Montreal Protocol
1991 Assessment

UNEP

Report of the

Halons Technical Options Committee

December 1991

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Notice

Pursuant to Article 6 of the Montreal Protocol on Substances that Deplete the Ozone Layer three panels of international experts have prepared Scientific, Environmental Effects and Technology & Economics Reports.

This final Report of the Halons - Technical Options Committee is one of seven volumes on technology. The Technology & Economics Review Panel Report, co-chaired by Dr. Stephen Andersen (United States of America) and Steve Lee-Bapty (United Kingdom) will provides the overview and integrated statement of findings. Six other, sector specific Technical & Economic Options Reports, as follows, have also been prepared:

Refrigeration, Air Conditioning and Heat Pumps

Chair - Dr. L. Kuijpers (Netherlands)
Co-chair - Dr. H. Haukas (Norway)
Co-chair - Mr. P. Vadiantskaia (Brazil)
Co-chair - Mr. J. Kanyua (Kenya)

Rigid and Flexible Foams

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Solvents, Coatings and Adhesives

Chair - Dr. Stephen Andersen (U.S.A.)
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Co-chair - Mrs. M. Holmes-Hanek (Bahamas)

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The opinions expressed are those of the committee and do not necessarily reflect the views of any sponsoring or supporting organizations.

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Section One

Introduction

The Halons are halogenated hydrocarbons that exhibit exceptional fire fighting and explosion prevention/suppression effectiveness. They are electrically nonconductive, dissipate quickly and leave no residue. Halon 1211 and halon 1301 have proven remarkably safe for human exposure. This unique combination of properties has led to their selection as an agent of choice for many fire protection situations: computer, communications, and electronic equipment facilities; museums; engine and ancillary spaces on ships and aircraft; ground protection of aircraft; general office fire protection, industrial applications and residential use.

In 1981, in response to the growing scientific consensus that CFCs and halons would ultimately deplete the ozone layer, the United Nations Environment Program (UNEP) began negotiations to develop multilateral protection of the ozone layer. These negotiations resulted in the Vienna Convention for the Protection of the Ozone Layer, in March 1985. The convention provided a framework for international cooperation in research, environmental monitoring and information exchange. In September 1987, 24 nations signed the Montreal Protocol on Substances that Deplete the Ozone Layer. As of April 1, 1991, 68 nations have ratified the Protocol. These countries represent over 90 percent of the world's production of CFCs and halons. The Montreal Protocol entered into force on January 1, 1989. This international environmental agreement limited production of specified CFCs to 50 percent of 1986 levels by the year 1998 and called for a freeze in production of specified halons at 1986 levels starting in 1992. A list of CFCs, halons and other substances controlled under the Montreal Protocol is shown in Table 1-A, at the end of this section.

Shortly after the 1987 Protocol was negotiated, new scientific evidence conclusively linked CFCs to depletion of the ozone layer and indicated that depletion had already occurred (Ozone Trends Panel 1988). Consequently, many countries called for further actions to protect the ozone layer by expanding and strengthening the control provisions of the 1987 Protocol. In June 1990, the Parties to the Montreal Protocol met in London and agreed to Protocol adjustments requiring more stringent controls on the CFCs and halons specified in the original agreement and amendments placing controls on other ozone depleting substances, including carbon tetrachloride and 1,1,1-trichloroethane.

In April 1991 the National Aeronautics and Space Administration of the United States (NASA) concluded that depletion of the ozone layer has occurred over the past decade, at a rate faster than previously predicted. Depletion of 4 to 5 percent has occurred since 1978 over Northern latitudes. Past studies had shown about half that amount.

As a result of this new information regarding increased ozone depletion, many countries have proposed more stringent phase-out schedules than those proposed at the June 1990, London meeting of the Parties to the Protocol. The London Amendments of 1990 are shown in Table 1-B, found at the end of this section.

The June 1990 London meeting of the Parties to the Montreal Protocol reconvened the 1989 Assessment Panels. The 1989 assessment panels consisted of the scientific assessment, the environmental effects assessment, the technology assessment and the economics assessment panels. The technical and economics panels have been combined for the 1991 Assessment. The three international assessment panels will report on:

The science of stratospheric ozone depletion. The environmental and public health effects of stratospheric ozone depletion and the technical feasibility and earliest possible date, in each of the major use sectors, of phasing out production of ozone depleting substances and the related anticipated economic concerns.

The 1991 Technical and Economic Assessment is divided into six Options Committees:

(1) Technical Options Committee for Foams
(2) Solvents, Coatings and Adhesives Technical Options Committee
(3) Halons Technical Options Committee
(4) Economic Options Committee
(5) Refrigeration Options Committee
(6) Aerosols, Sterilants, Miscellaneous Uses Technical Options Committee

The 1991 Assessment Panels consist of some members of the 1989 Assessment Panels and additional new experts, to provide the widest possible international participation in the review. Experts from industry, government, academic institutions and non-government organizations were invited to prepare a comprehensive and technically specific "Options Report" for each sector. In the case of the Halons Technical Options Committee, UNEP staff, Technical and Economics Panel Chairpersons and the Halons Technical Options Committee Co-chairs contacted producers, equipment manufacturers, trade associations, users, research institutions, fire protection organizations, standards making organizations and others to arrange for comprehensive technical input. A similar procedure was followed in the development of the other Technical and Economic Options reports. All of the Technical and Economics Options Reports have been peer reviewed before final release. Finalized Technical and Economics Options Reports will be distributed internationally by UNEP.

This report is part of the UNEP review under Article 6 of the Montreal Protocol. Article 6 specifically directs Parties (nations that have ratified the Protocol) to assess whether the control measures, as provided for in Article 2 of the Protocol, are sufficient to meet the goals for reducing ozone depletion based on a review of the current state of knowledge on technical, scientific, environmental and economic issues related to stratospheric ozone protection.

Specific to the halons, Decision II/3 of the Parties states the following:

Decision II/3 Halons

To establish an ad hoc working group of experts to investigate, and make recommendations to the Fourth Meeting of the Parties in 1992 on the availability of substitutes for halons, the need to define essential uses of halons, methods of implementation and, if there is such a need, the identification of such uses.

The Halons Technical Options Committee has been charged with the responsibility to perform the function of the ad hoc group working group of experts as required by Decision II/3 of the Parties. The response of the Halons Technical Options Committee will be found in Section Eleven - Essential Uses and Their Needs, of this Report.

During the course of preparation of these reports the Parties met in Nairobi, Kenya June 19 to 21, 1991. Decision III/12 of the Parties, as follows, is specific to the assessment panels:

Decision III/12 Assessment Panels

(a) To request the Assessment Panels and in particular the Technology and Economic Assessment Panel to evaluate, without prejudice to Article 5 of the Montreal Protocol, the implications, in particular for developing countries, of the possibilities and difficulties of an earlier phase-out of the controlled substances, for example of the implications of a 1997 phase-out;

(b) Taking into account the London Resolution on transitional substances (Annex VII to the report of the Second Meeting of the Parties to the Montreal Protocol), to identify the specific areas where transitional substances are required to facilitate the earliest possible phase-out of controlled substances, taking into account environmental, technological and economic factors, where no other more environmentally suitable alternatives are available. The quantities likely to be needed for those areas and for those areas of application currently served by transitional substances shall both be assessed;

(c) To request the assessment panels to identify the transitional substances with the lowest potential for ozone depletion required for those areas and suggest, if possible, a technically and economically feasible timetable, indicating associated costs, for the elimination of transitional substances;

(d) To request the assessment panels to submit their reports in time for their consideration by the Open-Ended Working Group with a view to their submission for consideration by the Fourth Meeting of the Parties;

(e) To endorse Decision II/2, paragraph 2, of the Second Conference of the Parties to the Vienna Convention.

An orderly transition to alternative fire protection measures, establishment of procedures to adequately manage the bank of halons and increased efforts to develop transitional and eventual replacement fire extinguishing agents with the beneficial characteristics of the present halons may minimize the loss of fire protection capability represented by the halons. The alternative protection choices proposed in this report may not achieve the same level of fire protection offered by the use of the present halons and in some circumstances greater fire loss and risk to people and property may result from the use of the alternatives outlined. However, as members of a global society, the international fire protection community, as represented by the members of the Halons Technical Options Committee, shares a common concern and recognizes the importance of the environmental risk posed by the halons. The risk to human life is the crux of the problem. This report attempts to provide an integrated overview that balances threat from ozone depletion and threat from fire or explosion.

Table 1-A

Substances Controlled by the Montreal Protocol
(ODP values are relative to CFC-11)

Annex A

Group I		ODP
CFC - 11	Trichlorofluoromethane	1.00
CFC - 12	Dichlorodifluoromethane	1.00
CFC - 113	1,1,2-Trichloro-1,2,2-trifluoroethane	0.82
CFC - 114	1,2-Dichlorotetrafluoroethane	0.76
CFC - 115	Chloropentafluoroethane	0.43
Group II		
Halon 1211	Bromochlorodifluoromethane	3.0
Halon 1301	Bromotrifluorometahne	10.0
Halon 2402	Dibromotetrafluoroethane	6.0

Annex B

Group I		
CFC - 13	Chlorotrifluoromethane	1.00
CFC - 111	Pentachlorofluoroethane	1.00
CFC - 112	Tetrachlordifluoroethane	1.00
CFC - 211	Heptachlorofluoropropane	1.00
CFC - 212	Hexachlorodifluoropropane	1.00
CFC - 213	Pentachlorotrifluoropropane	1.00
CFC - 214	Tetrachlorotetrafluoropropane	1.00
CFC - 215	Trichloropentafluoropropane	1.00
CFC - 216	Dichlorohexafluoropropane	1.00
CFC - 217	Chloroheptafluoropropane	1.00
Group II		
CCl_4	Carbon Tetrachloride (Tetrachloromethane)	1.11
Group III		
1,1,1-Trichloroethane	Methyl Chloroform (1,1,1-Trichloroethane)	0.11

Annex C

Partially halogenated fluorocarbons (including HCFC - 22, HCFC - 123, and HCFC - 141) all with ODPs of less than 0.12, are defined as transitional substances by the Montreal Protocol under Annex C.

Table 1-B

Summary of Proposed London Amendments to the Montreal Protocol

Annex A - Group I
Chlorofluorocarbons: CFC-11, CFC-12, CFC-113, CFC-114 and CFC-115

Freeze at 1986 levels by July 1989
20 percent reduction from 1986 levels by January 1993
50 percent reduction from 1986 levels by January 1995
85 percent reduction from 1986 levels by January 1997
100 percent reduction from 1986 levels by January 2000

Annex A - Group II
Halons: halon 1211, halon 1301 and halon 2402

Freeze at 1986 levels by July 1992
50 percent reduction from 1986 levels by 1995
100 percent reduction from 1986 levels by January 2000 (with possible exemptions for essential uses)

Annex B - Group I
Other fully halogenated CFCs
CFC-13, CFC-111, CFC-112, CFC-211, CFC-212, CFC-213, CFC-214, CFC-215, CFC-216, CFC-217

Freeze at 1986 levels by July 1992
20 percent reduction from 1986 levels by January 1993
85 percent reduction from 1986 levels by January 1997
100 percent reduction from 1986 levels by January 2000

Annex B - Group II
Carbon Tetrachloride

Freeze at 1989 levels by July 1992
85 percent reduction from 1989 levels by January 1995
100 percent reduction from 1989 levels by January 2000

Annex B - Group III
1,1,1-trichloroethane

Freeze at 1989 levels by January 1993
30 percent reduction from 1989 levels by January 1995
70 percent reduction from 1989 levels by January 2000
100 percent reduction from 1989 levels by January 2005

Annex C - Transitional Substances
Partially halogenated fluorocarbons

Resolution calling for use only where other alternatives are not feasible with phase-out by 2020 if feasible, and no later than 2040.

Section Two

Historical Development of Halon Usage

The halon terminology system provides a convenient means to reference halogenated hydrocarbon fire extinguishants. Halogenated hydrocarbons are acyclic saturated hydrocarbons in which one or more of the hydrogen atoms have been replaced by atoms from the halogen series; i.e. fluorine, chlorine, bromine, iodine. By definition the first digit of the halon numbering system represents the number of carbon atoms in the compound molecule; the second digit, the number of fluorine atoms; the third digit, the number of chlorine atoms; the fourth digit, the number of bromine atoms; and the fifth digit, the number of iodine atoms. Trailing zeros are not expressed. Valence requirements not accounted for are assumed to be hydrogen atoms.

# of hydrogen atoms = [((# of carbon atoms x 2)+2)-(Sum of halogen atoms)].

Example: Bromotrifluoromethane - CF_3Br - halon 1301

The first member of this family of chemicals was carbon tetrachloride (halon 104). Use as a fire extinguishant probably occurred before 1900 and by 1910 portable fire extinguishers, tested by independent agencies, had appeared. The growing popularity of the automobile and other uses of internal combustion engines signalled an increasing need for fire extinguishants, suitable for use on flammable liquid fires. By 1917, there were discussions regarding the possible effects that carbon tetrachloride could have on the human system. During 1919 the first recorded deaths due to carbon tetrachloride use occurred. Two men working on the construction of a submarine were killed. One man's clothing had caught fire and the other man extinguished the fire with a carbon tetrachloride agent fire extinguisher. Both were overcome by the fumes and later died. During the 1920's the discussions regarding the toxicity of carbon tetrachloride continued with particular attention to the possibility that freezing point depressants and impurities were contributing factors.

Methyl bromide (halon 1001) gained popularity after it was discovered in the late 1920s. Due to its high toxicity it was never popular for use in portable extinguishers although it was used in British and German aircraft and ships during World War II. During World War II Germany developed chlorobromomethane (halon 1011) to replace methyl bromide. In 1947 a report by Underwriters' Laboratories (U.S.A.) showed that the toxicity of carbon tetrachloride (halon 104) and chlorobromomethane (halon 1011) were comparable, however chlorobromomethane (halon 1011) was a more efficient fire extinguishing agent.

In the post World War II era, the addition of stearate to sodium bicarbonate based dry powder provided improved flow and moisture repellency characteristics to sodium bicarbonate based dry powder. This in turn encouraged the use of portable dry powder fire extinguishers as a viable alternative to vaporizing liquid extinguishers that used early halons as extinguishants.

By the 1950's the era of the early halons (halons 104, 1001 and 1011) was ending. Increased popularity of dry powder had decreased the need for widespread use of these early halons and growing concerns with their toxic effects resulted in their substantial phase-out by the 1960's.

In 1947, the Purdue Research Foundation performed a systematic evaluation of more than 60 new candidate extinguishing agents. Simultaneously, the U.S. Army Corps of

Engineers undertook toxicological studies of these same compounds. As a result four halons were selected for further study: dibromodifluoromethane (halon 1202), bromochlorodifluoromethane (halon 1211), bromotrifluoromethane (halon 1301) and dibromotetrafluoroethane (halon 2402). Testing indicated that halon 1202 was the most effective fire extinguishant however it was also the most toxic. Halon 1301 ranked second in fire extinguishing effectiveness and least toxic. As a direct result of this program a portable fire extinguisher employing halon 1301 was developed for use by the U.S. Army, primarily for use inside armored personnel carriers and tanks. The U.S. Air Force selected halon 1202 for military aircraft engine protection and the U.S. Federal Aviation Administration approved the use of halon 1301 for commercial aircraft engine fire protection.

In 1966, attention began to focus on the use of halon 1301 as a total flooding extinguishant for the protection of computer rooms. In the past twenty years halon 1301 has grown in usage as an agent for use in fixed fire protection systems primarily for the protection of vital electronics facilities, such as computer rooms and communications equipment rooms. Other significant applications for halon 1301 systems have included: repositories of cultural heritage; shipboard machinery spaces and pipeline pumping stations. Halon 1211 has been the halon of choice for portable fire extinguisher usage. In commercial and industrial applications halon 1211 portable fire extinguishers have been used in computer rooms, museums, art galleries and in offices for photocopy machines, personal computers and other electronic equipment.

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Section Three

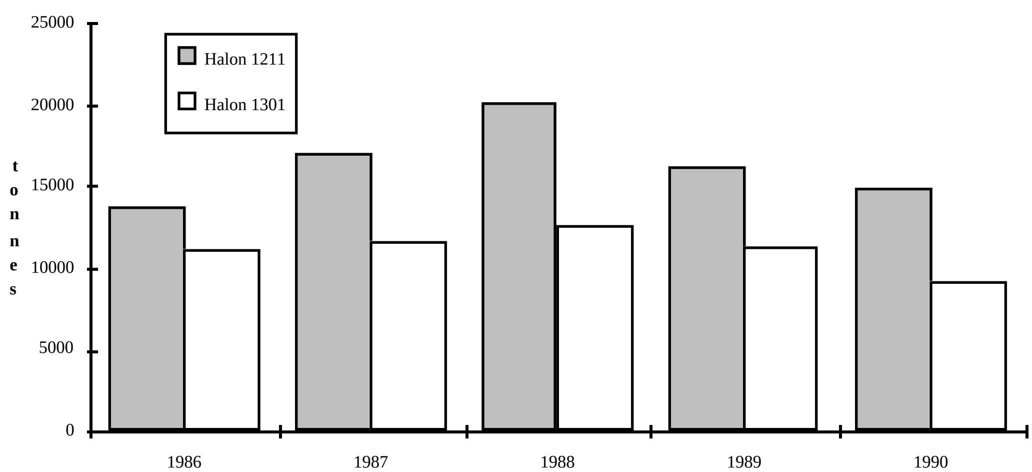
Use Patterns, Production and Bank Estimates

3.1 Introduction

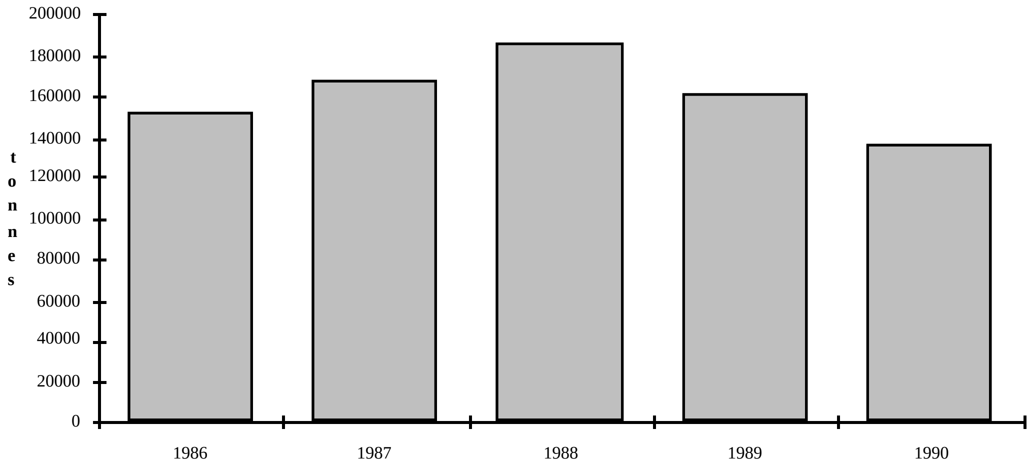
Estimated production figures for halon 1211 and halon 1301 are based on data submitted by producers within the Organization for Economic Cooperation and Development (OECD) and from estimates of production in the USSR and China.

Fire protection organizations, through educational programs, changes in technical standards and various other means have played an important role in making it known that use of halons must be drastically reduced and wherever possible alternative fire protection measures employed. The effect of these programs can be seen by the fact that production of halon 1211 and halon 1301 peaked in 1988 and is now declining. Production of halon 2402 within OECD nations has virtually ceased.

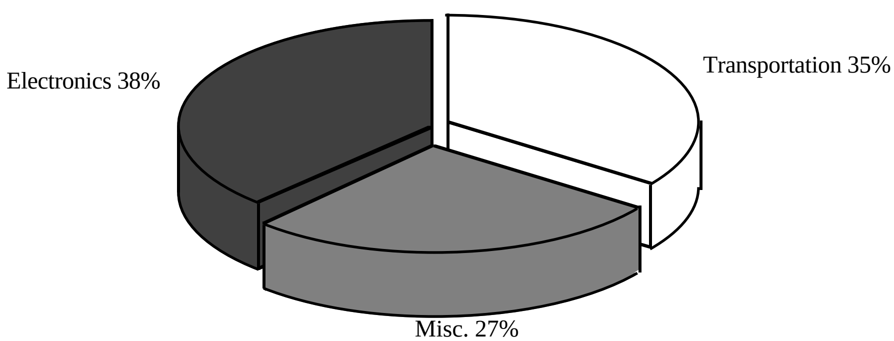
Estimated World Production of Halons - 1986 to 1990
by actual weight (metric tonnes)



Estimated World Production of Halons - 1986 to 1990 (ODP weighted)

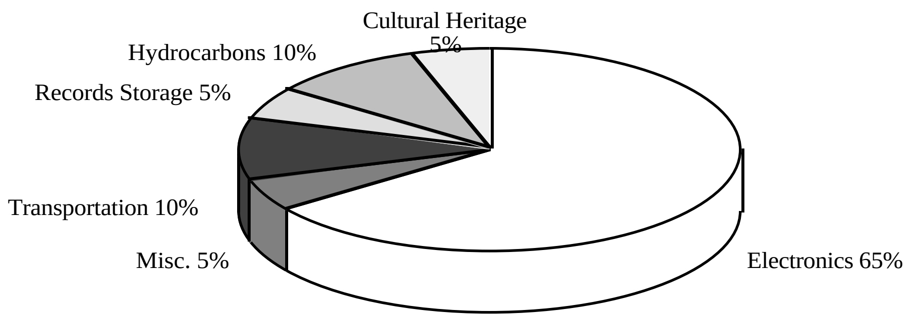


Estimated 1990 Usage of Halon 1211 by Application



Note: The use pattern charts are provided for general information only and are based on the collective opinion of the members of the Halons Technical Options Committee.

Estimated 1990 Usage of Halon 1301 by Application



Note: The use pattern charts are provided for general information only and are based on the collective opinion of the members of the Halons Technical Options Committee.

3.2 Supply and Demand

At present supply and demand of the halons are balanced and the balance is being maintained by reduced production of the halons. Supply however is a little more complex than simply considering new production as the sole source of supply. In fact supply is composed of both new production and recycled material. It is important to understand that recycled material is a critical factor in assessing halon supply.

Total supply = production + quantity available for recycle
and
Total demand = fires + other emissions + new installations

The above assumes that all halon produced will eventually be emitted.

In the future, maintaining the balance between supply and demand will likely be affected by various new factors such as an early phase-out of production, possible growth of use in the less developed countries, commercialization of acceptable replacement chemicals and uncertainty of the rate of decommissioning of halon fire equipment which could occur in the developed countries.

3.3 Future Bank Estimates

In the future it will be necessary to recover and recycle both halon 1301 and halon 1211. Halon use falls into several categories and certain use patterns are changing dramatically. For example discharge testing of halon 1301 systems accounting for almost 20% of annual usage up until 1987, has been drastically reduced. The percentage of available halon being emitted is being reduced by improved training of service personnel, by public awareness, by changes in the design of installations, by improved initial fill techniques, by increased recycle of recovered halon and by the development of alternative procedures for testing and training. However, not all emissions of halons can be curtailed. Use on fires will continue as that is the purpose of the halons. Also, even though other emissions due to other causes such as service, leakage, etc. are being reduced, it is unlikely that they can be completely eliminated.

A computer program was used in preparing order of magnitude estimates of the future banks of the halons, shown in Appendix C. The computer program uses global production data as a basis for calculating the bank of halons. The rationale for the computer program is outlined in Appendix C. For the years from 1963 to 1990, estimated production figures for halon 1211 and halon 1301 are based on data submitted by producers within the Organization for Economic Cooperation and Development (OECD) and from estimates of production in the USSR and China. For the years 1991 to 2000 production figures are estimates based on equal annual reduction of halon production.

3.4 Discussion

3.4.1 Halon 1211

The estimates generated for halon 1211 were based on complete curtailment of production by the year 2000, recovery before 1988 of 0% and a maximum recovery to be achieved by 1994 of 25%. A calculation for 20 year equipment life is shown in Appendix C of this report. The halon quantity recovered in excess of service requirements would be available for initial fill of new equipment. The calculations presented indicate that recycled halon would be sufficient to maintain existing equipment before the bank expires, except for the years 1998 through 2002 where non-essential equipment would have to be taken out of service to provide maintenance quantities of halon 1211. Between 2003 and 2010 when for all practical purposes the bank of 1211 expires, small quantities of halon 1211 would be available for new equipment.

3.4.2 Halon 1301

Calculations have been provided for halon 1301 based on production ceasing by 2000. Calculations based on a usable equipment life of 15 years has been provided. Minimum recovery of 50% and maximum of 75% has been utilized. After the phase-out year, it is assumed that recovered halon 1301 will be recycled. The resultant charts and calculated results will be found in Appendix C of this report. This report estimates the years in which recycled halon 1301 falls below 30%, 20% and 10% of 1986 total supply, based on 2000 as the last year of production. It is estimated that for all practical purposes the halon 1301 bank expires 45 years after the year of production phase-out.

3.5 Key Results

The following tables summarizes some key results derived from the calculations provided in Appendix C.

Table One
1986 Usable Supply of Halon
(Production + Recycle - Unrecovered)

Halon 1301	Halon 1211
12 892	13 731

Note: All quantities are in metric tonnes

Table Two
Usable Supply of Halon in Production Phase-Out Year
(Recycle - Unrecovered)

Production Phase-Out Year	Halon 1301	Halon 1211
2000	7 013	1 552
1997	6 115	1 487
1995	5 825	1 408

Note: All quantities are in metric tonnes

Table Three
Usable Supply of Halon in Phase-Out Year
Compared to 1986

Phase-Out Year	Halon 1301	Halon 1211
2000	54%	11%
1997	47%	11%
1995	45%	10%

Table Four
Year in Which Available Halon For New Installations Falls Below 30% of 1986 Level

Phase-Out Year	Halon 1301	Halon 1211
2000	2013	1998
1997	2008	1996
1995	2007	1994

Table Five
Year in Which Available Halon For New Installations Falls Below 20% of 1986 Level

Phase-Out Year	Halon 1301	Halon 1211
2000	2020	1998
1997	2015	1996
1995	2014	1994

Table Six
Year in Which Available Halon For New Installations Falls Below 10% of 1986 Level

Phase-Out Year	Halon 1301	Halon 1211
2000	2031	1999
1997	2026	1996
1995	2024	1995

3.6 Conclusions

Production of halon 1211 and halon 1301 peaked in 1988 and is now declining. There are persuasive reasons to consider recycled halons as the prime supply of these agents. The first is to encourage responsible stewardship of the bank of halons and reduce potential ozone depletion. Users should also consider that it may not be economical for producers to continue to manufacture halons as markets continue to decline. There may be a transition phase where costs to produce halons rise dramatically to offset rising costs involved in producing smaller quantities.

The bank of halon 1211 should be sufficient to maintain existing equipment using recycled halon. However, for some early years after production phase-out some equipment may have to be taken out of service to provide maintenance quantities of halon 1211. Following expected shortages of maintenance quantities in the early years after production phase-out, it is expected that small quantities of halon 1211 may be available for new equipment until the bank expires.

It is estimated that the bank of halon 1301 will be adequate to supply maintenance quantities for equipment for at least 40 years after production ceases. Also, it appears that recycled halon 1301 could be provided for new equipment after new production is curtailed (see Appendix C). It is estimated that for all practical purposes the halon 1301 bank expires 45 years after the production phase-out year.

It should be noted that the estimates provided for the bank will likely be affected by various new factors such as an early phase-out of production, efficiency of recycle programs, possible growth of use in the less developed countries, commercialization of acceptable replacement chemicals and uncertainty of the rate of decommissioning of halon fire equipment which could occur in the developed countries.

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Section Four

Fire Protection Alternatives to the Use of Halons

Halon Fixed Systems

4.1 Background/Philosophy

This section of the report investigates procedures for evaluating the properties of suppression systems and agents, the optimum uses of specific agent/system combinations and a method to evaluate alternatives. This section concentrates on the technical capabilities of fire suppression systems, but does not fully address the important issues of hazard reduction and risk management. The primary purpose is to present a logical framework in which to evaluate alternatives to halon total flooding systems which considers the necessary advantageous technical features of halon systems. It is also intended that the evaluation system be sensitive to the features and requirements of the hazard being protected.

It is important that the need for protection, if halon is the only safe extinguishing agent, should be justified based on the probability of a fire occurring and the consequences of the fire. All reasonably practical measures should be taken to prevent the fire and mitigate the consequences to avoid the need for halon. Where other agents cannot be used, measures should be investigated to overcome the specific reasons for their unacceptability and these should be implemented provided that the fire fighting effectiveness is not impaired.

The provision of a fire/explosion detection and suppression system is only one part of an adequate protection scheme for a particular installation or facility. Other fire protection features include, but are not limited to: fire resistive enclosures; smoke control systems; manual fire fighting equipment; provision of high ignition resistance, low flammability cable and wire insulation, furnishings and interior finish; and "smoke resistant" electronics components. The total fire risk of a facility is also reduced by such methods as: preventative maintenance, redundant facilities, backup of records and other media, proper planning, minimizing of single point failures (relative to the facility, mission or objective), adequate post fire reclamation procedures and contingencies.

Halogenated fire suppression systems have been installed primarily to provide a very high level of property protection with minimal secondary damage and minimal disruption to resumption of operations. The ability of halon 1301 total flooding systems to prevent explosions and to extinguish fires very quickly with minimal potential disruption to the facility being protected often has effects on safety, other than direct fire safety. For example, protecting a telecommunications facility has numerous societal impacts, many of which are related to public safety, such as the ability to communicate a medical emergency. In a very limited number of installations, halon systems are installed primarily to protect human life from fire. It can also be installed to protect both the personnel within an area and to prevent escalation to surrounding areas and personnel, for example on a hydrocarbon processing installation. In some cases the protection is directly related to safety, although not fire safety; an example of this case might be the protection of an aircraft engine. In most installations however, the system is installed to protect equipment, facilities, and their associated mission, not to protect human life. This has been accomplished by the actuation of the system at very early stages in the fire development curve or before explosive concentrations of vapour or gases are reached and of course, through the application of a clean agent with minimum secondary damage.

Additional positive aspects of halon 1301 are: low toxicity at typical protection concentrations, low space and weight requirements and a non conductor of electricity (hence non-damaging to energized electrical and electronic equipment).

Although the requirement for fixed systems (of which halon systems are an option) is sometimes driven by statutory regulations, halogenated fire suppression systems are generally not mandated by Building Codes/Standards. The main objectives of Codes/Standards is to establish an acceptable level for: life safety/egress capability, safety for responding fire fighting crews, limitation of expected fire sizes to those which can be reasonably addressed by the fire department, and some consideration for preventing fire spread between structures. Halon 1301 systems are used to meet specific property protection and/or life safety objectives and the mission associated with the property protected. The remainder of this report section assumes this point of view. The remaining issue is to what extent halon 1301 systems are required as opposed to inherent design, prevention, alternative systems and agents to achieve similar property protection levels.

The requirement for a protection system is also driven by the risk posture of the organization. Obviously as the exposure increases, the justification for fire or explosion protection increases. Losses are rarely entirely born by corporations or organizations but are spread through the use of insurance. The protection cost includes expected losses and installed cost and maintenance of the fire protection systems. Most fire safety analyses are not quantitative. Financial considerations are important in arriving at a fire protection selection, but many uses of halon make purely financial decisions very difficult. Military systems and public safety (e.g., air traffic control, aircraft avionics, etc.) are especially difficult to evaluate in this way.

The decision on the need for protection is critical but it is often taken for historic reasons, a particular perception of the fire hazard or the knowledge that a protection system is available and effective. This, by default deems its necessity. Decisions on the need for protection must be taken following a clear examination of the fire risks, the scale of potential fires, the rate of fire growth and the consequences to life, property and equipment availability.

It is useful to concentrate on the engineering aspects of protecting a particular hazard. That is, assume for example, that a the person responsible for the fire protection of a computer facility has evaluated the risk and has decided that a fire suppression system is required, that the fire suppression system must be of low toxicity, cause minimal collateral damage, and that the total direct and indirect fire damage must not exceed one cabinet. In the past the system of choice would have been a total flooding halon 1301 system. The use of a system other than halon 1301 may cause the owner to bear other costs, such as increased damage levels, water damage, etc. In effect, the use of alternative systems may "cost" the facility owner more.

More difficult choices lie in the area of the use of more toxic fire suppression agent. Suppose that CO_2 could be used as a replacement to halon 1301 except for the increased risk of accidental death caused by discharge of the system. How does the risk balance against the fire risk and/or the environmental risk? These are not technical issues; rather, they are political, social and economic questions and to some extent, independent of the desirable features of any particular fire suppression system/agent combination.

4.2 Other Fire Safety Features

As mentioned earlier, the need for a fire suppression system is driven by the risk associated with the facility to be protected and the presence of other fire protection features and fire safety design, installation and prevention aspects. For the specific example of a computer, these include but are not limited to:

- redundancy
- ignition resistant wire, cable, and electronic components
- minimum ignition source severity from external sources
- low or slow rate of fire development
- low rates of smoke production
- components hardened to the effects of heat and smoke
- low smoke corrosivity
- isolation of HVAC system
- fire resistive compartment boundaries
- detection and alarm systems
- full time manning
- training of staff
- availability of manual fire suppression equipment
- fire department response time

This partial list of other fire protection features reflects on several fire protection aspects. First, the provision of additional fire safety features may obviate the need for a suppression system. Secondly the provision of these features may reflect (albeit indirectly) on the value of the facility as perceived by the owner. An owner who has invested in the protection of a facility through these other fire protection measures is indicating the relative value of the facility.

There is therefore some rationale for providing a scheme for dealing with these additional fire safety features in the evaluation of alternatives to the use of halogenated fire suppressants. The most straightforward approach is to prescribe some minimum set of requirements for a facility before a halogenated fire suppression system can be considered. For example a computer facility may be required to meet all aspects of a technical standard such as NFPA 75 "Standard for the Protection of Electronic Computer/Data Processing Equipment" or British Standard 6266 "Code of Practice for Fire Protection of Data Processing Installations".

Since the details of alternative fire protection features will vary dramatically depending upon the particular hazard being evaluated, it is difficult to treat this problem in general. A baseline level of other fire protection features should be considered in all cases before the selection of an active fire suppression system is finalized.

4.3 Agent/System Selection Matrices

The use of halons as a trade off for other fire protection features is unacceptable. However it is recognized that there are fire/explosion risk scenarios which would result in severe consequences for society, if halon or halon like replacement agents were not used for protection. The following criteria should be satisfied before reaching the conclusion that a new installation is an essential halon use:

A critical need must exist to minimize damage due to fire, explosions or extinguishing agent application, which would otherwise result in serious impairment of an essential service to society, or pose an unacceptable threat to life, the environment, or national security

and

All other appropriate fire protection measures have been taken.

Note: Time to make appropriate changes in national fire codes, standards and regulations will be necessary before fully and safely applying these criteria.

For applications where halons have typically been used in the past that do not meet the preceding criteria the matrix approach outlined in Appendix D provides a logical way to evaluate alternative fire protection systems.

The alternative fire protection choices proposed in Appendix D of this report may not provide the same level of fire protection offered by the use of the present halons. In some circumstances greater fire loss and risk to people and property may result from the use of the alternatives outlined. However, concerns regarding environmental risk associated with the continued use of halons necessitate the serious evaluation of all other fire protection options.

The concept of a selection matrix is that the benefits of halon total flooding systems, given in terms of low toxicity, ability to permeate, low space/weight requirements, minimum collateral damage, minimum down time, etc. are not equally important in all applications.

The method proposed in Appendix D of this report should be viewed as a guide. The important features of alternative fire protection systems are described, but the weighting of the relative importance of these features is not rigourously derived. It is the result of the consensus opinion of the committee responsible for this report. The method is developed primarily as a means of structuring the thought process relative to the evaluation of the use of alternative fire protection systems for a particular use and more importantly, the evaluation of alternatives. It is fully expected that any application of point values may vary between countries.

An important consideration is that the system, not just the agent, impacts the relative benefits of a particular choice. The system in this context is limited to the fire suppression system. It does not include, but perhaps should, other important factors such as the existence of other fire protection features, the fire hazard and the risk associated with a particular facility. These factors could be considered in a more detailed fashion using a decision tree.

Manual Application Halon Usage

4.4 Introduction

The desirable attributes of halon 1211, including high fire extinguishing effectiveness, limited toxicity, low secondary damage, stream range, and no electrical conductivity are important to varying degrees across the range of applications.

The committee has developed a use evaluation matrix for alternatives to manually applied halon 1211 similar to that presented in the discussion of halon total flooding systems. This method will be found in Appendix E of this report.

The alternative fire protection choices proposed in Appendix E of this report may not provide the same level of fire protection offered by the use of the present halons. In some circumstances greater fire loss and risk to people and property may result from the use of the alternatives outlined. However, concerns regarding environmental risk associated with the continued use of halons necessitate the serious evaluation of all other fire protection options.

4.5 Conclusions

For many cases where halons have been employed there are alternative fire protection methods that can be utilized to reduce risk. The alternative fire protection choices offered in this report may not provide the same level of fire protection offered by the use of the present halons. In some circumstances greater fire loss and risk to people and property may result from the use of the alternatives outlined. However, concerns regarding environmental risk associated with the continued use of halons necessitate the serious evaluation of all other fire protection options.

Section Five

Explosion Protection

5.1 Introduction

Working spaces, whether manned or not, which may contain dispersed mixture 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.

5.2 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.

5.3 Explosion Protection Methods

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

i. Prevention

   a. through application of appropriate principles of safe engineering design, construction, operation, and maintenance of process systems.

   b. through application of inerting agents to atmospheres which are, or may reasonably be expected to become, flammable.

   c. through high-rate mechanical ventilation of atmospheres which are, or may reasonably be expected to become, flammable to eliminate combustible conditions.

ii. Mitigation - by designing spaces at risk to achieve:

   a. Containment of the pressure developed.

   b. Pressure relief venting - release of gas through relieving panels to avoid attainment of pressures which would cause the process enclosure to fail.

   c. Combustion isolation - prevent transmission of the combustion process to associated equipment spaces.

   d. Deflagration suppression - extinguishment of the deflagration front prior to attainment of a condition resulting in equipment damage or personal injury.

Halons are used in deflagration suppression, inertion and, occasionally in chemical isolation of duct systems.

5.4 Fundamentals of Deflagration Suppression

Deflagration 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 is called for in settings in which uncontrolled combustion:

A. Presents the risk of development of a rise in pressure sufficient to cause a confining enclosure to fail, or

B. Poses a direct threat to people in the vicinity of a deflagrating cloud of combustible gases, mists, or dusts.

The mechanisms of deflagration suppression include chemical inhibition and thermal quenching at the boundaries of the advancing flame and agent cloud fronts. The relative importance of chemical inhibition to thermal effects to achieve flame extinction depend on the nature of the agent employed. When water is employed as an agent the extinguishing mechanism is thermal only. Significant chemical inhibition comes into play in addition to thermal effects when halons are employed as the agents. (See Appendix F for a discussion of flame inhibition chemistry of halons.)

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 is ineffective in this regard when the combustible is a gas. Dry powder agents offer significant short¬term re-ignition protection against combustible gases. This protection is lost when the agent dust settles out. Halons offer sustained re-ignition protection due to the presence of agent vapours.

In the interest of extinguishing a deflagration in progress, deflagration suppression systems deliver much larger amounts of agent in much shorter time frames 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 fire ball. 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 typically discharge in 10 s. 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 times scales in which these systems must operate in order to achieve successful suppression.

5.5 Applications of Deflagration Suppression

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

Examples of Type B applications (personal injury) include commercial aerosol filling operations, solvent storage or pump rooms, oil and gas processing facilities, crew bays of military vehicles, war ship machinery spaces, and any application in which a person may reasonably be 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.

Chemical isolation of ducts and Type A applications (above) may be served 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 may, in some Type A applications, pose significant health risks to personnel involved in required service and maintenance activities such as in certain aircraft systems.

Agent toxicity is generally a major consideration in Type B applications. Such applications are routinely manned or may be manned at the time of actuation of the suppression system. The agent of choice in such applications is halon 1301 due to its low toxicity, extinguishing effectiveness, and protection against re¬ignition. There is at present no known alternative extinguishing agent for these applications.

Protection of aerosol fill operations constitutes an important use of halon 1301 among Type B applications. 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.

The discovery of hydrocarbons in areas where extreme low temperature climatic conditions occur has led to the enclosing of hydrocarbon processing 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 unique 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.

The crew bays of military vehicles, such as armoured personnel carriers and tanks, face a potential mist cloud deflagration threat should one of the vehicle's fuel tanks be penetrated by armour piercing rounds. The main machinery spaces of war ships face a hazard from deflagrations of combustible machinery fluids in both peace time and war time. Halon 1301 deflagration suppression systems are employed in these spaces.

5.6 Conclusion

Deflagration is a class of combustion characterized by rapid flameball growth and high rates of energy release. Explosion protection is achieved through methods to prevent or mitigate deflagrations. Effective protection of systems and personnel at risk from such events requires operating systems which:

i. Create inerted atmospheres, or

ii. 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.

Halon 1301 has the unique property of being able to inert an enclosed space or suppress deflagrations at vapour concentrations which are tolerable to humans. Replacement of halon 1301 in such applications presents a significant challenge in fire or explosion protection situations involving human life safety for at present there are no known alternative agents which have this property.

Section Six

Halon Emission Reduction Strategies

6.1 Introduction

Releasing halon into the atmosphere is fundamental to the process of flame extinction and enclosed space inertion. However, as the data in Appendix C illustrates, these necessary emissions only account for a small proportion of the available supply of halon in any year. Techniques for reducing emissions resulting from discharge testing, training, servicing and accidental discharges are presented below. Predictions of the future effectiveness of these measures will be found in Appendix C.

6.2 Alternative Fire Protection Strategies

Clearly halon emissions can be reduced if halon is not deployed 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, the concept of 'essential uses', as presented in Section Eleven, should be applied.

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, inherent design, minimisation of personnel exposure, passive protection, equipment duplication, detection and manual intervention should be considered.

i) Prevention

Where there is a low probability of fire and that probability can be reduced to insignificant proportions by procedures and diligence, the need for protection can be minimized. 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 may be considered as acceptable protection.

ii) 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 that there is no immediate threat to life or critical equipment before evacuation of the area or manual intervention can take place.

iii) Minimisation Of Personnel Exposure

Where the only threat to life is within the protected area, the need to man the area may be minimized 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.

iv) Passive Protection

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

v) 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.

vi) Detection

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

vii) 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.

6.3 Halon Minimisation Strategies

When protection against fire or explosion hazards with halon is considered essential, the following practices should be observed to minimize installed halon, and thus reduce emissions potential:

i) 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.

ii) Reserve Systems

Reserve systems should not be installed unless there is a confirmed immediate need to restore fire protection to the facility before the primary halon system containers can be recharged, or if 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.

iii) Extended Discharge

Extended discharge systems should be avoided as they normally require more halon than the initial 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.

iv) 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.

v) Preventive Maintenance and Technology Improvement

Continued opportunity to improve discharge system reliability is achieved through enhanced maintenance procedures or replacement with new technology.

6.4 Halon 1301 Emissions Due To Discharge Testing

A principal emission control measure adopted by the fire protection community has been the reduction of halon 1301 full discharge tests by utilizing several alternative procedures to ensure operational readiness of a system - these procedures are incorporated in the most recent edition of NFPA 12A - 1989, Halon 1301 Fire Extinguishing Systems [1]. The reasons for discharge tests using halon 1301 were to check enclosure integrity, distribution 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 that uses air pressure, developed with a fan and measured with calibrated gauges, to determine the ability of an enclosure to hold 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 [2], 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. Similar requirements can be found in British Standards [4]. Only systems with complex piping arrangements should require additional agent distribution testing. Candidate alternatives to halon 1301 for such tests have been proposed.

Although the exact decrease in emissions, caused by the reduction in discharge testing using halon 1301, is not known, it is believed to have been substantial. The Committee therefore believes that eliminating such testing on a global basis could be effected without major impact on protection system integrity.

6.5 Halon 1301 Emissions Due To Inadvertent System Discharge

This component of halon 1301 emissions can be relatively high where the automatic discharge of halon is activated by flame, smoke, heat or gas detection systems. Early discharge type systems, relying on single UV, IR, or ionization detectors, are liable to experience false releases due to equipment failure or human error during maintenance. Technological advances, driven by normal commercial pressures, have improved equipment reliability and resulted in combination detectors that reduce false alarms. Also, the introduction of voting logic now allows system designs to require two or more detectors to be in alarm before halon is released, thus reducing the incidences of inadvertent discharge.

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.

Clearly reductions in false releases can be achieved if users are encourage to upgrade existing detection systems to take advantage of the latest technology.

Improved personnel training is vital to reduce unwanted discharges.

6.6 Halon 1211 Emissions Due To Training

The Committee believes that it may now be possible to virtually eliminate this source of halon emissions. Discussions within the industry suggest that fire training organizations 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 only one is discharged. With the increase in awareness of the environmental problems associated with halon, many users are switching to CO_2, dry powder or AFFF spray extinguishers. Thus, the demand for training in the use of portable halon extinguishers is declining. Chemical agents for fire fighter training that behave similarly to halon 1211, in many applications, but are not fire extinguishants, have been developed [3]. Therefore, it is reasonable to assume that the use on halon 1211 for training purposes could be virtually eliminated.

6.7 Emissions Caused During Filling

This component of halon 1211 and halon 1301 emissions 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 of a safe standard and be compatible for halon use.

Environmental and operator safety dictates that all filling procedures should be carried out by trained, and possibly licensed, personnel. Filling operations should be carried out in a well ventilated area with all safety relief valves from the rig connected directly to the outside atmosphere. All equipment, particularly flexible connects, 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.

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 discharged into the recovery container. 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.

6.8 Emissions Caused During Servicing

System cylinders should be visually inspected every four weeks to check for obvious damage to the cylinders, valves, etc., which may allow halon leakage. The contents of cylinders should be checked every six months to monitor losses. Valves and fittings etc. should be inspected at the same time using a local halon sensor such as those used to check refrigeration systems for leaks. Cylinders should not be replaced unless more than 5% by weight of the initial halon fill has been lost, or will have been lost by the next inspection if the measured loss rate continues at the same rate. This loss allowance is to minimize the number of cylinders disturbed and the consequent potential losses.

Current 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 by using approved recovery rigs.

Recovery rigs should be operated so as to avoid contaminating reclaimed halon supplies. Cylinders containing halon should be emptied by pressurizing with dry nitrogen or by use of positive displacement pumps. Vapours should also be recovered and, if possible, halons should not be mixed thereby enhancing recycling possibilities. Although halon recovery/recycling techniques are covered in Section Seven, it is worth noting here that halon 1211 recovery systems with an efficiency of 98% are readily available today, and that high efficiency (>96%) halon 1301 recovery systems are under development and expected to be commercially available in 1992.

6.9 Conclusions

Avoidable halon releases account for greater halon emissions than those needed for fire protection and explosion prevention. Clearly such releases can be minimized, as quantified in Appendix C, if a concerted effort is made by the fire protection community, with support from national governments. In reviewing reduction strategies, the Committee recommends the following:

- Reduce halon usage to essential applications only.
- Discontinue protection system discharge testing using halon as the test gas.
- Discontinue the discharge of portable halon fire extinguishers for training purposes.
- Discontinue the discharging to the atmosphere of portable halon extinguishers and system cylinders during equipment servicing.
- Encourage users of automatic detection/release equipment to take advantage of the latest technology.
- Encourage the application of risk management strategies and good engineering design to take advantage of alternative protection schemes.

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Section Seven

Management of the Bank of Halons

The quantities of halons banked in extinguishing systems containers, portable extinguishers and mobile units is far greater than the quantities emitted each year for extinguishing fires, discharge testing, training and unwanted discharges. For the year 1990, it is estimated that 65% of the supply (production + recycle) of halon 1301 and 52% of the halon 1211 was stored in cylinders or containers installed on end-users premises.

Managing this bank at a national level is necessary for the following reasons:

> To provide a precise means of evaluating the quantities of halon emitted to the atmosphere and to pursue efforts to reduce unnecessary emissions.
>
> To eliminate unnecessary emissions associated with periodic maintenance of pressure vessels or dismantling of installations.
>
> To recover the highest possible quantities, complying with necessary purity requirements, for recycling and reuse.
>
> To destroy quantities which cannot be recovered due to contamination in an environmentally acceptable manner.

Bank management consists of keeping track of halon quantities identified at each stage: initial filling, installing, recovery, recycling (or destruction) and recharging. This management is only possible through the companies which are in charge of these various operations. National organizations should be authorized to accredit these companies, to ensure quality control of materials and to centralize the data and information necessary to assume the responsibility of this bank management. Government support and funding, to stimulate the development of recycle and reuse will encourage the success of these programs. When contemplating regulatory actions regarding the halons, agencies of government should consider the possible effect on encouraging wise management of the banked halons. Regulatory measures which could assign destruction costs to holders of banked halons or impose restrictive use regulations will discourage bank management efforts.

Procurement policies by agencies of government and other halon users requiring use of recycled halons for recharge or initial fill will provide a strong motivation to establish bank management facilities. Procedures which are flexible and motivating enough must be developed specifically for existing fixed systems and portable extinguishers, as well as for new systems and equipment.

7.1 Fixed Extinguishing Systems

7.1.1 Filling of Containers

Filling of containers should be conducted in facilities where:

The condition of the container is checked before filling

Equipment to fill with the exact required quantity of halon is provided

Nitrogen is available for pressurization

Halon leak detection equipment is provided

A recovery rig is available

In order to properly manage the halon bank and to facilitate proper tracking of quantities, companies which have facilities for filling should keep written records of quantities of halons received from producers and quantities shipped to installers and/or end-users. They should be required to systematically supply the organization in charge of the bank management with all required data.

This implies a quality control on both technical and administrative aspects, e.g. ISO standards. The organization in charge of accrediting companies which do filling operations must be entitled to verify the quality control procedures.

7.1.2 Installation

Fixed extinguishing systems should be installed by companies capable of designing efficient systems that are reliable and specifically designed for the risk to be protected. These companies should be capable of providing preventive maintenance and recharging and re-commissioning after a discharge.

Certification of components in conformity with technical standards or rules, and the accreditation of installers by an independent organization, are measures which will assist in achieving best use of the available halons.

Preventive maintenance is an important factor in the elimination of unwanted operation of the system, for the extinguishing sub-system as well as for the detection sub-system. To ensure the efficiency of the system, preventive maintenance should include periodic verification of the room integrity in the case of total flooding systems. This can be accomplished, for example, by use of door fans and room pressurization techniques to determine enclosure leakage and estimate halon leakage rates after discharge.

Installing companies should keep written records of the quantities of halon used in each installed system, as well as for the recharge or replacement of containers after a discharge. Quantities of recovered and recycled halon should also be recorded.

Even when preventive maintenance is done directly by the end-user, accredited fire equipment maintenance personnel should be called upon to undertake periodic testing of the halon storage containers (pressure vessels). An accredited fire protection contractor should be consulted when a halon system is dismantled for modification or removal.

All containers should bear a label that:

1. Advises that the halon contained is an ozone depleting substance and provides a warning to avoid unnecessary emission

2. Encourages or requires return for recycle at the end of useful equipment life to accredited companies

Installers should educate users in the operation of these systems in order to avoid unwanted discharge, and in the maintenance and verification operations that can be performed by the user.

The quality of all types of services provided by installers should be controllable by the organization in charge of their accreditation. The case of suspension of activities of an installing company should be resolved within the national accreditation system.

7.1.3 Return Or Exchange (of Halon Containers)

When mandatory testing of pressure vessels is required, containers are often taken back and exchanged by the installing company. This should be the opportunity for a complete inspection of both the detection and the extinguishing parts of the system. Modifications of the protected risk which would not have been taken into account during periodic maintenance should be considered at this point.

Dismantling without reinstallation of a system must be undertaken by an accredited company. Any incentive that could be developed at a national level should be considered.

When containers are not taken back by the original installer - if he has ceased his activities for example - an exchange may not be possible due to incompatibility between equipment. The owner then has the choice between a modification of the system to make it compatible with new containers, or refilling the original containers after verification, which implies that the risk will not be protected during the period of time necessary for this testing.

7.1.4 Re-cycling (of Products)

Installing/recovering companies should hand over the containers to companies in charge of recycling unless they have adequate facilities themselves for this task. Recycling includes:

Analyzing products by chromatography to ensure that halon quality is in conformance with ISO 7201. (Ambiguous and unreliable data from other detectors is not suitable for identifying specific halons).

Emptying the container in an installation designed and constructed for recovering the liquid and vapour phases, while releasing less than 5% of the contents to the atmosphere and reconditioning the halon in accordance with ISO 7201, in order to obtain original purity.

Re-filling clean and dry containers.

Applicable fire protection equipment standards should require container valves to be equipped with a means for recovery at recycling stations.

Several configurations for recycling facilities, with recovery efficiency rates as high as 98% expected, are under study.

Unless means are developed to economically recycle contaminated halons and separate blends of halons, it appears that the halon will have to be stored until a destruction process is available.

A convenient scheme, which could be attractive from an economic and technical feasability standpoint is as follows:

a) Recovery and pre-treatment (depressurization, analysis, nitrogen removal) by 'local' recovery companies.

b) Final treatment leading to original purity (or storage for destruction of severly contaminated halon) by producers, after collection from 'local' recovery facilities.

As in previous steps, records will allow identification of quantities of halons received by recycling stations, quantities recycled with their destination (filling station or installer) as well as quantities shipped to accredited facilities.

Recovery and recycling of halon contained in a system installed in a country with no recycling facilities raises a particular problem of import/export that should be resolved at the international level. If it is not possible to require the installer to recover the product, then the contents of cylinders cannot be identified before analyzing it (in the recycling station). Thus, samples must be sent to a recycling station for examination.

7.1.5 Existing Installations

Quantities of halon contained in existing installations can be dealt with in the same way as halon in new installations after they have been identified.

Installations which are covered by a maintenance contract with an accredited installer will be identified immediately. For others, all possible means have to be put in place to make owners aware of the necessity of getting their system registered. As soon as procedures for new installations are established, a national information campaign should be undertaken with the participation of the halon bank administrator, insurance companies, professional associations of fire contractors, fire protection associations, fire engineers associations, etc. Incentives should probably be established at a national level, as a supplement.

Proof of registration of the halon could be the labelling of the containers, with the identification (name, address, etc,) of the recovering contractor which has registered the installation in its records.

For installations which would not have been included in this registration procedure, instructions could be given to government inspectors of the workplace to record such installations during their visits.

If the contractor who installed the system in the first place is no longer in business or did not obtain accreditation, the owner of the system should nominate an accredited installing-recovering contractor, under a special procedure put in place by the national organization in charge of management of the halon bank.

7.2 Fire Extinguishers

The management of that part of the halon bank contained in portable and mobile units (portable extinguishers, wheeled units, fire trucks and extinguishers installed in a fixed position), is far more problematic than for fixed systems due to the great number of suppliers, the small quantities per unit, the lack of precise identification of the contents, and the differences in the applicable regulations from country to country.

Several measures may allow an acceptable level of management:

Forbid extinguishers that do not allow for a high percentage recovery of contained halon.

Limit the use of halon extinguishers to the protection of risks where there is no alternative and take dissuasive measures to discourage use in less than essential applications.

Formalize the bonds between suppliers and companies which fill these units within the context of accreditation, in order to ensure the traceability of halon banks to the owner and to get all information back to the organization in charge of managing the halon bank.

Mandate a periodic check, for example every five years, by an accredited service company.

All these measures should allow the same measures applicable to fixed systems to be applied to the portable extinguishers for filling, recovery, recycling and destruction.

Labelling should be applied to the extinguishers that:

Advises that the halon contained is an ozone depleting substance and provides a warning to avoid unnecessary emission.

Requires return for checking at the end of the prescribed period.

Advises that in case of partial use, remaining halon should be retained and the extinguisher should be returned for recharge without emptying it.

The use of various blends in extinguishers makes recycling a difficult and onerous operation. It is possible that significant quantities of halon will have to be sent to accredited destruction facilities. International standardization of the extinguishing agent, of its propelling gas and of a recovery connection would encourage recycling.

7.3 Halon Destruction Options

The Halons - Technical Options Committee does not advocate unnecessary destruction of the uncontaminated halon bank, however destruction of contaminated halons must be considered. It seems contradictory, on a global basis, for some jurisdictions to require destruction of halons that would otherwise be suitable for recycle, even when continued production is allowed. On a global basis the required destruction by one country may in fact place pressure on production in another country to continue. Thus, exchange of halons, suitable for recycle, between countries must be encouraged. The use of recycled halons is a positive way to accelerate phase-out of new production and decrease the possible further environmental impact associated with the destruction process. Destruction of contaminated halons must be undertaken, when feasible, by accredited companies using approved methods. Until destruction capabilities are available, the cost of storage, including civil liability of the owner, must be addressed on a national basis.

7.4 Conclusion

Management of the bank of halons at a national level is possible through the various trades, producers, installers of fixed systems, extinguisher suppliers, companies in charge of filling, recovery or recycling. A national organization could be appointed to manage the bank of halons and should be responsible for certifying the companies involved in the process, in addition to the certification of equipment and installers. Environmental concern and restricted availability of the halons will likely encourage achievement of initiatives to manage the bank of halons.

Management of the banked halons is feasible only if the following items are addressed:

> Financial assistance and positive national policies are developed to encourage accreditation and investment in recovery and recycle organizations and facilities.
>
> National policies and financial assistance are developed to deal with the storage and eventual destruction of contaminated halons.

In addition, to avoid the paradox of some nations requiring destruction of otherwise recyclable halons, at the same time that the Montreal Protocol allows continued production, it is recommended that international exchange of recyclable and recycled halons be encouraged to reduce requirements for new production of halons.

Section Eight

Halon Replacement Agent Research

8.1 Introduction

The need for halons or halon-like materials to serve vital roles in life safety and fire/explosion protection in many applications will continue despite the development of new non-halon technologies as alternatives to the use of halons. The halon bank is expected to serve a portion of those needs for a period of time; however, replacements are needed now to ensure wise allocation of banked material with minimal environmental impact and to allow an eventual, orderly phaseout of halon use without unacceptable threats to safety. Replacements will also be needed once the bank is exhausted. This section of the report covers the development of such chemicals.

For clarity, two terms must be defined. A "replacement" agent is a halon-like, gaseous or volatile, clean fire extinguishant, explosion suppression agent and/or inertion agent. An "alternative" agent is defined as a not-in-kind, non-halon-like agent (e.g., carbon dioxide, water, foam and dry powder extinguishants). This Section discusses only the development of halon replacement agents. Chemical alternatives are discussed elsewhere in this report.

8.2 Approaches to Replacement Agents

The halon/ozone issue is not a single problem and has no single solution. Multiple replacement agents, varying according to application, are a likely outcome. The development of one or two general-purpose "drop-in" replacements having a low or zero ozone depletion potential (ODP) and all other significant characteristics equal to those of the existing halons may be an unrealistic research goal, at least in the near future. On the other hand, low- or zero-ODP clean replacements for selected specific applications are realistic objectives, though there is some concern about the commercial viability of small-volume chemicals and significant equipment changes could be required.

Four requirements make halons difficult to replace: cleanliness/volatility, low ODP, low toxicity and effectiveness. It is relatively easy to find chemical agents that meet any three of these requirements; chemicals that meet all four are much more difficult to identify. Of course, other considerations for replacement agents exist; cost, storage stability and compatibility with engineering materials are among these.

Halon fire extinguishants can be separated into two groups according to their application: halons 1211 and 2402, with higher boiling points, in one group and the more gaseous halon 1301 in the other. Different chemicals will likely be needed for replacement of each group. Halons 1211 and 2402 are usually applied by streaming (direct discharge from a nozzle positioned remote from the fire). Such agents are used in localized applications and are often applied manually. Halon 1301 is most often used in total-flood applications (filling of an enclosed volume with sufficient agent to suppress combustion or explosions following ignition or to "inert" atmospheres to prevent ignition). Both clean streaming agents and clean total-flood agents are needed. Some very specialized applications may be best served by agents that combine characteristics of both types of agents. Other applications are difficult to categorize exactly.

Nevertheless, it is useful to consider and contrast streaming and total-flood agents. Both replacement streaming agents and replacement total-flood agents must be clean and sufficiently volatile to provide adequate three-dimensional protection and suppression. Cleanliness (lack of residue upon evaporation), volatility and tolerability by humans for brief exposures are the primary reasons for the use of halon agents in most applications and such properties are the primary distinction between halon-like replacement agents and most halon alternatives (carbon dioxide being an exception). Note, however, that a streaming agent requires good deliverability; the material must not be too gaseous. Most (though, possibly, not all) clean, volatile halon-like chemicals will be compatible with electronic and energized electrical equipment.

Replacement agents must also have acceptable ODPs, the primary driving force for development of new agents. What ODP is "acceptable" is uncertain; an ODP of zero is a desirable goal. The setting of very low limits for ODP at this early stage in the search for replacement agents could be counterproductive. Such limits set in one nation could become targets for worldwide application and, thereby, prevent the rapid introduction of transition agents with significantly lower ODPs than the present halons.

Toxicity requirements may be less stringent for the less volatile streaming agents, since personnel are not usually in direct contact with discharged agent. In contrast, a total- flood agent may require a very low toxicity for application where people are present without pre-discharge evacuation. An ideal target is for toxicities no higher than those of the halons to be replaced. On the other hand, it is recognized that the neat agent toxicity of halon 1301 is sufficiently low that a somewhat higher toxicity than that of halon 1301 for total-flood replacements may be acceptable.

It must be noted that the term "toxicity" used here is somewhat ambiguous. Acute toxicity is usually of primary initial concern. In most realistic discharge scenarios, human exposure, if any, is usually no more than a few minutes. On the other hand, chronic toxicity and mutagenicity may be of importance in accessing safety related to manufacture, filling and handling, where long-term exposures to low levels of agent are possible. Combustion product toxicity must also be considered. Toxicity is discussed further below. Finally, a replacement agent must have an acceptable effectiveness. This does not necessarily mean that the amount of agent needed to provide adequate protection must not exceed that required for the existing halons. However, in many cases, space and weight limitations and oxygen depletion concerns may force restrictions on what is deemed an acceptable effectiveness.

8.3 Toxicity

Most research and development programs for halon replacements have emphasized halogenated hydrocarbons (halocarbons, the family of chemicals to which the present halon fire extinguishants belong). This is not to say, however, that other types of compounds are not being considered. Human and animal research indicates several principal adverse health effects are possible for halocarbons. Note that these effects are only possible and may not be present or significant in many cases. First, halocarbons can stimulate or suppress the central nervous system (CNS) to produce symptoms ranging from lethargy and unconsciousness to convulsions and tremors.[1] Second, halocarbons can cause cardiac arrhythmias and can sensitize the heart to epinephrine (adrenaline).[2] Arrhythmias may be of particular concern because personnel in an area exposed to a fire and to the shock of discharging agents could be exposed to these compounds while under highly stressful conditions, when their bodies have high levels of circulating adrenaline. In most cases, however, firefighters will have respiratory protection. Third, inhalation of halogenated hydrocarbons can produce broncho constriction, reduce pulmonary compliance, depress respiratory volume, reduce mean arterial blood pressure and produce tachycardia (rapid heartbeat).[3] Fourth, these agents can cause organ damage due to degradative by-products produced by metabolism.[4] CNS effects, cardiac sensitization and pulmonary disorders appear to be reversible upon termination of exposure to these chemicals. Organ toxicity, on the other hand, is a latent effect and sequelae (delayed effects due to the compound or its metabolites) are usual.

The immediate effects of a halocarbon on the nervous system, cardiovascular system and respiratory system appear to be caused by the compound itself. However, it is thought that the latent effects that take place in specific organs, such as the liver, kidneys and lungs, are caused by the degradative products formed when the halocarbons enter into metabolic processes. Both the immediate effects and the latent organ damage must be considered when evaluating potential candidates for firefighting agents. Generalization to the entire class of halocarbons would be convenient; however, toxicity information on each candidate must be acquired in order to assess fully its potential health hazards.

Halocarbons decompose when exposed to flames and sufficiently high temperatures, giving hydrogen halides (usually, hydrogen bromide, HBr, hydrogen fluoride, HF and/or hydrogen chloride, HCl)[5]. Bromine (Br_2) and trace quantities of carbonyl halides (carbonyl chloride, $COCl_2$ and carbonyl bromide, $COBr_2$) have also been observed, but their levels are usually too small to cause concern for the present halon extinguishants. The predominant effect of the acidic decomposition products is irritation. The by-products have a characteristic sharp, acrid odour, even at low concentrations, which provides a warning of their presence. Irritation becomes severe well before extremely hazardous and life-threatening conditions persist, though this does not rule out the possibility of dangerous exposures.

Studies may be required to not only determine the amount of acidic decomposition products produced by halon replacements, but also to identify and quantify any other toxic compounds (e.g., certain unsaturated halocarbons) that may be produced.

When evaluating the toxicities of halon replacements, one must consider which is more hazardous, the fire and its combustion by-products or the extinguishing agent and its decomposition by-products. Generally, the decomposition products formed by the fire itself, especially carbon monoxide, smoke, heat and oxygen depletion, create an extremely hazardous condition. These factors must be weighed against the potential dangers of extinguishment by replacement agents.

Toxicity testing is likely to be the most time-consuming part of studies of potential firefighting agents. For example, under the accelerated testing schedule of the Programme for Alternative Fluorocarbon Toxicity Testing (PAFTT), thorough testing of a new halocarbon compound being considered as a CFC replacement in refrigeration, cleaning, or foam blowing applications requires six years.[6] This gives an indication of what might be required for new halon replacement candidate having no toxicity data available; however, it is not meant to indicate that a program similar to that established for CFC replacements will be required for fire extinguishants. Considerations of the short- and long-term health hazards to exposure, the relationships between chemical structure and toxic effects, and the biodegradation and production of reactive metabolites are of key importance when deciding which compounds hold potential for future use as firefighting agents.

8.4 Development of Replacement Agents

The steps needed to identify replacement agents have been vigourously debated. Some favour a broadly based effort with a foundation and/or parallel effort of basic research. This type of program begins with consideration of all possible families of chemicals and screens these to end up with a set of final agents. Others favour a targeted approach, directing their effort toward those chemical families considered to offer the most promise as replacement agents.

Halocarbons have received most consideration as halon replacements because of their cleanliness, fire suppression capabilities and well developed commercial processes for manufacture. Four major problems exist in carrying out these efforts. First, no limits on "acceptable" ODP values have been established. In fact, as pointed out earlier, some doubt exists as to whether any ODP value greater than zero is acceptable. Moreover, the reliability of ODP estimates is controversial. The uncertainty in the reliability of ODP values will be an obstacle to halon replacement agent research until the atmospheric models can be better defined and the chemistry of ozone depletion, clarified. While many consider low-, but nonzero-, ODP halocarbons to be a solution to the problem, rather than the source of the problem, this is not universaly accepted. What has been widely accepted, however, is that such substances can serve as transitional agents. Unfortunately, even if the international environmental and political communities were to adopt values for acceptable ODPs, no guarantee exists that these limits would not change.

Second, the concern about global warming is increasing. The global warming potential (GWP) of a chemical is the calculated relative ability of a volatile compound to affect global climate through absorption and emission of infrared radiation. GWPs are calculated from atmospheric models similar to those used for ODPs. The GWP is becoming of increasing concern and many of the candidates being evaluated as clean firefighting agents have significant GWPs. Of potential concern is that two groups of replacement candidates having zero ODPs -- perfluorocarbons and, to a lesser extent, hydrofluorocarbons -- may have relatively high GWPs. On the other hand, any possible impact of halons or halon replacements on global warming must be put in perspective considering the low amounts of anticipated releases and the vital role in protection against fires and explosions.

Third, the absence of bromine may be required to obtain carbon-based replacements with very low or zero ODPs; however, it is precisely bromine chemistry that gives the present halons their high effectiveness. Compounds not containing bromine will likely depend primarily on less efficient physical extinguishment mechanisms such as heat absorption. Thus, unless high discharge rates can be achieved, zero- or very low-ODP replacements may have relatively inefficient extinguishment with increased production of toxic and corrosive combustion products.

Fourth, in assessing the commercial viability of new, clean extinguishing agents, chemical manufacturers must consider trends regarding acceptable toxicity evaluations. It is likely that future health and safety requirements may be more stringent. Moreover, to limit liability, chemical producers are likely to be even more demanding in toxicity testing than are regulatory agencies. While it is difficult to fault such an approach, this cautious attitude may significantly increase the time required to introduce new halon replacements. Any evaluation of toxicity data for neat halon replacement agents or their decomposition products must take into consideration the historic experience available on the toxicity and use of the current halons. The degree of testing needed to assess safety risks from toxicity products must still be defined. Of particular concern is the testing and risk assessment for combustion products. A number of the candidate agents now being examined produce significantly increased levels of hydrogen halides during fire extinguishment.

Most of the research and development programs for halon replacements have been sponsored by producers or by government. The majority of the candidates that have been reported are similar to the candidate CFC replacements in that they contain no chlorine or bromine and/or they are designed to have reduced atmospheric lifetimes. Reduced lifetimes can be obtained by the addition of hydrogen atoms to the molecule to allow reaction with tropospheric hydroxyl free radicals (the most common method used to date) or through molecular modification to increase susceptibility to photolysis and/or rain-out. A number of candidates have been announced; however, all of them require some trade-offs in effectiveness, ODP and/or toxicity. Moreover, many of these candidates have not been thoroughly tested and may not be applicable or adequate for all fire threat scenarios. Finally, some of the announced candidates, in particular the hydrochlorofluorocarbons, are or will probably be regulated under the Montreal Protocol and will provide only an interim solution. Among the specific compounds that have been announced as candidates for halon replacements are those shown in Table 1. In this table, the prefixes "HCFC," "HFC," "HBFC," and "FC" denote, respectively, "hydrochlorofluorocarbon," "hydrofluorocarbon," "hydrobromofluorocarbon," and "perfluorocarbon." Note that this table contains information only on pure compounds and does not include formulated blends that have also been proposed as halon replacements. The use of blends may create additional problems for recycling.

TABLE 1. ANNOUNCED HALON REPLACEMENT CANDIDATES

Candidate	Formula	Application	Reference
HCFC-123	CF_3CHCl_2	Streaming	7
HFC-125	CF_3CHF_2	Total Flood	8
HFC-23	CHF_3	Total Flood/Pressure *	9
HFC-227ea	CF_3CHFCF_3	Streaming/Total Flood	10
HBFC-22B1	CHF_2Br	Streaming/Total Flood	11
HBFC-124B1	CF_3CHBrF	Streaming	12
FC-218	$CF_3CF_2CF_3$	Total Flood	13
FC-3-1-10	$CF_3CF_2CF_2CF_3$	Streaming/Total Flood	14
FC-4-1-12	$CF_3CF_2CF_2CF_2CF_3$	Streaming	15
FC-5-1-14	$CF_3CF_2CF_2CF_2CF_2CF_3$	Streaming	15

* HFC-23 has also been proposed as a pressurizing agent for use in expelling other halon replacement agents.

Table 2 gives the molecular weights, extinguishment concentrations, ODPs and LC_{50} or ALC values for these candidates. Halons 1301 and 1211 are included for reference.

TABLE 2. COMPARISON OF CANDIDATES AND HALONS

Candidate	Mol Wt	Ext Conc, %	ODP	LC_{50} or ALC, %
Halon 1301	148.9	3	10	>40
Halon 1211	165.4	3	3	>8
HCFC-123	152.8	7.5	0.02	3.2
HFC-125	120.0	9.1	0	>70
HFC-23	70.0	13.0	0	>65
HFC-227ea	170.0	5.9	0	>80
HBFC-22B1	130.9	3.9	1.1	10.8
HBFC-124B1	180.9	≈3	0.4	--
FC-218	188.0	6	0	>80
FC-3-1-10	238.0	5	0	>80
FC-4-1-12	288.0	5	0	>80
FC-5-1-14	338.0	4.4	0	>30

The ODP values for the Table 2 compounds containing no chlorine or bromine (the HFCs and FCs) are assumed to be zero. The remaining ODPs in Table 2 are those calculated by the Lawrence Livermore National Laboratory in the United States using an atmospheric model that does not take into account the temperature dependence of the absorption spectra.[16] The values for the bromine-containing compounds (halon 1301, halon 1211, HBFC-22B1 and HBFC-124B1) are from a 1-dimensional atmospheric model; values for the remaining compounds are from a 2-dimensional model. Recent work indicates that these values may change when the temperature dependence of the absorption cross sections are taken into account.

With the exceptions of FC-218, FC-3-1-10 and FC-4-1-12, whose LC_{50} values are estimated and halons 1301 and 1211, the LC_{50} values and the fire extinguishment concentrations in Table 2 are taken from the references cited in Table 1. The data for halons 1301 and 1211 are taken from Reference 17. The LC_{50} is the concentration lethal to 50% of a population and the ALC is the approximate lethal concentration. These are acute toxicities (usually determined in 4-hour rat studies) and do not necessarily reflect the many other toxicity issues that may need to be assessed. Note that in the case of FC-5-1-14, which has a boiling point well above room temperatures, the lower limit of the LC_{50} is the highest concentration possible.

The fire extinguishment concentrations in this table are the agent concentrations in air required to extinguish a heptane flame as determined with a cup burner. Extinguishment concentrations depend on the specific apparatus and methodology used; however, values determined by different organizations are likely to agree within $\pm$ 1 percentage point (e.g., 5% $\pm$ 1%). Fire extinguishment concentrations are good indicators of efficiency in total-flood fire extinguishment applications, but they may not reflect well agent performance in streaming applications, in explosion suppression, or in inertion.

HCFC-123, HFC-125 and HFC-23 are or will be produced as CFC replacements or as by-products, and are, therefore, expected to be readily available in bulk. HFC-227ea is being considered as a CFC alternative. HCFC-123, HFC-125, HFC-23 and HFC-227ea are being considered as halon replacements. HFC-23 has also been suggested for pressurization of extinguishers for streaming agents. A large number of toxicity studies have been completed or are in progress on these HCFC and HFC candidates and they are known to have very low or zero ODPs; however, they have decreased fire suppression capabilities compared to the existing halons. The relatively high acute toxicity of HCFC-123 may require a risk assessment before consideration for use, particularly in enclosed areas with unprotected personnel present. HFC-125, HFC-23 and HFC-227ea have low acute toxicities. Owing to the decrease in efficiency of these HFC candidates, a considerably increased storage volume (compared to that required for halon 1301) would be needed in any fire protection system. It should be noted, however, that the extinguishment concentrations given in Table 2 are expressed in percent by volume. Concentrations based on weight, which is more closely tied to economics and storage, make the lower molecular weight HFC candidates compare more favourably with the existing halons.

HBFC-22B1, a bromine-containing compound which is now available in relatively large amounts, is being commercialized for both total-flood and streaming applications. At present, this material is being marketed only for use where human exposure is minimized. Toxicity testing to the subchronic stage will be complete by the end of 1992. While the ODP of this material is an order of magnitude less than that of halon 1301, it is still significant. The relatively low acute toxicity and the excellent fire extinguishment characteristics make HBFC-22B1 otherwise attractive.

HBFC-124B1, a streaming agent with excellent fire extinguishment characteristics, is still very much in the experimental stage. No quantitative toxicological data have been reported; however, industry sources state that early toxicological results look good. Because the estimated ODP for this chemical is above the U.S. Clean Air Act regulatory limits for ozone depleting materials (an indication of possible regulatory problems in other nations), no plans exist to make a capital investment in production of this material until such time as the ODP issue becomes clearer.

The perfluorocarbons, FC-218, FC-3-1-10, FC-4-1-12 and FC-5-1-14, have zero ODPs and are believed or known to have very low toxicities; however, their high stability is expected to give them a high atmospheric lifetime. Considerable research and development is in progress on these and other perfluorocarbon extinguishants.

Some blends containing CFCs are now being marketed. The fully halogenated chlorofluorocarbons have significant fire extinguishing capabilities and have well-defined, low toxicities. Since CFCs have lower ODPs than do the present halon fire extinguishing agents, substitution of CFCs for halons in selected fire protection applications could reduce the threat to the ozone layer. On the other hand, these materials are regulated under the Montreal Protocol and are in a different category than are the halons. This makes substitution a highly sensitive issue and unlikely to be widely supported. In particular, the viability of halon replacement candidates containing components having a more stringent phaseout schedule than the present halons is questionable.

8.5 Conclusions

Work to date indicates that the development of general purpose, zero-ODP, direct replacements having attributes equal to those of the present halons may be unrealistic in the short-term and also possibly in the far-term. On the other hand, clean halon replacements with lower ODPs for selected specific uses are a realistic goal, particularly if trade-offs in fire extinguishment capability, toxicity and/or other characteristics are acceptable. However, there is some concern about the commercial viability of small volume chemicals.

Even though the research on halon alternatives is still in the early stages (as compared to CFCs), several zero- and low-ODP alternatives have been announced. Preliminary research indicates that the zero-ODP candidates have performance characteristics and design criteria that are significantly different from those of halons. Some of the low- ODP alternatives perform very similarly to halons. Such chemicals may prove to be important transitional substances as they may allow for reduced production of halons prior to the phaseout date. After the phaseout date, the use of low-ODP transitional substances may augment usage of banked halons for essential applications.

Uncertainties about future ODP, GWP and toxicity requirements are of great concern in the development and commercial viability of halon replacements. Government funding would shorten the time required for development of halon replacements. In considering the relative environmental issues, halon replacements must be evaluated in terms of existing halons and the roles of these agents. Regulatory actions have been largely based on the excellent progress made in CFC replacements with little recognition of the special role and developmental status of halon replacements.

Though the development of halon replacements continues and although very promising results have been obtained, it is unwise to make decisions based on announcements of candidate agents whose applicability remains to be confirmed and which, for the most part, require significant trade-offs in effectiveness, ODP and/or toxicity. Halon replacement chemicals are not at the same advanced stage of development as are many of the CFC replacements for refrigeration, solvents and other applications. Furthermore, considerable work must be done on systems engineering, approval testing must be performed and standards must be developed after acceptable replacements are identified.

For most applications, significant additional investment in research and development work is required to obtain acceptable agents which approach the efficiency of the existing halons. High-efficiency may require significant chemical suppression, which usually means the presence of bromine (or iodine). At present, very low-ODP, highly effective candidates have not yet been proven, nor have many such candidates even been identified.

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Section Nine

Reduction of Military Halon Use

9.1 Background

Many of the military applications for halons are similar to those found in either the public or private sectors. Military organizations typically operate bases which contain industrial, administrative, residential, telecommunications, computer, and other functions which are typical of any city in the world. On the other hand, some applications are unique to the military.

This section of the report describes those applications which are specific to the military and provides specific examples, estimates the amount of halon needed to support military applications globally, and describes possible alternatives to halon which could offer comparable high levels of protection to combatants and equipment.

There are a number of characteristics which make military halon applications different. These include differences in threat, the need to preserve combat capability for the national defense, the long lead times involved in the development and acquisition of major weapons systems, and the difficulty in modifying weapons systems because they are more extensively integrated and precision engineered than most industrial or commercial hardware. This distinction is made to dispel the notion that all applications by military organizations contribute directly to military capability. For example, portable halon extinguishers used to meet life safety requirements or replacement requirements in military administrative offices could be replaced with water, dry chemical, or other extinguishers as easily as if they were in any other business or government office. Surveys conducted in the United States suggest the majority of halon used by military services are not for direct support of combat capability. Each application for halon can be evaluated to determine whether it is unique to military requirements. Some of these features that distinguish military applications involve the nature of the fire threat in combat capability on the battlefield.

9.2 Threat of Fire

Conventional fire protection systems are installed to protect life and property from accidental fire. The risk and consequences of fire are managed by balancing the fire threat against the protection achievable through careful application of proven fire protection principles by competent design engineers. The result is a design which through a combination of passive and active fire protection measures brings the overall risk to within acceptable limits. The military applications addressed in this section are limited to those in which the threat is from an expected deliberate use of violence by an opposing military force or from an accidental means that would have a direct impact on combat capability.

9.3 Preservation of Combat Capability

The distinction between military and non military application concerns the consequence of equipment loss due to a fire. In a non military setting, the difference between preserving equipment function is usually one of economics. During military operations, the loss of equipment can be decisive to the outcome of battle. Modern high tech warfare consists of relatively short and intense battles. The weaponry used are sophisticated, precisely engineered, highly integrated, and many times more potent than previous weaponry. Military arsenals consist of fewer assets, each with a higher military and financial value than ever before. Manufacturing replacements takes longer than ever before. These factors pose a number of challenges to the military user of halon dependent weapons. First, the duration of modern warfare and the production time required for weapons systems means that on today's battlefield the assets a military organization takes to war are the assets it will have to fight the war. Today's military cannot depend on the industrial capacity of the nation to produce replacements for aircraft and tanks attrited during battle. For this reason, the impact of a proposed halon alternative on battlefield survivability is a driving force in evaluating its suitability. Secondly because the systems are so highly integrated, modification to replace existing halon systems may require extensive and/or in some cases impossible reconstruction. Space, weight and configuration are generally more crucial in weapons systems than for civilian applications.

9.4 Sea, Land and Air Forces

The military is divided into sea, land and air forces. Each of the following sections discusses why it is different from any comparable civilian application, presents possible alternatives, and describes strategies for reducing and eventually eliminating military dependence on halons.

9.4.1 Sea Forces

9.4.1.1 Background

Military ships and boats constitute a national asset for the owning country. Aircraft carriers, submarines, modern cruisers and destroyers, hydrofoils, air cushion landing craft, high speed patrol boats, etc, are highly sophisticated examples of precision engineering. These vessels represent an enormous monetary investment with a long lead time for replacement. Additionally, these vessels have an intangible value due to their strategic and critical requirement to protect national and in some cases global peace.

Unlike merchant fleets, the sea forces are intended to sail into harms way which makes them susceptible not only to accidental fires but to enemy-induced fires. In this severe threat environment halon enhances the combat survivability and preservation of mission capability. To be forced to pull a ship off-line for repair of fire damage during periods of international crisis could have serious ramifications.

There are other differences between military and merchant fleets which make halons more critical to military fire protection. Not only do military vessels cost more per ton of displacement but also have a smaller weight margin. Adding emphasis to the need for lighter more efficient fire extinguishing systems (such as halon 1301 as opposed to much heavier CO_2 systems). Also, unlike merchant ships, propulsion machinery spaces on military ships are usually manned which increases the importance of a non-toxic agent such as halon 1301. Additionally, the fire protection emphasis on merchant ships is for the safety of passengers while for military ships the vessel must be protected to maintain mission capability. Accordingly, fires that might disable the ship without endangering the passengers are more tolerable on a merchant ship. Under the International Maritime Organization (IMO) Safety of Life at Sea (SOLAS) regulations, halon is not required in the propulsion machinery spaces of merchant ships. US Coast Guard requirements for US Flag merchant vessels dictates CO_2 flooding for machinery spaces, with halon treated as an "acceptable alternative" to CO_2.

Boats and small crafts are another area where military and civilian requirements differ. Obviously there is a difference in fire protection requirements for pleasure craft as opposed to landing crafts which must deliver troops to the beach under enemy fire or patrol boats which operate in hostile enemy waters during combat. Under IMO and US Coat Guard regulations, pleasure motor craft, commercial tugs and fishing boats are classified as "unregulated vessels". For such vessels, there is no requirement for halon systems to protect engine compartments. Halon is available as a "buys option".

9.4.1.2 Specific Naval Military Halon Applications

Complete information has not been available from all world navies however, military sea applications may be typified by the current usage of halon by the U.S. Navy.

The U.S. Navy currently has approximately 2000 halon 1301 systems on 300 ships. These systems represent an investment value (material and installation costs) of approximately US$ 500 million. The inventory of halon 1301 systems as a function of the types of spaces protected is as follows:

U.S. Navy Inventory of Halon Systems by Application

Propulsion Machinery Spaces:	592 Systems
Auxiliary Machinery Spaces:	409 Systems
Diesel Generator Rooms:	320 Systems
Fuel Pump Rooms:	176 Systems
Gas Turbine Modules:	102 Systems
Flammable Liquid Storerooms:	200 Systems
Miscellaneous Spaces:	206 Systems
Paint Mix and Issues	
Compressed Gas Cylinders	
RAST Machinery	
Towed Array Sonar	
Weapons Hoists	

The halon storage cylinders contained in the systems listed above hold approximately 550 tonnes of halon 1301. On-board spare reserve cylinders on ships would hold an additional 227 tonnes. Additionally, about 18.2 tonnes are contained in fire extinguishing systems on approximately 250 U.S. Navy boats, landing craft, explosive ordnance disposal boats, and miscellaneous small craft. The use of halon 1211 is minimal; approximately 2.7 tonnes of halon 1211 is contained in hose reel units and portable extinguishers on air cushion landing craft.

The U.S. Coast Guard also uses halon 1301 systems to protect machinery spaces on Coast Guard cutters, ice breakers, and patrol boats. Additionally, the US Army has halon 1301 engine protection on 29 boats, halon 1211 engine protection on 28 boats, and small 1.25kg halon 1301 portable units on 23 liquid barges.

Internationally, most Navies use halon for fire protection applications similar to the U.S. Navy. For example, the British Navy currently has halon 1301 systems containing a total of approximately 85 tonnes of halon on about 250 ships and boats (including the Royal Navy Auxiliary). Halon 1301 systems are used to protect propulsion machinery spaces and fuel pump rooms. Some portable halon 1211 extinguishers are used and a few 1211 total flooding systems are installed in the engine rooms of old mine-sweepers and in some gas turbine modules.

Some Navies of the world (UK, USSR, Japan, Sweden) also install halon fire extinguishing systems in submarines. In the UK, for example, halon 1301 is installed in the engine room, auxiliary machinery room and motor generator room on diesel submarines, while halon 1301 is installed in diesel generator rooms of nuclear subs.

9.4.1.3 Possible Alternative Fire Protection

Designs/Strategies

Most of the military sea halon applications are installed to counter the threat of flammable liquid fires. The uses of fire extinguishing systems is only one of several options available to offset a potential threat. Other alternatives to fire extinguishment include passive fire protection design features, fire prevention measures, fire safety tactics and procedures, and in the case of combat survivability, hit avoidance (i.e. evasive action). Enhancements to fuel system integrity, isolation of fuel from ignition of hot surfaces, installation of fire resistive enclosures, good housekeeping, strict enforcement of fire prevention regulations, provision of adequate drains and ventilation to remove liquid spills and combustible vapours, reliable fire detection, etc... are examples of alternative strategies that can be used to reduce the need for halon fire extinguishing systems. Alternative fire extinguishing systems are as follows:

Alternative systems to halon 1301

Halon type gaseous (or vaporizing liquid) total flooding systems having zero ODP. A drop-in one for one replacement for halon 1301 would be ideal, but no such agent exists at present. In the absence of this the following systems are recommended;

CO_2 systems,
Spray and sprinkler systems (foam or water),
Fine water mist systems,
Combinations of the above systems,
High expansion foam systems, and
Powder systems (total flooding or local).

Alternative systems to halon 1211

CO_2 extinguishers or hose systems,
Powder extinguishers and hose systems,
Replacement halons,
Water extinguishers and hose systems,
Fine water mist extinguishers and hose systems, and
Foam extinguishers or hose systems.

9.4.1.4 Impact of Halon Alternatives

Halon 1301 has been widely used for military sea applications because it possesses the following desirable characteristics:

a. It is very effective on flammable liquid fires (both pool fires and three dimensional fires), as low as 1/3.12 kg/m^3 of 1301 provides immediate flame extinguishment for many fuels.

b. It is clean (leaves no residue, required no clean-up, does no damage to machinery or electrical equipment).

c. It is relatively non-toxic (design concentrations are not life threatening).

d. It is electrically non-conductive (hence safe to use on energized electrical equipment).

e. It rapidly fills an enclosed volume.

On the other hand, halon 1301 has certain limitations:

a. It provides no cooling (hot surfaces thus remain as sources of ignition).

b. It does not vapour-secure flammable liquids.

c. It requires a tight enclosure because of the tendency of halon 1301 to be carried away by ventilation systems.

d. Under certain conditions halon decomposition products may cause corrosion.

The impact of using any halon alternative depends on how the characteristics of the alternative compare to halon. The use of alternatives in certain application may necessitate greater assumption of risk, more emphasis on fire prevention and passive design features, and perhaps a greater dependence on manual fire-fighting.

The most likely candidates among existing fire suppression agents (with a proven history of performance and known characteristic) are CO_2 and foam. The new emerging substitute gaseous agents and fine water mist require additional development, testing, and system design to adequately assess their viability as alternatives.

CO_2 has two distinct disadvantages relative to halon 1301; it is less effective (more weight per volume protected), and it is an asphyxiant. However, for small unmanned spaces, CO_2 can be an adequate alternative. Protection of shipboard gas turbine modules and engine spaces on boats and small craft are likely roles for CO_2 systems.

Foam, unlike halon 1301, is potentially damaging to machinery and electrical equipment, is electrically conductive, does not rapidly fill a volume, and has only limited effectiveness on three dimensional flammable liquid fires (it can extinguish fuel running over a surface due to gravity flow, but cannot handle pressurized releases of fuel). On the other hand, foam does provide cooling, secures fuel pool surfaces, and does not require an air-tight enclosure. Accordingly, foam can be an acceptable substitute for halon in spaces lacking the potential for releases of fuel under pressure. Shipboard flammable liquid storerooms may be adequately protected by foam, as well as machinery spaces containing propulsion engines totally within enclosures, or as a contingency last ditch fire protection system for other flammable liquid spaces.

Because of the unique aspects of military sea fire threats and the many variables involved, the impact of adopting halon alternatives will have to be assessed on a case-by-case base.

9.4.1.5 Halon Requirements After the Year 2000.

In view of the proceeding discussion, the most probable course of action for world Navies relative to military sea halon 1301 applications would be:

a. Immediately adopt halon conservation practices (discontinue releases of halon for discharge testing or training, utilize recapture/recovery equipment for recharging and servicing).

b. Vintage existing systems. Adopt a policy that what is now owned will be kept (i.e. halon systems now in existence, or to be installed during the next few years, will continue to be supported for the remaining life of the vessel).

c. Minimize new halon installations for the next few years beginning immediately to adopt CO_2 or AFFF where appropriate.

d. As development/testing/system engineering is completed, specify new gaseous agents (or perhaps fine water mist) in lieu of halon for new installations.

e. Prior to the phase-out year, totally prohibit the incorporation of new halon systems in new ships designs.

9.4.1.6 Sea Forces Recommendations.

Under this course of action, the only need for halon 1301 after the phase-out year will be to support the remaining economic life of whatever systems exist at that time. The key question then becomes: "Will the quantities of halon 1301 available to military sea applications from military stockpiles and/or via priority allocations from a global bank be sufficient to support existing systems for their remaining life?"

The support required for existing systems will consist essentially of replacement of leaky cylinders, refill cylinders following use on a fire, or refill following accidental or malicious discharges. With the cessation of discharge testing these continuing "support" requirements will constitute a small percentage of existing systems storage quantities. Additionally, halon quantities available to support existing systems will be continuously replenished as halon is recovered from decommissioned ships and added to the stockpile.

9.4.2 Land Forces

9.4.2.1 Fire Survivability Versus Overall Survivability of Military Ground Vehicles.

Fire survivability of military ground vehicles is one of at least seven key design features which contribute to overall survivability. When factored together these features determine the overall probability of a vehicle "Kill" (Pk) in combat. The seven features of probabilities of being are: Detected (Pd), Identified (Pi), Acquired (Pa), Hit (Ph), Penetrated (Pp), Set Afire (Pf), and Exploded (Pe). Mathematically expressed as:

$$Pk = Pd \times Pi \times Pa \times Ph \times Pp \times Pf \times Pe$$

Usually both passive (inherent) and active (component and sub-system) counter measures affect each feature. For example, Pa could include active jammers that might disrupt enemy acquisition radars or passive stealth-like features to absorb radar signals. In the case of Pp, a reactive type armour might be used to explode and tilt incoming High Energy Anti-Tank (HEAT) munitions; while inherent vehicle geometry (oblique surfaces) might defeat kinetic energy munitions by presenting more armour to the incoming round. Usually passive measures when included in the initial vehicle design are at least an order of magnitude less expensive. These measures typically don't have moving parts to wear out nor do they require maintenance and therefore are "transparent" to the vehicle operator. Unfortunately, retrofitting passive measures into existing vehicles is often very expensive. In the case of Pf many designers fail to fully exploit the passive aspects in their initial designs and all too often include only active (fire suppression) considerations. Design considerations that "design-out" flammables from high value areas (crew and turret), use of quick sealing fuel and hydraulic lines requiring use of non-flammable hydraulic fluid, adding ballistic protection to high pressure hydraulic components, using electric drives instead of hydraulics and using diesel instead of more flammable fuels, are just typical passive countermeasures that improve survivability. These measures are typically military unique when compared with non-military ground vehicles. Some notable military vehicles have been developed over the past decade that have eliminated the need for a fixed halon fire suppression system in specific crew area and minimize class A and B type fire sources. Usually hand-held extinguishers are provided in these situations to handle peacetime slow-growth fires. In these hand- held extinguishers, carbon dioxide has been recognized as a suitable near term agent.

9.4.2.2 Military Ground Vehicle Suppression Applications

The common fear of fires throughout the worlds' Armies is best summarised as follows: "Fire is the hideous, unspeakable nightmare of armour." Not since World War I aviation, where pilots (without parachutes) fought in "tinder boxes" of wood and fabric, surrounded by fuel and ammunition has a fear of a fiery death been shared so universally within the military.

There are three basic applications in military ground vehicles:

a. Engine compartment fixed systems.
b. Crew/Turret area fixed systems.
c. Hand-held units.

Engine compartment systems are by far the earliest designs, dating back to World War II German tanks. These early installations proved relatively effective compared to opposing tanks without such protection. Post war studies leveraged the operational lessons learned by assessing various agents and even some binary combinations to include carbon dioxide, water and halons. These laboratory assessments included limited performance (against N-heptane) and toxicity issues. Little was done until the early 1960's when the need to improve crew and vehicle survivability of gasoline powered vehicles became a driving combat operational requirement. Today, engine compartment systems include a wide range of fire sensors form ultra-high speed optic sensors to slower thermal devices. These sensors are either part of an automatic discharge system or in some case simply provide a fire warning light to a crew member who then manually activates the agent discharge. Typically, fires in the engine compartment that occur during normal peacetime operations are relatively slow-growth events which are measures in seconds.

In this context, engine compartment fire suppression is most often viewed as a crew/vehicle safety enhancement. In the past decade, the use of automatic systems, with cheaper and more robust thermal sensors have been utilized very successfully. These systems use a wide variety of clean agents including carbon dioxide and halons. Some critical agent parameters in engine compartments are: effectiveness against class A and B fires, ability to fill the entire engine compartment, persistence, cleanliness, and no electrical conductivity. Other important but less critical parameters include toxicity and space and weight claims. As discussed earlier, passive techniques to mitigate reliance on the suppression systems have met with mixed acceptance. Some of these techniques such as automatic engine fuel shut-down, closing the cooling/vent grilles, using self-sealing fuel and lubricating oil lines, and shielding high temperature surfaces are just some examples of sound design practices. While these passive technique can reduce the amount of agent, it is not anticipated that elimination of all flammables is practicable. It is therefore projected that the use of fire suppression systems (even for new designs) will continue.

Of the three basic applications in military ground vehicles, alternative/substitute agents for halons in engine compartments is viewed as a medium technical risk. Near term agents such as carbon dioxide and long term candidates such as the new agents identified by chemical producers, appear to have reasonable chances for acceptance.

Verification of overall agent effectiveness must be assessed in a logical sequence. A typical test protocol might contain a literature review, small scale laboratory tests, full scale surrogate vehicle (mock-up) tests, and finally a fully configured and equipped vehicle. These tests would be conducted under actual fire situations and as they progress to full scale vehicle testing become relatively more complicated, costly and time consuming. A complete set of tests on a agent might take three years to complete and cost upwards of US$ 250,000. It is therefore important to ensure only the most promising agents reach the more expensive full-up tests. Less effective agents must be eliminated in the earlier portions of the test protocol.

Normally occupied areas which include the crew positions, passenger and turret portions of the vehicle, pose a significantly greater challenge than the engine compartment. In this application, the typical fires are threat-induced and much more violent. Flame front propagation measured in milliseconds moves through these areas causing death and destruction. Unlike engine compartment fires, the crew has little time to evacuate the vehicle. Many times if the penetrating round or initial fire ball does not incapacitate or kill the crew member, secondary explosions from "cook-off" will. Actual combat statistics show explosions in these areas are ten times more likely to occur in combat than engine fires. One reason for this involves the fact that most modern tanks are rear engine designs and in combat most enemy direct fire penetrations come from the frontal aspect. Also, world armies train their gunners to aim at the vehicle centroid which typically is the turret area from both the front and side views.

Whereas an engine compartment fire suppression system is normally classified as a vehicle/crew safety enhancement, a crew compartment explosion suppression system is a "combat force multiplier". The military deployment of these systems over the past two decades has demonstrated substantially improved combat effectiveness. They not only mitigate the risk of explosions but also result in significantly less collateral damage. The vehicles that are penetrated by enemy fire can more readily be reconditioned/repaired and re-enter the battle. Tank crew survivability is significantly increased and this has a non-quantifiable but rather real morale effect.

Although this application is most critical from a combat survivability viewpoint, it has the best potential to be eliminated in new vehicles. It is projected that with sound passive designs, sufficient flammables can be eliminated from normally occupied areas of future vehicles.

The overriding critical agent parameter in this application is toxicity. Unlike some other military and civilian applications, the crew is exposed to neat agent and attendant pyrolysis products during and after the explosion. Halon 1301 was evaluated for this application by the U.S. Army in the mid-1960's. Almost five years of actual live fire performance and extensive toxicity test culminated in the 1969 Army U.S. Surgeon General's approval for the use of halon 1301. To date, no other agent has demonstrated the characteristics to replace halon 1301 in this application nor has any new substitute been publicly announced. The identification and acceptance of a replacement agent is viewed as very high risk. If potential substitute agents are identified for retrofit, similar fire performance test protocols to the engine compartment would be used. The most significant difference is the verification of acceptable toxicity performance.

It has been demonstrated in past alternate agents that the toxicity issues require resolution before (or at the latest concurrent with) initial fire performance tests. This is required for two reasons. First, toxicity tests require more time to conduct and secondly, costly full scale vehicle tests should not be conducted on an agent not approved for the intended application by the military medical community. The conduct of explosion-type full-up vehicle fire tests are usually much more costly than engine compartment tests for many reasons. A full-up test is one in which the vehicle is completely outfitted for full combat. This generally includes all fuel, ammunition and other supplies. The most important is the nature of the ignition source. To accurately simulate the combat scenario, this source (an actual munition penetration) is often detonated through the vehicle into the on-board fuel. In the U.S., this type of live fire test is required by law for all ground combat vehicles. Cost of this full-up live fire test can be millions of dollars particularly if the agent proves unsuccessful in even one test shot! When toxicity test are added to the cost of the performance tests, the overall test program can be prohibitive. It is most critical that less effective agents (for agents which are not first approved from a toxicity viewpoint) are not used in these tests.

The third application (hand-held units) presents the best opportunity for near term replacement action. These hand-held units are usually located within the crew compartments and are used to extinguish slow growth fires which normally occur in peacetime operational conditions. Carbon dioxide has and is being used in combat vehicles together with halon 1301 and 1211 and 2402. Other than addressing bottle size, it is not anticipated that extensive performance and toxicity tests need be conducted for near replacement of halons in this application.

9.4.2.3 Global Estimated halon Use in Combat Vehicles

The global quantities of armoured vehicles are given below in rounded off quantities: (Source: The Military Balance 1989-90, International Institute for Strategic Studies).

Country	Main Battle Tanks	Support & Auxiliary Equipment
Australia	150	750
Canada	100	1,700
China	14,000	8,600
Germany	5,000	6,500
Israel	3,800	2,600
Soviet Union	55,000	113,500
United Kingdom	1,700	5,200
United States	16,000	55,000
All other countries	79,000	100,000
Approximate Total	**175,000**	**300,000**

The ratio of main battle tanks designed with halon fixed systems to the total number of tanks is estimated by using the United States as an example. Therefore, it is assumed that globally, approximately 35 percent of the total 175,000 (61,000) tanks contain fixed halon systems. Of the 61,000 tanks it is estimated that 41,000 hold 3.3 kg in the crew compartment and 6.7 kg of halon 1301 in engine compartment for a total 390 tonnes. The 20,000 remaining tanks are estimated to contain 3.3 kg of halon 2402 for a total 45.5 tonnes. It is also estimated that an additional 117 tonnes of halon 1211 and 1301, and an additional 14 tonnes of halon 2402 are used in hand helds. However, it is anticipated that the halon in these hand helds will be replaced with other agents, such as carbon dioxide, in the near term.

The estimate for support auxiliary vehicles which contain fixed halon systems is much more difficult to make. For purposes of this estimation, a value of 10 percent, or 30,000 vehicles will be used. (It is reasonable to assume that the 10% value is somewhat higher than actual). Using the same rationale as for the main battle tanks, 20,000 vehicles contain 6.7 kg in the crew compartment and 3.4 kg of halon 1301 in the engine compartment for a total 191 tonnes. The remaining 10,000 support vehicles contain 2.3 kg of 2402 for a total 23 tonnes. As is true for the main battle tanks, halon hand helds will not be a long term requirement, but currently are estimated to contain an additional 57 tonnes of halon 1211 and 1301, and an additional 29 tonnes of halon 2402.

9.4.2.4 Land Forces Recommendations

In summary, it is recommended that the following steps be taken: replace halon hand-held extinguishers with carbon dioxide or some other environmentally acceptable clean agent. The second effort should be the development of evaluation programs for engine compartment substitutes. If these first two tasks are pursued, peacetime fire suppression applications and discharges will be addressed. These applications are important because discharge of fire suppression systems in peacetime occur much more than actual combat (wartime) discharges. Third, design of future combat vehicles should eliminate the need for an on-board fixed system in normally occupied areas. Passive design techniques to eliminate the flammables from these areas should be made a top priority for designers. It is recognized that there is currently no alternative to halon 1301 for explosion suppression that meets toxicity requirements in normally occupied crew areas of currently designed armoured vehicles. (See also Section 5.4 Applications of Deflagration Suppression of this report). It is expected that halon 1301 will continue to be used in this application until new designs limit this threat to the crew. Fourth, for those current applications of halon 1301 in fixed flooding systems for normally occupied areas, consideration should be given to only installing those bottles in times of actual combat (and also during live fire exercise or training) from a dedicated war reserve. This should be done only until new vehicles without fire suppression systems in normally occupied areas begin to replace the currently fielded vehicles.

It is unlikely that new halon production will be required to support military land forces applications after the year 2000. It is anticipated that reliance on halon will decrease as engine compartment fire suppression systems and hand helds are converted from halon to currently available alternatives. The combat systems still in existence which require crew compartment explosion suppression systems will be supportable through the existing bank of halon.

9.4.3 Air Forces

9.4.3.1 Background

Many of the halon uses on-board military aircraft are identical to those on civil aircraft, however, some are unique. This section will address on-board military requirements for halon. Because some combat survivability applications contribute to flight safety, many of the uses covered will be identical to those found in commercial aviation and are required for flight certification.

Unlike civil aircraft, military aircraft which do not have civil equivalents, such as fighters and bombers, generally do not carry a formal flight certification. Aircraft which are used for both military and civil aviation are flight certified. Flight certification requirements, such as those imposed by the U.K. Civil Aviation Board (CAB) and the U.S. Federal Aviation Administration (FAA), drive requirements to install halon on civil aircraft and by default, the military versions of those aircraft. Some certification requirements prescribe the use of halon, while others establish performance requirements for which halon is the only currently accepted means of passing the certification standard. Requirements for halon on military aircraft are usually driven by the concerns for survivability. Today, there appears to be little work in process to find replacements for halon in aviation applications. Clearly, there is commonality between military and civil uses of halon in aviation. Technical solutions applicable to one will go a long way to solving the dependence of the other.

9.4.3.2 Engine Nacelles

One of the most common aviation uses for halon, in both fixed and rotary wing aircraft, is protection of engine nacelles, the enclosure surrounding aircraft engines. the active portion of this system typically consists of thermal links, fuel shut-off controls and the halon suppression system. Halon 1301 is overwhelmingly the agent of choice. The thermal links melt at a predetermined temperature, illuminating a fire warning in the cockpit. This is the only automatic portion of the system. The fuel shut-off valve and activation of the halon system are controlled by the pilot. Halon is preferred for two reasons. First, it is very effective, conserving space and weight, both of which are very important to aircraft designers and operators. Second, it is a high vapour pressure gas, making it extremely easy to deliver under a broad range of environmental conditions. It completely penetrates the nacelle's complex geometry and becomes entrained by the fire's location within the nacelle. The quantity of halon used in these systems averages about 4.5 kg .

Halon has been used for engine nacelle fire protection for over 20 years. Before halon 1301, halon 1202 was used and some older military aircraft are still fitted with these systems. Halon 1202 is reported to have an ODP of 0.4 and performs comparably to halon 1301 in the nacelle application. However, halon 1202 is much more toxic and requires special handling by maintenance crews.

The military use of halon 1202 is the only one that the Committee is aware of and suspects that this is because military aircraft tend to have longer service lifetimes than civil aircraft. Halon 1202 is not a substances currently controlled, however its contribution to atmospheric bromine loading would increase as its use increased. Its popularity would be self limiting because of its toxicity.

Currently, the military obtains halon 1202 from halon 1211 producers because it is a side-stream of halon 1211 production. However, when halon 1211 production stops, the military will have to find other sources.

9.4.3.3 Auxiliary Power Units

Auxiliary Power Units (APU) fire protection systems are similar to the engine nacelle systems and operate much the same way. APU systems are used in both fixed and rotary wing aircraft. Some APU systems use their own stand alone halon bottles, while others utilize the same bottles that serve the nacelles. High temperatures, complex geometry and high airflows characterize the potential fire situation that exists in the APU. Because the volume needing protection is usually less than that of the nacelle, the quantity of halon needed is usually less. Based on the similarities between the two fire threats, any non-halon system which is suitable for engine nacelles would likely also meet the needs of the APU.

9.4.3.4 Cargo Compartments

In commercial aviation, cargo compartments are classified by their use, with only some requiring total flooding halon protection. For example, Class C compartments (not crew accessible) require total flooding halon 1301 systems. Class B compartments require only hand held extinguishers, for which halon 1211 is the most popular choice. Class B compartments are crew accessible and usually on the main deck rather than below the floor compartments, such as those found on "Combi" (cargo/passenger) aircraft.

For military aircraft, the decision to protect cargo compartments with total flooding halon 1301 systems appears to be less clear cut. For example, the C-5 Galaxy is protected with a total flooding halon 1301 system but the C-130 is not. The question of how to protect the new C-17 is still under debate, with the Montreal Protocol being one of the weighing factors. When halon 1301 total flooding systems are used, the quantity needed is generally very large relative to the other systems on the aircraft. Some compartments require up to 68 kg of halon. Most cargo compartments of military aircraft are accessible like the class B commercial compartments. Because of this and the fact that there appears to be no consistent practice of using total flooding systems, it would be difficult to make the case that these systems are required.

9.4.3.5 Cabin/Cockpit Areas

Cabin and cockpit area are not protected with total flooding systems, however, halon portable extinguishers are used. Both halon 1211 and halon 1301 extinguishers are widely used. Halon is attractive for this application because a likely source of fire is often electrical circuits whose location is obscured by panels. As a gas, halon need not be delivered directly onto the fire, but becomes entrained into the fire. There is also a desire not to interfere with other circuits located nearby the fire which may be critical to the operation of the aircraft or to communications. Before halon was available, carbon dioxide was widely used, but it is less effective than halon.

9.4.3.6 Miscellaneous

There are other areas requiring fire protection for which halon is the most popular choice. The most common are lavatories and galleys. Galley systems typically use less than .25 kg of halon 1301 and lavatory systems about the same.

9.4.3.7 Total Military Usage for Aviation

The Military Use Sub-Committee conducted a survey using publicly available literature to determine the total number of military aircraft worldwide. Using an informal survey conducted within the United States, the working group further attempted to determine the total amount of halon contained on-board these aircraft and the quantity needed for annual servicing.

There are about 56,000 military aircraft worldwide. For the purpose of this survey, they were categorized as helicopters, fighter-type aircraft, or large-body. Of the 56,000 total, about 30,000 are helicopters, about 18,000 are fighter-type and about 8,000 are large-body. The term "large-body" as used here, is unrelated to the terms wide-body and narrow-body commonly used in civil aviation. An aircraft was classified as fighter-type or large-body based on function and configuration.

The survey revealed that helicopters contain approximately 4 kg of halon 1301, 2.3 kg of halon 1211 and 6.6 kg of halon 1202, on average.

Large-body aircraft contain about 43.6 kg of halon 1301, 11 kg of halon 1211 and 6.6 kg of halon 1202, on average.

Fighter-type aircraft contain about 6 kg of halon 1301, 6 kg of halon 1211 and no halon 1202.

The survey revealed a lack of consistent maintenance practices for halon fire bottles. At the extremes were respondents who indicated the bottles were discharged and recharged annually regardless of condition and those who only weighed and inspected the bottles annually and performed hydrostatic testing every 10 years. A consistent code of practice could greatly reduce the quantity of halon needed to maintain the existing fleet of aircraft.

9.4.3.8 Air Forces Recommendations

The ability to recycle the halon would greatly reduce the amount needed to maintain the existing fleet. The Federal Aviation Administration in the United States is working on a system to accomplish this. the project is nearly complete and the results are promising. It appears that a system to recover and recycle super pressurized halon 1301 from aircraft fire bottles will soon be commercially available. One of the issues that needs to be addressed is the quality specification for the recycled halon. Most specifications allow for negligible amounts of noncondensable gas (eg. nitrogen). this is reasonable assuming virgin material delivered from the halon producer. Sine the halon must be pressurized with nitrogen after being put in the bottle, it seems unreasonable to require it all to be removed before returning the recycled halon to the bottle. Additional testing is required to determine whether any contaminants surviving the recycling process can be detrimental to extinguishment. The project is also investigating whether halon from non-aviation sources, such as computer rooms, can be recycled into aviation halon bottles.

Comparing the amount of halon needed to service global military aviation requirements to the global bank and assuming a recycling capability, there appears to be an available supply that could last well beyond the expected lifetime of most existing aircraft.

9.4.4 Command, Control and Communication Facilities

9.4.4.1 Background

Military command centres are often housed in facilities that have been specially hardened to withstand the effects of weapons detonations. The communications hubs within these facilities are sealed in special metal enclosures designed to insulate against electromagnetic interference. These occupied areas are often designed to use halon. The reason halons have been the fire protection strategy of choice in these facilities is the same as those cited for commercial data processing or communications facilities. Occupants can tolerate the halon and it does not damage equipment or facilities. The fire threat is primarily because the facility is a target during conflict, which is when the equipment is needed most. Occupant evacuation is usually not an option. These facilities are extremely expensive to construct and even more expensive to modify.

9.4.4.2 Fire Protection Options

If halon were not an option during the design of the facilities, other fire protection strategies could be employed. One option would be to separate people from the most critical equipment and protect the equipment with carbon dioxide. However, this option would greatly complicate the design and construction of the metal enclosures, from both the blast resistance and electromagnetic isolation standpoints. Given an existing facility, it would be extremely difficult and expensive to modify the facility to eliminate halon.

9.4.4.3 Command, Control and Communication Facilities Recommendations

Unfortunately, there is little data on the number of facilities or the amount of halon installed. This makes it difficult to estimate the amount of halon needed to service these facilities, however, provided the halon can be recycled, future requirements for new halon should be minimal.

Section Ten

Special Needs of Developing Countries

10.1 Overview

For the developing countries, which account for the major share of the global population, rapid industrial development for improving the quality of life is a national priority

The modern trend of using sophisticated, high technology equipment is also found in the developing countries. The installation of this type of equipment is very expensive in terms of cost and scarce foreign currency reserves. In order to protect this substantial investment the use of a high technology fire protection system, such as halon is viewed as necessary.

Some developing countries are also engaged in the production of military equipment such as aircraft and submarines. The fabrication and launching of rockets, satellites and missiles, as well as the use of nuclear power is also in vogue in some developing countries.

Halons 1211 and 1301 are used by many developing countries for the protection of such facilities and their support systems. Halons are also used for the protection of computer facilities, tape libraries, industrial plant control rooms, telecommunications sites and other electronic equipment facilities.

In addition, the high technology equipment (particularly telecommunications equipment) which originates from several developed countries is usually purchased as a turn-key package that includes halon based fire protection systems. Also, subsidiaries of large foreign corporations often select halon fire protection equipment based on a corporate policy. Military equipment purchases may also include halon fire protection systems as part of a defence contract.

However, unlike the developed countries, the quantities of halons currently banked by individual developing countries are not substantial and will not be adequate to meet their essential needs in the future.

Many developing countries have not yet developed the infrastructure to provide water supplies adequate for fire fighting purposes or for the connection of automatic sprinkler systems. In many cases, central monitoring facilities for receiving fire alarm signals are not yet available.

The reluctance to use water sprinklers for the protection of electronic equipment, which originated in the developed countries, has continued in the developing countries. Although the use of water sprinklers for the protection of electronic equipment facilities is increasingly acceptable in the developed countries, the developing countries have not reached this level of acceptance.

Developing countries nevertheless realize that progress cannot be made at the cost of the environment and that the use of halons must be governed by the criteria for essential use as outlined in Section Eleven of this report. In respect of developing countries, there is therefore a case for maintaining a less rapid phase-out of halon consumption. The phase-out could be on a somewhat different timescale compared to the developed countries.

10.4 Conclusions

The Halons Technical Options Committee recognizes that developing countries have shown a willingness to co-operate in the phasing-out of consumption of halons. Considering their present low levels of consumption and banked quantities, maintaining a different time scale is perhaps justifiable for the Less Developed Countries.

The following would assist the developing countries in protecting their present investment in halon systems and assist in reducing dependency in the future:

(a) Provide funding for technology transfer from national fire protection organizations in the developed countries. This could include training courses, seminars, etc. that would be provided in the nation seeking assistance.

(b) Provide assistance when new, environmentally acceptable, clean extinguishing agents become available to upgrade existing systems and equipment in as economical manner as possible.

(c) For multi-national corporations with subsidiary operations and/or joint ventures in developing countries, ensure that their subsidiaries are included in corporate policies and practices to reduce halon use to the same degree as is being followed in developed countries.

(d) Ensure that recovered halons from the developed countries that are suitable for recycle are made available for use in the developing countries to provide for recharge and service of existing halon fire protection equipment.

Section Eleven

Essential Uses and Their Needs

11.1 Introduction

This section of the report documents the recommendations of the Halons Technical Options Committee functioning as the ad hoc working group of experts as required by Decision II/3 of the Parties

Halogenated fire suppression systems have been installed primarily to provide a very high level of property protection with minimal secondary damage and minimal disruption to resumption of operations. In some cases, halon systems are installed principally to protect human life from death or traumatic injury due to fire or explosions.

When considering whether or not use of halon is 'essential', it is necessary to balance the environmental risk posed by the ozone depletion potential of the agent against the social implications of the immediate affect on human life, the environment, and national security. Ultimately the decision must be made by policy makers, after full consideration of all factors. Nevertheless, it is the opinion of the Halons Technical Options Committee that there are fire/explosion risk scenarios for which the only safe protection method involves the use of halon or a yet to be developed gaseous agent with similar properties. Examples of such situations can be found in military applications (eg. armoured personnel carriers, command centres, etc.), the industrial processing of flammable liquids and gases (eg. crude oil production, flammable liquids pumping facilities, etc.) in certain geographic regions, and aviation (eg. aircraft engine nacelles, cargo bays, etc.). In each case, human beings are likely to be subjected to life threatening situations should a fire or explosion occur that could not be rapidly suppressed. It is the unique ability of the halons to provide this function that renders their use 'essential' in such applications.

The Committee recognizes that not all current uses of halon fall into this category, but for those that do, such needs are ongoing and must be addressed as halon production is phased out. It is also noted that in some cases existing facilities have been designed and constructed in such a manner that reduction of fire risk to acceptable levels is dependant on the use of halons over the life of the facility. Design and construction of future facilities providing similar functions offers the opportunity to reduce halon dependency by utilizing other appropriate fire protection measures. Therefore all appropriate fire prevention and protection options must be considered before arriving at a conclusion that halon use is necessary for the protection of facilities designed and constructed in the future.

Although some applications are obvious, such as the examples previously listed, others will be affected by geographical location, climate, and the individual needs of a nation's security. Also, the essentiality of facilities to be protected can change. For example, telephone exchanges are very important in providing essential public services, but new technology now allows for redundant or alternative communication paths. Is their protection still essential, or does the availability of alternative communication paths reduce the dependency on a given facility?

There are essential uses for halons. However, the perception of what constitutes an essential use will be dependant on future changes in technology. Halons have found widest use in the protection of high technology applications. Creating a list of 'essential applications' is neither appropriate nor necessary. Establishing criteria for what constitutes an essential application would appear to be of greater benefit.

11.2 Essential Use Criteria

The term 'essential' should be qualified in that it is not the halon that is essential rather it is the essentiality of a particular facility or equipment, protected by halon equipment that is of concern.

The key benefit of the halons is that from a fire protection stand-point they, unlike other extinguishing agents, do not cause secondary damage to protected facilities and do not constitute an unacceptable risk to persons in the immediate vicinity when discharge occurs. As such the halons can be applied at a very early stage of fire development without risk of physical damage to the facility or equipment, or an unacceptable risk to the occupants. This is of particular importance for facilities where there is a critical need to minimize service interruption.

The second important ability offered by the halons is their suitability to prevent explosions. For certain facilities where flammable gases/liquids are processed or transferred, halons are used to 'inert' in the event of an accidental release of the flammable gas/liquid. The release of halon into the enclosure prevents an explosion from occurring, allows personnel to evacuate and corrective actions to be undertaken.

Although the use of halon is desirable in a wide range of facilities where the important characteristics indicated above are valuable, the importance of protecting the ozone layer is critical. Therefore the following criteria should be satisfied before reaching the conclusion that a new installation is an essential halon use:

A critical need must exist to minimize damage due to fire, explosions or extinguishing agent application, which would otherwise result in serious impairment of an essential service to society, or pose an unacceptable threat to life, the environment, or national security

and

All other appropriate fire protection measures have been taken.

Note: Time to make appropriate changes in national fire codes, standards and regulations will be necessary before fully and safely applying these criteria.

11.3 Meeting The Needs Of 'Essential Uses'

Having established that there are fire/explosion risk scenarios that require protection through the use of halon or halon like substances, the next question is how best to meet those needs during and following halon production phase out. This question can best be addressed by considering three options:

11.3.1 Newly Developed Chemical Replacements

Aggressive programs are underway to find clean, chemical replacement agents to the halons. To date that effort has not resulted in a product or products that can meet all of the attributes of present halon extinguishing agents. However, several replacement agents have been announced which may meet the needs of some essential uses once testing has proven them safe to do so. Their use should therefore be encouraged.

Non-zero, low ODP halon replacements are considered as important transitional substances in eliminating dependency on the present halons. However they should only be used where no other fire protection method offers acceptable protection.

The contribution of the resources of national governments in assisting with basic research, toxicology testing and fire testing will be a valuable contribution in speeding the commercialisation and availability of replacement extinguishing agents.

11.3.2 Recycled Halon

There is a large inventory of halon stored in containers awaiting use. At the end of useful life and as public awareness grows, it is anticipated that much of this halon will become available for transfer from one use to another. It is estimated that in the case of halon 1301, as much as 20% of the amount supplied in 1986 will be available annually for at least 20 years after production ceases by use of recycled halon 1301 alone. The problem is one of establishing recycling facilities and procedures for managing what is known as the "Halon Bank". Government support and funding will greatly assist in stimulating the development of recycle and reuse programs. This resource has the best potential for meeting the needs of essential uses now and in the foreseeable future. The current bank of halon 1301, for example, appears to be adequate to supply essential uses well into the next century. It is especially important to note that halons should not be destroyed if they can be recycled and redeployed to essential uses. Recycle and reuse of an important fire protection asset avoids or delays the need to produce halons.

11.3.3 Additional New Production of Halons 1211, 1301 and 2402.

The avoidance of the production of additional halon after the production phase-out date to meet the needs of essential uses, is of paramount importance for two reasons. First, because of the potential for greater ozone depletion. Second, allowing additional production, after the production phase-out date, may not encourage recycling, bank management and rapid commercialisation of environmentally acceptable replacement fire extinguishing agents.

Leadership by agencies of national governments, believed to be the largest essential users of halon, is crucial to this effort to encourage investment in recycling facilities and the formation of national halon banks. Further, cooperation at the international level must be established to ensure that one nation does not destroy halon while another continues to produce it to meet the needs of essential uses.

On the basis that 11.3.1 and 11.3.2, above are given national government support to the fullest extent possible, and recycling and banking facilities are made available, the Committee believes that there is no need to make provision for additional new halon production (above current limits) to meet the needs of essential uses. However, at this time a bank management and recycling infrastructure is not in place, and the status of replacement agents is only in the early stages of development. Therefore, the Committee believes that it is inappropriate to make a decision on the need for additional production after the phase-out year at this time, and recommends that the subject be re-evaluated at a later date.

11.4 Special Needs of Less Developed Nations

The Halons Technical Options Committee recognizes the special needs of less developed nations that will not have adequate halon banks to support the need to satisfy future essential uses. Parties should consider special measures to address these concerns as outlined in Section 10 of this report.

11.5 Conclusions

The Committee recognizes that there are fire/explosion risk scenarios for which current fire protection technology cannot provide adequate protection without the use of halons or halon-like replacement extinguishants. These uses involve an unacceptable threat to human life, the environment or national security, or an unacceptable impairment of the ability to provide essential services to society. At the same time, the Committee is of the qualified opinion that with proper management, the future needs of essential uses can be satisfied by redeployment of existing, banked halons until such time, beyond the turn of the century, as the bank expires. The Committee also notes that application specific, replacement extinguishing agents, are currently under development. In the long term, use of these extinguishing agents and others that may be developed in the future, may satisfy the needs of essential uses and restore the capability to provide fire protection with similar desirable characteristics to those of the present halons for other important facilities.

The requirement to produce new halons for essential uses can be avoided if sufficient incentive is provided and investment is made in halon recycling, banking facilities, and halon alternatives utilization. Although it may be necessary to reconsider this issue in the future, the combination of successful bank management, and the proper utilization of lower and zero ODP halon alternatives, offers the best potential to eliminate the need for a production exemption for essential uses in the foreseeable future.

Establishing a fixed list of essential uses is neither appropriate or necessary at this time. However, use of the criteria detailed in this section is appropriate. Cooperation at the international level is necessary to ensure that one nation's surplus halon is exported to meet the needs of another nation, rather than destroyed. Parties are encouraged to cooperate with the international fire protection community on bank management, emission reduction and the wise future allocation of the banked halons. Until this is accomplished, a decision on the need for additional halon production after the phase-out year to meet the needs of essential uses should be deferred.

Section Twelve

Summary and Conclusions

12.1 Introduction

The Halons are halogenated hydrocarbons that exhibit exceptional fire fighting and explosion prevention/suppression effectiveness. They are electrically nonconductive, dissipate quickly and leave no residue. Halon 1211 and halon 1301 have proven remarkably safe for human exposure.

12.2 Historical Development of Halon Usage

In the past twenty years halon 1301 has grown in usage as an agent for use in fixed fire protection systems primarily for the protection of vital electronics facilities, such as computer rooms and communications equipment rooms. Other significant applications for halon 1301 systems have included: repositories of cultural heritage; shipboard machinery spaces and pipeline pumping stations. Halon 1211 has been the halon of choice for portable fire extinguisher usage. In commercial and industrial applications halon 1211 portable fire extinguishers have been used in computer rooms, museums, art galleries and in offices for photocopy machines, personal computers and other electronic equipment.

12.3 Use Patterns, Production and Bank Estimates

Fire protection organizations, through educational programs, changes in technical standards and various other means have played an important role in making it known that use of halons must be drastically reduced and wherever possible alternative fire protection measures employed. The effect of these programs can be seen by the fact that production of halon 1211 and halon 1301 peaked in 1988 and is now declining. Production of halon 2402 within OECD nations has virtually ceased.

There are persuasive reasons to consider recycled halons as the prime supply of these agents. The first is to encourage responsible stewardship of the bank of halons and reduce potential ozone depletion. Users should also consider that it may not be economical for producers to continue to manufacture halons as markets continue to decline. There may be a transition phase where costs to produce halons rise dramatically to offset rising costs involved in producing smaller quantities.

The bank of halon 1211 should be sufficient to maintain existing equipment using recycled halon. However, for some early years after production phase-out some equipment may have to be taken out of service to provide maintenance quantities of halon 1211. Following expected shortages of maintenance quantities in the early years after production phase-out, it is expected that small quantities of halon 1211 may be available for new equipment until the bank expires.

It is estimated that the bank of halon 1301 will be adequate to maintain existing equipment for at least 40 years after production ceases. Also, it appears that recycled halon 1301 could be provided for new equipment after new production is curtailed (see Appendix C). It is estimated that for all practical purposes the halon 1301 bank expires 45 years after the production phase-out year.

It should be noted that the estimates provided for the bank will likely be affected by various new factors such as an early phase-out of production, efficiency of recycle programs, possible growth of use in the less developed countries, commercialisation of acceptable replacement chemicals and the uncertainty of the rate of decommissioning of halon fire equipment which could occur in the developed countries.

12.4 Fire Protection Alternatives to the Use of Halons

For many cases where halons have been employed there are alternative fire protection methods that can be utilized to reduce risk. The alternative fire protection choices offered in this report may not provide the same level of fire protection offered by the use of the present halons. In some circumstances greater fire loss and risk to people and property may result from the use of the alternatives outlined. However, concerns regarding environmental risk associated with the continued use of halons necessitate the serious evaluation of all other fire protection options.

12.5 Explosion Protection

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.

Protection of aerosol fill operations constitutes an important use of halon 1301. 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.

The discovery of hydrocarbons in areas where extreme low temperature climatic conditions occur has led to the enclosing of hydrocarbon processing 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 unique 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.

The crew bays of military vehicles, such as armoured personnel carriers and tanks, face a potential mist cloud deflagration threat should one of the vehicle's fuel tanks be penetrated by armour piercing rounds. The main machinery spaces of war ships face a hazard from deflagrations of combustible machinery fluids in both peace time and war time. Halon 1301 deflagration suppression systems are employed in these spaces.

Halon 1301 has the unique property of being able to inert an enclosed space or suppress deflagrations at vapour concentrations which are tolerable to humans. Replacement of halon 1301 in such applications presents a significant challenge in fire or explosion protection situations involving human life safety for at present there are no known alternative agents which have this property.

12.6 Halon Emission Reduction Strategies

Avoidable halon releases account for greater halon emissions than those needed for fire protection and explosion prevention. Clearly such releases can be minimized if a concerted effort is made by the fire protection community with support from national governments. In reviewing reduction strategies, the Committee recommends the following:

- Reduce halon usage to essential applications only.
- Discontinue protection system discharge testing using halon as the test gas.
- Discontinue the discharge of portable halon fire extinguishers for training purposes.
- Discontinue the discharging to the atmosphere of portable halon extinguishers and system cylinders during equipment servicing.
- Encourage users of automatic detection/release equipment to take advantage of the latest technology.
- Encourage the application of risk management strategies and good engineering design to take advantage of alternative protection schemes.

12.7 Management of the Bank of Halons

Management of the bank of halons at a national level is possible through the various trades, producers, installers of fixed systems, extinguisher suppliers, companies in charge of filling, recovery or recycling. A national organization could be appointed to manage the bank of halons and should be responsible for certifying the companies involved in the process, in addition to the certification of equipment and installers. Environmental concern and restricted availability of the halons will likely encourage achievement of initiatives to manage the bank of halons.

Management of the banked halons is feasible, only if the following items are addressed:

> Financial assistance and positive national policies are developed to encourage accreditation and investment in recovery and recycle organizations and facilities.
>
> National policies and financial assistance are developed to deal with the storage and eventual destruction of contaminated halons.

In addition, to avoid the paradox of some nations requiring destruction of otherwise recyclable halons, at the same time that the Montreal Protocol allows continued production, it is recommended that international exchange of recyclable and recycled halons be encouraged to reduce requirements for new production of halons.

12.8 Halon Replacement Agent Research

The need for halons or halon-like materials to serve vital roles in life safety and fire/explosion protection in many applications will continue despite the development of new non-halon technologies as alternatives to the use of halons. The halon bank is expected to serve a portion of those needs for a period of time; however, replacements are needed now to ensure wise allocation of banked material with minimal environmental impact and to allow an eventual, orderly phaseout of halon use without unacceptable threats to safety. Replacements will also be needed once the bank is exhausted.

For clarity, two terms must be defined. A "replacement" agent is a halon-like, gaseous or volatile, clean fire extinguishant, explosion suppression agent and/or inertion agent. An "alternative" agent is defined as a not-in-kind, non-halon-like agent (e.g., carbon dioxide, water, foam and dry powder extinguishants).

Four requirements make halons difficult to replace: cleanliness/volatility, low ODP, low toxicity and effectiveness. It is relatively easy to find chemical agents that meet any three of these requirements; chemicals that meet all four are much more difficult to identify. Of course, other considerations for replacement agents exist; cost, storage stability and compatibility with engineering materials are among these.

Halon fire extinguishants can be separated into two groups according to their application: halons 1211 and 2402, with higher boiling points, in one group and the more gaseous halon 1301 in the other. Different chemicals will likely be needed for replacement of each group. Halons 1211 and 2402 are usually applied by streaming (direct discharge from a nozzle positioned remote from the fire). Such agents are used in localized applications and are often applied manually. Halon 1301 is most often used in total-flood applications (filling of an enclosed volume with sufficient agent to suppress combustion or explosions following ignition or to "inert" atmospheres to prevent ignition). Both clean streaming agents and clean total-flood agents are needed. Some very specialized applications may be best served by agents that combine characteristics of both types of agents. Other applications are difficult to categorize exactly.

TABLE 1. ANNOUNCED HALON REPLACEMENT CANDIDATES

Candidate	Formula	Application	Reference
HCFC-123	CF_3CHCl_2	Streaming	7
HFC-125	CF_3CHF_2	Total Flood	8
HFC-23	CHF_3	Total Flood/Pressure *	9
HFC-227ea	CF_3CHFCF_3	Streaming/Total Flood	10
HBFC-22B1	CHF_2Br	Streaming/Total Flood	11
HBFC-124B1	CF_3CHBrF	Streaming	12
FC-218	$CF_3CF_2CF_3$	Total Flood	13
FC-3-1-10	$CF_3CF_2CF_2CF_3$	Streaming/Total Flood	14
FC-4-1-12	$CF_3CF_2CF_2CF_2CF_3$	Streaming	15
FC-5-1-14	$CF_3CF_2CF_2CF_2CF_2CF_3$	Streaming	15

* HFC-23 has also been proposed as a pressurizing agent for use in expelling other halon replacement agents.

Work to date indicates that the development of general purpose, zero-ODP, direct replacements having attributes equal to those of the present halons may be unrealistic in the short-term and also possibly in the far-term. On the other hand, clean halon replacements with lower ODPs for selected specific uses are a realistic goal, particularly if trade-offs in fire extinguishment capability, toxicity and/or other characteristics are acceptable. However, there is some concern about the commercial viability of small volume chemicals.

Even though the research on halon alternatives is still in the early stages (as compared to CFCs), several zero- and low-ODP alternatives have been announced. Preliminary research indicates that the zero-ODP candidates have performance characteristics and design criteria that are significantly different from those of halons. Some of the low- ODP alternatives perform very similarly to halons. Such chemicals may prove to be important transitional substances as they may allow for reduced production of halons prior to the phaseout date. After the phaseout date, the use of low-ODP transitional substances may augment usage of banked halons for essential applications.

Uncertainties about future ODP, GWP and toxicity requirements are of great concern in the development and commercial viability of halon replacements. Government funding would shorten the time required for development of halon replacements. In considering the relative environmental issues, halon replacements must be evaluated in terms of existing halons and the roles of these agents. Regulatory actions have been largely based on the excellent progress made in CFC replacements with little recognition of the special role and developmental status of halon replacements.

Though the development of halon replacements continues and although very promising results have been obtained, it is unwise to make decisions based on announcements of candidate agents whose applicability remains to be confirmed and which, for the most part, require significant trade-offs in effectiveness, ODP and/or toxicity. Halon replacement chemicals are not at the same advanced stage of development as are many of the CFC replacements for refrigeration, solvents and other applications. Furthermore, considerable work must be done on systems engineering, approval testing must be performed and standards must be developed after acceptable replacements are identified.

For most applications, significant additional investment in research and development work is required to obtain acceptable agents which approach the efficiency of the existing halons. High-efficiency may require significant chemical suppression, which usually means the presence of bromine (or iodine). At present, very low-ODP, highly effective candidates have not yet been proven, nor have many such candidates even been identified.

12.9 Reduction of Military Halon Use

12.9.1 Sea Forces

The most probable course of action for world Navies relative to military sea halon 1301 applications would be:

a. Immediately adopt halon conservation practices (discontinue releases of halon for discharge testing or training, utilize recapture/recovery equipment for recharging and servicing).

b. Vintage existing systems. Adopt a policy that what is now owned will be kept (i.e. halon systems now in existence, or to be installed during the next few years, will continue to be supported for the remaining life of the vessel).

c. Minimize new halon installations for the next few years beginning immediately to adopt CO_2 or foam where appropriate.

d. As development/testing/system engineering is completed, specify new gaseous agents (or perhaps fine water mist) in lieu of halon for new installations).

e. Prior to the phase-out year, totally prohibit the incorporation of new halon systems in new ship designs.

Under this course of action, the only need for halon 1301 after the phase-out year will be to support, for their remaining economic life, whatever systems exist at that time. The key question then becomes: "Will the quantities of halon 1301 available to military sea applications (from military stockpiles and/or via priority allocations from the global bank) be sufficient to support existing systems for their remaining life?"

The support required for existing systems will consist essentially of replacement of leaky cylinders, refill cylinders following use on a fire, or refill following accidental or malicious discharges. With the cessation of discharge testing, these continuing "support" requirements will constitute a small percentage of existing systems storage quantities. Additionally, halon quantities available to support existing systems will be continuously replenished as halon is recovered from decommissioned ships and added to the stockpile.

12.9.2 Land Forces

The common fear of fires throughout the worlds' Armies is best summarized as follows: "Fire is the hideous, unspeakable nightmare of armour." Not since World War I aviation, where pilots (without parachutes) fought in "tinder boxes" of wood and fabric, surrounded by fuel and ammunition has a fear of a fiery death been shared so universally within the military. It is recommended that the following steps be taken: First replace halon hand-held extinguishers with carbon dioxide or some other environmentally acceptable clean agent. Second, develop evaluation programs for engine compartment substitutes. If these two tasks are pursued, peacetime fire suppression applications and discharges will be addressed. These applications are important because discharge of fire suppression systems in peacetime occur much more than actual combat (wartime) discharges. Third, the design of future combat vehicles should eliminate the need for an on-board fixed halon system in normally occupied areas. Passive design techniques to eliminate the flammables from these areas should be made a top priority for designers. Fourth, for those current applications of halon 1301 in fixed flooding areas of normally occupied areas, consideration should be given to only installing those bottles in times of actual combat and perhaps during live fire exercise or training from a dedicated war reserve. This should be done only until new vehicles without fire suppression systems in normally occupied areas begin to replace the currently fielded vehicles.

12.9.3 Air Forces

Many of the halon uses on-board military aircraft are identical to those on civil aircraft, however, some are unique. Because some combat survivability applications contribute to flight safety, many of the uses covered are identical to those found in commercial aviation and are required for flight certification.

Unlike civil aircraft, military aircraft which do not have civil equivalents, such as fighters and bombers, generally do not carry a formal flight certification. Aircraft which are used for both military and civil aviation are flight certified. Flight certification requirements, such as those imposed by the U.K. Civil Aviation Authority (CAA) and the U.S. Federal Aviation Administration (FAA), drive requirements to install halon on civil aircraft and by default, the military versions of those aircraft. Some certification requirements prescribe the use of halon, while other establish performance requirements for which halon is the only currently accepted means of passing the certification standard. Requirements for halon on military aircraft are usually driven by the concerns for survivability. Today, there appears to be little work in progress to find replacements for halon in aviation applications. Clearly, there is commonality between military and civil uses of halon in aviation. Technical solutions applicable to one will go a long way to solving the dependence of the other.

The ability to recycle the halon would greatly reduce the amount needed to maintain the existing fleet. The Federal Aviation Administration in the United States is working on a system to accomplish this. The project is still underway, but early indications are promising. It appears that a reasonably priced system to recover and recycle super pressurized halon 1301 from aircraft fire bottles will soon be commercially available. One of the issues that needs to be addressed is the quality specification for the recycled halon. Most specifications allow for negligible amounts of noncondensable gas (eg. nitrogen). This is a reasonable assuming virgin material delivered from the halon producer. Since the halon must be pressurized with nitrogen after being put in the bottle, it seems unreasonable to require it all to be removed before returning the recycled halon to the bottle. Additional testing is required to determine whether any contaminants surviving the recycling process can be detrimental to extinguishment. The project is nearly complete and the results are promising that halon from non- aviation sources, such as computer rooms, can be recycled into aviation halon bottles.

Comparing the amount of halon needed to service global military aviation requirements to the global bank and assuming a recycling capability, there appears to be an available supply that could last well beyond the expected lifetime of most existing aircraft.

12.9.4 Command, Control and Communications Facilities

Military command centres are often housed in facilities that have been specially hardened to withstand the effects of weapons detonations. The communications hubs within these facilities are sealed in special metal enclosures designed to insulate against electromagnetic interference. These occupied areas are often designed to use halon. The reason halons have been the fire protection strategy of choice in these facilities is the same as those cited for commercial data processing or communications facilities. Occupants can tolerate the halon and it does not damage equipment or facilities. The fire threat is primarily because the facility is a target during conflict, which is when the equipment is needed most. Occupant evacuation is usually not an option. These facilities are extremely expensive to construct and even more expensive to modify.

If halon were not an option during the design of the facilities, other fire protection strategies could be employed. One option would be to separate people from the most critical equipment and protect the equipment with carbon dioxide. However, this option would greatly complicate the design and construction of the metal enclosures, from both the blast resistance and electromagnetic isolation standpoints. Given an existing facility, it would be extremely difficult and expensive to modify the facility to eliminate halon.

Unfortunately, there is a little data on the number of facilities or the amount of halon installed. This makes it difficult to estimate the amount of halon needed to service these facilities. However, provided the halon can be recycled, future requirements for new halon should be minimal.

12.10 Special Needs of Developing Countries

The Halons Technical Options Committee recognizes that developing countries have shown a willingness to co-operate in the phasing-out of consumption of halons. Considering their present low levels of consumption and banked quantities, maintaining a different time scale is perhaps justifiable for the Less Developed Countries.

The following would assist the developing countries in protecting their present investment in halon systems and assist in reducing dependency in the future:

(a) Provide funding for technology transfer from national fire protection organizations in the developed countries. This could include training courses, seminars, etc. that would be provided in the nation seeking assistance.

(b) Provide assistance when new, environmentally acceptable, clean extinguishing agents become available to upgrade existing systems and equipment in as economical manner as possible.

(c) For multi-national corporations with subsidiary operations and/or joint ventures in developing countries, ensure that their subsidiaries are included in corporate policies and practices to reduce halon use to the same degree as is being followed in developed countries.

(d) Ensure that recovered halons from the developed countries that are suitable for recycle are made available for use in the developing countries to provide for recharge and service of existing halon fire protection equipment.

12.11 Decision II/3 of the Parties - Essential Uses and Their Needs

The following responds to the request that the Halons Technical Options Committee function as the ad hoc working group of experts established by Decision II/3 of the Parties.

Decision II/3 Halons: To establish an ad hoc working group of experts to investigate, and make recommendations to the Fourth Meeting of the Parties in 1992 on the availability of substitutes for halons, the need to define essential uses of halons, methods of implementation and, if there is such a need, the identification of such uses.

Response: The term 'essential' should be qualified in that it is not the halon that is essential, but rather it is the essentiality of a particular facility or equipment, protected by halon equipment, that is of concern.

The Halons Technical Options Committee recognizes that there are fire/explosion risk scenarios for which current fire protection technology cannot provide adequate protection without the use of halons or halon-like replacement extinguishants. These uses involve an unacceptable threat to human life, the environment or national security, or an unacceptable impairment of the ability to provide essential services to society. At the same time, the Committee is of the qualified opinion that with proper management, the future needs of essential uses can be satisfied by redeployment of existing, banked halons until such time, beyond the turn of the century, as the bank expires. The Committee also notes that application specific, replacement extinguishing agents, are currently under development. In the long term, use of these extinguishing agents, and others that may be developed in the future, may satisfy the needs of essential uses and restore the capability to provide fire protection with similar desirable characteristics to those of the present halons for other important facilities.

Although use of halon is desirable in a wide range of facilities, where the important characteristics indicated above are valuable, the Committee is of the opinion that establishing a list of essential uses is neither appropriate nor necessary at this time. However, because the importance of protecting the ozone layer is critical, the following criteria should be satisfied before reaching the conclusion that a new installation is an essential halon use:

A critical need must exist to minimize damage due to fire, explosions or extinguishing agent application, which would otherwise result in serious impairment of an essential service to society, or pose an unacceptable threat to life, the environment, or national security

and

All other appropriate fire protection measures have been taken.

Note: Time to make appropriate changes in national fire codes, standards and regulations will be necessary before fully and safely applying these criteria.

Cooperation at the international level is necessary to ensure that one nation's surplus halon is exported to meet the needs of another nation, rather than destroyed. This is particularly important for meeting the special needs of less developed nations, who will not have adequate halon banks to support their essential uses, and the Parties should consider special measures to address these needs.

The requirement to produce new halons for essential uses can be avoided if sufficient incentive is provided and investment is made in halon recycling, banking facilities, and halon alternatives utilization. Although it may be necessary to reconsider this issue in the future, the combination of successful bank management, and the proper utilization of lower and zero ODP halon alternatives, offers the best potential to eliminate the need for a production exemption for essential uses in the foreseeable future.

At this time a bank management and recycling infrastructure is not in place, and the status of replacement agents is only in the early stages of development. Therefore, the Committee believes that it is inappropriate to make a decision on the need for additional production after the phase-out year at this time, and recommends that the subject be re-evaluated at a later date.

12.12 Decision III/12 of the Parties

Decision III/12 (a) ... to evaluate, without prejudice to Article 5 of the Montreal Protocol, the implications, in particular for developing countries, of the possibilities and difficulties of an earlier phase-out of the controlled substances, for example of the implications of a 1997 phase-out;

Response: Should an earlier phase-out date be required to meet environmental objectives there are persuasive reasons to consider recycled halons as the prime supply of these agents. The first is to encourage responsible stewardship of the bank of halons and reduce potential ozone depletion. Users should also consider that it may not be economical for producers to continue to manufacture halons as markets continue to decline. There may be a transition phase where costs to produce halons rise dramatically to offset rising costs involved in producing smaller quantities.

A major difficulty of an earlier phaseout of production of the halons is that our knowledge of the existing bank is incomplete and future requirements are uncertain as no direct replacement agents have been identified. The final impact of "transitional substances" is uncertain are their environmental acceptability and fire protection usage is still in doubt. It should also be recognized that, as yet, no country has established halon bank management on a national basis. In addition, a problem exists in most developing countries and some developed countries in that existing national halon banks may be inadequate to satisfy future essential needs and the ability to trade recycled halons internationally is uncertain.

The developing countries have shown a willingness to co-operate in the phasing-out of consumption of halons and considering the low levels of consumption and banked quantities maintaining a some difference in a phase-out time scale is perhaps justifiable for the Less Developed Countries.

Decision III/12 (b) ... to identify the specific areas where transitional substances are required to facilitate the earliest possible phase-out of controlled substances, taking into account environmental, technological and economic factors, where no other more environmentally suitable alternatives are available. The quantities likely to be needed for those areas and for those areas of application currently served by transitional substances shall both be assessed;

and

Decision III/12 (c) ... to identify the transitional substances with the lowest potential for ozone depletion required for those areas and suggest, if possible, a technically and economically feasible timetable, indicating associated costs, for the elimination of transitional substances;

Response: Though the development of halon replacements continues and although very promising results have been obtained, it is unwise to make decisions based on announcements of candidate agents whose applicability remains to be confirmed and which, for the most part, require significant trade-offs in effectiveness, ODP and/or toxicity. Halon replacement chemicals are not at the same advanced stage of development as are many of the CFC replacements for refrigeration, solvents and other applications. Furthermore, considerable work must be done on systems engineering, approval testing must be performed and standards must be developed after acceptable replacements are identified. The final impact of "transitional substances" is uncertain as their fire protection usage and environmental acceptability is still in doubt.

Conclusion

An orderly transition to alternative fire protection measures, establishment of procedures to adequately manage the bank of halons and increased efforts to develop transitional and eventual replacement fire extinguishing agents with the beneficial characteristics of the present halons, may minimize the loss of fire protection capability represented by the phaseout of the halons.

As members of a global society, the international fire protection community, as represented by the members of the Halons Technical Options Committee, shares a common concern and recognizes the importance of the environmental risk posed by the halons. The risk to human life is the crux of the problem and as such a decision based on an integrated overview that balances threat from ozone depletion and threat from fire or explosion must be made by the Parties.

Appendix A

Guidelines For the Work of The Halons Technical Options Committee

Scope

The Halons Technical Options Committee has been established under Article 6 of the Montreal Protocol On Substances That Deplete The Ozone Layer to report on the current state of technologies that will facilitate utilization of necessary fire protection measures and accommodate the timely phase-out of production and consumption of Group II Substances (halons). As required by Decision II/3 of the Parties the Halons Technical Options Committee is to provide recommendations to the Fourth Meeting of the Parties in 1992 on the availability of substitutes for halons, the need to define essential uses of halons, methods of implementation and if there is such a need, the identification of such uses.

Relationship with Montreal Protocol Assessment Panels

Article 6 of the Montreal Protocol On Substances That Deplete The Ozone Layer requires that beginning in 1990, the Parties assess the control measures; i.e. production and consumption limits; on the basis of available scientific, environmental, technical and economic information. Before each assessment, the Parties convene appropriate panels of experts qualified in the fields mentioned and determine the composition and terms of reference of any such panels.

At the second meeting of the Parties to the Montreal Protocol, the Parties decided to convene members of each of the assessment panels established by the first meeting. The Panels are to review new information and to consider its inclusion in supplementary reports in time for consideration by the fourth meeting of the Parties. Three panels have been convened; Science, Environmental Effects and Technology and Economics. Six, sector specific, options committees will report to the Technology and Economics Panel, on current technology that could be used in lieu of substances controlled by the Protocol. The Report of the Technology and Economics Review Panel will provide an overview and summary of the findings of the six committees and will be submitted to the Open-Ended Working Group of the Parties to the Montreal Protocol. Each committee will prepare a sector specific report intended to provide more detailed guidance to those with a particular interest in the issues discussed in the individual report.

Halons Technical Options Committee

The Halons Technical Options Committee has been established to provide guidance for those who regulate, or own, or manufacture, or install, or service, fire equipment utilizing halon 1211, halon 1301 and/or halon 2402. As well the report provides guidance to those requiring, recommending or otherwise considering appropriate fire protection measures for specific fire hazards where achievement of minimum collateral agent damage and risk to occupants is of importance.

Transaction of Business

Except as otherwise provided in this statement of intent, Robert's Rules of Order Revised shall govern the transaction of business at meetings of the Halons Technical Options Committee.

Language

All committee meetings will be conducted in English. All committee correspondence and documents will be issued in English.

Appointment of Members

It is the intent that the Halons Technical Options Committee represent a broad cross section of geo-political interests, specific to the use of Group II (halons) substances. In seeking to meet this intent members are:

Nominated by National Government
or
Nominated by the Chair

The Chair of the Halons Technical Options Committee shall nominate members in addition to those nominated by National Governments in such cases where such a nomination is necessary for any or all of the following three reasons:

The technical expertise of the member would contribute strongly to the committee effort

The member would provide a geographical balance and provide representative advice to the committee

The member would provide advice, representative of the viewpoint of an interest category that would assist the committee in achieving a balance

All nominations and appointments of Members of Record shall be subject to review, at any time, by the Technology and Economics Review Panel.

Alternates

Any Member of Record may have one Alternate. The Alternate shall represent the Member of Record and may vote at meetings only when the Member is absent. When the Member of Record and the Alternate are both present at a meeting, the alternate may have the privilege of the floor only with the consent of the Member of Record and the Chair of the committee or subcommittee. All written comments shall be submitted by the Member of Record or by the Alternate. Where written comments are submitted by the alternate the submission shall also bear the signature of the Member of Record indicating that the comments have been reviewed by and represent the views of the Member of Record.

Appointment of Advisors

Where such an appointment serves a useful purpose the Chair of the committee or a sub-committee, may appoint a person to provide advice. An advisor may serve the committee by providing technical or other advice, and/or by liaison with other organizations that could contribute to reducing dependency on the use of Group II (halons) Substances. Advisors do not have voting privileges.

Balloted Votes

Where a balloted vote is appropriate to indicate the degree of concensus achieved by the Committee the balloted vote shall be cast by the Members of Record.

Subcommittees

The Committee may create Subcommittee(s) to help carry out its work. The Subcommittee shall be appointed and discharged by the Chair. The Chair of the Subcommittee shall be a Member of Record of the Halons Technical Options Committee. Persons serving on a sub-committee need not be Members of Record of the Halons Technical Options Committee.

Each Subcommittee shall report only to the Halons Technical Options Committee and shall not release any report except as the Halons Technical Options Committee may specifically direct for the purpose of securing comments and criticisms prior to any official action. The Chair of the Halons Technical Options Committee shall ensure that the Subcommittee is balanced in a manner necessary to achieve a balance in the report of the Subcommittee to the halons Technical Options Committee.

Establishing Committee Meeting Dates and Locations

Committee and Subcommittee meetings shall be coordinated as to time and place. Meeting dates and locations shall be established by Chair of the Halons Technical Options Committee with due regard for compliance with the schedule of work and with cognizance of other scheduled events. Selected venue of meetings shall recognize that cost of travel and representation of geo-political interests is of importance.

Publication of Committee Reports and Documents Restricted

The Halons Technical Options Committee shall not issue Reports or release Documents except as herein provided:

a) During the development of such material, the distribution of background material, analyses, and tentative or draft reports shall be limited to: (1) Members of Record, Alternates to Members of Record and Advisors to the Halons Technical Options Committee (2) Members of Subcommittees (3) Others whom the Technical Committee specifically desires to receive such drafts (4) Members of the Technology and Economics Review Panel. All Draft Reports or other material generated by the committee or subcommittee(s) shall bear a date and issue reference and the warning "**Do Not Quote Or Cite**".

b) A Peer Review draft of the report shall be issued by the committee. The purpose of the peer review is to obtain comments from individuals and organizations that will enhance the technical content of the report.

c) The final Report of the Halons Technical Options Committee shall be submitted to the Technology and Economics Review Panel. The final report shall contain a list of Members of Record of the Committee and shall include a summary of the conclusions of the members of the committee.

d) The final Report of the Halons Technical Options Committee shall be released to the Secretariat of the Montreal Protocol On Substances That Deplete The Ozone Layer and all others by the Technology and Economics Review Panel.

Public Comment

Anyone may comment to the Chair of the Halons Technical Options Committee concerning substantive matters related to the development, content or issuance of any draft report of the Halons Technical Options Committee. Such comments or views should be submitted in written form, not latter than 21 days after release of the version of the draft report to which the comment applies.

The Chair of the Halons Technical Options Committee or a designated member of the committee will make every reasonable effort to respond within 21 days of receipt of the comment.

Should the response be unsatisfactory or should the comment relate to the final report of the Halons technical Options Committee as submitted to the Technology and Economics Review Panel the comment should be submitted to the Chair of the Technology and Economics review panel, with a copy to the Chair of the Halons Technical Options Committee.

Appendix B

Peer Reviewers

Adams, C.	Royal Navy	U.K.
Mari, Andre	Atochem SA	France
Baes, G.	ANPI - NVBR	Belgium
Baker, Chris	Environment Protection Authority, Victoria	Australia
Bhatia, Sandip	Navin Fluorine Industries	India
Brown, Bernard	Civil Aviation Authority	U.K.
Catchpole, David	B.P. Exploration (Alaska) Inc.	U.S.A.
Clemons, Calvin K.	Fire Suppression Systems Association	U.S.A.
Coate, C.M.	Fire Protection Industry Association	Australia
Cousins, Caroline	Building Research Establishment	U.K.
Dalzell, Graham A.	United Kingdom Offshore Operators Association	U.K.
Daws, Steven	C.S. Todd & Associates, Ltd.	U.K.
Evre, Lars	Swedish Telecom	Sweden
Fairclough, T.A.	The Deaprtment of Transport	U.K.
Goodall, Kieth	FIC	U.K.
Hansson, Ingvar	Raddnings Verket	Sweden
Harrison, Peter	Cranfield Institute of Technology	U.K.
Hedlund, Tom	Stavens Naturvardsverk	Sweden
Huston, Paul O.	Amerex Corp.	U.S.A.
Jin, Zhejiang	Zhejiang Chemical Industry Research Institute	China
Johnson, Peter F.	Scientific Services Laboratory	Australia
Jones, A.R.	London Fire Brigade	U.K.
Keeley, George W.	Halon Research Institute	U.S.A.
Kistner, Stephen I.	U.S. Army Environmental Hygiene Agency	U.S.A.
Kopylov, Nikloai P.	USSR Fire Defence Research Institute	U.S.S.R.
Kostecki, Joseph A.	Pem All Fire Extinguisher Corp.	U.S.A.
Kuwabara, S.	Fire Suppression Systems Association of Japan	Japan
Lavelle, Laurie	Australian Assembly of Fire Authorities	Australia
Lee, Barry	Wormald Australia Pty Ltd.	Australia
LePere, Maurice E.	U.S. Army Belvoir Research Center	U.S.A.
Linden, G.	VDS	Germany
Mansfeld, Jan	The Swedish Fire Protection Association	Sweden
Marty, Yvon	CTFHE	France
Musset, Mrs.	Environment Ministry	France
Negishi, Suetaka	Building Constructors Society	Japan
Newsum, A.R.	Royal Automobile Club Motor Sports Association	U.K.
Nilsson, Erik	Svenkt Stal Tunnplat	Sweden
	Norwegian Fire Protection Association	Norway
O'Sullivan, John J.	British Airways	U.K.
Pope, Pamela	BP Exploration, U.K. Operations	U.K.
Ramaswamy, Dr. S.	Bombay Chamber of Commerce & Industry	India
Renneus, Gustaf	The Swedish Fire Protection Association	Sweden
Shearer, Eoin	Insurance Council of Australia	Australia
Sheinson, Ron	Naval Research Laboratory	U.S.A.
Shepherd, Denis	W.S. Atkins	U.K.
Siljeahlhl, C-M	ArxCon AB	Sweden
Slonski, Stanley J.	NAFED	U.S.A.
Sparring, Bjorn	SVEBRA	Sweden

Spring, Dr. D.J.	Fire & Safety International	U.K.
Stevens, Peter H.	British Telecom	U.K.
Straney, Richard W.	Niagra Mohawk Power Corporation	U.S.A.
Sweval, Mark A.	Great Lakes Chemical Corporation	U.S.A.
Tanabe, Susumu	Japan Halon Co., Ltd.	Japan
Tapscott, Robert E.	NMERI	U.S.A.
Ulmer, Philip E.	Arco Alaska, Inc.	U.S.A.
Verdonik, Daniel P.	U.S. Army, Materiel Command	U.K.
Walker, D.R.	Thorn Security Limited	U.K.
Waterfall, K.W.	E&P Forum - Shell International Petroleum	Netherlands
Williams, D.J.	Institution of Fire Engineers	U.K.
Wilson, Laurie	Commonwealth Fire Board	Australia
Wooliscroft, D.H.	BSI Standards	U.K.
Xie, Yuanhui	Zhejiang Chemical Industry Research Institute	China
Young, R.A.	The Loss Prevention Council	U.K.
Young, R.I.	Department of the Environment	U.K.
Zhang, Wenxu	Zhejiang Chemical Industry Research Institute	China

Appendix C

Estimated Historic and Future Halon Supplies

The computer program BANK was used to develop the estimates used in this section of the report.

For halon 1211 based fire equipment the following base assumptions were used in the calculations shown. Equipment life has been estimated as 20 years. The computer program calculates that 5% of the additions to the bank for a year reach the end of useful life for each of 20 years thereafter. This 5% per year becomes the theoretical maximum available for recovery and recycle. The calculations for halon 1211 assume that before 1988 there was no recovery. Between 1988 and 1992 the recovery rate increases to a maximum of 25%. Interviews with North American fire equipment suppliers were the basis for these estimates and are much lower than for halon 1301 based fire equipment. This is not an indication of lack of effort by industry or others it is merely a reflection of the difficulty of recovering the typical small amounts found in a great number of widely dispersed hand held fire extinguishers.

For halon 1301 based fire equipment the following base assumptions were used in the calculations shown. Equipment life has been estimated as 15 years. The computer program calculates that 6.7% of the additions to the bank for a year reach the end of useful life for each of 15 years thereafter. This 6.7% per year becomes the theoretical maximum available for recovery and recycle. The calculations for halon 1301 assume that before 1988 there was a 50% recovery. Between 1988 and 1992 the recovery rate increases to a maximum of 75%. The shorter equipment life is due to application dependence. The study of North American and European halon use patterns used in the development of the computer program indicated that the useful life of the protected facilities was the factor that governed the life of the halon 1301 fire protection systems used to provide protection. The significantly higher recovery rates reflect the higher storage capacities of halon 1301 systems containers. A typical fixed system may provide a single source of more than 50 times the recoverable halon from a portable fire extinguisher.

The calculations shown in this report assume that recycled halon, in excess of bank maintenance requirements, will be made available for new installations to protect "essential" facilities. For comparison purposes, calculations are provided for 2000, 1997 and 1995 as phase-out years.

Explanation of Individual Factors Used by the Computer Program BANK to Generate Halon Bank Estimates

C1 Year

The current year

C2 Production/Imports (Prod)

Production, in metric tonnes. The term Production has been used in lieu of the Montreal Protocol term "consumption" to avoid confusion when used in conjunction with recycle of halons. The global production data were developed on the basis of audited, CEFIC production data with estimates for other world production data added. The estimated production figures are as follows:

C3 Recycle

Theoretically all halon that has been banked eventually becomes available for recycle. After extensive interviews and discussions regarding usable equipment life it became apparent that the life of the facility being protected was the governing factor rather than the life of the equipment. In many computer facilities, rapid technological change results in relatively short usable life times (as low as one year). In other applications, such as shipboard machinery spaces, longer usable lifetimes are to be expected. The term recycle includes recycle of the halon, either as a bulk chemical, or in the original system container. In the latter case, when a system is reconfigured, or reuse of system containers occurs, recycle is considered to have occurred. Halon 1211 recovered and recycled when internal inspection of portable fire extinguishers is undertaken is not included in this category, losses however are accounted for under category (C7). Losses that occur when halon 1301 is recovered and recycled during hydrostatic test of the system container are dealt with in a similar manner.

The computer program divides the quantity of halon added to the bank in a given year (C 11) by the usable life, entered by the user of the program. This equal portion of halon is then returned each year (C1) over the usable equipment life to form part of the amount available for recycle (C3) for any given year.

C4 Supply

The total supply equals Production (C2), plus Recycle (C3).

C5 Fires

This is the quantity of halon used annually to extinguish fires. The quantity used is a factor of the bank size at the start of the year (C 10). From industry studies conducted in the United States and Europe the following factors were derived to calculate this estimated quantity:

For Halon 1301	1.5% of the Bank at the start of the year (C 10)
For Halon 1211	2% of the Bank at the start of the year (C 10)

C6 Testing and Training (Tst/Tng)

It is recognized that awareness will be a driving force to reduce emissions attributed to these causes. Again the starting factors used were derived from industry studies. Future values are judgement estimates.

For Halon 1301

Before 1988	15% of Supply (C4)
1988	12.5% of Supply (C4)
1989	10% of Supply (C4)
1990	7.5% of Supply (C4)
1991	5% of Supply (C4)
1992	2.5% of Supply (C4)
1993 and beyond	2% of Supply (C4)

For Halon 1211

Before 1988	10% of the Bank at the start of the year (C10)
1988	7.5% of the Bank at the start of the year (C10)
1989	5% of the Bank at the start of the year (C10)
1990	2.5% of the Bank at the start of the year (C10)
1991	2% of the Bank at the start of the year (C10)
1992	1.5% of the Bank at the start of the year (C10)
1993 and beyond	1% of the Bank at the start of the year (C10)

C7 Other (Other emissions including service, leakage, false & unwanted discharges)

It is recognized that awareness will be a driving force to reduce emissions attributed to these causes. Again the starting factors used were derived from industry studies. Future values are judgement estimates.

For Halon 1301

Before 1988	2.5% of the Bank at the start of the year (C10)
1988	2.25% of the Bank at the start of the year (C10)
1989	2% of the Bank at the start of the year (C10)
1990	1.75% of the Bank at the start of the year (C10)
1991	1.5% of the Bank at the start of the year (C10)
1992	1.25% of the Bank at the start of the year (C10)
1993 and beyond	1% of the Bank at the start of the year (C10)

For Halon 1211

Before 1988	5% of the Bank at the start of the year (C10)
1988	4.75% of the Bank at the start of the year (C10)
1989	4.5% of the Bank at the start of the year (C10)
1990	4% of the Bank at the start of the year (C10)
1991	3.5% of the Bank at the start of the year (C10)
1992	3% of the Bank at the start of the year (C10)
1993 and beyond	2.5% of the Bank at the start of the year (C10)

C8 Unrecovered Halon

This factor is calculated in conjunction with the theoretical Recycle quantity. As it is recognized that it is impractical to recover the full quantity theoretically available for recycle, the quantity that is not recycled is treated as an emission. This calculation is performed as follows:

(1 - Recovery Factor) X Recycle (C3) = Unrecovered Quantity (C8)

Up until 1988 the minimum recovery factor entered by the user of the program is used to perform this calculation. After 1994 the maximum recovery factor is used to calculate this quantity. The calculations for the years 1989 to 1994 use an incremental recovery. The minimum and maximum recovery values are entered by the user of the program. The values used in the calculation are printed at the top of each spreadsheet and chart.

C9 Destruct

Should the policy decision be made to not allow use of a halon to be recycled into new equipment the excess halon that becomes available annually through recycle would be available for environmentally acceptable destruction, for all years after the year in which production/imports cease. This quantity is not treated as an emission. As a result cumulative emission quantities would be less than cumulative production quantities. If the recycle option has been selected then halon in excess of bank maintenance requirements is assigned to (C11) additions to the bank. The user of the program enters the choice of recycle or destruct. The choice selected is printed at the top of each spreadsheet and chart.

C10 Bank at the Start of the Year (Strt Bnk)

This is equal to the bank at the end of the previous year, less the quantity that becomes available for recycle; ie. (C12) for the previous year less (C3) for the current year.

C11 Bank Change (Bnk Chng)

This is the annual supply, less all annual emissions and represent the quantity that can be used for new installations of halon fire equipment. In some cases this quantity is negative, which indicates that additional halon would have to be removed from the bank to provide sufficient halon to service the remainder of the bank in the current year.

C12 Bank at the End of the Year (End Bnk)

This quantity equals the Bank at the start of the year (C10), plus the additions to the bank for the year (C11).

C13 Yearly Emissions (Yr Emis)

The total emission quantity for the current year.

C14 Cumulative Emissions

The total of all emissions to date including those of the current year.

C15 Cumulative Production

The total of all production to date including the production for the current year,

Discussion

Estimates of total emissions of halons have been developed by two, independent methods. The first method developed by A. McCulloch of ICI Chemicals & Polymers Ltd. has been proposed in the paper "Global Production and Emissions of Bromochlorodifluoromethane and Bromotrifluoromethane (Halons 1211 and 1301). The second method was developed by Gary Taylor of Taylor/Wagner Inc. and was published as "Halon Bank Management, A Rationale to Evaluate Future World Supplies", Proceedings of Halon and Environment Conference '90, Geneva, Switzerland, October 1 - 3, 1990. Sponsored by BVD/SPI, CFPA Europe and NFPA.

Mr. McCulloch examined the estimates of production and emissions provided by chemical manufacturers to arrive at an estimate of total halon emissions, which was consistent with atmospheric concentrations. Mr. Taylor examined North American and European industry statistics relating to emissions of halons. These two methods produced order of magnitude estimates of total emissions that were similar. Both original papers presented at the Geneva Conference by Mr. McCulloch and Mr. Taylor have since been revised. The following chart compares the estimates of total cumulative emissions to the end of 1990 on the basis of atmospheric concentration and on the basis of emission estimates.

Estimated Total Cumulative Halon Emissions to the end of 1990

	On the Basis of Atmospheric Concentration	On the Basis of Emission Estimates
Halon 1211	102 165	101 894
Halon 1301	49 033	55 973

Note: All quantities are in metric tonnes

Computer generated calculations using the Emission Estimate method are included in this section of the report. Calculations and graphs for both halon 1211 and halon 1301, with production phase-out in the years 2000, 1997 and 1995 are provided for comparison purposes.

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World - Halon 1301 - Phase-Out Year is 2000 - Equip Life 15 yrs - From 2000 Recovered Halon to be Recycled
Up to 1988 recovery estimated as 50% then increasing to 75% by 1995.
World usage (tonnes) equals 100% of Global Production (based on audited CEFIC data + other estimated production)
The calculation terminates when the remaining bank decreases to less than 5% of maximum attained size.

C1 Year	C2 Prod	C3 Recycle	C4 Supply	C5 Fires	C6 Tst/Trng	C7 Other	C8 UnRec	C9 Destruct	C10 Strt Bnk	C11 Bnk Chng	C12 End Bnk	C13 Yr Emis	C14 Cum Emis	C15 Cum Prod
1963	10	0	10	0	-2	0	0	0	0	9	9	2	2	10
1964	20	1	21	0	-3	0	0	0	8	17	25	4	5	30
1965	30	2	32	0	-5	-1	-1	0	23	25	48	7	12	60
1966	40	3	43	-1	-7	-1	-2	0	45	33	78	10	22	100
1967	50	6	56	-1	-8	-2	-3	0	73	42	114	14	36	150
1968	60	8	68	-2	-10	-3	-4	0	106	50	156	19	54	210
1969	100	12	112	-2	-17	-4	-6	0	144	83	227	28	83	310
1970	200	17	217	-3	-33	-5	-9	0	210	168	378	50	132	510
1971	550	28	578	-5	-87	-9	-14	0	349	463	813	115	247	1060
1972	839	59	898	-11	-135	-19	-30	0	753	704	1457	195	442	1899
1973	1292	106	1398	-20	-210	-34	-53	0	1351	1081	2432	317	759	3191
1974	1461	178	1639	-34	-246	-56	-89	0	2254	1214	3468	425	1184	4652
1975	2019	259	2278	-48	-342	-80	-130	0	3209	1679	4887	600	1784	6671
1976	3172	371	3543	-68	-531	-113	-186	0	4516	2645	7162	898	2681	9843
1977	3550	548	4098	-99	-615	-165	-274	0	6614	2945	9559	1153	3834	13393
1978	4015	744	4759	-132	-714	-220	-372	0	8815	3320	12135	1438	5273	17408
1979	4718	965	5683	-168	-852	-279	-482	0	11171	3901	15072	1782	7054	22126
1980	4877	1224	6101	-208	-915	-346	-612	0	13848	4020	17868	2081	9135	27003
1981	5694	1490	7184	-246	-1078	-409	-745	0	16378	4706	21084	2478	11613	32697
1982	7565	1801	9366	-289	-1405	-482	-901	0	19283	6289	25572	3077	14690	40262
1983	7386	2218	9604	-350	-1441	-584	-1109	0	23354	6120	29475	3484	18173	47648
1984	8692	2623	11315	-403	-1697	-671	-1311	0	26852	7232	34084	4083	22256	56340
1985	9781	3099	12880	-465	-1932	-775	-1550	0	30985	8159	39144	4721	26977	66121
1986	11076	3632	14708	-533	-2206	-888	-1816	0	35512	9265	44777	5443	32420	77197
1987	11604	4219	15823	-608	-2373	-1014	-2109	0	40559	9718	50276	6105	38525	88801
1988	12551	4820	17371	-682	-2171	-1023	-2259	0	45457	11236	56692	6135	44660	101352
1989	11152	5497	16649	-768	-1665	-1024	-2405	0	51195	10787	61983	5861	50521	112504
1990	9115	6135	15250	-838	-1144	-977	-2492	0	55848	9799	65646	5451	55973	121619
1991	8400	6676	15076	-885	-754	-885	-2504	0	58970	10050	69020	5026	60999	130019
1992	7685	7170	14855	-928	-371	-1546	-2465	0	61850	9545	71395	5310	66309	137704
1993	6970	7610	14580	-957	-292	-638	-2378	0	63785	10316	74101	4264	70573	144674

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World - Halon 1301 - Phase-Out Year is 2000 - Equip Life 15 yrs - From 2000 Recovered Halon to be Recycled

Up to 1988 recovery estimated as 50% then increasing to 75% by 1995.

World usage (tonnes) equals 100% of Global Production (based on audited CEFIC data + other estimated production)

The calculation terminates when the remaining bank decreases to less than 5% of maximum attained size.

C1 Year	C2 Prod	C3 Recycle	C4 Supply	C5 Fires	C6 Tst/Trng	C7 Other	C8 UnRec	C9 Destruct	C10 Strt Bnk	C11 Bnk Chng	C12 End Bnk	C13 Yr Emis	C14 Cum Emis	C15 Cum Prod
1994	6255	8076	14331	-990	-287	-660	-2271	0	66025	10122	76147	4209	74782	150929
1995	5538	8491	14029	-1015	-281	-677	-2123	0	67656	9934	77590	4095	78877	156467
1996	4510	8885	13395	-1031	-268	-687	-2221	0	68705	9188	77894	4207	83083	160977
1997	3482	9184	12666	-1031	-253	-687	-2296	0	68709	8399	77108	4267	87351	164459
1998	2454	9325	11779	-1017	-236	-678	-2331	0	67784	7517	75301	4261	91612	166913
1999	1028	9418	10446	-988	-209	-659	-2354	0	65883	6235	72119	4210	95822	167941
2000	0	9351	9351	-942	-187	-628	-2338	0	62767	5257	68025	4094	99916	167941
2001	0	9158	9158	-883	-183	-589	-2289	0	58867	5214	64080	3944	103861	167941
2002	0	8888	8888	-828	-178	-552	-2222	0	55193	5108	60301	3780	107640	167941
2003	0	8580	8580	-776	-172	-517	-2145	0	51720	4971	56691	3610	111250	167941
2004	0	8163	8163	-728	-163	-485	-2041	0	48528	4746	53274	3417	114667	167941
2005	0	7760	7760	-683	-155	-455	-1940	0	45514	4527	50041	3233	117900	167941
2006	0	7409	7409	-639	-148	-426	-1852	0	42632	4342	46975	3066	120966	167941
2007	0	7028	7028	-599	-141	-399	-1757	0	39947	4132	44078	2896	123863	167941
2008	0	6667	6667	-561	-133	-374	-1667	0	37411	3932	41343	2735	126598	167941
2009	0	6242	6242	-527	-125	-351	-1560	0	35101	3679	38780	2563	129161	167941
2010	0	5812	5812	-495	-116	-330	-1453	0	32968	3419	36387	2393	131554	167941
2011	0	5378	5378	-465	-108	-310	-1344	0	31009	3151	34160	2227	133781	167941
2012	0	4975	4975	-438	-100	-292	-1244	0	29184	2902	32087	2073	135854	167941
2013	0	4609	4609	-412	-92	-275	-1152	0	27478	2677	30155	1931	137786	167941
2014	0	4286	4286	-388	-86	-259	-1072	0	25869	2482	28351	1804	139590	167941
2015	0	4036	4036	-365	-81	-243	-1009	0	24315	2338	26654	1698	141287	167941
2016	0	3841	3841	-342	-77	-228	-960	0	22812	2234	25046	1607	142895	167941
2017	0	3643	3643	-321	-73	-214	-911	0	21404	2124	23528	1519	144413	167941
2018	0	3444	3444	-301	-69	-201	-861	0	20084	2012	22096	1432	145845	167941
2019	0	3246	3246	-283	-65	-188	-812	0	18849	1899	20748	1348	147193	167941
2020	0	3057	3057	-265	-61	-177	-764	0	17691	1789	19480	1268	148461	167941
2021	0	2874	2874	-249	-57	-166	-719	0	16606	1683	18289	1191	149652	167941
2022	0	2697	2697	-234	-54	-156	-674	0	15592	1579	17171	1118	150770	167941
2023	0	2527	2527	-220	-51	-146	-632	0	14645	1478	16123	1048	151818	167941
2024	0	2363	2363	-206	-47	-138	-591	0	13760	1381	15141	982	152800	167941

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World - Halon 1301 - Phase-Out Year is 2000 - Equip Life 15 yrs - From 2000 Recovered Halon to be Recycled

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The calculation terminates when the remaining bank decreases to less than 5% of maximum attained size.

C1 Year	C2 Prod	C3 Recycle	C4 Supply	C5 Fires	C6 Tst/Trng	C7 Other	C8 UnRec	C9 Destruct	C10 Strt Bnk	C11 Bnk Chng	C12 End Bnk	C13 Yr Emis	C14 Cum Emis	C15 Cum Prod
2025	0	2210	2210	-194	-44	-129	-552	0	12931	1290	14221	920	153720	167941
2026	0	2068	2068	-182	-41	-122	-517	0	12153	1206	13359	862	154582	167941
2027	0	1938	1938	-171	-39	-114	-485	0	11420	1129	12550	809	155391	167941
2028	0	1820	1820	-161	-36	-107	-455	0	10730	1060	11790	760	156151	167941
2029	0	1712	1712	-151	-34	-101	-428	0	10078	998	11076	714	156865	167941
2030	0	1613	1613	-142	-32	-95	-403	0	9463	941	10404	672	157537	167941
2031	0	1520	1520	-133	-30	-89	-380	0	8884	888	9771	633	158170	167941
2032	0	1430	1430	-125	-29	-83	-358	0	8341	836	9176	595	158764	167941
2033	0	1345	1345	-117	-27	-78	-336	0	7832	786	8618	559	159323	167941
2034	0	1263	1263	-110	-25	-74	-316	0	7355	738	8093	525	159848	167941
2035	0	1185	1185	-104	-24	-69	-296	0	6907	693	7600	493	160341	167941
2036	0	1112	1112	-97	-22	-65	-278	0	6488	650	7137	463	160803	167941
2037	0	1044	1044	-91	-21	-61	-261	0	6094	609	6703	434	161238	167941
2038	0	979	979	-86	-20	-57	-245	0	5724	571	6296	407	161645	167941
2039	0	918	918	-81	-18	-54	-230	0	5378	536	5914	382	162027	167941
2040	0	862	862	-76	-17	-51	-216	0	5051	503	5554	359	162387	167941
2041	0	810	810	-71	-16	-47	-202	0	4745	472	5217	337	162724	167941
2042	0	761	761	-67	-15	-45	-190	0	4457	444	4900	317	163041	167941
2043	0	715	715	-63	-14	-42	-179	0	4185	417	4603	298	163338	167941
2044	0	672	672	-59	-13	-39	-168	0	3931	392	4323	280	163618	167941
2045	0	4323	4323	0	0	0	-4323	0	0	0	0	4323	167941	167941

All quantities in metric tonnes

End of calculation WA3R1575

WB3R1575 - calculated using version 7.0 of the computer program BANK

World - Halon 1301 - Phase-Out Year is 1997 - Equip Life 15 yrs - From 1997 Recovered Halon to be Recycled

Up to 1988 recovery estimated as 50% then increasing to 75% by 1995.

World usage (tonnes) equals 100% of Global Production (based on audited CEFIC data + other estimated production)

The calculation terminates when the remaining bank decreases to less than 5% of maximum attained size

C1 Year	C2 Prod	C3 Recycle	C4 Supply	C5 Fires	C6 Tst/Trng	C7 Other	C8 UnRec	C9 Destruct	C10 Strt Bnk	C11 Bnk Chng	C12 End Bnk	C13 Yr Emis	C14 Cum Emis	C15 Cum Prod
1963	10	0	10	0	-2	0	0	0	0	9	9	2	2	10
1964	20	1	21	0	-3	0	0	0	8	17	25	4	5	30
1965	30	2	32	0	-5	-1	-1	0	23	25	48	7	12	60
1966	40	3	43	-1	-7	-1	-2	0	45	33	78	10	22	100
1967	50	6	56	-1	-8	-2	-3	0	73	42	114	14	36	150
1968	60	8	68	-2	-10	-3	-4	0	106	50	156	19	54	210
1969	100	12	112	-2	-17	-4	-6	0	144	83	227	28	83	310
1970	200	17	217	-3	-33	-5	-9	0	210	168	378	50	132	510
1971	550	28	578	-5	-87	-9	-14	0	349	463	813	115	247	1060
1972	839	59	898	-11	-135	-19	-30	0	753	704	1457	195	442	1899
1973	1292	106	1398	-20	-210	-34	-53	0	1351	1081	2432	317	759	3191
1974	1461	178	1639	-34	-246	-56	-89	0	2254	1214	3468	425	1184	4652
1975	2019	259	2278	-48	-342	-80	-130	0	3209	1679	4887	600	1784	6671
1976	3172	371	3543	-68	-531	-113	-186	0	4516	2645	7162	898	2681	9843
1977	3550	548	4098	-99	-615	-165	-274	0	6614	2945	9559	1153	3834	13393
1978	4015	744	4759	-132	-714	-220	-372	0	8815	3320	12135	1438	5273	17408
1979	4718	965	5683	-168	-852	-279	-482	0	11171	3901	15072	1782	7054	22126
1980	4877	1224	6101	-208	-915	-346	-612	0	13848	4020	17868	2081	9135	27003
1981	5694	1490	7184	-246	-1078	-409	-745	0	16378	4706	21084	2478	11613	32697
1982	7565	1801	9366	-289	-1405	-482	-901	0	19283	6289	25572	3077	14690	40262
1983	7386	2218	9604	-350	-1441	-584	-1109	0	23354	6120	29475	3484	18173	47648
1984	8692	2623	11315	-403	-1697	-671	-1311	0	26852	7232	34084	4083	22256	56340
1985	9781	3099	12880	-465	-1932	-775	-1550	0	30985	8159	39144	4721	26977	66121
1986	11076	3632	14708	-533	-2206	-888	-1816	0	35512	9265	44777	5443	32420	77197
1987	11604	4219	15823	-608	-2373	-1014	-2109	0	40559	9718	50276	6105	38525	88801
1988	12551	4820	17371	-682	-2171	-1023	-2259	0	45457	11236	56692	6135	44660	101352
1989	11152	5497	16649	-768	-1665	-1024	-2405	0	51195	10787	61983	5861	50521	112504
1990	9115	6135	15250	-838	-1144	-977	-2492	0	55848	9799	65646	5451	55973	121619
1991	7326	6676	14002	-885	-700	-885	-2504	0	58970	9029	68000	4973	60945	128945
1992	5538	7102	12640	-913	-316	-1522	-2441	0	60898	7447	68345	5193	66138	134483
1993	4510	7402	11912	-914	-238	-609	-2313	0	60943	7837	68780	4075	70213	138993

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World - Halon 1301 - Phase-Out Year is 1997 - Equip Life 15 yrs - From 1997 Recovered Halon to be Recycled

Up to 1988 recovery estimated as 50% then increasing to 75% by 1995.

World usage (tonnes) equals 100% of Global Production (based on audited CEFIC data + other estimated production)

The calculation terminates when the remaining bank decreases to less than 5% of maximum attained size

C1 Year	C2 Prod	C3 Recycle	C4 Supply	C5 Fires	C6 Tst/Trng	C7 Other	C8 UnRec	C9 Destruct	C10 Strt Bnk	C11 Bnk Chng	C12 End Bnk	C13 Yr Emis	C14 Cum Emis	C15 Cum Prod
1994	3482	7703	11185	-916	-224	-611	-2166	0	61077	7268	68345	3917	74130	142475
1995	2454	7927	10381	-906	-208	-604	-1982	0	60417	6682	67099	3700	77830	144929
1996	1028	8105	9133	-885	-183	-590	-2026	0	58994	5449	64443	3684	81514	145957
1997	0	8154	8154	-844	-163	-563	-2039	0	56288	4546	60834	3609	85123	145957
1998	0	8038	8038	-792	-161	-528	-2010	0	52796	4548	57344	3490	88613	145957
1999	0	7933	7933	-741	-159	-494	-1983	0	49410	4556	53967	3377	91991	145957
2000	0	7755	7755	-693	-155	-462	-1939	0	46212	4506	50717	3249	95240	145957
2001	0	7511	7511	-648	-150	-432	-1878	0	43206	4403	47609	3108	98348	145957
2002	0	7187	7187	-606	-144	-404	-1797	0	40422	4236	44658	2951	101299	145957
2003	0	6822	6822	-568	-136	-378	-1705	0	37836	4034	41870	2788	104087	145957
2004	0	6342	6342	-533	-127	-355	-1585	0	35528	3741	39270	2600	106687	145957
2005	0	5872	5872	-501	-117	-334	-1468	0	33398	3452	36849	2420	109108	145957
2006	0	5449	5449	-471	-109	-314	-1362	0	31400	3193	34593	2256	111364	145957
2007	0	5060	5060	-443	-101	-295	-1265	0	29533	2955	32489	2104	113468	145957
2008	0	4760	4760	-416	-95	-277	-1190	0	27728	2782	30510	1979	115447	145957
2009	0	4423	4423	-391	-88	-261	-1106	0	26087	2577	28664	1846	117293	145957
2010	0	4111	4111	-368	-82	-246	-1028	0	24553	2387	26940	1724	119017	145957
2011	0	3824	3824	-347	-76	-231	-956	0	23116	2214	25329	1610	120628	145957
2012	0	3609	3609	-326	-72	-217	-902	0	21721	2091	23812	1517	122145	145957
2013	0	3445	3445	-306	-69	-204	-861	0	20367	2006	22373	1439	123584	145957
2014	0	3276	3276	-286	-66	-191	-819	0	19097	1914	21011	1362	124946	145957
2015	0	3099	3099	-269	-62	-179	-775	0	17912	1815	19726	1285	126231	145957
2016	0	2920	2920	-252	-58	-168	-730	0	16806	1711	18518	1209	127439	145957
2017	0	2741	2741	-237	-55	-158	-685	0	15777	1606	17383	1134	128574	145957
2018	0	2565	2565	-222	-51	-148	-641	0	14818	1502	16320	1063	129637	145957
2019	0	2396	2396	-209	-48	-139	-599	0	13924	1401	15325	995	130632	145957
2020	0	2240	2240	-196	-45	-131	-560	0	13085	1308	14393	932	131564	145957
2021	0	2097	2097	-184	-42	-123	-524	0	12296	1224	13520	874	132437	145957
2022	0	1966	1966	-173	-39	-116	-492	0	11553	1147	12700	820	133257	145957
2023	0	1846	1846	-163	-37	-109	-461	0	10854	1076	11930	770	134027	145957
2024	0	1732	1732	-153	-35	-102	-433	0	10198	1009	11208	723	134749	145957

WB3R1575 - calculated using version 7.0 of the computer program BANK

World - Halon 1301 - Phase-Out Year is 1997 - Equip Life 15 yrs - From 1997 Recovered Halon to be Recycled

Up to 1988 recovery estimated as 50% then increasing to 75% by 1995.

World usage (tonnes) equals 100% of Global Production (based on audited CEFIC data + other estimated production)

The calculation terminates when the remaining bank decreases to less than 5% of maximum attained size

C1 Year	C2 Prod	C3 Recycle	C4 Supply	C5 Fires	C6 Tst/Trng	C7 Other	C8 UnRec	C9 Destruct	C10 Strt Bnk	C11 Bnk Chng	C12 End Bnk	C13 Yr Emis	C14 Cum Emis	C15 Cum Prod
2025	0	1627	1627	-144	-33	-96	-407	0	9580	948	10529	679	135428	145957
2026	0	1532	1532	-135	-31	-90	-383	0	8997	893	9890	638	136067	145957
2027	0	1443	1443	-127	-29	-84	-361	0	8447	843	9289	601	136668	145957
2028	0	1360	1360	-119	-27	-79	-340	0	7929	795	8724	565	137233	145957
2029	0	1279	1279	-112	-26	-74	-320	0	7444	748	8192	532	137765	145957
2030	0	1202	1202	-105	-24	-70	-300	0	6991	703	7693	499	138264	145957
2031	0	1128	1128	-98	-23	-66	-282	0	6565	659	7224	469	138733	145957
2032	0	1057	1057	-93	-21	-62	-264	0	6167	618	6785	440	139172	145957
2033	0	992	992	-87	-20	-58	-248	0	5793	579	6372	413	139585	145957
2034	0	930	930	-82	-19	-54	-233	0	5442	543	5985	387	139972	145957
2035	0	873	873	-77	-17	-51	-218	0	5112	509	5622	363	140335	145957
2036	0	820	820	-72	-16	-48	-205	0	4802	478	5280	341	140677	145957
2037	0	770	770	-68	-15	-45	-192	0	4510	449	4960	321	140997	145957
2038	0	723	723	-64	-14	-42	-181	0	4236	422	4658	301	141299	145957
2039	0	680	680	-60	-14	-40	-170	0	3979	397	4375	283	141582	145957
2040	0	639	639	-56	-13	-37	-160	0	3737	373	4110	266	141847	145957
2041	0	601	601	-53	-12	-35	-150	0	3509	351	3860	250	142097	145957
2042	0	3860	3860	0	0	0	-3860	0	0	0	0	3860	145957	145957

All quantities in metric tonnes **End of calculation WB3R1575**

WC3R1575 - calculated using version 7.0 of the computer program BANK

World - Halon 1301 - Phase-Out Year is 1995 - Equip Life 15 yrs - From 1995 Recovered Halon to be Recycled

Up to 1988 recovery estimated as 50% then increasing to 75% by 1995.

World usage (tonnes) equals 100% of Global Production (based on audited CEFIC data + other estimated production)

The calculation terminates when the remaining bank decreases to 5% of maximum attained size.

C1 Year	C2 Prod	C3 Recycle	C4 Supply	C5 Fires	C6 Tst/Trng	C7 Other	C8 UnRec	C9 Destruct	C10 Strt Bnk	C11 Bnk Chng	C12 End Bnk	C13 Yr Emis	C14 Cum Emis	C15 Cum Prod
1963	10	0	10	0	-2	0	0	0	0	9	9	2	2	10
1964	20	1	21	0	-3	0	0	0	8	17	25	4	5	30
1965	30	2	32	0	-5	-1	-1	0	23	25	48	7	12	60
1966	40	3	43	-1	-7	-1	-2	0	45	33	78	10	22	100
1967	50	6	56	-1	-8	-2	-3	0	73	42	114	14	36	150
1968	60	8	68	-2	-10	-3	-4	0	106	50	156	19	54	210
1969	100	12	112	-2	-17	-4	-6	0	144	83	227	28	83	310
1970	200	17	217	-3	-33	-5	-9	0	210	168	378	50	132	510
1971	550	28	578	-5	-87	-9	-14	0	349	463	813	115	247	1060
1972	839	59	898	-11	-135	-19	-30	0	753	704	1457	195	442	1899
1973	1292	106	1398	-20	-210	-34	-53	0	1351	1081	2432	317	759	3191
1974	1461	178	1639	-34	-246	-56	-89	0	2254	1214	3468	425	1184	4652
1975	2019	259	2278	-48	-342	-80	-130	0	3209	1679	4887	600	1784	6671
1976	3172	371	3543	-68	-531	-113	-186	0	4516	2645	7162	898	2681	9843
1977	3550	548	4098	-99	-615	-165	-274	0	6614	2945	9559	1153	3834	13393
1978	4015	744	4759	-132	-714	-220	-372	0	8815	3320	12135	1438	5273	17408
1979	4718	965	5683	-168	-852	-279	-482	0	11171	3901	15072	1782	7054	22126
1980	4877	1224	6101	-208	-915	-346	-612	0	13848	4020	17868	2081	9135	27003
1981	5694	1490	7184	-246	-1078	-409	-745	0	16378	4706	21084	2478	11613	32697
1982	7565	1801	9366	-289	-1405	-482	-901	0	19283	6289	25572	3077	14690	40262
1983	7386	2218	9604	-350	-1441	-584	-1109	0	23354	6120	29475	3484	18173	47648
1984	8692	2623	11315	-403	-1697	-671	-1311	0	26852	7232	34084	4083	22256	56340
1985	9781	3099	12880	-465	-1932	-775	-1550	0	30985	8159	39144	4721	26977	66121
1986	11076	3632	14708	-533	-2206	-888	-1816	0	35512	9265	44777	5443	32420	77197
1987	11604	4219	15823	-608	-2373	-1014	-2109	0	40559	9718	50276	6105	38525	88801
1988	12551	4820	17371	-682	-2171	-1023	-2259	0	45457	11236	56692	6135	44660	101352
1989	11152	5497	16649	-768	-1665	-1024	-2405	0	51195	10787	61983	5861	50521	112504
1990	9115	6135	15250	-838	-1144	-977	-2492	0	55848	9799	65646	5451	55973	121619
1991	7326	6676	14002	-885	-700	-885	-2504	0	58970	9029	68000	4973	60945	128945
1992	5538	7102	12640	-913	-316	-1522	-2441	0	60898	7447	68345	5193	66138	134483
1993	3692	7402	11094	-914	-222	-609	-2313	0	60943	7035	67978	4059	70197	138175

WC3R1575 - calculated using version 7.0 of the computer program BANK

World - Halon 1301 - Phase-Out Year is 1995 - Equip Life 15 yrs - From 1995 Recovered Halon to be Recycled

Up to 1988 recovery estimated as 50% then increasing to 75% by 1995.

World usage (tonnes) equals 100% of Global Production (based on audited CEFIC data + other estimated production)

The calculation terminates when the remaining bank decreases to 5% of maximum attained size.

C1 Year	C2 Prod	C3 Recycle	C4 Supply	C5 Fires	C6 Tst/Trng	C7 Other	C8 UnRec	C9 Destruct	C10 Strt Bnk	C11 Bnk Chng	C12 End Bnk	C13 Yr Emis	C14 Cum Emis	C15 Cum Prod
1994	1846	7650	9496	-905	-190	-603	-2151	0	60328	5646	65974	3850	74047	140021
1995	0	7766	7766	-873	-155	-582	-1941	0	58209	4214	62422	3552	77599	140021
1996	0	7779	7779	-820	-156	-546	-1945	0	54644	4312	58956	3466	81065	140021
1997	0	7753	7753	-768	-155	-512	-1938	0	51203	4379	55583	3373	84438	140021
1998	0	7625	7625	-719	-153	-480	-1906	0	47958	4368	52325	3258	87696	140021
1999	0	7508	7508	-672	-150	-448	-1877	0	44817	4361	49177	3148	90844	140021
2000	0	7317	7317	-628	-146	-419	-1829	0	41860	4295	46155	3022	93866	140021
2001	0	7059	7059	-586	-141	-391	-1765	0	39096	4176	43272	2883	96749	140021
2002	0	6720	6720	-548	-134	-366	-1680	0	36552	3992	40544	2728	99477	140021
2003	0	6338	6338	-513	-127	-342	-1585	0	34205	3772	37977	2566	102044	140021
2004	0	5841	5841	-482	-117	-321	-1460	0	32136	3460	35597	2380	104424	140021
2005	0	5352	5352	-454	-107	-302	-1338	0	30244	3151	33395	2201	106626	140021
2006	0	4909	4909	-427	-98	-285	-1227	0	28486	2872	31358	2038	108663	140021
2007	0	4499	4499	-403	-90	-269	-1125	0	26859	2613	29472	1886	110549	140021
2008	0	4176	4176	-379	-84	-253	-1044	0	25295	2416	27712	1760	112309	140021
2009	0	3868	3868	-358	-77	-238	-967	0	23843	2228	26071	1641	113950	140021
2010	0	3641	3641	-336	-73	-224	-910	0	22431	2097	24527	1544	115494	140021
2011	0	3499	3499	-315	-70	-210	-875	0	21028	2029	23057	1471	116964	140021
2012	0	3347	3347	-296	-67	-197	-837	0	19710	1951	21660	1396	118361	140021
2013	0	3185	3185	-277	-64	-185	-796	0	18475	1863	20339	1322	119683	140021
2014	0	3018	3018	-260	-60	-173	-755	0	17320	1770	19091	1248	120930	140021
2015	0	2846	2846	-244	-57	-162	-711	0	16245	1671	17916	1174	122105	140021
2016	0	2671	2671	-229	-53	-152	-668	0	15245	1568	16814	1102	123207	140021
2017	0	2497	2497	-215	-50	-143	-624	0	14317	1465	15782	1032	124239	140021
2018	0	2328	2328	-202	-47	-135	-582	0	13453	1363	14817	965	125204	140021
2019	0	2168	2168	-190	-43	-126	-542	0	12649	1266	13915	902	126106	140021
2020	0	2022	2022	-178	-40	-119	-505	0	11894	1178	13072	843	126949	140021
2021	0	1890	1890	-168	-38	-112	-473	0	11182	1100	12282	790	127739	140021
2022	0	1772	1772	-158	-35	-105	-443	0	10510	1031	11541	741	128480	140021
2023	0	1667	1667	-148	-33	-99	-417	0	9874	970	10844	697	129177	140021
2024	0	1570	1570	-139	-31	-93	-393	0	9274	914	10188	656	129833	140021

WC3R1575 - calculated using version 7.0 of the computer program BANK

World - Halon 1301 - Phase-Out Year is 1995 - Equip Life 15 yrs - From 1995 Recovered Halon to be Recycled

Up to 1988 recovery estimated as 50% then increasing to 75% by 1995.

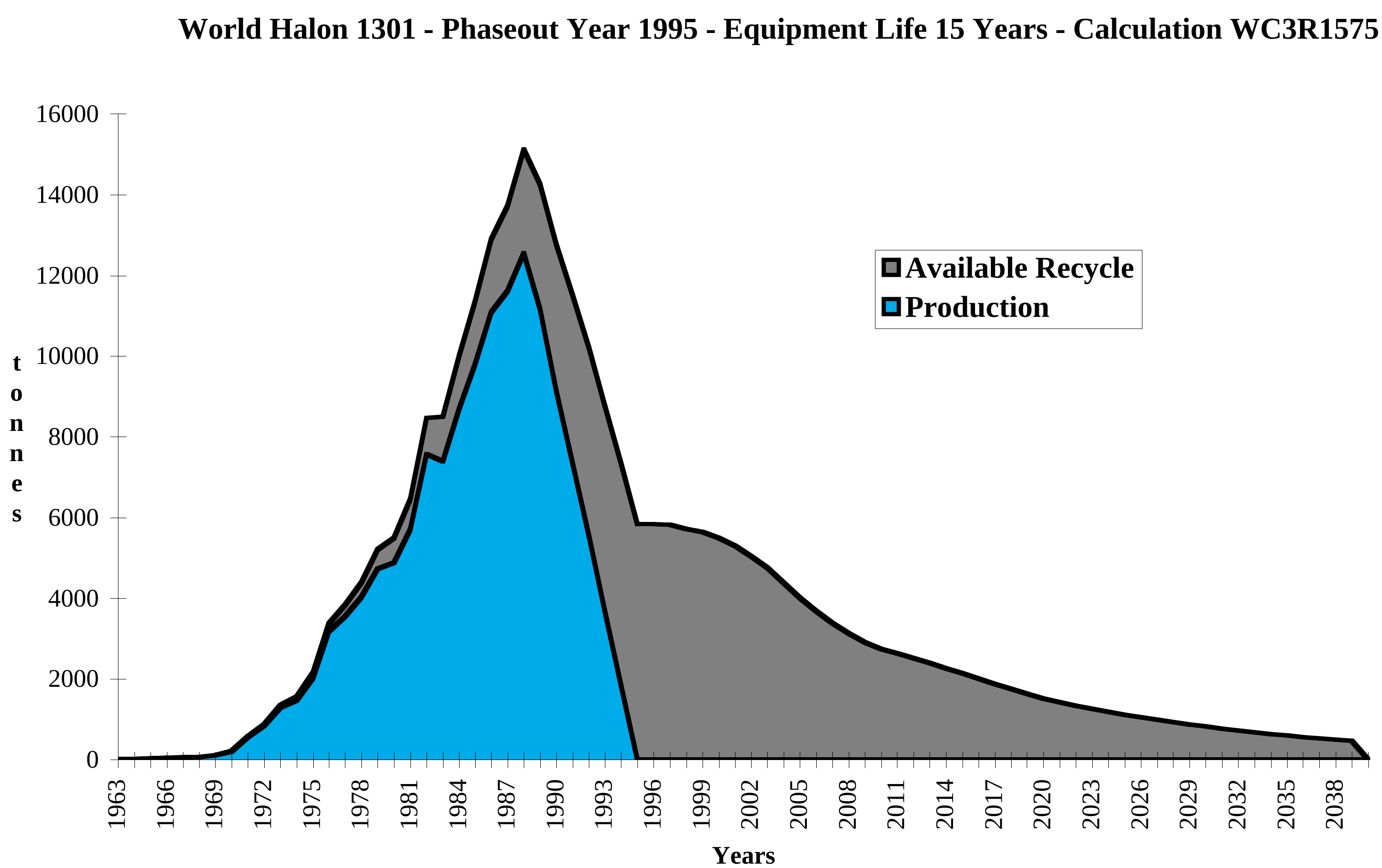
World usage (tonnes) equals 100% of Global Production (based on audited CEFIC data + other estimated production)

The calculation terminates when the remaining bank decreases to 5% of maximum attained size.

C1 Year	C2 Prod	C3 Recycle	C4 Supply	C5 Fires	C6 Tst/Trng	C7 Other	C8 UnRec	C9 Destruct	C10 Strt Bnk	C11 Bnk Chng	C12 End Bnk	C13 Yr Emis	C14 Cum Emis	C15 Cum Prod
2025	0	1483	1483	-131	-30	-87	-371	0	8706	865	9570	618	130451	140021
2026	0	1400	1400	-123	-28	-82	-350	0	8170	818	8988	582	131033	140021
2027	0	1320	1320	-115	-26	-77	-330	0	7668	772	8440	548	131581	140021
2028	0	1241	1241	-108	-25	-72	-310	0	7199	726	7925	515	132096	140021
2029	0	1165	1165	-101	-23	-68	-291	0	6760	682	7441	484	132580	140021
2030	0	1093	1093	-95	-22	-63	-273	0	6349	639	6988	454	133033	140021
2031	0	1024	1024	-89	-20	-60	-256	0	5964	598	6562	426	133459	140021
2032	0	959	959	-84	-19	-56	-240	0	5603	560	6163	399	133858	140021
2033	0	899	899	-79	-18	-53	-225	0	5264	525	5789	374	134232	140021
2034	0	843	843	-74	-17	-49	-211	0	4946	492	5438	351	134583	140021
2035	0	791	791	-70	-16	-46	-198	0	4646	461	5108	330	134913	140021
2036	0	743	743	-65	-15	-44	-186	0	4364	434	4798	310	135223	140021
2037	0	699	699	-61	-14	-41	-175	0	4099	408	4507	291	135514	140021
2038	0	657	657	-58	-13	-38	-164	0	3849	384	4233	274	135788	140021
2039	0	618	618	-54	-12	-36	-155	0	3615	361	3976	257	136045	140021
2040	0	3976	3976	0	0	0	-3976	0	0	0	0	3976	140021	140021

All quantities in metric tonnes

End of calculation WC3R1575


World Halon 1301 - Phaseout Year 1995 - Equipment Life 15 Years - Calculation WC3R1575
tonnes
16000
14000
12000
10000
8000
6000
4000
2000
0
1963
1966
1969
1972
1975
1978
1981
1984
1987
1990
1993
1996
1999
2002
2005
2008
2011
2014
2017
2020
2023
2026
2029
2032
2035
2038
Years
Available Recycle
Production

WA2R2025 - calculated using version 7.0 of the computer program BANK

World - Halon 1211 - Phase-Out Year is 2000 - Equip Life 20 yrs - From 2000 Recovered Halon to be Recycled

Up to 1988 recovery estimated as 0% then increasing to 25% by 1995.

World usage (tonnes) equals 100% of Global Production (based on audited CEFIC data + other estimated production)

The calculation terminates when the remaining bank decreases to 5% of maximum attained size.

C1 Year	C2 Prod	C3 Recycle	C4 Supply	C5 Fires	C6 Tst/Trng	C7 Other	C8 UnRec	C9 Destruct	C10 Strt Bnk	C11 Bnk Chng	C12 End Bnk	C13 Yr Emis	C14 Cum Emis	C15 Cum Prod
1963	50	0	50	0	-5	0	0	0	0	45	45	5	5	50
1964	100	2	102	-1	-4	-2	-2	0	43	93	135	10	15	150
1965	200	7	207	-3	-13	-6	-7	0	129	178	307	29	43	350
1966	300	16	316	-6	-29	-15	-16	0	291	251	541	65	109	650
1967	500	28	528	-10	-51	-26	-28	0	513	413	926	116	224	1150
1968	700	49	749	-18	-88	-44	-49	0	877	551	1428	198	422	1850
1969	900	77	977	-27	-135	-68	-77	0	1351	670	2022	306	728	2750
1970	1260	110	1370	-38	-191	-96	-110	0	1912	935	2847	435	1163	4010
1971	1700	157	1857	-54	-269	-134	-157	0	2690	1243	3933	614	1777	5710
1972	2200	219	2419	-74	-371	-186	-219	0	3714	1569	5282	850	2628	7910
1973	2750	297	3047	-100	-499	-249	-297	0	4985	1903	6888	1145	3772	10660
1974	3300	392	3692	-130	-650	-325	-392	0	6495	2196	8691	1497	5269	13960
1975	3800	502	4302	-164	-819	-409	-502	0	8189	2408	10597	1894	7163	17760
1976	4356	623	4979	-199	-997	-499	-623	0	9974	2660	12634	2318	9482	22116
1977	5000	756	5756	-238	-1188	-594	-756	0	11879	2981	14859	2775	12257	27116
1978	5650	905	6555	-279	-1395	-698	-905	0	13955	3278	17232	3277	15534	32766
1979	6280	1069	7349	-323	-1616	-808	-1069	0	16164	3532	19696	3816	19350	39046
1980	6910	1245	8155	-369	-1845	-923	-1245	0	18451	3773	22224	4382	23732	45956
1981	6689	1434	8123	-416	-2079	-1040	-1434	0	20790	3155	23945	4968	28700	52645
1982	7485	1592	9077	-447	-2235	-1118	-1592	0	22353	3685	26038	5392	34092	60130
1983	8259	1776	10035	-485	-2426	-1213	-1776	0	24262	4134	28397	5900	39992	68389
1984	10408	1980	12388	-528	-2642	-1321	-1980	0	26416	5917	32334	6471	46463	78797
1985	12491	2272	14763	-601	-3006	-1503	-2272	0	30062	7380	37443	7382	53845	91288
1986	13731	2632	16363	-696	-3481	-1741	-2632	0	34811	7813	42624	8550	62395	105019
1987	17058	3010	20068	-792	-3961	-1981	-3010	0	39614	10324	49938	9744	72139	122077
1988	20181	3505	23686	-929	-3482	-2206	-3396	0	46433	13674	60106	10012	82152	142258
1989	16182	4161	20343	-1119	-2797	-2518	-3901	0	55945	10008	65953	10335	92487	158440
1990	14852	4628	19480	-1226	-1533	-2453	-4194	0	61325	10073	71398	9407	101894	173292
1991	13367	5085	18452	-1326	-1326	-2321	-4450	0	66313	9029	75342	9423	111317	186659
1992	11742	5475	17217	-1397	-1048	-2096	-4619	0	69868	8056	77924	9161	120477	198401
1993	10117	5799	15916	-1442	-72	-1803	-4712	0	72125	7887	80011	8029	128507	208518
1994	8492	6098	14590	-1478	-74	-1848	-4764	0	73913	6426	80339	8164	136671	217010
1995	6865	6310	13175	-1481	-74	-1851	-4732	0	74029	5037	79066	8138	144809	223875
1996	5492	6441	11933	-1453	-73	-1816	-4831	0	72625	3762	76387	8172	152980	229367

WA2R2025 - calculated using version 7.0 of the computer program BANK

World - Halon 1211 - Phase-Out Year is 2000 - Equip Life 20 yrs - From 2000 Recovered Halon to be Recycled

Up to 1988 recovery estimated as 0% then increasing to 25% by 1995.

World usage (tonnes) equals 100% of Global Production (based on audited CEFIC data + other estimated production)

The calculation terminates when the remaining bank decreases to 5% of maximum attained size.

C1 Year	C2 Prod	C3 Recycle	C4 Supply	C5 Fires	C6 Tst/Trng	C7 Other	C8 UnRec	C9 Destruct	C10 Strt Bnk	C11 Bnk Chng	C12 End Bnk	C13 Yr Emis	C14 Cum Emis	C15 Cum Prod
1997	4119	6496	10615	-1398	-70	-1747	-4872	0	69890	2528	72419	8087	161067	233486
1998	2746	6474	9220	-1319	-66	-1649	-4855	0	65945	1331	67276	7889	168956	236232
1999	1373	6376	7749	-1218	-61	-1522	-4782	0	60900	166	61065	7584	176540	237605
2000	0	6208	6208	-1097	-55	-1371	-4656	0	54857	-971	53886	7179	183719	237605
2001	0	6019	6019	-957	-48	-1197	-4514	0	47867	-697	47170	6716	190435	237605
2002	0	5862	5862	-826	-41	-1033	-4396	0	41308	-435	40873	6296	196732	237605
2003	0	5677	5677	-704	-35	-880	-4258	0	35196	-200	34996	5877	202609	237605
2004	0	5471	5471	-591	-30	-738	-4103	0	29526	9	29535	5461	208070	237605
2005	0	5175	5175	-487	-24	-609	-3881	0	24360	173	24533	5002	213072	237605
2006	0	4815	4815	-394	-20	-493	-3611	0	19719	297	20015	4518	217590	237605
2007	0	4439	4439	-312	-16	-389	-3329	0	15576	393	15969	4046	221636	237605
2008	0	3942	3942	-241	-12	-301	-2957	0	12027	432	12459	3510	225146	237605
2009	0	3280	3280	-184	-9	-229	-2460	0	9179	398	9577	2883	228028	237605
2010	0	2800	2800	-136	-7	-169	-2100	0	6777	388	7165	2412	230440	237605
2011	0	2316	2316	-97	-5	-121	-1737	0	4850	356	5205	1960	232400	237605
2012	0	5205	5205	0	0	0	-5205	0	0	0	0	5205	237605	237605

All quantities in metric tonnes

End of calculation WA2R2025

WB2R2025 - calculated using version 7.0 of the computer program BANK

World - Halon 1211 - Phase-Out Year is 1997 - Equip Life 20 yrs - From 1997 Recovered Halon to be Recycled

Up to 1988 recovery estimated as 0% then increasing to 25% by 1995.

World usage (tonnes) equals 100% of Global Production (based on audited CEFIC data + other estimated production)

The calculation terminates when the remaining bank decreases to 5% of maximum attained size.

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
Year	**Prod**	**Recycle**	**Supply**	**Fires**	**Tst/Trng**	**Other**	**UnRec**	**Destruct**	**Strt Bnk**	**Bnk Chng**	**End Bnk**	**Yr Emis**	**Cum Emis**	**Cum Prod**
1963	50	0	50	0	-5	0	0	0	0	45	45	5	5	50
1964	100	2	102	-1	-4	-2	-2	0	43	93	135	10	15	150
1965	200	7	207	-3	-13	-6	-7	0	129	178	307	29	43	350
1966	300	16	316	-6	-29	-15	-16	0	291	251	541	65	109	650
1967	500	28	528	-10	-51	-26	-28	0	513	413	926	116	224	1150
1968	700	49	749	-18	-88	-44	-49	0	877	551	1428	198	422	1850
1969	900	77	977	-27	-135	-68	-77	0	1351	670	2022	306	728	2750
1970	1260	110	1370	-38	-191	-96	-110	0	1912	935	2847	435	1163	4010
1971	1700	157	1857	-54	-269	-134	-157	0	2690	1243	3933	614	1777	5710
1972	2200	219	2419	-74	-371	-186	-219	0	3714	1569	5282	850	2628	7910
1973	2750	297	3047	-100	-499	-249	-297	0	4985	1903	6888	1145	3772	10660
1974	3300	392	3692	-130	-650	-325	-392	0	6495	2196	8691	1497	5269	13960
1975	3800	502	4302	-164	-819	-409	-502	0	8189	2408	10597	1894	7163	17760
1976	4356	623	4979	-199	-997	-499	-623	0	9974	2660	12634	2318	9482	22116
1977	5000	756	5756	-238	-1188	-594	-756	0	11879	2981	14859	2775	12257	27116
1978	5650	905	6555	-279	-1395	-698	-905	0	13955	3278	17232	3277	15534	32766
1979	6280	1069	7349	-323	-1616	-808	-1069	0	16164	3532	19696	3816	19350	39046
1980	6910	1245	8155	-369	-1845	-923	-1245	0	18451	3773	22224	4382	23732	45956
1981	6689	1434	8123	-416	-2079	-1040	-1434	0	20790	3155	23945	4968	28700	52645
1982	7485	1592	9077	-447	-2235	-1118	-1592	0	22353	3685	26038	5392	34092	60130
1983	8259	1776	10035	-485	-2426	-1213	-1776	0	24262	4134	28397	5900	39992	68389
1984	10408	1980	12388	-528	-2642	-1321	-1980	0	26416	5917	32334	6471	46463	78797
1985	12491	2272	14763	-601	-3006	-1503	-2272	0	30062	7380	37443	7382	53845	91288
1986	13731	2632	16363	-696	-3481	-1741	-2632	0	34811	7813	42624	8550	62395	105019
1987	17058	3010	20068	-792	-3961	-1981	-3010	0	39614	10324	49938	9744	72139	122077

WB2R2025 - calculated using version 7.0 of the computer program BANK

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The calculation terminates when the remaining bank decreases to 5% of maximum attained size.

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
Year	**Prod**	**Recycle**	**Supply**	**Fires**	**Tst/Trng**	**Other**	**UnRec**	**Destruct**	**Strt Bnk**	**Bnk Chng**	**End Bnk**	**Yr Emis**	**Cum Emis**	**Cum Prod**
1988	20181	3505	23686	-929	-3482	-2206	-3396	0	46433	13674	60106	10012	82152	142258
1989	16182	4161	20343	-1119	-2797	-2518	-3901	0	55945	10008	65953	10335	92487	158440
1990	14852	4628	19480	-1226	-1533	-2453	-4194	0	61325	10073	71398	9407	101894	173292
1991	12730	5085	17815	-1326	-1326	-2321	-4450	0	66313	8392	74705	9423	111317	186022
1992	10608	5443	16051	-1385	-1039	-2078	-4592	0	69262	6956	76219	9094	120411	196630
1993	8486	5712	14198	-1410	-71	-1763	-4641	0	70507	6314	76820	7884	128296	205116
1994	6364	5933	12297	-1418	-71	-1772	-4635	0	70888	4401	75289	7896	136191	211480
1995	4242	6043	10285	-1385	-69	-1731	-4532	0	69246	2567	71813	7718	143909	215722
1996	2121	6051	8172	-1315	-66	-1644	-4538	0	65762	609	66371	7563	151472	217843
1997	0	5948	5948	-1208	-60	-1511	-4461	0	60422	-1292	59130	7241	158713	217843
1998	0	5799	5799	-1067	-53	-1333	-4349	0	53331	-1003	52327	6803	165516	217843
1999	0	5635	5635	-934	-47	-1167	-4227	0	46692	-739	45953	6374	171890	217843
2000	0	5459	5459	-810	-40	-1012	-4094	0	40494	-498	39996	5957	177847	217843
2001	0	5270	5270	-695	-35	-868	-3953	0	34726	-280	34446	5550	183397	217843
2002	0	5112	5112	-587	-29	-733	-3834	0	29334	-71	29262	5184	188581	217843
2003	0	4928	4928	-487	-24	-608	-3696	0	24334	113	24447	4816	193396	217843
2004	0	4727	4727	-394	-20	-493	-3545	0	19720	275	19994	4452	197849	217843
2005	0	4445	4445	-311	-16	-389	-3334	0	15549	396	15945	4049	201898	217843
2006	0	4096	4096	-237	-12	-296	-3072	0	11850	479	12329	3617	205515	217843
2007	0	3729	3729	-172	-9	-215	-2797	0	8599	537	9136	3192	208707	217843
2008	0	3240	3240	-118	-6	-147	-2430	0	5896	539	6435	2701	211408	217843
2009	0	2583	2583	-77	-4	-96	-1937	0	3852	469	4321	2114	213522	217843
2010	0	4321	4321	0	0	0	-4321	0	0	0	0	4321	217843	217843

All quantities in metric tonnes

End of calculation WB2R2025

WC2R2025 - calculated using version 7.0 of the computer program BANK

World - Halon 1211 - Phase-Out Year is 1995 - Equip Life 20 yrs - From 1995 Recovered Halon to be Recycled

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The calculation terminates when the remaining bank decreases to 5% of maximum attained size.

C1 Year	C2 Prod	C3 Recycle	C4 Supply	C5 Fires	C6 Tst/Trng	C7 Other	C8 UnRec	C9 Destruct	C10 Strt Bnk	C11 Bnk Chng	C12 End Bnk	C13 Yr Emis	C14 Cum Emis	C15 Cum Prod
1963	50	0	50	0	-5	0	0	0	0	45	45	5	5	50
1964	100	2	102	-1	-4	-2	-2	0	43	93	135	10	15	150
1965	200	7	207	-3	-13	-6	-7	0	129	178	307	29	43	350
1966	300	16	316	-6	-29	-15	-16	0	291	251	541	65	109	650
1967	500	28	528	-10	-51	-26	-28	0	513	413	926	116	224	1150
1968	700	49	749	-18	-88	-44	-49	0	877	551	1428	198	422	1850
1969	900	77	977	-27	-135	-68	-77	0	1351	670	2022	306	728	2750
1970	1260	110	1370	-38	-191	-96	-110	0	1912	935	2847	435	1163	4010
1971	1700	157	1857	-54	-269	-134	-157	0	2690	1243	3933	614	1777	5710
1972	2200	219	2419	-74	-371	-186	-219	0	3714	1569	5282	850	2628	7910
1973	2750	297	3047	-100	-499	-249	-297	0	4985	1903	6888	1145	3772	10660
1974	3300	392	3692	-130	-650	-325	-392	0	6495	2196	8691	1497	5269	13960
1975	3800	502	4302	-164	-819	-409	-502	0	8189	2408	10597	1894	7163	17760
1976	4356	623	4979	-199	-997	-499	-623	0	9974	2660	12634	2318	9482	22116
1977	5000	756	5756	-238	-1188	-594	-756	0	11879	2981	14859	2775	12257	27116
1978	5650	905	6555	-279	-1395	-698	-905	0	13955	3278	17232	3277	15534	32766
1979	6280	1069	7349	-323	-1616	-808	-1069	0	16164	3532	19696	3816	19350	39046
1980	6910	1245	8155	-369	-1845	-923	-1245	0	18451	3773	22224	4382	23732	45956
1981	6689	1434	8123	-416	-2079	-1040	-1434	0	20790	3155	23945	4968	28700	52645
1982	7485	1592	9077	-447	-2235	-1118	-1592	0	22353	3685	26038	5392	34092	60130
1983	8259	1776	10035	-485	-2426	-1213	-1776	0	24262	4134	28397	5900	39992	68389
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1986	13731	2632	16363	-696	-3481	-1741	-2632	0	34811	7813	42624	8550	62395	105019
1987	17058	3010	20068	-792	-3961	-1981	-3010	0	39614	10324	49938	9744	72139	122077
1988	20181	3505	23686	-929	-3482	-2206	-3396	0	46433	13674	60106	10012	82152	142258
1989	16182	4161	20343	-1119	-2797	-2518	-3901	0	55945	10008	65953	10335	92487	158440
1990	14852	4628	19480	-1226	-1533	-2453	-4194	0	61325	10073	71398	9407	101894	173292
1991	11882	5085	16967	-1326	-1326	-2321	-4450	0	66313	7544	73857	9423	111317	185174
1992	8912	5400	14312	-1369	-1027	-2054	-4557	0	68457	5306	73763	9006	120323	194086
1993	5942	5587	11529	-1364	-68	-1704	-4540	0	68176	3854	72029	7676	127999	200028

WC2R2025 - calculated using version 7.0 of the computer program BANK

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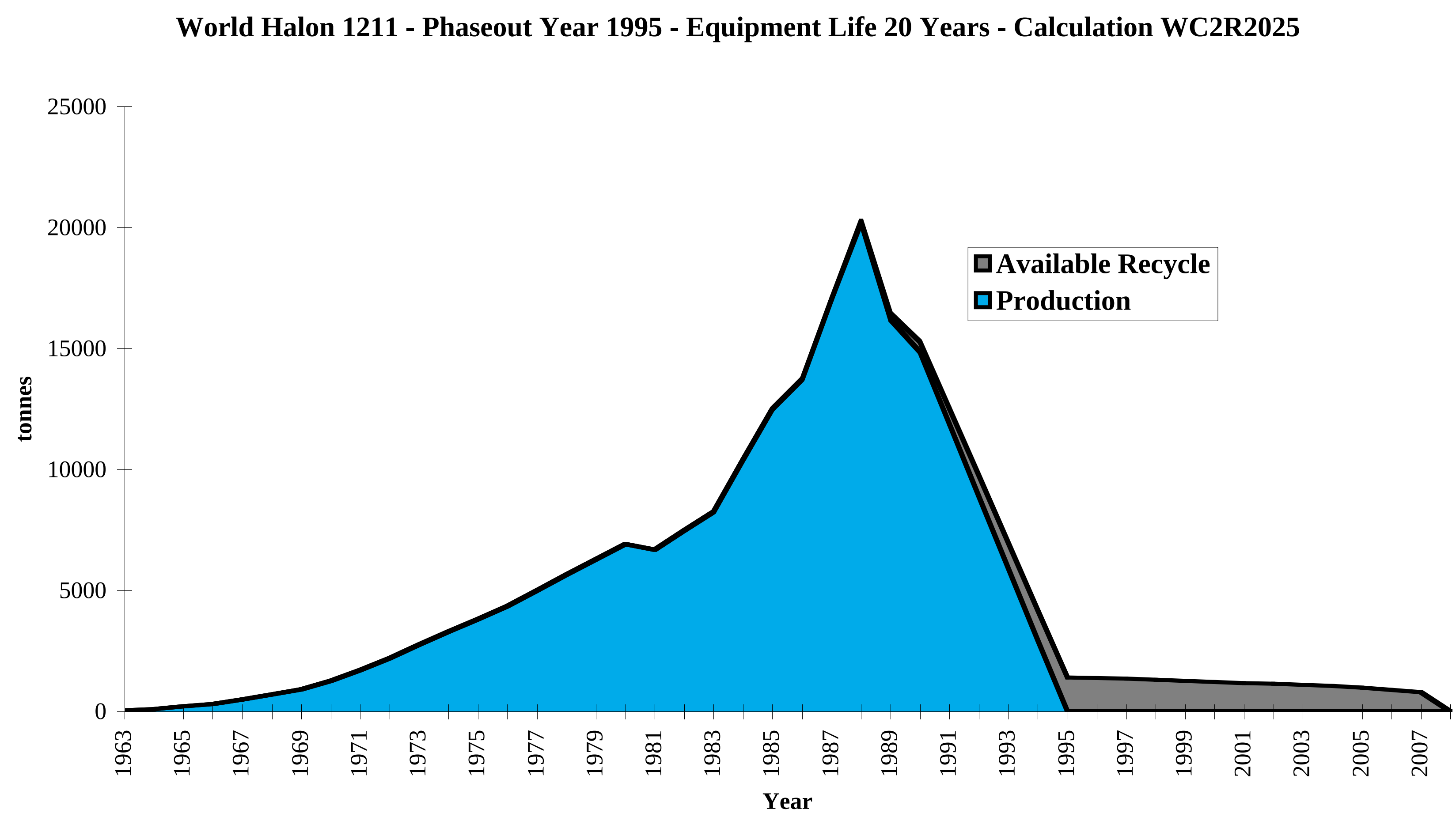
C1 Year	C2 Prod	C3 Recycle	C4 Supply	C5 Fires	C6 Tst/Trng	C7 Other	C8 UnRec	C9 Destruct	C10 Strt Bnk	C11 Bnk Chng	C12 End Bnk	C13 Yr Emis	C14 Cum Emis	C15 Cum Prod
1994	2972	5685	8657	-1327	-66	-1659	-4441	0	66344	1164	67508	7493	135492	203000
1995	0	5633	5633	-1237	-62	-1547	-4225	0	61875	-1438	60437	7071	142563	203000
1996	0	5513	5513	-1098	-55	-1373	-4135	0	54924	-1148	53776	6661	149224	203000
1997	0	5380	5380	-968	-48	-1210	-4035	0	48396	-881	47515	6261	155485	203000
1998	0	5231	5231	-846	-42	-1057	-3923	0	42284	-637	41647	5868	161353	203000
1999	0	5067	5067	-732	-37	-914	-3800	0	36580	-416	36164	5483	166836	203000
2000	0	4890	4890	-625	-31	-782	-3668	0	31274	-216	31058	5106	171942	203000
2001	0	4702	4702	-527	-26	-659	-3526	0	26356	-37	26319	4739	176681	203000
2002	0	4544	4544	-436	-22	-544	-3408	0	21775	134	21910	4410	181091	203000
2003	0	4366	4366	-351	-18	-439	-3275	0	17543	285	17828	4082	185172	203000
2004	0	4174	4174	-273	-14	-341	-3130	0	13654	415	14069	3758	188931	203000
2005	0	3899	3899	-203	-10	-254	-2924	0	10171	507	10677	3392	192323	203000
2006	0	3555	3555	-142	-7	-178	-2666	0	7122	561	7684	2994	195317	203000
2007	0	3192	3192	-90	-4	-112	-2394	0	4491	592	5083	2601	197917	203000
2008	0	5083	5083	0	0	0	-5083	0	0	0	0	5083	203000	203000

All quantities in metric tonnes **End of calculation WC2R2025**


World Halon 1211 - Phaseout Year 1995 - Equipment Life 20 Years - Calculation WC2R2025
tonnes
25000
20000
15000
10000
5000
0
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
Year
Available Recycle
Production

Appendix D

Methodology for Selecting Alternative Fire Protection Measures Fixed Fire Protection Systems

Halon 1301 Total Flooding Systems

The method developed to compare uses and alternative systems to halon 1301 total is comprised of several distinct parts:

1. An evaluation of the attributes of halon 1301 systems and alternative in general. This section is independent of the particular application being evaluated.

2. The importance of these system attributes to a particular application is then valuated by using weighting factors which determine how important a particular attribute (e.g., occupant risk, toxicity) is in a particular application. Note that a given attribute (e.g., ability to extinguish flammable liquids) may be unimportant in some applications (e.g., computer rooms) and very important in others (flammable liquid stores).

Aspects of the agent/system are assigned a numeric score. Higher values imply higher positive features. For example, a zero ODP clean agent system has a higher score for ability to permeate than automatic sprinklers. Figure D - Base Case gives base values in comparing selected aspects of agent/systems or combinations of systems. Note that these scores are independent of end use application and a higher score implies a positive feature.

The particular application then weights the importance of each parameter. A flammable liquid pump room would have a lower weighting factor for ability to permeate than a typical computer application. By multiplying the agent/system score by the application weighting factor, the relative merits of a particular system/agent in a particular application can be compared.

The method should be viewed as a guide. The important features of alternative fire protection systems are described, but the weighting of the relative importance of these features is not rigourously derived. It is the result of the consensus opinion of the committee responsible for this report. The method is developed primarily as a means of structuring the thought process relative to the evaluation of the use of alternative fire protection systems for a particular use and more importantly, the evaluation of alternatives. It is fully expected that any application of point values may vary between countries.

The alternative fire protection choices offered may not provide the same level of fire protection offered by the use of the present halons. In some circumstances greater fire loss and risk to people and property may result from the use of the alternatives outlined. However, concerns regarding environmental risk associated with the continued use of halons necessitate the serious evaluation of all other fire protection options.

Definition of Agent Selection Parameters

Each fire suppression agent has specific properties which may be advantageous in a particular application. In addition, the system which discharges and applies the agent will have associated advantages and disadvantages. Each parameter is discussed in detail below. Potential environmental damage associated with certain fire protection alternatives is not integrated into the matrix, such as water runoff. This should be evaluated on a case specific basis.

Low Space or Weight (Maximum Value 5)

An agent or system is scored against the weight based effectiveness of the agent and system. The weight and space based score is compared against a zero ODP, clean agent which is taken as the best possible score.

Damage Limiting Capability (Maximum Value 10)

This parameter refers to the relative level of direct and secondary fire damage expected for a similar fire using a particular fire suppression system. It is primarily a measure of response time of the system. Systems actuated by early warning detectors have higher scores than those actuated by fusible links. Presumably manual intervention would be scored lower still. Quick Response Sprinklers are scored higher than standard response sprinklers.

This parameter also refers to damage that is caused by the agent and system to the equipment protected and to the expected downtime resulting from the re-conditioning of equipment not directly damaged by fire.

Ability to Permeate (Maximum Value 5)

This property refers to the ability of the agent to be effective in obstructed geometry situations. It implies that the agent need not be directly applied to the burning surfaces. This property is especially important in subfloor areas, in electronics cabinets, etc. All gaseous total flooding agents will have a high score for this property.

Occupant Risk (Maximum Value 10) (Toxicity)

The toxicity of undecomposed agent in the concentrations necessary for extinction is scored. Water of course has the highest score, CO_2 the lowest.

The need for a low toxicity fire suppression system is evaluated for each proposed application.

Flammable Liquid Extinguishing Capability (Maximum Value 10)

This parameter refers to the ability of the agent and application method to extinguish liquid fuel fires in two dimensions and liquid and gas phase fuel fires in three dimensions. Examples include liquid spray fires and gas jets. Total flooding gaseous agents are scored highest in this parameter.

Efficacy (Maximum Value 10)

This parameter refers to the effectiveness of a particular system in a given application and its reliability on that application. It is taken both as a measure of the effectiveness of the system in a particular application as well as how reliable it will be in that particular application.

Of critical importance in any fire suppression system is reliability. This variable refers to both hardware and agent reliability. Automatic sprinklers are assumed to have the highest reliability score at 10. Typical total flooding applications are scored at 8.

Use on Energized Electrical Equipment (Maximum Value 5)

Since gaseous agents are electrically non-conductive, they can be applied to energized equipment without causing shorts and damage and without safety risk to nearby occupants. Hence gaseous agents are scored high in this regard. Automatic sprinklers of course are scored lower. This agent property is also related to minimum secondary damage. The importance of this feature can be minimized by isolating power upon detector actuation, prior to release of conductive agents.

Installed Cost (Maximum Value 5)

This parameter refers to the installation and maintenance cost for the system being evaluated. It should be considered in the evaluation of alternatives, especially since for some alternatives there is at least an order of magnitude in assumed cost difference over a total flooding Zero ODP agent system. It should be noted that variability of cost is a function of the specific application being evaluated.

Application Specific Weighting Factors

The next section of the evaluation requires that the relative importance of the desirable agent/system characteristics be weighted for specific applications.

It is an implicit assumption that all agent/system features are not of equal importance in any given application. Obvious examples include low weight as an unimportant parameter in typical computer rooms. Toxicity should be weighted lightly in unoccupied flammable liquid risks. Each parameter is weighted separately for each application or use. The weighting factors range from 0 to the maximum value of the factor, with 0 being unimportant and the maximum being very important. Examples used in this report include:

Base Case Values	D-Base Case
General Purpose Computer Room	D-1
Power Plant Control Room	D-2
Communications Facility	D-3
Military Electronics Facility	D-4
Military Shipboard Machinery Space	D-5
Flammable Liquid Pump Room	D-6
Cultural Heritage Collection Room	D-7

These examples are meant to be just that; the need for specific agent/system features will be driven by the specific requirements of a specific application. These examples set weighting factors intentionally high to demonstrate differences between agent/system parameters in the total scores.

Alternative Fire Suppression Methods

Monitored Early Warning Detection System

A monitored early warning detection system has an external connection to a constantly manned facility or fire department dispatch station. This is intended to result in a rapid fire department response and thus provide extinguishment at an earlier stage in fire development than would be expected otherwise.

Automatic Sprinklers + Early Warning Detection

Automatic sprinklers with early warning detection is a system based on a network of piping installed throughout a protected structure and incorporating heat sensitive sprinkler heads (nozzles) spaced at regular intervals. As proposed, an early warning system, connected to a constantly manned facility would also be provided.

Fast Response Sprinklers + Early Warning Detection

This alternative attempts to limit the amount of direct damage caused by the relatively slow actuation of the sprinkler head by decreasing the lag time of the fusible link. It is recognized that short of using detector actuated heads the response characteristics will never equal products of combustion detectors. The impact of this response delay on direct fire damage is a strong function of the growth rate of the fire and the exposed equipment. For very slow growth fires there may not be a significant difference between standard and quick response sprinklers. In addition an early warning fire detection system is proposed. It may be desirable to isolate the HVAC on the actuation of a smoke detector to minimize the delay time of the sprinkler actuation.

Pre-Action Sprinkler System

In this case, a separate detection system is provided. The sprinkler system is normally dry with water to the system controlled by a valve. Upon detection of a fire, the valve opens, admitting water to the system. The remainder of operation is similar to that of a conventional sprinkler system.

In Cabinet and Sub-Floor Carbon Dioxide

This refers to an hybrid system involving a total flooding carbon dioxide system for underfloor spaces and independently actuated, hazard specific carbon dioxide systems for individual equipment enclosures. A separate early response detection system is used to actuate the carbon dioxide system(s).

Fast Response Sprinklers + In Cabinet and Sub-Floor Carbon Dioxide

This approach is a hybrid.

Total Flood Carbon Dioxide

A total flood carbon dioxide system is designed to provide an extinguishing concentration of carbon dioxide throughout the complete enclosure. An early warning fire detection system would be provided to cause actuation of the carbon dioxide system. When designing a carbon dioxide system care must be exercised to avoid damage that could result from the low temperatures usually present in the immediate vicinity of the nozzles during discharge.

Total Flood Dry Powder (Chemical)

This type of system has the capability of extinguishing three dimensional running fuel fires and pressurized fuel fires, however, upon completion of discharge there is no sustained capability to extinguish or prevent re-ignition. This type of system utilizes a separate detection system to cause actuation of the dry powder system.

Deluge Water Spray

A sprinkler system with open heads or controllable heads. Actuation is caused by a separate detection system.

Closed Head Aqueous Film Forming Foam Sprinkler System

A system similar to the deluge water spray system but Aqueous Film Forming Foam (AFFF) concentrate is added to the water supply. This type of system is capable, within limits, of preventing ignition or re-ignition of pooled flammable liquid by forming a residual vapour suppressing film on the surface of the flammable liquid. This type of system can be actuated automatically in response to fire by a separate fire detection system.

Total Flood Carbon Dioxide System + Low Expansion Foam

This is a hybrid.

High Expansion Foam System

A high expansion foam system is designed to generate 500:1 - 1000:1, expansion ratio foams having three dimensional fire fighting capabilities. It is suitable for a wide range of fires involving flammable liquids and ordinary combustibles. This system can be actuated by a separate detection system.

Total Flood, Zero ODP Clean Agent

This is an example of the scores that could be achieved by a replacement for halon 1301. The scores are predicated on the replacement agent having an ozone depletion potential of zero. Cost is assumed as high relative to other choices.

Total Flood, Zero ODP Clean Agent + Fast Response Sprinklers

This is a hybrid.

Limitations

This procedure has some obvious limitations; these include:

- Any generic procedure is limited in that unique requirements of a particular proposed installation are ignored. It is by nature a method which loses the detail which may be critical to the decision making process. It is possible and we have attempted to outline the important parameters in a logical way.

- The efficacy of any particular alternative is driven by the engineering details of both the proposed alternative and the facility which it is proposed to protect. This makes such alternatives very cost variable.

- The sensitivity of electronic components to heat, smoke and water is highly variable. Further technical resolution would be helpful in determining the real importance of direct and secondary damage with respect to the use of water as a suppression agent in electronic facilities.

- The logic and structure of the proposed approach must be field verified. If the logic and structure of the method hold, the field verification can be used to fine tune the scoring and weighting values.

- The ability of detection systems coupled with manual fire suppression activities as an alternative to fixed fire protection systems needs to be further addressed. Given adequate training and manpower the issue becomes one of response time and reliability.

- Direct substitution of halon 1301 with typical standard fire protection options without loss of some of the positive aspects of halon 1301 is difficult. Some additional engineering and creativity in design will be required. The results thus far indicate that some of the positive aspects of halon 1301 can be preserved.

- The requirement for "other fire safety features" as prerequisites for the installation of a halon system needs to be developed.

- Substitution of fixed fire protection systems with other hazard and risk reduction concepts needs to be developed.

- The relative scores and weighting factors given in this report are preliminary estimates based on judgement. More detailed and objective analysis should be conducted in addition to the field trials to provide a more rigourous technical basis for the evaluation system.

- Additional alternative technologies should also be incorporated into this analysis as appropriate.

- The risk/need assessment procedure, if found useful in evaluating the need for alternative approaches, should be further developed.

Use Evaluation

The evaluation of the appropriateness of a particular application is summarized. The total score is an indication of how that particular agent/system combination meets the requirements for that particular application.

The example given in Figure D-1 is a typical commercial data processing facility with no real time requirements. The use evaluation is performed for a range of possible agent and system combinations. Each cell of the matrix shows the multiplication of the agent score for that property and the weighting factor placed on that property for a typical computer room facility. The total score is then the summation of each weighted score and is given for a range of system/agent combinations. A higher score indicates a better application.

D - Base Case	Low Space Weight (max 5)	Damage Limiting (max 10)	Ability To Permeate (max 5)	Occupant Risk (max 10)	Flam Liq Ext Cap (max 10)	System Efficacy (max 10)	Energized Elec Equip (max 5)	Installed Cost (max 5)	**Total**
Hazard Specific Weighting Factor	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	
Monitored Detection	0	5	0	10	0	5	1	5	**26**
Automatic Sprinklers	0	5	0	10	0	10	2	4	**31**
Fast Response Sprinklers (FRS)	0	8	0	10	0	10	3	4	**35**
Detection + Pre-Action Sprinklers	0	5	0	10	0	8	3	3	**29**
Detection + In Cabinet & Sfloor CO2 (C&SCO2)	5	8	5	8	0	3	5	4	**38**
Detection + FRS + C&SCO2	0	9	5	8	0	10	2	3	**37**
Detection + Zero ODP Clean Agent	5	10	5	9	10	8	5	2	**54**
Detection + Total Flood CO2	4	9	5	2	8	8	5	1	**42**
Detection + Total Flood Dry Powder	4	4	1	7	7	7	4	1	**35**
Detection + Deluge Water Spray	0	3	0	10	1	9	1	3	**27**
Detection + Low Expansion Foam	1	3	0	9	7	7	1	3	**31**
Detection + CO2 + Low Expansion Foam	0	3	5	2	10	10	1	1	**32**
Detection + High Expansion Foam	2	6	0	2	5	7	3	3	**28**

D-1: Fixed Fire Protection Systems - General Purpose Computer Room (Manned at all times)

	Low Space Weight (max 5)	Damage Limiting (max 10)	Ability To Permeate (max 5)	Occupant Risk (max 10)	Flam Liq Ext Cap (max 10)	System Efficacy (max 10)	Energized Elec Equip (max 5)	Installed Cost (max 5)	**Total**
Hazard Specific Weighting Factor	**0**	**10**	**5**	**10**	**0**	**10**	**0**	**5**	
Monitored Detection	0	50	0	100	0	50	0	25	**225**
Automatic Sprinklers	0	50	0	100	0	100	0	20	**270**
Fast Response Sprinklers (FRS)	0	80	0	100	0	100	0	20	**300**
Detection + Pre-Action Sprinklers	0	50	0	100	0	80	0	15	**245**
Detection + In Cabinet & Sfloor CO2 (C&SCO2)	0	80	25	80	0	30	0	20	**235**
Detection + FRS + C&SCO2	0	90	25	80	0	100	0	15	**310**
Detection + Zero ODP Clean Agent	0	100	25	90	0	80	0	10	**305**
Detection + Total Flood CO2	0	90	25	20	0	80	0	5	**220**

D-2: Fixed Fire Protection Systems - Power Plant Control Room (Manned at all times)

	Low Space Weight (max 5)	Damage Limiting (max 10)	Ability To Permeate (max 5)	Occupant Risk (max 10)	Flam Liq Ext Cap (max 10)	System Efficacy (max 10)	Energized Elec Equip (max 5)	Installed Cost (max 5)	**Total**
Hazard Specific Weighting Factor	**0**	**10**	**5**	**10**	**0**	**10**	**5**	**0**	
Monitored Detection	0	50	0	100	0	50	5	0	**205**
Automatic Sprinklers	0	50	0	100	0	100	10	0	**260**
Fast Response Sprinklers (FRS)	0	80	0	100	0	100	15	0	**295**
Detection + Pre-Action Sprinklers	0	50	0	100	0	80	15	0	**245**
Detection + Zero ODP Clean Agent	0	100	25	90	0	80	25	0	**320**

D-3: Fixed Fire Protection Systems - Communications Facility (Manned 50% of the time)

	Low Space Weight (max 5)	Damage Limiting (max 10)	Ability To Permeate (max 5)	Occupant Risk (max 10)	Flam Liq Ext Cap (max 10)	System Efficacy (max 10)	Energized Elec Equip (max 5)	Installed Cost (max 5)	**Total**
Hazard Specific Weighting Factor	**0**	**10**	**5**	**5**	**0**	**10**	**5**	**0**	
Monitored Detection	0	50	0	50	0	50	5	0	**155**
Automatic Sprinklers	0	50	0	50	0	100	10	0	**210**
Fast Response Sprinklers (FRS)	0	80	0	50	0	100	15	0	**245**
Detection + Pre-Action Sprinklers	0	50	0	50	0	80	15	0	**195**
Detection + Zero ODP Clean Agent	0	100	25	45	0	80	25	0	**275**
Detection + Total Flood CO2	0	90	25	10	0	80	25	0	**230**

D4: Fixed Fire Protection Systems - Military Electronics Facility (Manned at all times)

	Low Space Weight (max 5)	Damage Limiting (max 10)	Ability To Permeate (max 5)	Occupant Risk (max 10)	Flam Liq Ext Cap (max 10)	System Efficacy (max 10)	Energized Elec Equip (max 5)	Installed Cost (max 5)	**Total**
Hazard Specific Weighting Factor	**0**	**10**	**5**	**10**	**0**	**10**	**5**	**0**	
Monitored Detection	0	50	0	100	0	50	5	0	**205**
Automatic Sprinklers	0	50	0	100	0	100	10	0	**260**
Fast Response Sprinklers (FRS)	0	80	0	100	0	100	15	0	**295**
Detection + Pre-Action Sprinklers	0	50	0	100	0	80	15	0	**245**
Detection + In Cabinet & Sfloor CO2 (C&SCO2)	0	80	25	80	0	30	25	0	**240**
Detection + FRS + C&SCO2	0	90	25	80	0	100	10	0	**305**
Detection + Zero ODP Clean Agent	0	100	25	90	0	80	25	0	**320**
Detection + Total Flood CO2	0	90	25	20	0	80	25	0	**240**

D5: Fixed Fire Protection Systems - Military Shipboard Machinery Space (Manned at all times)

	Low Space Weight (max 5)	Damage Limiting (max 10)	Ability To Permeate (max 5)	Occupant Risk (max 10)	Flam Liq Ext Cap (max 10)	System Efficacy (max 10)	Energized Elec Equip (max 5)	Installed Cost (max 5)	**Total**
Hazard Specific Weighting Factor	**0**	**10**	**0**	**5**	**10**	**10**	**0**	**0**	
Monitored Detection	0	50	0	50	0	50	0	0	**150**
Automatic Sprinklers	0	50	0	50	0	100	0	0	**200**
Fast Response Sprinklers (FRS)	0	80	0	50	0	100	0	0	**230**
Detection + Pre-Action Sprinklers	0	50	0	50	0	80	0	0	**180**
Detection + Zero ODP Clean Agent	0	100	0	45	100	80	0	0	**325**
Detection + Total Flood CO2	0	90	0	10	80	80	0	0	**260**
Detection + Total Flood Dry Powder	0	40	0	35	70	70	0	0	**215**
Detection + Deluge Water Spray	0	30	0	50	10	90	0	0	**180**
Detection + Low Expansion Foam	0	30	0	45	70	70	0	0	**215**
Detection + C02 + Low Expansion Foam	0	30	0	10	100	100	0	0	**240**
Detection + High Expansion Foam	0	60	0	10	50	70	0	0	**190**

D6: Fixed Fire Protection Systems - Flammable Liquid Pump Room (Unmanned)

	Low Space Weight (max 5)	Damage Limiting (max 10)	Ability To Permeate (max 5)	Occupant Risk (max 10)	Flam Liq Ext Cap (max 10)	System Efficacy (max 10)	Energized Elec Equip (max 5)	Installed Cost (max 5)	**Total**
Hazard Specific Weighting Factor	**0**	**10**	**0**	**0**	**10**	**10**	**0**	**5**	
Monitored Detection	0	50	0	0	0	50	0	25	**125**
Automatic Sprinklers	0	50	0	0	0	100	0	20	**170**
Fast Response Sprinklers (FRS)	0	80	0	0	0	100	0	20	**200**
Detection + Pre-Action Sprinklers	0	50	0	0	0	80	0	15	**145**
Detection + Zero ODP Clean Agent	0	100	0	0	100	80	0	10	**290**
Detection + Total Flood CO2	0	90	0	0	80	80	0	5	**255**
Detection + Total Flood Dry Powder	0	40	0	0	70	70	0	5	**185**
Detection + Deluge Water Spray	0	30	0	0	10	90	0	15	**145**
Detection + Low Expansion Foam	0	30	0	0	70	70	0	15	**185**
Detection + C02 + Low Expansion Foam	0	30	0	0	100	100	0	5	**235**
Detection + High Expansion Foam	0	60	0	0	50	70	0	15	**195**

D7: Fixed Fire Protection Systems - Cultural Heritage Collection Room (Occupied)

	Low Space Weight (max 5)	Damage Limiting (max 10)	Ability To Permeate (max 5)	Occupant Risk (max 10)	Flam Liq Ext Cap (max 10)	System Efficacy (max 10)	Energized Elec Equip (max 5)	Installed Cost (max 5)	**Total**
Hazard Specific Weighting Factor	**0**	**10**	**5**	**10**	**0**	**10**	**0**	**5**	
Monitored Detection	0	50	0	100	0	50	0	25	**225**
Automatic Sprinklers	0	50	0	100	0	100	0	20	**270**
Fast Response Sprinklers (FRS)	0	80	0	100	0	100	0	20	**300**
Detection + Pre-Action Sprinklers	0	50	0	100	0	80	0	15	**245**
Detection + Zero ODP Clean Agent	0	100	25	90	0	80	0	10	**305**
Detection + Total Flood CO2	0	90	25	20	0	80	0	5	**220**

Appendix E

Methodology for Selecting Alternative Fire Protection Measures Manual Application Fire Equipment

Halon 1211 Manual Use

This section outlines a method for comparing alternatives to halon 1211 manual application fire equipment. Manually applied, alternative agents are evaluated relative to their ability to meet certain objectives. These technical objectives include effectiveness on Class A and B fires, electrical non-conductivity, ability to permeate, stream range, high effectiveness to weight ratio, minimal secondary damage and cost. The theoretical scores that could be achieved by a zero ODP, clean agent are based on similar fire fighting and toxicity characteristics to halon 1211.

Each agent is scored from 0 to 5, 0 being the lowest score, 5 the highest, relative to the agent's ability to meet these objectives. The baseline scoring which does not include weighting for particular applications is given in Figure E-Base Case. The weighting for particular applications is discussed later in this section.

The method should be viewed as a guide. The important features of alternative, manually applied fire protection equipment choices are described, but the weighting of the relative importance of these features is not rigourously derived. It is the result of the consensus opinion of the committee responsible for this report. The method is developed primarily as a means of structuring the thought process relative to the evaluation of the use of alternative fire protection systems for a particular use and more importantly, the evaluation of alternatives. It is fully expected that any application of point values may vary between countries.

The alternative fire protection choices offered may not provide the same level of fire protection offered by the use of the present halons. In some circumstances greater fire loss and risk to people and property may result from the use of the alternatives outlined. However, concerns regarding environmental risk associated with the continued use of halons necessitate the serious evaluation of all other fire protection options.

The parameters evaluated for each agent are discussed below.

Effectiveness on Ordinary Combustibles

This parameter scores the ability of the agent to extinguish fires in ordinary solid polymer combustibles, including cellulosics. It includes consideration of deep seated burning. The lowest score is given to carbon dioxide, the highest to water based and multipurpose dry powder extinguishers as seen in Figure E-Base Case.

Effectiveness on Flammable/Combustible Liquid Fires

The agents are scored on the ability to extinguish flames above liquid fuels. No consideration is given to preventing reignition. The ability to extinguish three dimensional liquid fires (sprays or fuels cascades) is evaluated. The most effective agent is multipurpose dry powder with a score of 5, Zero ODP clean agent is next highest at 3, with straight stream water being scored at 0.

Electrical Conductivity

The electrical conductivity of the agent is scored in this category. The highest scores are given to Zero ODP clean agent and CO_2. Dry powder is scored at 3, water spray at 1 and all other agents at 0.

Ability to Permeate

This parameter reflects the ability of the agent as typically discharged to extinguish fires in locations where direct application to the fuel surface or flame reaction zone is not possible, for example, inside electronics equipment cabinet. As expected, the gaseous agents are scored highest in this category.

Range

This parameter reflects the ability of the agent to maintain a coherent effective stream over a modest distance. The highest score is given to straight stream water extinguishers, the lowest to carbon dioxide. Zero ODP clean agent is ranked just beneath water.

Effectiveness to Weight Ratio

This parameter considers the relative fire suppression capability across all fuels per unit weight of agent. In this category, multipurpose dry powder is rated highest.

Secondary Damage

This category refers to the "clean agent" aspects of the agents, i.e. secondary damage caused by the suppressant agent itself. Here carbon dioxide is rated highest, the lowest score is given to multipurpose dry powder.

Cost

This parameter reflects the average cost of typical portable fire extinguishers. Carbon dioxide portables are expensive due to the shell costs, AFFF, and water based portables are scored just slightly lower than multipurpose dry powder. The cost of a Zero ODP agent fire extinguisher is assumed as relative to carbon dioxide.

Use Evaluation

Each parameter evaluated (e.g., electrical conductivity, effectiveness on Class A fires) is weighted as to its importance for each application. Example use evaluations provided include: residential, telephone exchange, and a commercial computer room.

The weighting and final score is performed in a similar manner to Fixed Fire Protection Systems, as previously described.

E - Base Case	Ordinary Combust (Max 5)	Flammable Liquids (Max 5)	Electrically Non-Cond. (Max 5)	Ability To Permeate (Max 5)	Stream Range (Max 5)	Effectiveness \ Weight (Max 5)	Secondary Damage (Max 5)	Cost (Max 3)	**Total Score**
Hazard Specific Weighting Factor	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	
CO2	1	2	5	5	1	1	5	0	**20**
Zero ODP Clean Agent	4	3	5	5	4	5	4	0	**30**
Multipurpose Dry Powder (Chemical)	5	5	3	1	4	5	0	3	**26**
AFFF	5	2	0	0	4	3	1	2	**17**
Water Stream	5	0	0	0	5	1	2	2	**15**
Water Spray	5	1	1	0	3	2	2	2	**16**
Water Spray+C02	5	2	1	5	3	0	2	0	**18**

E1: Manually Applied Fire Equipment - Passenger Aircraft Cabin

	Ordinary Combust (Max 5)	Flammable Liquids (Max 5)	Electrically Non-Cond. (Max 5)	Ability To Permeate (Max 5)	Stream Range (Max 5)	Effectiveness \ Weight (Max 5)	Secondary Damage (Max 5)	Cost (Max 3)	**Total Score**
Hazard Specific Weighting Factor	**5**	**0**	**5**	**5**	**5**	**5**	**5**	**0**	
CO2	5	0	25	25	5	5	25	0	**90**
Zero ODP Clean Agent	20	0	25	25	20	25	20	0	**135**
Multipurpose Dry Powder (Chemical)	25	0	15	5	20	25	0	0	**90**
AFFF	25	0	0	0	20	15	5	0	**65**
Water Stream	25	0	0	0	25	5	10	0	**65**
Water Spray	25	0	5	0	15	10	10	0	**65**
Water Spray+C02	25	0	5	25	15	0	10	0	**80**

E2: Manually Applied Fire Equipment - Communications Facility

	Ordinary Combust (Max 5)	Flammable Liquids (Max 5)	Electrically Non-Cond. (Max 5)	Ability To Permeate (Max 5)	Stream Range (Max 5)	Effectiveness \ Weight (Max 5)	Secondary Damage (Max 5)	Cost (Max 3)	**Total Score**
Hazard Specific Weighting Factor	**5**	**0**	**5**	**5**	**2**	**0**	**5**	**1**	
CO2	5	0	25	25	2	0	25	0	**82**
Zero ODP Clean Agent	20	0	25	25	8	0	20	0	**98**
Multipurpose Dry Powder (Chemical)	25	0	15	5	8	0	0	3	**56**
AFFF	25	0	0	0	8	0	5	2	**40**
Water Stream	25	0	0	0	10	0	10	2	**47**
Water Spray	25	0	5	0	6	0	10	2	**48**
Water Spray+C02	25	0	5	25	6	0	10	0	**71**

E3: Manually Applied Fire Equipment - General Purpose Computer Room

	Ordinary Combust (Max 5)	Flammable Liquids (Max 5)	Electrically Non-Cond. (Max 5)	Ability To Permeate (Max 5)	Stream Range (Max 5)	Effectiveness \ Weight (Max 5)	Secondary Damage (Max 5)	Cost (Max 3)	**Total Score**
Hazard Specific Weighting Factor	**5**	**0**	**5**	**5**	**2**	**1**	**5**	**3**	
CO2	5	0	25	25	2	1	25	0	**83**
Zero ODP Clean Agent	20	0	25	25	8	5	20	0	**103**
Multipurpose Dry Powder (Chemical)	25	0	15	5	8	5	0	9	**67**
AFFF	25	0	0	0	8	3	5	6	**47**
Water Stream	25	0	0	0	10	1	10	6	**52**
Water Spray	25	0	5	0	6	2	10	6	**54**
Water Spray+C02	25	0	5	25	6	0	10	0	**71**

E4: Manually Applied Fire Equipment - Cultural Heritage Collection Room

	Ordinary Combust (Max 5)	Flammable Liquids (Max 5)	Electrically Non-Cond. (Max 5)	Ability To Permeate (Max 5)	Stream Range (Max 5)	Effectiveness \ Weight (Max 5)	Secondary Damage (Max 5)	Cost (Max 3)	**Total Score**
Hazard Specific Weighting Factor	**5**	**0**	**0**	**5**	**2**	**1**	**5**	**3**	
CO2	5	0	0	25	2	1	25	0	**58**
Zero ODP Clean Agent	20	0	0	25	8	5	20	0	**78**
Multipurpose Dry Powder (Chemical)	25	0	0	5	8	5	0	9	**52**
AFFF	25	0	0	0	8	3	5	6	**47**
Water Stream	25	0	0	0	10	1	10	6	**52**
Water Spray	25	0	0	0	6	2	10	6	**49**
Water Spray+C02	25	0	0	25	6	0	10	0	**66**

E5: Manually Applied Fire Equipment - Flammable Liquid Pump Room

	Ordinary Combust (Max 5)	Flammable Liquids (Max 5)	Electrically Non-Cond. (Max 5)	Ability To Permeate (Max 5)	Stream Range (Max 5)	Effectiveness \ Weight (Max 5)	Secondary Damage (Max 5)	Cost (Max 3)	**Total Score**
Hazard Specific Weighting Factor	**5**	**5**	**0**	**0**	**5**	**0**	**0**	**3**	
CO2	5	10	0	0	5	0	0	0	**20**
Zero ODP Clean Agent	20	15	0	0	20	0	0	0	**55**
Multipurpose Dry Powder (Chemical)	25	25	0	0	20	0	0	9	**79**
AFFF	25	10	0	0	20	0	0	6	**61**
Water Stream	25	0	0	0	25	0	0	6	**56**
Water Spray	25	5	0	0	15	0	0	6	**51**
Water Spray+C02	25	10	0	0	15	0	0	0	**50**

E6: Manually Applied Fire Equipment - Military Electronics Facility

	Ordinary Combust (Max 5)	Flammable Liquids (Max 5)	Electrically Non-Cond. (Max 5)	Ability To Permeate (Max 5)	Stream Range (Max 5)	Effectiveness \ Weight (Max 5)	Secondary Damage (Max 5)	Cost (Max 3)	**Total Score**
Hazard Specific Weighting Factor	**5**	**0**	**5**	**5**	**0**	**0**	**5**	**0**	
CO2	5	0	25	25	0	0	25	0	**80**
Zero ODP Clean Agent	20	0	25	25	0	0	20	0	**90**
Multipurpose Dry Powder (Chemical)	25	0	15	5	0	0	0	0	**45**
AFFF	25	0	0	0	0	0	5	0	**30**
Water Stream	25	0	0	0	0	0	10	0	**35**
Water Spray	25	0	5	0	0	0	10	0	**40**
Water Spray+C02	25	0	5	25	0	0	10	0	**65**

E7: Manually Applied Fire Equipment - Military Shipboard Machinery Space

	Ordinary Combust (Max 5)	Flammable Liquids (Max 5)	Electrically Non-Cond. (Max 5)	Ability To Permeate (Max 5)	Stream Range (Max 5)	Effectiveness \ Weight (Max 5)	Secondary Damage (Max 5)	Cost (Max 3)	**Total Score**
Hazard Specific Weighting Factor	**1**	**5**	**0**	**0**	**5**	**5**	**1**	**0**	
CO2	1	10	0	0	5	5	5	0	**26**
Zero ODP Clean Agent	4	15	0	0	20	25	4	0	**68**
Multipurpose Dry Powder (Chemical)	5	25	0	0	20	25	0	0	**75**
AFFF	5	10	0	0	20	15	1	0	**51**
Water Stream	5	0	0	0	25	5	2	0	**37**
Water Spray	5	5	0	0	15	10	2	0	**37**
Water Spray+C02	5	10	0	0	15	0	2	0	**32**

E8: Manually Applied Fire Equipment - Power Plant Control Room

	Ordinary Combust (Max 5)	Flammable Liquids (Max 5)	Electrically Non-Cond. (Max 5)	Ability To Permeate (Max 5)	Stream Range (Max 5)	Effectiveness \ Weight (Max 5)	Secondary Damage (Max 5)	Cost (Max 3)	**Total Score**
Hazard Specific Weighting Factor	**5**	**0**	**5**	**5**	**0**	**0**	**5**	**3**	
CO2	5	0	25	25	0	0	25	0	**80**
Zero ODP Clean Agent	20	0	25	25	0	0	20	0	**90**
Multipurpose Dry Powder (Chemical)	25	0	15	5	0	0	0	9	**54**
AFFF	25	0	0	0	0	0	5	6	**36**
Water Stream	25	0	0	0	0	0	10	6	**41**
Water Spray	25	0	5	0	0	0	10	6	**46**
Water Spray+C02	25	0	5	25	0	0	10	0	**65**

E9: Manually Applied Fire Equipment - Private Residential	Ordinary Combust (Max 5)	Flammable Liquids (Max 5)	Electrically Non-Cond. (Max 5)	Ability To Permeate (Max 5)	Stream Range (Max 5)	Effectiveness \ Weight (Max 5)	Secondary Damage (Max 5)	Cost (Max 3)	**Total Score**
Hazard Specific Weighting Factor	**5**	**3**	**5**	**2**	**3**	**2**	**1**	**2**	
CO2	5	6	25	10	3	2	5	0	**56**
Zero ODP Clean Agent	20	9	25	10	12	10	4	0	**90**
Multipurpose Dry Powder (Chemical)	25	15	15	2	12	10	0	6	**85**
AFFF	25	6	0	0	12	6	1	4	**54**
Water Stream	25	0	0	0	15	2	2	4	**48**
Water Spray	25	3	5	0	9	4	2	4	**52**
Water Spray+C02	25	6	5	10	9	0	2	0	**57**

Appendix F

Combustion and Extinguishment - An Overview of the Science

Introduction

An understanding of the issues in identifying low or non-ozone depleting fire extinguishing agents as replacements for halons requires some knowledge of fire extinguishment processes. This paper is to help serve in giving and using that understanding of combustion, as well as of the factors involved in halon replacement research. In no way should it be regarded as a detailed or complete treatment. Further information is contained in Reference 1 and its literature references.

Combustion

Combustion is an oxidation/reduction reaction sufficiently intense to generate heat and light. Fire is a combustion process most often characterized by diffusion flame behaviour. A diffusion flame is one in which fuel and oxidizer are not mixed before combustion. In contrast, deflagration and possible transition to detonation (explosion) occur in premixed fuel-oxidizer mixtures (See Section Five). An unwanted fire is uncontrolled combustion.

The oxidizer for nearly all unwanted fires is oxygen from the air. In specific hazard cases, the oxidizer may be pure or enriched oxygen, hydrogen peroxide, organic peroxides, ozone, metal peroxides, dinitrogen tetroxide, fluorine, or other strong oxidants. The reducing agents (fuels) are typically solid, cellulosic materials (paper, wood), which give Class A fires; liquid fuels (gasoline, alcohol, kerosine, aviation fuels, other petroleum products), which give Class B, flammable gases that give Class C fires; and metals (magnesium, lithium, sodium, titanium), which give Class D fires. A typical fire threat is an unwanted Class A, Class B or Class C fire where the oxidation agent is air that enters the flame zone by diffusion. Halon fire extinguishing agents are not suitable for Class D fires, nor for deep seated, smouldering Class A fires.

There are several other characteristics that are used to describe combustion processes and fire types. These do bear on fire fighting and prevention approaches but will not be described in detail. The usually encountered flaming combustion occurs primarily in the gas phase, as opposed to smouldering combustion which is a surface process. Deep seated smouldering can be hard to reach with extinguishing agents and can lead to the more vigourous flaming combustion.

The energy release rates of diffusion flames are limited by mixing rates of fuel and oxidizer. Turbulence, fluctuations in fluid flow velocity, can significantly increase mixing and thus cause more intense fires. The turbulence can be from an external flow, or self generated for large fires. Flow in small fires, such as small candles or laboratory burners, is usually laminar.

Pre-mixed gas mixtures, depending on the ratio of fuel to oxidizer, can range from fuel lean to fuel rich concentrations. Stoichiometric refers to the ratio required for complete consumption of fuel and oxidizer, which produces final products only. Flame speed and fire intensity are functions of the ratio and concentrations. Depending on conditions, a pre-mixed gas fire can lead to an explosion. The time scale and energy release rates make much more rigourous demands on extinguishing agents for explosion protection.

Suppression Mechanisms

Chemistry (molecular reactions) is usually more important in fire initiation and suppression, while physics (macroscopic, dynamics) has a dominant role in fire spread. Both are involved in fire extinguishment. Fires can be suppressed by a number of mechanisms, usually occurring in combinations. The Fire Tetrahedron with sides of fuel, oxidizer, energy, and free radicals (reactive intermediates) can be further elucidated as related to suppressant action. The extinguishment pathways listed in Table 1 serve as a convenient framework for discussion. A more detailed molecular description will follow.

Table 1

Extinguishment Pathways

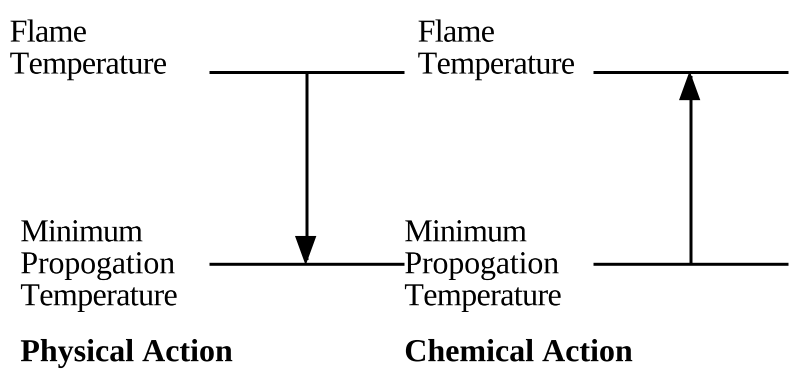
Physical - Non-Reactive		**Chemical - Reactive**
Energy	**Spatial**	**Scavenging**
Heat Capacity	Dilution	Catalytic
Thermal Conductivity	Separation	Third-Body Effects
Decomposition	Decoupling	Ionic

Physical - Energy:

An organic fuel flame can normally exist only between two temperature limits (See Figure 1). The adiabatic flame temperature is the highest temperature to which the reaction exoergicity (released energy) can heat the product gases. The minimum propagation temperature is the lowest temperature that will allow sufficiently rapid chemical reactions to maintain the flame. When energy losses, such as heat capacity or thermal conductivity processes, lower the flame zone temperature below the minimum propagation temperature (approximately 1600 K), chemical reaction rates slow and extinguishment results. Agent decomposition also requires energy input to break bonds. This mode, but not possible inhibiting reactions of the decomposition products, is usually considered a physical process.

Figure 1

Flame Suppression



Physical - Spatial:

Dilution slows reaction rates by the Law of Mass Action. Addition of an agent at 10 percent means dilution of all other components by 10 percent. Bimolecular reaction rates are then slowed to 81 percent (0.9 x 0.9) of their former rate. Separation is the classical concept of isolation of fuel from oxidizer. A blanket and a foam layer are examples. Decreasing energy feedback to unburnt fuel reduces fuel vaporization and decomposition. Examples of decoupling of the energy and radical rich zone from the unburnt gases are blowing out a candle or blasting out an oil-well fire. In total flooding applications, separation and decoupling mechanisms are not usually significant.

Chemical:

Gaseous fire suppression agents will always have some degree of physical extinguishment action. Agent chemical structure and components may also provide chemical extinguishment action. Chemical pathways can be very efficient. The radical species responsible for flame propagation are directly removed from supporting combustion by establishing alternative reaction paths. In order for the combustion chemistry to maintain itself and overcome unproductive thermal diffusion, radical diffusion, and radical reaction, it must generate additional reactive radicals to keep their concentrations above the required minimums. Chemical activity on the part of bromine is a primary reason for employing the bromine containing halons. Due to the endothermic (energy requiring) character of the reactions that generate such species, an increased minimum propagation temperature is required. Very rapid radical removal requiring a minimum propagation temperature above the adiabatic flame temperature will cause extinguishment (See Figure 1).

A suppressant that removes one radical acts as a radical scavenger. Formation of HF by a fluorine containing agent is an example. A species that can remove more than one radical may be functioning as a catalyst, having a much greater suppressant impact. HBr, formed by a bromine containing species combining with a hydrogen atom, can react with a second hydrogen atom to form a much less reactive hydrogen molecule, while generating the bromine radical to continue its chemical suppression action.

Facilitation of recombination reactions by agent acting as a third-body has a measurable effect, but not as significant. Such interaction could be called physical as there are no agent chemical changes involved. The significance of ionic suppression pathways has not been adequately demonstrated.

Combustion Chemistry

Thermodynamics deals with energy and determines the extent to which, if at all, a reaction can occur. Kinetics deals with the rates of achieving those final conditions. Thermodynamics predicts a mixture of methane and air will generate carbon dioxide, water, and excess energy. Kinetic considerations dictate it will happen only if sufficient energy or reactive free radicals are introduced to cause reaction initiation. Thus at room temperature a flammable methane-air mixture must be ignited.

Combustion chemistry primarily involves reactions of free radicals. Free radicals have one or more unpaired electrons available for bond formation, and are very reactive. Typically hydrogen atoms (H), hydroxyl radicals (OH), oxygen atoms (O), and methyl radicals (CH_3) are the most important species. Free radical initial generation, increased production, reaction, and consumption, mark the major phases of combustion chemistry. These reaction regimes are denoted as initiation, branching, propagation and termination. The specifics are determined by the fuels involved.

Initiation:

Sufficient energy must be provided to break bonds in order to generate free radicals from stable molecules. Sparks, hot surfaces, and electric discharges are common energy sources. An existing flame provides an initiation source not only by its energy, but also due to its existing radical presence. This is an example of piloted ignition as opposed to spontaneous ignition. Methane pyrolyses generates radicals as

$$CH_4 \quad -> \quad CH_3 + H - 439 \text{ kJ/mole} \qquad (1)$$

Thermodynamic data[2] are for 298 K.

Branching:

A branching reaction is one that produces more radicals than are consumed. In this way the initial radicals generate a sufficiently high radical concentration to allow the flame to self propagate. The reaction

$$H + O_2 \quad -> \quad OH + O - 70 \text{ kJ/mole} \qquad (2)$$

is usually the major oxygen consumption and primary branching combustion reaction. It is key in flame propagation as one reactive radical generates two reactive radicals. The rate of reaction (2) can be given as

$$\text{Rate} = AT^n[H][O_2]\exp(-E_a/RT) \qquad (3)$$

where AT^n relates to collision frequency and orientation effectiveness, [H] and [O_2] are reactant concentrations, and E_a is the activation energy. The exponential operation on this last term means that for typical positive activation energy values, rates will be significant only at elevated temperatures.

On the molecular level, if the rate of reaction (2) is decreased sufficiently, the fire will be extinguished. Dilution (lowering reactant concentrations), energy removal (reducing temperature) and radical removal (chemical scavenging or catalytic reaction) all take place with chemical suppression agents.

Propagation:

Reactions that consume fuel or oxidizer without changing the total number of flame radicals are called propagation reactions. One such reaction for methane is

$$CH_4 + H \ -> \ CH_3 + H_2 - \ 3 \text{ kJ/mole} \qquad (4)$$

Termination:

The overall reaction rate is decreased when radicals recombine to form stable molecules or react to produce much less reactive radicals. Examples are

$$H + OH + M \rightarrow H_2O + M + 499 \text{ kJ/mole} \quad (5)$$

$$H + O_2 + M \rightarrow HO_2 + M + 216 \text{ kJ/mole} \quad (6)$$

In these cases significant energy is released which is removed by a third body denoted as M. The need for an entity to stabilize the energy rich product is the interaction that allows agents to help cause extinguishment by serving as efficient third-bodies. In reaction (6), while HO_2 is a free radical, it is much less reactive than H. The combustion reaction rate thus decreases.

Halon Interaction

While a detailed understanding of chemical flame suppression remains incomplete, the most likely mechanism for Halon 1301 can be described as

$$CF_3Br + H \rightarrow CF_3 + HBr + 76 \text{ kJ/mole} \quad (7)$$

The bromine containing HBr can then enter into a cycle catalyzing recombination of hydrogen free radicals.

$$H + HBr \rightarrow H_2 + Br + 70 \text{ kJ/mole} \quad (8)$$

$$Br + H + M \rightarrow HBr + M + 372 \text{ kJ/mole} \quad (9)$$

Other reactions contribute as well. The removal of a number of hydrogen atoms for each bromine via catalytic reactions is the reason for the high suppression efficiency of halons. The fluorine containing radical also contributes to chemical suppression via formation of HF. In this case, one hydrogen free radical is scavenged per reacting fluorine.

Chemical activity:

As described above, all agents possess some degree of physical suppression mechanisms. When there are significant chemical suppression mechanisms operating as well, the agent is considered a chemical suppression agent. A method to estimate the physical suppression efficiency of chemical agents for air-liquid hydrocarbon fires[4] shows that halon 1301 efficiency is 20 per cent physical and 80 per cent chemical.

The classic Purdue University study[5] demonstrated that the effectiveness of halogenated fire suppressants increases as F < Cl < Br < I and that a molecule containing two atoms of a given halogen is usually more effective than a molecule containing only one. More recent studies have assigned relative effectiveness values for the halogens. Bromine and iodine are shown[6] to have similar high effectiveness, with the CF_3 radical also possessing significant chemical effectiveness, and chlorine much less so. A more recent study shows that while the effectiveness of physical agents is independent of concentration, the effectiveness of halon 1301 increases (per molecule) as its concentration decreases[7]. The implication is that mixtures, including at least one chemical agent, may give improved extinguishing performance, due to nonlinear effects. Further detailed experimental and associated computer modeling studies are needed to better understand these effects.

Halon Replacement Strategies

There are several approaches to selecting candidate suppression agents that would minimize damage to the stratospheric ozone layer. Assuming replacements will be based on fluorinated hydrocarbons, the compromises involve forgoing, to various degrees, the chemical suppression efficiency of bromine and iodine.

1. Reduced ODP - Minimize the bromine, chlorine and iodine content by employing mixtures of chemical and physical agents.

2. Zero ODP - Eliminate bromine, chlorine and iodine from the agents completely.

3. Low ODP - Retain bromine, chlorine and iodine, but on molecules that will not get to the stratosphere.

The first approach reduces the ODP to the mixture weighted average. Some measure of efficient chemical suppression activity is thus retained. However, the use of ozone depleting substances is continued.

The second approach employing non-ozone depleting substances results in relying on less efficient physical mechanisms unless new clean agent type breakthroughs occur. Agent weight and volume requirements will increase, and toxic and corrosive hydrogen fluoride product may increase significantly.

The last approach relies on rapid removal in the troposphere to significantly reduce tropopause crossing. Such removal can be via photolysis, reaction, or washout. The advantage is that some measure of chemical suppression action can be retained. The tradeoff is that the tendency for increased photolysis or reaction also leads to unwanted reactions with resulting toxicity, corrosion, and material compatibility concerns. This is especially so for iodine compounds.

General guidelines on candidate replacement design include:

Molecular size

Physical effectiveness; heat capacity increases with number of atoms

Fluorine	Effectiveness (if Reactive - radical scavenging), Stability
Chlorine	Physical (streaming - elevated boiling point), but low chemical action
Bromine	High chemical effectiveness
Iodine	High chemical effectiveness, but increased toxicity and corrosion considerations

Hydrogen
UV absorption Atmospheric lifetime reduction, photolysis, or rain-out
Reactive bonds
Hydrophilic

Halons have been the convenient, clean, safe, agents for a vast variety of fire suppression requirements. There will not be just a single replacement. Selecting an agent (or agent mixture) for a specific need will depend on the values placed on a compromise matrix. Considerations will include ODP, fire threat, efficiency, weight, volume, toxicity, GWP, material compatibility, cost, system criticality, and life safety applications. What is technically optimum for one criteria, could be unsatisfactory for a second criteria. Societal decisions will then determine what tradeoffs are acceptable for specific cases.

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