly similar to halon 1301. HFC-227BC has been shown to effectively suppress crew compartment fuel mist deflagrations without producing hazardous concentrations of hydrogen fluoride (HF) as a by-product.

13.7 Conclusions

Halons have been widely used to prevent explosions by suppressing deflagrations in their early stages of development. Explosions are events resulting in personal injury or destruction of property. Effective protection of facilities and personnel at risk from deflagration events requires operating systems which can:

1) Create inert atmospheres, rendering them non-flammable, or
2) Respond automatically to the incipient event and achieve extinguishing agent concentrations to suppress a deflagration in time scales of the order of 100 milliseconds, and which require agent concentrations much higher than typically employed in total flooding fire suppression applications.

Halons have been specified in industrial, commercial, and military explosion protection applications where either “clean” or people-safe agents were essential. Halon 1301 has the unique property of being able to inert an enclosed space or suppress deflagrations at vapour concentrations that are safe for brief human exposures. Replacement of halon 1301 in such applications has presented a significant challenge in fire and explosion protection situations involving human life safety. Industrial studies have shown that fluorocarbon agents can be used to good effect in some deflagration suppression or duct isolation applications. Additionally, halon 1301 has been effectively replaced in some new military crew-bay protection applications by use of HFC-227BC.

13.8 References

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AppendixList of Acronyms and Abbreviations

AAAV	Advanced Amphibious Assault Vehicle
AAWG	Advanced Agent Working Group
ABC	Dry Chemical Powder
AFFF	Aqueous Film Forming Foam
APU	Auxiliary Power Unit
ASTM	American Society for Testing and Materials
BSI	British Standards Institute
BTP	Bromotrifluoropropene
CCTV	Close Circuit Television
CEFIC	European Chemical Industry Council
CEIT	Countries with Economies in Transition
CEN	European Committee for Standardization
CFC	Chlorofluorocarbons
CO_2	Carbon Dioxide
CTOC	Chemicals Technical Options Committee
DE	Destruction Efficiency
DRE	Destruction and Removal Efficiency
DOD	US Department of Defense
EC	European Commission
EFV	Expeditionary Fighting Vehicles
EPA	US Environmental Protection Agency
EU	European Union
FEPN	Fire and Environment Protection Network
FIC	Fluoroiodocarbon
FK	Fluoroketone
FRP	Fiberglass-Reinforced Plastic
GEF	Global Environment Facility
GWP	Global-Warming Potential
HARC	Halon Alternatives Research Corporation
HBr	Hydrogen Bromide
HCFC	Hydrochlorofluorocarbons
HFC	Hydrofluorocarbons
HTOC	Halons Technical Options Committee
HVAC	Heating, Ventilating, and Air-Conditioning
HWC	Hazardous Waste Combustors
IASFPWG	International Aircraft Systems Fire Protection Working Group
ICAO	International Civil Aviation Organization
IMO	International Maritime Organization
IPCC	Intergovernmental Panel and Climate Change
ISO	International Organization for Standards
ITEQ	International Toxic Equivalency
LAV	Light Armored Vehicles

LAVEX	Lavatory Extinguishing
LCG	Liquefied Compressed Gas
LOAEL	Lowest Observed Adverse Effect Level
MAP	Monoammonium Phosphate
MEC	Minimum Extinguishing Concentration
MFS	Multilateral Fund Secretariat
MLF	Multilateral Fund
MOD	UK Ministry of Defence
MPS	Minimum Performance Standards
MRLS	Multiple Launch Rocket System
MSDS	Material Safety Data Sheets
MT	Metric Tonnes
NATO	North Atlantic Treaty Organization
NFPA	National Fire Protection Association
NGP	Next Generation Fire Suppression Technology Program
NOAEL	No Observed Adverse Effect Level
OBIGGS	Onboard Inert Gas Generating Systems
ODP	Ozone Depletion Potential
ODS	Ozone Depleting Substance
PBPK	Physiologically-based Pharmacokinetic
PCBs	Polychlorinated Biphenyls
PCDDs	Polychlorinated Dibenzodioxins
PCDFS	Polychlorinated Dibenzofurans
PFCs	Perfluorocarbons
PGA	Pyrotechnically Generated Aerosols
PICs	Products of Incomplete Combustion
POHCs	Principal Organic Hazardous Constituents
SA	Southern Africa
SAP	Science Assessment Panel
SNAP	Significant New Alternatives Policy
SOLAS	Safety of Life at Sea
TEAP	Technology and Economic Assessment Panel
TFDT	Task Force for Destruction Technologies
TRI	Toxic Releases Inventory
TSP	Total Suspended Particles
UK	United Kingdom
UL	Underwriters Laboratories Inc.
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
US	United States
USSR	Soviet Union
VNIIPO	The All-Russian Research Institute for Fire Protection