STATUS OF INDUSTRY EFFORTS TO REPLACE HALON FIRE EXTINGUISHING AGENTS

Robert T. Wickham, P.E.

March 16, 2002

WICKHAM ASSOCIATES

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Wickham Associates
9 Winding Brook Drive
Stratham, New Hampshire 03885 USA
Tel: +603-772-3229
Fax: +603-772-7305
email: wickham@attbi.com

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Preface

This report is not intended to be a market study, but instead a snapshot of the progress industry and the government are making in employing non ozone depleting alternatives to halons in the fire protection sector. Further, the report attempts to give a balanced view of the situation, accentuating neither the positive nor the negative, but presenting a picture of both the bright side and the areas that should be of concern.

In writing this report, it became apparent at the outset that even though halon 1301 and halon 1211 have identical adverse effects on the environment, their employment as fire extinguishing agents is very different with halon 1301 in its system's role and halon 1211 in its portable extinguisher use. Thus it was necessary to treat the two quite separately in the report.

A recent event has created some uncertainty about the price and supply of recycled halon 1301 in the US. A new European Union regulation [1] mandates the decommissioning of all halon systems and extinguishers in the EU by the end of the year 2003 (except for those applications that are defined as critical uses). Since October 1, 2000 when this legislation became effective, the price for recycled halon 1301 in the US has dropped from $10+ per pound to $4+ per pound as some of the decommissioned halon in Europe is imported to satisfy the needs of critical users in this country. It will take some time to see how this plays out before concluding who is hurt and who is helped by this European action.

In the preparation of this report, in addition to tapping the 35 years of experience I have accumulated in dealing with halons going back to their early days of development, I was able to interview over 40 people who are immersed in the subject of alternatives. The contributions of these experts – when added to my own experiences – provide a broad spectrum of views on which this report is based. I acknowledge and thank all of these people for their input, but add that I alone am responsible for the completeness and accuracy of the information in this report.

Finally, I would like to thank the peer reviewers of this report: David V. Catchpole, Anchorage, AK, Robert L. Darwin, P.E. of Hughes Associates, Inc., Baltimore, MD and Jeff L. Harrington, P.E. of the Harrington Group, Inc., Duluth, GA. I appreciate the time they took to review and comment on the report. I have incorporated either the letter or the spirit of the comments of these peer reviewers into this report

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[1] "Of The European Parliament And Of The Council of 29 June 2000 on Substances that Deplete the Ozone Layer," Official Journal of the European Communities L 244/1 of 29.9.2000, Regulation (EC) No 2037/2000.

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1 Introduction

The discovery of the adverse effect of halons on the stratospheric ozone layer stunned those who had grown to rely on these excellent fire extinguishing agents. The 1987 Montreal Protocol on Substances that Deplete the Ozone Layer[2] mobilized global action on ozone-depleting substances including halons. For many – the end users, the engineers, the manufacturers and the authorities – it was the start of a process not unlike that described as some of the progressive stages of grieving: moving through shock, denial, anger, depression, acceptance and growth.

Since the start of that process in the mid 1980's most people in the U.S. and other countries have worked their way through the early reactions and have adapted to dealing with life after halons. Some people – or market segments – have found this easier to do than others.

This report considers several market segments, how differently some have reacted to the loss of the halons and possible reasons for this. It also considers future progress in the US transition.

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[2] "Montreal Protocol On Substances That Deplete The Ozone Layer," Secretariat for The Vienna Convention for the Protection of the Ozone Layer & The Montreal Protocol on Substances that Deplete the Ozone Layer, United Nations Environment Programme, Nairobi, Kenya.

2 Objective of Report

The objective of this report is to provide information and guidance to the US EPA, other government agencies, the US fire protection industry, end users and the public on the options available for the replacement of halons in fixed fire extinguishing systems and portable fire extinguishers and the choices being made by some end users in several representative market segments.

Specific goals of the report are:

- Provide an overview of fire protection including a description of the classification of fires, the methods of applying halons and halon like agents and a summary of the process that led to the broad acceptance of halons 1211 and 1301 in the US.
- Outline of the progress that government and industry have made in their individual and collective efforts to manage the halons.
- Summarize the available information that attempts to quantify the amount of halon 1301 and 1211 in service in the US together with estimates on the rate at which that halon is being consumed.
- For fixed fire extinguishing systems, select five market segments that have been significant users of halon systems and describe …..
    - the fire protection objectives of the end users in those segments, …..
    - the fire extinguishing system characteristics these end users are seeking, …..
    - the options these end users have and the economics of those options and …..
    - how the end users are doing in each of the segments with regard to (1) replacing their existing halon systems with alternatives and (2) employing alternative systems for the protection of their new equipment or facilities.
- For portable fire extinguishers, describe …..
    - the classification of fires and the rating system for portable fire extinguishers, …..
    - the end users' fire protection objectives, …..
    - the options these end users have and the economics of those options and …..
    - how the end users are doing in replacing their existing halon 1211 portable extinguishers with those using alternative agents and in employing alternatives to halon 1211 in extinguishers for new equipment or facilities.
- Assess the level of protection achieved through the use of alternatives versus the protection afforded by halons.
- Identify reasons for any reluctance on the part of end users to replace their existing halon products with those employing alternative agents.

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3 Methodology

The methodology for assembling the information contained in the report consisted of two elements: (1) research of published documents, all of which are referenced in the report and (2) personal or telephone interviews with individuals with specific knowledge in the field of fire extinguishing agents, portable extinguishers and systems used to replace halons.

Table 1 is an illustration of the number of interviewees and their affiliations.

Table 1: Interviewees for this Report

Affiliation of Interviewee	Number of Interviewees in this Category
Architect or Engineering Firm	6
End User	6
Federal Regulator	5
Fire Detection Systems Manufacturer	4
Fire Extinguishing Agent Manufacturer	3
Fire Detection Systems Installer	3
Fire Extinguishing Systems Installer	3
Fire Extinguishing Systems Manufacturer	9
Halon Recycler	2
Portable Fire Extinguisher Distributor	2
Portable Fire Extinguisher Manufacturer	3

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4 Conclusions

4.1 General

- With the exception of the US Department of Defense, there has not been a significant concerted effort anywhere to remove halon 1301 systems from service and replace them with products using alternatives. Further, there is no reason to believe that this will change in the absence of some compelling reason to remove these systems.
- In the absence of directed regulatory actions in the US, there are no compelling reasons to intensify research or other efforts into areas of halon destruction, disposal or conversion to materials less damaging to the environment. Further, this is unlikely to change unless truly cost effective, in kind alternatives to halons are developed, thus providing today's end users of halons with something that is more economically attractive than the current options.
- Continuing research and development efforts are needed to achieve the heretofore elusive goals of cost effective, in kind replacements for both halon 1301 and halon 1211. The low market penetration levels of the in kind alternatives are due to end user resistance predominantly focused on one or more of these undesirable (when compared to the halons) characteristics: cost, space and / or weight.
- In general, in those segments where they have been deployed, the level of protection afforded the public by the systems and extinguishers using halon alternatives is similar to that achieved with halons themselves, although at significantly higher cost.
- Of the five segments covered in the report, significant and tangible progress can be seen and measured in four: (1) essential electronics, (2) mobile military weapons systems, (3) oil, gas & other process industries and (4) merchant shipping.
- The fifth segment, civil aviation, has had difficulties making progress toward selecting appropriate alternatives to halon for most of the applications on board aircraft. With the exception of the likely implementation of the newly approved lavatory bottles, the prognosis for providing non ozone depleting alternatives for (1) hand portable extinguishers, (2) cargo compartment fire protection systems and (3) engine fire protection systems is not encouraging.

4.2 Systems

4.2.1 <u>Existing Halon 1301 Systems</u>

- Owners of halon 1301 systems have little incentive to remove and replace them with systems using halon alternatives. Many look on these systems as the most cost effective approach in light of the fact that the halon alternatives are (1) all more expensive than the halons and (2) are all less effective than the halons.
- Many owners of halon 1301 systems have their systems regularly serviced by qualified servicing organizations and have invested heavily in updating their

detection and controls sub-systems to significantly reduce the likelihood of an accidental system discharge due to a spurious action of that sub-system.

- There is an adequate amount of recycled halon 1301 currently available on the market and it is priced so reasonably that the complete recharge of a halon 1301 system that had discharged is more economical than the replacement of the system with another alternative.
- With the exception of commendable work by the US Army, the deployment of systems using halon alternatives to 'retrofit' applications to replace existing halon 1301 systems is considered a rare event.

4.2.2 New Systems Using Halon Alternatives

- The deployment of system products to assume the role once played by halon 1301 systems is limited to new applications; that is, a new building, a new business, a new data center, a completely refurbished operation, etc.
- There are several alternatives to halon 1301 systems that are being deployed, the most common are (1) gaseous total flooding systems using HFC-227ea (marketed as FM-200 or FE-227) or an inert gas blend (marketed as Inergen); (2) water mist systems for gas turbines and similar machinery or (3) pre-action water sprinkler systems. These fire extinguishing systems are sometimes used in conjunction with very early warning detection systems that permit manual intervention far in advance of an automatic application of an extinguishing agent.
- Of these alternate approaches, one can find firm advocates for each in the end user organizations which would imply that those approaches are all technically defendable and commercially viable.

4.3 Portable Extinguishers

- Halon 1211 hand portable extinguishers are still in widespread use and adequate amounts of recycled halon 1211 agent at reasonable prices make the ongoing recharging and use of halon 1211 extinguishers possible for years to come.
- While halon 1211 extinguishers were widely employed often well beyond the areas where clean agents were necessary, end users are being more selective in the number and location of the extinguishers using the in kind halocarbon alternatives.
- For the most part, the employment of hand portable extinguishers is dictated by codes but the end user has a choice in types of agents to be used as long as the extinguishers have adequate fire ratings as called out in the applicable code.
- The end users have several alternatives to halon 1211 hand portables including (1) ABC rated dry chemical extinguishers, (2) HFC-236ea (marketed as FE-36) or HCFC Blend B (marketed as Halotron I) halocarbon extinguishers with ABC ratings or, where allowed by local authorities, (3) the use of two extinguishers – one a BC rated carbon dioxide unit and the other an A rated water unit.

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5 Background

A brief discussion is presented covering three subjects …..

- an overview of fire protection, …..
- a short history of halons and …..
- a review of government and industry halon management efforts.

5.1 Overview of Fire Protection

5.1.1 Types of Fires

Generally speaking, there are five classes of fires as defined in Table 2. Halon agents and some of their alternatives are being used quite effectively on the first three, Classes A, B and C. Halon agents are not recommended for use on the other two classes, D and K, where specialized agents are usually employed.

Table 2: Classification of Fires [3]

Class	Description
A	Fires in ordinary combustibles such as wood, cloth, paper, rubber, and many plastics.
B	Fires in flammable liquids, oils, greases, tars, oil-base paints, lacquers, and flammable gases.
C	Fires that involve energized electrical equipment.
D	Fires of combustible metals, such as magnesium, titanium, zirconium, sodium, lithium, and potassium.
K	Fires that involve cooking appliances with flammable cooking oils and fats, vegetable or animal.

5.1.2 Methods of Applying Fire Extinguishing Agents

There are two common methods for applying fire extinguishing agents: (1) total flooding and (2) local application. In addition, there are two rather specialized applications (3) explosion suppression and (4) inerting against explosions and fires. The explosion suppression and inerting applications are not discussed further in this report due to their specialized nature and, relatively speaking, limited market presence.

5.1.2.1 Total Flooding

Systems working on a total flooding principle apply an extinguishing agent to an enclosed space in order to achieve a concentration of the agent (volume percent of the agent in air) adequate to extinguish the fire. These types of systems may be operated automatically by detection and related controls or manually by the operation of a system actuator. This is true for any gaseous total flooding agent irrespective of its mechanism of extinguishment.

According to Senecal, [4] ……

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[3] "UL Standard for Safety for Fire Extinguishers, Rating and Fire Testing of, UL 711," Fifth Edition, Underwriters Laboratories Inc., Northbrook, IL: (revised) June 2000.

[4] Senecal, Joseph A., Kidde-Fenwal, Inc., Ashland, MA; personal communication, February 2002.

"………. the means of fire extinguishment by gaseous agents is a combination of three underlying mechanisms:

1. Chemical effects - inhibition by halogen atoms. Bromine, iodine and chlorine atoms can act catalytically, each atom participating multiple times to scavenge important free radicals from the combustion gases. Bromine and chlorine are both much more potent than fluorine in this regard. Fluorine also reacts with free radicals but forms strong chemical bonds. Thus, fluorine atoms react only once and are then "consumed."
2. Physical effects - thermal. The addition of any non-reactive gas to a flammable gas mixture leads to a reduction in flame temperature by virtue of the fact that the heat liberated by the reaction of oxygen molecule with a fuel species must be distributed into a larger heat sink. The rate of the combustion chemical reactions decreases rapidly with reductions in temperature. If the concentration of added inert gas is high enough the flame chemistry becomes too slow to propagate. The potency of an inert gas agent is related directly to the heat capacity of the gas composition.
3. Physical effects - dilution. Addition of a third gas to a fuel-air mixture has the effect of reducing the collision frequency of the oxygen and fuel species. This leads to a reduction in chemical reaction rates. The magnitude of the effect, however, is relatively minor compared to chemical inhibition or thermal effects.

In the case of inert gas agents the extinguishing effects are entirely physical. In the case of halons the chemical inhibition effects are most important. For example the extinguishing mechanisms of halon 1301 has been reported to be a combination of 80% chemical effects and 20% physical effects. [5] In the case of hydrofluorocarbons the extinguishing effects are predominantly physical with some (estimate at about 10 to 15%) chemical effects."

Total flooding is the most common system application of halons and has been employed for the protection of volumes containing essential electronics, machinery spaces on ships, aircraft engines and cargo bays, enclosed process modules in the oil and gas industry and both crew and engine compartments on military armored vehicles.

5.1.2.2 Local Application

In local application, the agent is applied directly onto a fire or into the region of a fire. There are some systems employing this technique but the most common method of local application is by manually operated wheeled or portable fire extinguishers. In those instances, this method is also referred to as a "streaming" application. One example of a local application system is the protection of wet benches in the semiconductor manufacturing industry. The wheeled extinguishers using halon 1211 found broad acceptance in the aviation sector for the extinguishments of aircraft engine fires and small pool fires around parked aircraft.

5.1.3 <u>Halons</u>

The halons most frequently encountered in fire protection applications are bromine-containing compounds that are generally described as liquefied compressed gases. For all practical purposes, only two halons reached any commercial significance in the United States: halon 1301, (bromotrifluoromethane - $CBrF_3$) and halon 1211, (bromochlorodifluoromethane - $CBrClF_2$). Halon 1301's major application has been in total flooding systems and halon 1211's use limited mostly to local application from hand

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[5] Sheinson, Ronald. S, James E. Penner-Hahn and Doren Indritz, "The Physical and Chemical Action of Fire Suppressants," Fire Safety Journal, 15 (1989), pp. 437-450.

portable and wheeled extinguishers. Both agents are effective on Classes A, B and C fires and both are considered ineffective for use on Class D fires.

5.2 Short History of Halons

As mentioned before, there are only two halons that have been used extensively in the United States: halon 1301 in fixed total flooding systems and halon 1211 in streaming applications, primarily in hand portable extinguishers. While there were other halons, such has halon 2402 (dibromotetrafluoroethane), 1011 (chlorobromomethane) and 1202 (dibromodifluoromethane), these agents quickly fell out of favor as the safer halons (1301 and 1211) emerged.

5.2.1 <u>Development of Halon 1301</u>

From the late 1950's through the early 1970's, several really difficult fire protection problems surfaced in the US military. An Air Force computer room in the basement of the Pentagon had a huge fire that burned for five hours and took 300 firefighters and 70 pieces of fire apparatus to control. Armored vehicles in Vietnam were losing entire infantry squads due to ordnance projectile initiated fuel explosions in the troop compartments. Machinery spaces in US Navy combat ships were continually experiencing fires that resulted in injuries and deaths on a regular basis. Military flight simulators were repeatedly experiencing fires in their hydraulic systems, resulting in serious injuries to pilots. There seemed to be no end to the fire problems.

The military worked with industry to solve these problems and, after much testing, halon 1301 evolved as the solution to protect essential electronic equipment, crew compartments in combat vehicles, machinery spaces in military ships and high bay rooms for flight simulators. The credibility halon 1301 achieved by being appointed the preferred solution to these tough military fire protection problems launched its success in both military and civilian sectors.

Halon 1301 has some interesting features that enhanced its success. It's a clean agent, it is safe for people, it's effective, it works well over a broad temperature range and it's an economical solution. But there's more: the design and installation of a halon 1301 system is rather easy when compared to other fire extinguishing systems. The basic system design calculations could be performed by people with a simple understanding of arithmetic. Thus, the application knowledge could be spread to all corners of the market, and it was. The simplicity of the system design is a cornerstone of the success of halon 1301 total flooding systems.

5.2.2 <u>Development of Halon 1211</u>

While halon 1301 was being developed in the US, halon 1211 initially seemed to be the agent of choice for systems in Europe, especially the UK. This was until it became apparent after cardiotoxicity testing that halon 1211 was not a suitable agent for total flooding systems in normally occupied spaces. Almost overnight, halon 1211 was abandoned as a total flooding agent and its proponents focused their efforts on the use of the agent in (a) local application systems and (b) hand portable extinguishers.

The halon 1211 local application effort stopped after a couple of years when it was concluded that this type of system was engineering intensive, problematical from a safety standpoint and would unlikely achieve any market acceptance when compared with the total flooding approach used by the halon 1301 supporters. The challenge was to design the system to give adequate area coverage without increasing that coverage so much that the agent supply was approaching that needed for a total flooding system. Adding to the problem was the concern about producing extremely high concentrations of the agent as it is deliberately focused on the fire area rather than being uniformly distributed about the protected volume, thus putting people at a real exposure risk. But the final and most important negative about the local application approach is that the system gave no assurance against reignition. Halon total flooding systems provide an atmosphere that prevents reignition as long as the agent does not fall below its extinguishing concentration due to leakage from of the protected volume.

Some US manufacturers started manufacturing halon 1211 portable extinguishers and the use of these units began to displace the carbon dioxide extinguisher. At the same time, the US Air Force was using halon 1011 (chlorobromomethane or 'CB') in their flight line wheeled extinguishers and vehicle mounted hose-line units, but were looking for a safer alternative. After a study, they elected to retrofit these CB extinguishers to make them suitable for use with halon 1211, which started the process of easing the CB out of service.

With the endorsement of halon 1211 by the US Air Force, the commercial acceptance of this agent was guaranteed. While the halon 1211 extinguishers were more expensive than versions using dry chemical, water or carbon dioxide, they were attractive to users in areas where (a) an agent leaving no residue was required and (b) there was a potential for either Class A and Class B fires around energized electrical equipment. The user then had the option of buying one halon 1211 extinguisher or two others: a carbon dioxide extinguisher for the Class B fire and anything involving energized electrical equipment and a water extinguisher for any Class A fires. The use of dry chemical extinguishers was discouraged around electrical and electronic equipment due to the agent residue. As the halon 1211 extinguishers became more popular, their promoters advocated the use beyond the areas containing the electronic equipment on the same basis that they leave no agent residue, even when the agent residue was not a serious issue. Thus the proliferation of halon 1211 into clearly unnecessary areas was started and the emissions began to accelerate.

5.3 Government and Industry Halon Management Efforts

5.3.1 US Halon Management Strategy

There has been much progress in providing guidance to end users to (1) responsibly manage the remaining halon in the US and (2) make informed choices on the selection of alternatives to halons. This progress is well described in the national halon management strategy [6] submitted by the US Administration to the Ozone Secretariat in response to Decision X/7 that was taken at the Tenth Meeting of the Parties to the Montreal Protocol, held in Cairo, Egypt on November 23 and 24, 1998.

The strategy covered several elements, including regulatory actions, public and industry outreach, industry standards and codes of practice, halon recovery and banking and research and development. This strategy identified many achievements, some the result of individual efforts by the US EPA, other government agencies, non government

[6] "Halon Management Strategy of the United States of America," United States Environmental Protection Agency, Washington, DC: July 24, 2000.

organizations and industry. Most achievements in this field however were made as the result of joint efforts between government and industry. Table 3 lists the key points that were enumerated in the US Halon Management Strategy.

5.3.2 Industry Efforts

The Montreal Protocol was adopted by the US Government in 1987 and in 1990 the President signed into law the Clean Air Act (CAA). With this Act - as amended - the US banned the production and import of virgin halons 1211, 1301, and 2402 beginning January 1, 1994 in compliance with the Montreal Protocol.[7] The US Government also imposed excise tax on halons and passed regulations to reduce emissions of halons through technician training and proper disposal. The fire protection industry readily accepted the challenge to find alternatives to halons and supported the early phase-out of halon production in 1994, two years before that of any other ozone depleting substances.

At the same time, industry took actions to minimize halon emissions. With the cooperation of the fire protection industry, halon recycling emerged as an important initiative both to reduce unnecessary emissions and to ensure supplies of halons during the transition. Fire protection codes and standards were changed to discourage the use of halons for testing and training. Also, substitute techniques such as the door fan test and discharge tests with surrogate agents were developed to preclude the need for discharging halons. In addition, efforts were doubled to improve the fire detection and control systems associated with the halon systems in order to reduce the high occurrence of system discharges from false alarms.

[7] "Montreal Protocol On Substances That Deplete The Ozone Layer," Secretariat for The Vienna Convention for the Protection of the Ozone Layer & The Montreal Protocol on Substances that Deplete the Ozone Layer, United Nations Environment Programme, Nairobi, Kenya.

Table 3: Elements of the US Halon Management Strategy

Strategy Element	Key Points
Regulatory Actions	• Clean Air Act of 1990 and Amendments • Ban on production • SNAP program • Import petition process • Technician training • Ban on venting • Ban on blends • Disposal rules • Excise tax on ozone-depleting substances • Presidential Executive Order on ozone-depleting substances
Public and Industry Outreach	• Brochure on halon recycling, banking and critical uses. • Fact sheet on halons and their substitutes • Brochure on "The Ozone Layer and Halons." • Supported development of a halon recovery program • Safety guide for decommissioning halon systems. • Risk guide for carbon dioxide systems • Report on the corporate structure of the fire protection industry • Report on halon recycling and banking • Report on alternatives to halon • Halon emissions reduction guidance document • NFPA Journal article on "Regulating Halon Emissions". • Internet site with information on ozone depletion
Research and Development	• DoD multi-million dollar programs for halon alternatives • Industry research in advanced chemical replacements • EPA and DoD program on pollution prevention technologies. • Commercialization of a number of safe halon alternatives
Halon Recovery and Banking	• Formed the Halon Recycling Corporation (HRC) • Several major users develop halon banks for critical needs. • DoD established the military halon bank.
Industry Standards and Codes of Practice	• Revised NFPA Standard 10 for Portable Fire Extinguishers • Revised NFPA Standard 12A for Halon 1301 Systems • Developed NFPA Standard 2001for Clean Agent Systems • Developed NFPA Standard 750 for Standard for Water Mist • Developed ASTM specifications for recycled halon • HARC voluntary code of practice for recycled halon • HRC developed an industry Code of Practice for Halon Reclaiming • North Slope oil & gas operators developed halon policies • AIHRWG developed standards for alternatives on aircraft

From 1987 and nearly up until the halt of production of new halon extinguishing agents in the United States in January 1994, the fire protection industry was generally optimistic that the development of alternatives to halons would produce an improved new line of replacement agents. This optimism began wearing thin, however, when it became apparent that some compromises were necessary in order to accept the alternatives to halons that were ultimately developed. Table 4 is an illustration of some of the agent characteristics the industry felt were important, the level expected and what was actually achieved.

Table 4: Alternatives to Halons - Expectations versus Reality

Characteristic	Expectations	Reality
Extinguishing Effectiveness	**More** effective than halons	**Less** effective than halons
Cost	**Less** expensive than halons	**More** expensive than halons
Environmental Impact	Zero ozone depletion potential	Achieved
Safety	Safer than halons	Achieved

During the early years of the search for alternatives, industry spent a lot of time and money on the development of agents that did not achieve commercial viability. In a sense, part of the reason for this can be traced to the narrow focus of the Montreal Protocol and the Clean Air Act, both of which ignore issues of climate change. In retrospect, "zero ODP," while by itself a commendable goal, has turned out to be only one of the environmental requirements being placed on agents in our marketplace. Market interest in the effect on climate change, or more specifically, global warming potential (GWP) and atmospheric lifetime (ALT), has eliminated at least one class of halocarbons – the perfluorocarbons – from commercial viability. Table 5 is an illustration of the environmental factors of the halocarbon agents that have been considered as replacements for halon 1301.

Had all the expectations in Table 4 been achieved, there would be no need for this report. Under those circumstances, many believe that halons would be a thing of the past, quickly relegated to the trash heap of earlier extinguishing agents that had found to be troublesome, such as carbon tetrachloride and chlorobromomethane. Historically, the fire protection industry and end users have enthusiastically embraced new products that are clear improvements over earlier options. However, in this case, the right choices have not been so apparent.

Table 5: Environmental Factors of Halocarbon Alternatives for Use in Systems [8]

Generic Name	**Trade Name**	**Ozone Depletion Potential**	**Global Warming Potential** (100 years time horizon)	**Global Warming Potential** (500 years time horizon)	**Atmospheric Lifetime (years)**
Halon 1301	BTM	10	6,900	2,700	65
HCFC Blend A	NAF S-III	HCFC-22 = 0.05 HCFC-124 = 0.02 HCFC-123 = 0.02	HCFC-22 = 1,900 HCFC-124 = 620 HCFC-123 =120	HCFC-22 = 590 HCFC-124 = 190 HCFC-123 = 36	HCFC-22 = 11.8 HCFC-124 = 6.1 HCFC-123 = 1.4
HCFC-124	FE-24	0.02	620	190	6.1
HFC-23	FE-13	0	14,800	11,900	243
HFC-125	FE-25	0	3,800	1,200	32.6
HFC-227ea	FM-200	0	3,800	1,300	36.5
HFC-236fa	FE-36	0	9,400	7,300	226
FC-2-1-8	CEA-308	0	8,600	12,400	2,600
FC-3-1-10	CEA-410	0	8,600	12,400	2,600
FIC-13I1	Triodide	0.0001	<1	<<1	0.005

[8] "Scientific Assessment of Ozone Depletion: 1998." World Meteorological Organization, Global Ozone Research and Monitoring Project - Report No. 44: 1998.

6 Halon Usage in North America

Trying to quantify the amount of halon deployed in the US has been a challenging task. The UNEP Halon Technical Options Committee (HTOC)[9] took on this challenge and did extensive modeling to estimate the amount of halon 1301 and halon 1211 in use worldwide and the rate at which these agents were being expended. The primary purpose of the HTOC modeling was to estimate halon emissions in order to aid the Parties to the Montreal Protocol in their deliberations regarding the ozone layer. In generating the models, many assumptions had to be made about the future behavior of end users in various market segments. With the benefit of hindsight, it is clear that some of those assumptions have not held up well. However, in the absence of confirming or contradictory studies, the HTOC report provides the best estimates available.

For the purposes of the HTOC model, all "uses" are considered to be emissions and the amount deployed is the sum of agent in existing extinguishers or systems, in storage for replenishment of existing extinguishers or systems or somewhere in between. The HTOC uses the expression "bank" to describe the agent deployed. The HTOC modeling covered the halon situation for the entire world and broke it into geographic areas, the most relevant to the US being the North American sector

6.1 Halon 1301 Usage in North America

For halon 1301, the HTOC modeling places the type of use of the agent into one of three categories:

- Systems with a maximum useful life of 10 years
- Systems with a maximum useful life of 25 years
- Systems with a minimum useful life of 25 years and maximum of 35 years

Table 6 is an illustration of some of the typical market applications in each of the categories.

Table 6: Useful Life of Various Halon 1301 Systems

10 Years Useful Life	25 Years Useful Life	35 Years Useful Life
Data processing centers Computer rooms Small telephone centers	Industrial control rooms Laboratories Oil, gas & other process industries Telephone exchanges Industrial processes	Military weapons systems Commercial aviation Merchant shipping OEM built in systems

This approach was necessary to track the halon 1301 as it was employed in the three categories, each of which had a different useful life and market growth rate. The modeling tracks the movement of the halon 1301 removed from the "10 years useful service" as it's then made available to be used as replenishment agent for longer service systems. The importance of this is shown in Table 7 where the total amount of halon in service in each of the three categories over a ten year period is illustrated:

[9] "1998 Assessment Report of the Halons Technical Options Committee," United Nations Environment Programme, UNEP Nairobi, Ozone Secretariat, Nairobi, Kenya: March 1999.

Table 7: Halon 1301 Bank Size in North America in Various Application Categories

Year End	10 Years Useful Life (Metric Tons)	25 Years Useful Life (Metric Tons)	35 Years Useful Life (Metric Tons)
1993	6,279	5,901	8,531
1994	4,794	5,659	9,121
1995	3,470	5,408	9,722
1996	2,343	5,100	10,249
1997	1,463	4,753	10,630
1998	851	4,388	10,824
1999	455	4,026	10,854
2000	217	3,669	10,766
2001	94	3,320	10,596
2002	39	2,980	10,382
2003	15	2,649	10,154

6.1.1 Halon 1301 System Installations

Using the information in the HTOC report and an estimate [10] of the average halon 1301 system size of 200 kilograms, a history of the approximate number of systems installed in North America can be developed as shown in Table 8. The expression 'approximate' is used since some of the halon 1301 in the bank is not in fixed systems but is in storage to be used to replenish systems that are ultimately discharged. This information indicates there were about 76,000 halon 1301 systems installed at the end of 2000, down from the peak year of 1992 when nearly 110,000 systems were installed. Care should be taken in extrapolating this information much further since the average system size is declining as the smaller military weapons systems and commercial aircraft systems become a more significant percentage of the remaining number of systems.

Table 8: Installed Base of Halon 1301 Systems in North America

Year	Remaining Bank (Metric Tons)	Approximate Number of Systems Installed	Year	Remaining Bank (Metric Tons)	Approximate Number of Systems Installed
1975	1,671	8,300	1988	18,510	92,500
1976	2,446	12,200	1989	20,082	100,400
1977	3,252	16,200	1990	21,157	105,700
1978	4,107	20,500	1991	21,857	109,200
1979	5,076	25,300	1992	21,977	109,800
1980	5,980	29,900	1993	21,508	107,500
1981	7,022	35,100	1994	20,325	101,600
1982	8,504	42,500	1995	19,315	96,500
1983	9,767	48,800	1996	18,376	91,800
1984	11,273	56,300	1997	17,503	87,500
1985	12,932	64,600	1998	16,697	83,400
1986	14,797	73,900	1999	15,946	79,700
1987	16,614	83,000	2000	15,241	76,200

[10] Taylor, Gary, Taylor/Wagner, Inc., Innisfil, ON, Canada, personal communications: December 1999 and November 2001.

6.1.2 Bank Size and Projected Emissions of Halon 1301

The modeling shows that the North American market absorbed a total of 51,102 metric tons of newly manufactured halon 1301 agent during the period of 1963 through the end of production in 1993 with the peak year in 1988 with 4,707 metric tons put into service. The report further shows that total emissions from North American halon 1301 systems were 35,861 metric tons from the beginning of production in 1963 through the end of 2000 with the peak year for emissions in 1988 at 2,810 metric tons.

In addition, the modeling predicts the annual halon 1301 emissions will decline from 665 tons in 2001 to 150 tons in 2030, and residual bank size for halon 1301 in North America will be approximately 3,500 tons in 2030.

It is encouraging to see the emissions levels projected to decline as we go forward. Much of this is due to the arithmetic that as the installed base declines so also will the emissions. On the other hand though, there are clear efforts being made by halon 1301 systems owners to reduce accidental discharges of their systems by improving the associated detection and control components. A case in point is in the oil and gas sector in Alaska's North Slope where significant reductions in halon 1301 emissions have been reported.[11]

6.1.3 Imports of Halon 1301

Table 9 is an illustration of the halon 1301 imports of recycled halon 1301 into the US since the halt of production of halons on December 31, 1993. Much of this halon was brought into the country specifically for the Department of Defense's halon bank managed by the Defense Logistics Agency. That halon 1301 is designated to support the halon systems in the military's mobile weapon systems including warships, armored vehicles and military aircraft. Also, some of the imported recycled halon 1301 in Table 10 was imported to support the needs of the commercial aviation sector.

Table 9: Recycled Halon 1301 Imports into the United States[12]

Year	**Amount of Halon 1301 Imported** (metric tons)
1994	0
1995	0
1996	35
1997	437
1998	191
1999	356
2000	392
2001	154

[11] Catchpole, David V., "Fire Suppression In Cold Climates - A Technical Review," December 20, 1999.

[12] Maranion, Bella, "Imports of Halons: 1994-2001," US Environmental Protection Agency, Washington, DC: November 2001.

6.2 Halon 1211 Usage in North America

As with halon 1301, the UNEP Halon Technical Options Committee (HTOC) [13] developed a model to estimate the amount of halon 1211 in use and the rate at which it was being expended. Again as with halon 1301, in the absence of confirming studies, the HTOC report provides the best estimates available.

6.2.1 Bank Size and Projected Emissions of Halon 1211

The modeling shows that the North American market absorbed a total of 59,117 metric tons of newly manufactured halon 1211 agent during the period of 1963 through the end of production in 1993 with the peak year in 1988 with 6,054 metric tons deployed. The report further shows that total emissions from North American halon 1211 systems were 39,098 metric tons from the beginning of production in 1963 through the end of 2000 with the peak year for emissions in 1988 at 2,523 metric tons.

In addition, the modeling predicts the annual halon 1211 emissions will decline from 1,302 tons in 2001 to 211 tons in 2030, and residual bank size for halon 1211 in North America will be approximately 3,400 tons in 2030 as illustrated in Table 10.

Table 10: Halon 1211 Bank Size and Projected Emissions in North America

Year	**Emissions this Year** (Metric Tons)	**Remaining Bank** (Metric Tons)	**Year**	**Emissions this Year** (Metric Tons)	**Remaining Bank** (Metric Tons)
2001	1302	20,019	2016	411	7,994
2002	1248	18,771	2017	391	7,603
2003	1182	17,589	2018	385	7,218
2004	1102	16,487	2019	392	6,826
2005	1033	15,454	2020	390	6,436
2006	971	14,483	2021	385	6,051
2007	912	13,571	2022	376	5,675
2008	856	12,715	2023	363	5,312
2009	798	11,917	2024	345	4,967
2010	738	11,179	2025	324	4,643
2011	680	10,499	2026	300	4,343
2012	614	9,885	2027	276	4,067
2013	542	9,343	2028	252	3,815
2014	492	8,851	2029	230	3,585
2015	446	8,405	2030	211	3,374

6.2.2 Imports of Halon 1211

US EPA records show that halon 1211 imports into the US virtually stopped with the ban on production in 1994 as that ban also applied to the import of virgin halons. Table 11 is an illustration of the imports of halon 1211 since 1990. As opposed to halon 1301 where

[13] "1998 Assessment Report of the Halons Technical Options Committee," United Nations Environment Programme, UNEP Nairobi, Ozone Secretariat, Nairobi, Kenya: March 1999.

there have been significant imports of agent in recent years, the only import of halon 1211 since 1994 was in 2000 for 221 kg of the agent.

Table 11: Recycled Halon 1211 Imports into the United States [14]

Year	**Amount of Halon 1211 Imported** (metric tons)
1994	0
1995	0
1996	0
1997	0
1998	0
1999	0
2000	<1
2001	0

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[14] Maranion, Bella, "Imports of Halons: 1994-2001," US Environmental Protection Agency, Washington, DC: November 2001.

7 Fixed Fire Extinguishing Systems

7.1 Historical Markets for Halons

7.1.1 Key Market Segments

A broad overview of the major segments served by halon 1301 systems includes:

- Essential Electronics
- Civil Aviation
- Military Mobile Weapons Systems
- Oil, Gas and other Process Industries
- Merchant Shipping

The list could go on to 20 other segments including libraries & museums, laboratories, flammable liquid storage buildings, etc.; but the fire protection challenges and system objectives of these additional segments are not especially unique when compared to one or more of the five identified above.

An estimate that is generally accepted in the fire protection industry is that over 90% of the halon 1301 systems ever installed protected hazards where the anticipated fire type was primarily Class A in nature, that is involving materials that are considered combustibles such as plastics (in electronic circuit boards), wood, paper and other cellulosic matter. The remaining 10% of the applications served by halon 1301 had hazardous materials of the Class B type, which are flammable liquids and gases.

Further estimates are that 75% of all the halon 1301 agent used in North America was employed in the protection of essential electronics with the remaining 25% spread across the four other segments above.

In looking at these segments, it's clear that they have some things in common but also have some fundamental differences. For example, many of the segments have extremely high fuel loading where fire intensities are enormous, including:

- Military mobile weapons systems (e.g. military combat vehicles; machinery spaces on ships; aircraft engines and fuel tanks, etc.)
- Oil, gas and process industries (e.g. gas and oil pumping / compressor stations)
- Civil aviation (aircraft engines)
- Merchant shipping (machinery space and cargo pump rooms)

On the other hand, there are several segments where the likelihood of fire is small and the fuel loading rather light, including …..

- Essential electronics (computers, telephone switches, process control areas)
- Civil aviation (cargo holds and restroom trash bins)

7.1.2 End Users' Fire Protection Objectives

When considering motives for investing in fire protection, people or organizations generally fit into three broad groups: (1) those who do it out of self interest, (2) those who do it to comply with codes or regulations and (3) those with a combination of the first two reasons.

Two of the five selected segments are clearly acting out of self interest because the type of protection they are providing by using halon 1301 systems is beyond that required by codes and regulations. These are the essential electronics and the mobile military weapons systems segments as illustrated in Table 12. That self interest can usually be further defined as a business continuity objective or, in the case of the military, an objective of mission continuity. In both of these segments, many end users have made a lot of progress in employing the alternatives to halons in their new electronics operations and, in the case of the military, in their new ships, aircraft and armored vehicles.

Table 12: Primary Motivation for Fire Protection Systems by Market Segment

Essential Electronics	Civil Aviation	Mobile Military Weapons Systems	Oil, Gas and other Process Industries	Merchant Shipping
Self Interest	Compliance	Self Interest	Combination	Compliance

In the case of the oil, gas and other process industries, many of the fire protection practices they employ are well beyond that required by codes and regulations. In those instances, these industries are motivated out of self interest for the obvious reasons of life safety, asset protection and business continuity. At the same time, there are instances where the fire protection types and levels in these industries fall under close scrutiny of the authorities due often to environmental or other concerns that would be the by-product of a fire or explosion. An example of this is the oversight and the requirements placed on the oil and gas operating companies by the State of Alaska for the North Slope operations, pipeline and terminals. Thus these types of industries are often motivated in one location out of self interest and another out of compliance. Many companies in the oil and gas industry have eliminated the need for gaseous fire extinguishing altogether in new process areas by proactive designs that allow the use of water mist for extinguishing fires.

The civil aviation segment is a pure compliance environment where the requirements and oversight of the Federal Aviation Administration must be factored into every aspect of on board aircraft fire protection. Of all five segments, civil aviation has yet to bring anything to a conclusion that has resulted in a tangible replacement for the halons for use on board aircraft although the implementation of halon free lavatory extinguishers is imminent.

The merchant shipping segment is clearly one where the primary motive is compliance alone, and at the lowest cost. There was a time when the marine industry moved in lock step away from carbon dioxide to halon 1301 systems to protect their manned machinery spaces. At the time, many believed this was a positive effort by that industry to make the ships safer. In retrospect, the owners made that move just because halon 1301 systems were less expensive than those using carbon dioxide. This became evident as the shipowners rush back to employing carbon dioxide systems now that halon 1301 cannot be installed on new vessels. It is estimated by Det Norske Veritas [15],

[15] Tosseviken, Anders, Det Norske Veritas, Norway: *"Maritime Water Mist Standards - The Statutory Side,"* International Water Mist Conference, 4 – 6 April 2001, Vienna, Austria.

the Norwegian ship classification society, that “over 90% of the new DNV ships recently constructed have carbon dioxide systems protecting their engine rooms.”

7.1.3 Product Features Necessary to Meet the Objectives

Just as the fire protection objectives can be somewhat different for the various segments, there are some subtle differences in the relative importance of the product features of a halon 1301 system. For example, the weight and the space occupied by the agent storage containers are important characteristics in all segments as there is always a cost penalty related to space usage. With the exception of retrofit situations, three of the five segments are relatively insensitive to weight and space requirements (essential electronics, oil, gas & process industries and merchant shipping).

On the other hand, weight and space are very important considerations in civil aviation and mobile military weapons systems where every pound added contributes to less range, less speed, more fuel, etc., etc. over the useful life of the aircraft or system.

Table 13 is an illustration of how the owners in various market segments might rank the following features of halon 1301:

- Weight and space (of the agent storage containers)
- Safety (use concentration below that harmful to humans)
- No residue (nothing to clean up after discharge)
- Handles obstructions (easily permeates volumes around obstructions)
- Low temperature (can operate in low temperature environments)
- Cost (relative to other options)

The table does not suggest that civil aviation people are not interested in the safety of the agent, just that when compared to the other features this is not a high priority with them as the halon 1301 is used in unoccupied spaces (engines and cargo bays). Likewise, the users of essential electronics equipment are indifferent to the low temperature characteristics of halon 1301 as they operate in carefully temperature controlled environments.

Table 13: Priorities of Halon 1301 Agent Features in Various Market Segments

Essential Electronics	Civil Aviation	Mobile Military Weapons Systems	Oil, Gas and other Process Industries	Merchant Shipping
Safety	Weight & space	Safety	Safety	Cost
No residue	Handles obstructions	Weight & space	Handles obstructions	Handles obstructions
Handles obstructions	Low temperature use	Handles obstructions	Low temperature use	Weight & space
Weight & space	No residue	Low temperature use	No residue	Low temperature use
Cost	Safety	No residue	Weight & space	No residue
Low temperature use	Cost	Cost	Cost	Safety

7.2 Options to Prospective Owners of Fixed Systems

While the list may get longer as time goes on, end-users who 15 years ago would have employed halon 1301 systems to protect their facilities or equipment have four clear options today:

1. Use an "in-kind" halon 1301 alternative such as a halocarbon, inert gas or carbon dioxide based system, …..
2. Use a "not-in-kind" alternative like water mist or pre-action water sprinkler system, …..
3. Use a very early detection system with no specialized fire suppression or …..
4. Do nothing.

7.3 Available Alternatives to Halons in Fixed Systems

7.3.1 <u>Gaseous Extinguishing Agents for Fixed Systems</u>

During the halon era (late 1960's to late 1980's), two halons emerged as the market leaders: halon 1301 for total flooding systems and halon 1211 for use as a streaming agent in hand portable and hand hose line extinguishers. The decision about what agent to use where and when was rather straight forward.

Today, as illustrated in Table 14, there is a proliferation of at least 13 different gaseous agents in various states of commercialization vying for a place in the markets once served by halon 1301. Indeed, there are even more under review at the US EPA for possible addition to the SNAP [16] list.

Table 14: Gaseous Alternatives to Halon 1301 [17, 18]

Generic Name	Trade Name	Group	Chemical Composition
HFC-23	FE-13	HFC	CHF_3
HFC-125	FE-25	HFC	CF_3CHF_2
HFC-227ea	FM-200	HFC	CF_3CHFCF_3
HFC-236fa	FE-36	HFC	$CF_3CH_2CF_3$
HCFC Blend A	NAF S-III	HCFC+ Blend	$CHClF_2 + CHClFCF_3 + CHCl_2CF_3 + C_{10}H_{16}$
HCFC-124	FE-24	HCFC	$CHClFCF_3$
FC-2-1-8	CEA-308	PFC	$CF_3CF_2CF_3$
FC-3-1-10	CEA-410	PFC	C_4F_{10}
FIC-13I1	Triodide	FIC	CF_3I
IG-01	Argotec	Inert Gas	A
IG-100	NN100	Inert Gas	N_2
IG-55	Argonite	Inert Gas Blend	N_2 + A
IG-541	Inergen	Inert Gas Blend	N_2 + A + CO_2

For a halon alternative to reach commercial acceptance in the US, there are at least 4 steps in the process and until all four are achieved, the agent will see little or no success. These steps, in the chronological sequence one would likely approach them, are:

1. Inclusion in the US EPA's SNAP [19] list as an acceptable alternative where the focus is primarily on the health and environmental effects of the agent.
2. Inclusion of the agent in a technical standard of the National Fire Protection Association which is intended to provide guidelines to the users concerning the design, installation, operation, testing and maintenance of systems or extinguishers employing the agent.
3. Component listing or approval of the agent itself by a nationally recognized testing laboratory such as Underwriters Laboratories or Factory Mutual.

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[16] Under section 612 of the Clean Air Act, EPA established the Significant New Alternatives Policy (SNAP) Program. SNAP's mandate is to identify alternatives to ozone-depleting substances and to publish lists of acceptable and unacceptable substitutes. Several rules and notices have expanded these lists, and they are available for online reading or for downloading (http://www.epa.gov/ozone). In addition, fact sheets cover more fully the eight industrial use sectors included within SNAP. Finally, information about enforcement actions is available.

[17] "International Standard on Gaseous Fire-Extinguishing Systems," ISO 14520-1 through 14520-15, available from Standards Association of Australia, GPO Box 5420, Sydney, NSW 2001, Australia: August 2000.

[18] "NFPA 2001 - Standard on Clean Agent Fire Extinguishing Systems - 2000 Edition," National Fire Protection Association, Quincy, MA: February 2000.

[19] "United States Environmental Protection Agency SNAP Program," Title 49, Code of Federal Regulations, Part 111.59, Sub-Chapter J, Federal Register, Volume 59, Page 13044.

4. Listing or approval by a nationally recognized testing laboratory of a fire extinguishing system or hand portable extinguisher incorporating the agent.

Table 15 is an illustration of the current status of the gaseous total flooding agents with the marked boxes indicating those steps have been achieved for the particular agent:

Table 15: Gaseous Total Flooding Agents - Progress Toward Commercialization

Generic Name	Trade Name	Step 1 EPA SNAP List	Step 2 NFPA Standard	Step 3 Component Listing	Step 4 Listing in a System
HFC-23	**FE-13**	X	X	X	X
HFC-125	FE-25	X	X		
HFC-227ea	**FM-200**	X	X	X	X
HFC-236fa	FE-36	X	X		
HCFC Blend A	NAF S-III	X	X		
HCFC-124	FE-24	X	X	X	X
FC-2-1-8	CEA-308	X	X		
FC-3-1-10	CEA-410	X	X	X	X
FIC-13I1	Triodide	X	X		
IG-01	**Argotec**	X	X	X	X
IG-100	NN100	X	X		
IG-55	Argonite	X	X		
IG-541	**Inergen**	X	X	X	X

It now appears that the manufacturers of FC-2-1-8, FC-3-1-10 and HCFC-124 have discontinued their promotion of these materials as fire extinguishing agents. Essentially, of the 13 gaseous alternatives for total flooding systems in Table 15, at this time only four (those in bold type in the table) can be considered commercially viable in the US market: HFC-23, HFC-227ea, IG-01 and IG-541.

7.3.2 Water Mist Systems

To many, water is perceived as a tremendous fire extinguishing agent, it's readily available, it's inexpensive and it's environmentally non-problematical. Further, the concept of using it in a mist form makes water even more attractive as a fire extinguishing agent since:

- The high effective surface area of the water mist "particles" makes it more capable (than a heavy stream of water) in its process of cooling the fuel and the surroundings and in readily evaporating (turning into steam) and diluting the oxygen, thus inhibiting the fuel burning rate and …..
- That increased effectiveness then translates into requiring very small quantities of water to achieve extinguishment (when compared to more conventional water application methods) thus minimizing the largest single objection to water systems - the collateral damage done by the water.

Water mist has made in-roads into 3 major market applications: the protection of turbine and diesel powered machinery, the protection of machinery spaces aboard ships and the protection of passenger cabins aboard ships. There are accepted test protocols

(Factory Mutual Research [20] for the turbines and the International Maritime Organization (IMO) [21, 22, 23] for shipboard) for these market applications and those who have their systems successfully tested have achieved the right to participate.

While the technology is certainly developing, there are two things that are really holding water mist back from gaining wide market acceptance: [24]

- First, the systems have been found to have difficulty extinguishing small fires in large volumes even to the point that they fail to extinguish those small fires.
- Second, the water mist industry has been unable to effectively bridge the gap between theory and practice, thus requiring that applications be limited (in size and characteristics) to those where fire test protocols have been developed against which system performance has been determined empirically. The economics of this approach are unattractive to systems' manufacturers and end users.

There is a lot of effort on an international scale going into solving these problems and many researchers are confident that the solutions are well within reach.

7.3.3 Preaction Automatic Sprinkler Systems

A preaction automatic sprinkler system is generally used where there is special concern for accidental discharge of water as in areas containing essential electronics. A preaction valve is placed in the water supply piping and a separate detection system, most often smoke detection, is used to activate the valve to allow water to flow into the sprinkler piping. The sprinkler piping is much like that found in a conventional system with closed head sprinklers that do not open until activated by the heat from a fire. When the system is in a standby mode with the preaction valve closed, the sprinkler piping downstream of the valve is often pressurized with air and that pressure is monitored as a continuous supervision of the integrity of the piping.

In the event of smoke detection, the preaction valve will be opened but water will not flow into the sprinkler piping until a sprinkler head is operated by the heat of a fire. When the sprinkler head operates, any supervisory air in the system vents through that open head followed by the water allowed into the piping by the opened preaction valve.

Much of the damage reported over the years caused by water to essential electronic equipment has been as the result of some form of failure of the wet pipe sprinkler

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[20] "Approval Fire Test Protocol for Water Mist Systems for the Protection of Combustion Turbine Enclosures With Volumes Up To, And Including, 2825 ft^3 (80 m^3)," Factory Mutual Research, Norwood, MA: 1985.

[21] "Amendments to the Test Method for Equivalent Water-Based Fire-Extinguishing Systems for Machinery Spaces of Category A and Cargo Pumprooms Contained in MSC/Circ.668, Annex, Appendix B," MSC Circular 728, International Maritime Organization, London: June 1996.

[22] "Guidelines for the Approval of Fixed Water-Based Local Application Fire-Fighting Systems for Use in Category A Machinery Spaces," MSC Circular 913, International Maritime Organization, London: May 1999.

[23] "Revised Guidelines for Approval of Sprinkler Systems Equivalent to That Referred to in SOLAS Regulations II-2/12 Including Appendix 1 Component Manufacturing Standards For Water Mist Nozzles and Appendix 2 Fire Test Procedures for Equivalent Sprinkler Systems in Accommodation, Public Space and Service Areas on Passenger Ships," IMO Res.A.800 (19), International Maritime Organization, London.

[24] Wickham, Robert, "Report On The Vienna Conference - International Water Mist Association, April 7, 2001.

system, either in the piping itself or some sort of failure of the sprinkler head itself. In the preaction system, two separate events consisting of the (1) detection of smoke adequate to cause the opening of the preaction valve and (2) the development of enough heat to open a sprinkler head are necessary before any water would be discharged. Thus the accidental discharge of water from this type of system is highly unlikely.

7.3.4 Other Types of Agents for Fixed Systems

In addition to the gaseous agents listed in Table 14 and the water based systems, there are several other types of agents being promoted as halon replacements in fixed systems, including inert gas generators, aerosols and some special halocarbon based compositions.

7.3.4.1 Inert Gas Generators

Inert gas generators utilize a solid material which oxidizes rapidly, producing large quantities of CO_2 and/or nitrogen. The use of this technology to date has been limited to specialized applications such as dry bays on military aircraft. This technology has demonstrated excellent performance in these applications with space and weight requirements equivalent to those of halon 1301 and is currently being deployed in the Navy's F/A-18E/F "Super Hornet" and the Marine Corps' MV-22 "Osprey."

7.3.4.2 Aerosols

Another technology being developed is the use of aerosols as extinguishing agents. These take advantage of the well established fire suppression capability of solid particulates – as demonstrated with dry chemicals - with the possibility of significantly reducing the amount of residue associated with the current dry chemical agents. The NFPA is in the process of forming a technical committee to write a standard for "Fine Aerosol Extinguishing Technology" [25] which will ultimately provide the guidance to assure these types of systems are employed in a manner that is safe and beneficial to society. As illustrated in Table 16, several other standards making organizations are in the process of or have completed their guidelines for the use of these types of agents.

Table 16: Organizations Developing Guidelines for Aerosol Systems

Organization	Document
International Maritime Organization (IMO)	"Guidelines for the Approval of Fixed Aerosol Fire-Extinguishing Systems Equivalent to Fixed Gas Fire-Extinguishing Systems, as Referred to in SOLAS 74, for Machinery Spaces;" MSC/Circ.1007, 26 June 2001.
Standards Australia	"(Draft) Australian Standard for Aerosol Fire Extinguishing Systems," AS 4487, Version 1.0, 26 July 2000.
CEN - Comite Europeen de Normalisation (European Committee for Standardization)	"(Draft) Standard for Fixed Firefighting Systems: Aerosol Extinguishing Systems, Physical Properties, System Design And Test Methods;" ICS CEN/TC 191/WG 6 N xxx, 10 August 2001.

[25] Letter from Leona Nisbet, Codes and Standards Administration, National Fire Protection Association to Robert T. Wickham, November 5, 2001.

7.3.4.3 Halocarbon Based Compositions

There are two compositions that are receiving attention for some specialized systems applications. Both consist of halocarbon and dry chemical components although neither uses the same halocarbon or dry chemical.

a. HFC-227ea and Sodium Bicarbonate. The US Army has done work to develop a new agent for the protection of the crew compartment in new models of armored combat vehicles to take on the role that is being filled by halon 1301 in current vehicles. The composition consists of 95% by weight HFC-227ea halocarbon agent together with 5% by weight sodium bicarbonate dry chemical. They have reported [26] that the sodium bicarbonate additive significantly reduces the generation of hydrogen fluoride normally found with the exposure of halocarbon agents to flames. They attribute this to the quick flame knockdown provided by the sodium bicarbonate. The Army has indicated that it has achieved a 40% increase in performance of the HFC-227ea with the addition of this small amount of sodium bicarbonate. The US EPA is reviewing this composition for addition to the SNAP list as an agent suitable for use in occupied areas.

b. Gelled Halocarbon and Dry Chemical Suspension. Similar to the earlier composition, the dry chemical component in this composition enhances the fire suppression capability of the HFC-236fa halocarbon component and reduces the generation of HF during fire suppression. This product is marketed under the name Envirogel. There are various compositions but one reported [27] is made up of 40% by weight of the gelled ammonium polyphosphate and 60% by weight HFC-236fa. The agent is on the US EPA SNAP list for use in occupied areas. It is not listed in National Fire Protection Association Standard 2001, Standard on Clean agent Fire Extinguishing Systems. Interest has been shown in several applications for this type of material, most notably in aircraft lavatory bottles and aircraft portable extinguishers.

7.4 Cost Comparisons for Gaseous Total Flooding Systems

As pointed out earlier, one of the reasons for halon 1301's widespread use was the cost efficiency of a system using that agent, so much so that a halon 1301 system was less expensive than one using carbon dioxide. That cost effectiveness, together with the safety of halon compared to carbon dioxide, was the primary reason for the near total displacement of carbon dioxide as a gaseous total flooding agent in all but a few applications during the market life of halon 1301.

Unfortunately, this is not the case with the new alternatives to halon. All of the systems using these agents cost more than the carbon dioxide systems. This was reported [28] in 1999 in conjunction with a study [29] about the use of perfluorocarbon extinguishing agents in shipboard fire extinguishing systems. The results of that cost comparison are shown in Table 17. These costs are based on the system hardware and agent to protect the

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[26] Meeting of the Halon Alternatives Research Corporation, Las Vegas, NV, December 6, 2001.

[27] "Options For Aircraft Cargo Compartment Fire Protection," International Aircraft System Fire Protection Working Group, September 2000.

[28] Wickham, Robert T., Letter to Dr. Reva Rubenstein, US Environmental Protection Agency, Washington, DC: June 17, 1999.

[29] Wickham, Robert T., "Alternatives to Perfluorocarbons in Shipboard Fire Extinguishing Systems," prepared for the US Environmental Protection Agency, Washington, DC: April 1999.

500m^3 test enclosure as specified by the International Maritime Organization for gaseous extinguishing agent systems [30] or water mist systems. [31] The costs are based on the selling price of the components from the system manufacturer to a distributor and they do not include the labor, materials or other costs related to the actual installation of the systems.

Table 17: Relative Costs for Fixed Gaseous Extinguishing Systems

Type of System	Agent Weight	Cylinder Volume	Number of Cylinders	Cost of Agent	Cost of System Equipm'nt	System Cost
	Kilograms	Liters / cylinder)	Each	US$	US$	US$
Halon 1301*	200	141	2	1,544	4,345	5,889
HFC-23	322	68	7	4,960	7,687	12,647
HFC-227ea	347	141	3	11,833	5,845	17,678
HFC-236fa	285	141	2	11,275	4,345	15,620
FC-2-1-8	391	141	3	13,760	5,845	19,605
FC-3-1-10	443	141	3	15,581	5,845	21,426
Inert Gas**		80	19	insignificant	22,897	22,897
Carbon Dioxide**	900	68	9	insignificant	11,345	11,345
Water Mist***		47	15	insignificant	21,015	21,015

* The halon 1301 cost information represents the situation prior to the halt of production of the agent and is shown merely as a point of reference of what this type of system cost before the awareness of the problems with the ozone layer.
** The costs of the inert gas (agent), the carbon dioxide (agent) and nitrogen for the water mist system are included in the equipment costs.
*** The 15 cylinders for the water mist system contain nitrogen to drive the high pressure water pump unit.

7.5 The Transition to Alternatives by Market Segment

In preparing this report, interviews were conducted with many industry experts to gather up to date information. While many subjects were discussed and are covered throughout the report, the most effort was put into trying to get a clear view of the current situation in two regards …..

- What are owners doing about converting their currently installed halon 1301 systems to some other type of protection (i.e. replacing existing systems)?
- What are the prospective owners of alternatives to halon 1301 systems doing to protect their operations?

While there are specific answers to these two that are market segment dependent and reported below, there are some generalizations that can be made about all segments.

- On the first question, the general answer is very little. With the exception of (1) the US Department of Defense, which has a program to remove halon 1301 from its non-essential applications, (2) three other federal agencies which have

[30] "Revised Guidelines for the Approval of Equivalent Fixed Gas Fire-Extinguishing Systems, as Referred to in SOLAS 74, for Machinery Spaces and Cargo Pump Rooms," Annex to IMO Maritime Safety Committee Circular 848, International Maritime Organization, 4 Albert Embankment, London SE1 7SR, England: June 1998.

[31] "Amendments to the Test Method for Equivalent Water-Based Fire-Extinguishing Systems for Machinery Spaces of Category A and Cargo Pumprooms Contained in MSC Circular 668, Annex, Appendix B," International Maritime Organization, 4 Albert Embankment, London SE1 7SR, England: June 1996.

directives to do the same and (3) two companies in the private sector that started across the board decommissioning, the consensus of the experts is that the organizations that have installed halon 1301 systems tend to keep them in place, maintain them and even upgrade them. The general belief is that continuing with the protection offered by a currently installed halon 1301 system is not only the most cost effective alternative but it offers the best level of fire protection. In the absence of any compelling reason(s) to remove these halon 1301 systems, they will likely continue in place until such time as the property protected becomes obsolete, the system reaches the end of its useful life, or they no longer have supplies of halon 1301 agent.

- The second question is market segment specific where organizations are taking several approaches from …..
  - using new extinguishing agents, …..
  - using recycled halon 1301 in new systems, …..
  - returning to the use of alternatives that pre-date halon 1301 …..
  - to doing nothing.

7.5.1 Essential Electronics

7.5.1.1 Existing Halon 1301 Systems

For the most part, the owners of halon 1301 systems protecting their essential electronics have chosen to keep those systems operational and not remove them just for the sake of using some newer technology. Fire protection systems installation and service companies speak in terms of well over 50% to as high as numbers approaching 90% of the systems they have ever installed as still being in service. There are exceptions to this, however:

- The US Department of Defense is methodically removing halon 1301 systems from non critical applications such as computer rooms, flight simulator computers and other applications where there are alternatives to halon 1301. This process frees up that halon 1301 for employment in the military's mobile weapons systems.
- Halon 1301 systems are being decommissioned when an essential electronics operation is relocated or a major remodeling of a facility takes place. Then, the owners tend to look toward a new fire protection system.

The owners who still have their halon 1301 systems are not just letting the systems stay in place, but most are maintaining them under agreement with service companies and replacing the detection and control systems to the latest technology to minimize false discharges of the systems. Some are even cannibalizing lower priority systems in their facilities to use to modify other higher priority systems that have to be enhanced due to facility changes.

There are several reasons that account for this behavior …..

- There is little economic incentive for a halon 1301 system owner to remove the system as not only does he lose the value of the current system but has to invest in another system that will cost 3 to 4 times the investment in the halon 1301 system.

- It is very difficult to employ the new extinguishing system alternatives in facilities where the storage space for extinguishing systems was intended for halon 1301. There just is not enough room to store the new alternatives cylinders in existing facilities without making major building modifications to accommodate them.
- Most owners of halon 1301 systems believe the protection those systems offer is still adequate even with the new alternatives available.
- Finally, there is no one advising the owner to remove the halon 1301 systems. It is certainly not the government at local, state or federal levels. In fact, the companies that sell, install and service fire suppression systems have often found that it is a waste of time to try to sell a new alternative system to replace a halon 1301 system.

With the abundant supply of recycled halon 1301 available in the market at the lowest prices ever and with qualified service companies willing to maintain and refurbish these systems, it seems that it will take quite some time for the attrition of halon 1301 systems to some other form of fire protection without some stimulus to accelerate the process.

7.5.1.2 New Fire Protection Systems

In the essential electronics segment, which absorbed about 75% of all the halon 1301 ever deployed in the US, the owners of new facilities or those housing new essential electronics are employing a whole range of types of fire protection. On one end of the spectrum, the highly protected owners are employing high sensitivity smoke detection (HSSD) systems to provide very early warning coupled with halocarbon or inert gas total flooding systems controlled by smart smoke detection systems. On the other end of the spectrum, the owners are doing nothing other than conventional automatic sprinklers if required by the code. In between are several other options as illustrated in Table 18 where level 1 is considered the highest and level 7 the lowest from a fire suppression system standpoint.

Table 18: Levels of Fire Suppression System Protection

Level	**Very Early Warning Smoke Detection** (alarm only)	**Detection and Controls** (alarm & suppression system actuation)	Suppression System
1	HSSD	Smart smoke detection	HFC-227ea or Inert Gas
2	None	Smart smoke detection	HFC-227ea or Inert Gas
3	None	Conventional smoke	Preaction sprinkler
4	HSSD	None	Automatic sprinkler
5	None	None	Automatic sprinkler
6	HSSD	None	None
7	None	None	None

It is really unclear why some owners choose to invest heavily in fire protection for their essential electronics and others seem to do nothing. The industry experts had an equally wide range of opinions on why this might be, including …..

- It is usually an unregulated market application where the motive for (or against) fire protection is at the owners discretion, so wide variances in behavior should be expected.

- The owners have been lulled into believing there is not a risk of fire since the fire losses have been nearly non-existent in very recent history.
- There are different groups promoting the various levels of protection, each armed with very believable arguments that its individual approach is the best.

In any case, the owners of new essential electronic systems and facilities have many options to provide protection for their systems and business continuity. Some appear to be taking more risks than others by limiting their level of fire protection. The willingness to assume this additional risk appears to be based more on financial considerations than the fire protection reality.

7.5.2 Civil Aviation

There are 4 types of fire extinguishing products on commercial aircraft: (1) lavatory bottle extinguishing system, (2) on board portable extinguishers, (3) cargo compartment systems and (4) engine fire protection systems.[32] All lavatory bottle systems, cargo compartment systems and engine fire protection systems being installed today use halon 1301. All on board portable extinguishers being sold today use halon 1211.

The popular belief is that the likelihood of seeing a halon free new commercial aircraft in the next five or perhaps even ten years is remote. The industry (1) knows it has enough halon 1301 to last for many years, (2) believes that there are no regulatory bodies ready to force the issue on this chronically financially ailing industry and (3) knows very well that all the systems employing alternatives to halons – with the exception of the lavatory bottle – will cost more, weigh more and take up more space on the aircraft.

7.5.2.1 Lavatory Bottle Systems

It now appears that several new lavatory bottle extinguishing systems employing non ozone depleting agents will be introduced soon. Three agents have successfully passed the FAA testing: HFC-227ea, HFC-236fa and the Envirogel product (gelled halocarbon and dry chemical suspension using HFC-236fa). It is nearly a certainty that these new products will be successfully introduced into the commercial fleet without a lot of resistance as ……

- they are more effective than the halon 1301 units, …..
- they cost less, …..
- they are the same size as the halon 1301 units, …..
- they mount on the same place in the aircraft, …..
- other than document changes, there's no engineering required to introduce these to the fleet.

7.5.2.2 Cargo Compartment Fire Protection

Industry experts feel that the cargo compartment fire protection problem is going to be the most difficult to solve without the use of halon 1301. The International Aircraft System Fire Protection Working Group (IASFPWG) considered six extinguishing agent

[32] Tapscott, Robert E. and Louise C. Speitel, "Report of the Task Group on Options to the Use of Halons for Aircraft Fire Suppression Systems," DOT/FAA/AR-99/63, Office of Aviation Research, Washington, D.C. 20591: February 2002.

alternatives and concluded that two should go forward for FAA testing: (1) a combination water mist / inert gas system and (2) a system employing HFC-125.[33]

The FAA has developed minimum performance standards[34] (MPS) for the fire extinguishing systems for the aircraft cargo compartments and is in the process of testing agents for this application. FAA testing has demonstrated that water mist by itself is unable to pass the exploding aerosol can fire test and testing of the two systems recommended by the IASFPWG has resulted in more interest in the water mist / inert gas system than one using HFC-125. However, the economic feasibility of the water mist / inert gas system depends to some degree on the ability to use an On-Board Inert Gas Generating System (OBIGGS) for the nitrogen supply, which too is not a reality. There is also discussion of adding pyrotechnic aerosols to the testing program.

7.5.2.3 Aircraft Engine Fire Protection

The FAA's aircraft engine fire protection testing program is similar to the cargo compartment program in that the IASFPWG considered six extinguishing agent alternatives and concluded that two should go forward for FAA testing: (1) iodotrifluoromethane (FIC-13I) and (2) a system employing HFC-125.[35]

While both of these agents have been tested exhaustively by the US Air Force on aircraft engines, the FAA chose to conduct its own engine testing. Indeed, the Air Force, Marine Corps and Navy all have operational aircraft flying with HFC-125 systems protecting their engines. It seems that the FAA has had some instrumentation and other test setup problems that have plagued their testing efforts with a long series of delays.

Generally, while this program appears to be open ended, there is optimism that it will provide more tangible results than that from the cargo compartment testing. The reason for the optimism is that no one expects the test results to be different than those found in the US Air Force program.

7.5.3 <u>Mobile Military Weapons Systems</u>

The military has done a commendable job in seeking out and selecting alternatives to halons for its mobile military weapons systems. To name a few, by service branch, in alphabetical order …..

7.5.3.1 US Air Force

The Air Force has chosen HFC-125 as the agent for the extinguishing systems on the F-22 "Raptor" which entered low level production on August 15, 2001

7.5.3.2 US Army

The Army has made several advances in employing halon alternatives including …..

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[33] "Options for Aircraft Cargo Compartment Fire Protection," International Aircraft System Fire Protection Working Group, September 2000.

[34] "Appendix A - Minimum Performance Standards For Aircraft Cargo Compartment Built-In Fire Suppression Systems." Available at http://www.fire.tc.faa.gov/systems/cargo/mps/cargomps.stm.

[35] "Options for Aircraft Engine Fire Protection," International Aircraft System Fire Protection Working Group, September 2000.

- Replacing the halon 1301 systems in the engine compartments with sodium bicarbonate dry chemical systems on the M1 Abrams Main Battle Tanks as they are brought in for major overhaul at a rate of approximately 200 vehicles per year.
- Replaced the halon 1301 systems for the engine compartment protection on the M2/M3 Bradley Fighting Vehicle with HFC-227ea systems.
- The selection of HFC-125 to protect the engine compartment and the HFC-227ea / dry chemical composition system for the crew compartment on the 2,131 Interim Armored Vehicles (IAV) entering production.
- The removal of halon 1301 systems from over 60 Army watercraft and replacing those with combination HFC-227ea / water-spray systems.

7.5.3.3 US Marine Corps

The Marine Corps has made these choices for halon alternatives …..

- The employment of HFC-125 as the agent for the extinguishing systems for the engines and gas generators for the mid-wing bays on the MV-22 "Osprey."
- The replacement of halon 1301 systems with those using HFC-125 for the engine protection on the UH1 "Huey" and AH1 "Cobra" fleets.
- The selection of dry chemical to protect the engine compartment and the HFC-227ea / dry chemical composition system for the crew compartment on the Advanced Amphibious Assault Vehicle (AAAV).

7.5.3.4 US Navy

The Navy has made these choices instead of continuing the use of halon 1301 …..

- The employment of HFC-125 as the agent for the extinguishing systems for the engines on the F-18 E/F "Super Hornet" and gas generators in the dry bays.
- The use of water spray in the main machinery spaces and HFC-227ea in the auxiliary machinery spaces and flammable liquid storerooms of the LPD-17 Amphibious Transport Dock Ship, a 12 ship lot designated the San Antonio Class.
- The use of HFC-227ea in lieu of the conventional approach of halon 1301 systems for selected machinery protection and flammable liquid storerooms on the new aircraft carrier USS RONALD REAGAN (CVN 76).

7.5.4 Oil, Gas and Other Process Industries

7.5.4.1 Process Protection

The use of halon 1301 systems in the oil, gas and other process industries in the US has been focused in Alaska where, due to the way the facilities were designed and constructed, the removal of the halon 1301 systems from the process areas is economically impossible. The process areas in the production modules and the pumping stations live under continuous threat of methane leaks and potential explosive atmospheres that are made inert by the existing halon 1301 systems.

For new process areas, involving enclosed modules with a potential methane buildup, gas detection systems and controls are being used to shutdown and blowdown processes and to turn on high rate ventilation systems rather than closing up the space and trying to inert it with an extinguishing agent. With the threat of explosion handled in this manner, the preferred means of protecting against a fire in these new modules is with a water mist system.

7.5.4.2 Control Room Protection

Halon 1301 use in the rest of the oil and gas and process industries is somewhat limited to the protection of electronics in control rooms as the process areas are not enclosed as they are in Alaska and the gas accumulation problem is not present. Thus the control rooms in the process industries are not unlike the protection of equipment in the essential electronics segment. In this regard …..

- Several oil companies are removing their halon 1301 systems from the electronics areas and (1) replacing those systems with high sensitivity smoke detection systems or (2) replacing the halon systems with a preaction sprinkler systems if sprinklers are required by code or (3) replacing the halon 1301 systems with a halocarbon alternative, most often FM-200.
- However, most companies are leaving their halon systems in place in the electronics areas just as in other industries; perhaps upgrading the detection and controls and just maintaining the halon protection.

7.5.5 Merchant Shipping

After nearly 25 years of declining shipbuilding of non-military vessels in the US, construction and orders for new boats and ships of all types are on the rise primarily due to replacement of aging ships that are part of the Jones Act fleet. While nearly all of the world's merchant ships are built in foreign shipyards and registered under flags of convenience, these foreign flag vessels cannot operate on voyages between two US ports. The Jones Act requires that cargo moving between US ports be carried in vessels that are US owned, built and crewed. Similar US cabotage laws reserve the movement of passengers and the performance of marine services such as dredging, towing and salvage to US owned, built and crewed vessels.

The new millennium has seen an unprecedented growth of the Jones Act fleet. Approximately 140 commercial vessels of all types with a market value of more than $4.4 billion are under construction in American shipyards. Included in that total are the first large US flag cruise ships in more than 40 years, a number of double-hulled tankers and tank barges that meet the requirements of The Oil Pollution Act (OPA90), and a new generation of roll-on/roll-off cargo carriers that incorporate the latest in environmental safeguards. Pending are contracts for another 150 vessels.[36]

Almost all of this construction has employed total flooding carbon dioxide systems for the required protection of the engine rooms. It is clearly a cost issue where the merchant shipping industry makes many of its procurement decisions on two criteria: "Is it USCG (United States Coast Guard) type approved" and "is it the lowest cost?" The use of carbon dioxide systems aboard ships is likely to continue indefinitely unless (1) a more cost effective system is developed and approved (unlikely, when looking at the costs of the new gaseous alternatives to halons) or (2) something is done to regulate the carbon

[36] Web-Site, Maritime Cabotage Task Force, http://www.mctf.com, December 2001.

dioxide systems out of the manned engine rooms. The US EPA report [37] on the risks of carbon dioxide systems that enumerated the injuries and deaths attributed to carbon dioxide extinguishing systems made special note of the fact that the marine industry had the most injuries and fatalities of this type.

The majority of the US shipowners have moved seamlessly from halon 1301 back to carbon dioxide for their mandatory engine room protection for new ships. As such, the halt of halon 1301 production has not inconvenienced this segment. For the existing ships with halon 1301 systems installed, these systems will likely continue to serve their purpose until the ships are scrapped as long as replacement halon 1301 is available to recharge the systems should they be discharged.

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[37] "Carbon Dioxide as a Fire Suppressant: *Examining the Risks,"* Report EPA430-R-00-002, United States Environmental Protection Agency, Washington, DC: February 2000.

8 Portable Fire Extinguishers

8.1 Historical Markets for Halons

8.1.1 Key Market Segments

Generally speaking, the market segments for hand portable extinguishers can be categorized into three:

- Industrial
- Commercial / Institutional
- Residential

……. and within those segments there are some sub-segments based on the purpose, type or function of occupancy. For example, industrial applications can range from a steel mill to the paint line in an automobile assembly plant to a clean room in a chip manufacturing plant. In the commercial sector, the occupancy may be office area, mercantile space or storage. Institutional segments can be classrooms, cafeterias, computer rooms or laboratories with flammable chemicals. Perhaps carrying it too far, the residential segment can be broken down further into kitchen, garage, living quarters or basement.

While some halon 1211 portable extinguishers were used in the residential market, the halocarbon alternatives' use as streaming agents has been restricted to non-residential applications by the SNAP program. The agent of choice for residential hand portable extinguishers has been dry chemical – due to its low cost – and every indication is that type of extinguisher will continue to be the primary choice for this segment going into the future.

In looking at the industrial and commercial / institutional segments, the requirements of sub-segments are often more important than the market segment itself in determining the suitable agent to be used in the portable extinguishers. That is to say that the clean room in a chip manufacturing plant in the industrial segment is more like a laboratory in an institutional segment than it is like a steel mill in the industrial segment.

From a practical standpoint, an easier way to discuss hand portable extinguishers would be to ask 4 questions about the application, the answers to which will lead one to the right extinguisher. Disregarding specialized extinguishers for Class D or Class K fires, these include:

- What are the code requirements for the extinguisher type and rating?
- What class of fire is anticipated, A or B?
- Is energized electrical equipment involved?
- Is a clean agent, leaving no residue, necessary?

8.1.2 Portable Fire Extinguisher Rating System

In order to deal with the different types of extinguishers and match them up with the needs of the end users, one must have an understanding of the rating system for the extinguishers. Disregarding the very specialized D and K class extinguishers, the common types of fires are Classes A, B and C.

Underwriters Laboratories, Inc. (UL) has, together with industry, developed fire testing procedures and a rating system for portable extinguishers. These requirements cover rating and performance during fire tests of fire extinguishers intended for use in attacking Class A, B, C fires. The ultimate rating of an extinguisher or the prescribed use of an extinguisher or agent is based on its fire-extinguishing potential as determined by fire tests and presupposes installation and use in accordance with the "Standard for Portable Fire Extinguishers, NFPA 10." [38]

There are five possibilities of ratings or rating combinations for fire extinguishers as shown in Table 19.

Table 19: Classification of Portable Extinguishers

Classification	Rating Format*	Suitable for Fires
A	#-A	Fires in ordinary combustibles such as wood, cloth, paper, rubber, and many plastics.
A:B	#-A:#-B	Same as for the 'A' rating above plus the 'B' rating below.
A:C	#-A:C	Same as for the 'A' rating plus can be safely used on fires that involve energized electrical equipment
B	#-B	Fires in flammable liquids, oils, greases, tars, oil-base paints, lacquers, and flammable gases.
B:C	#-B:C	Same as for the 'B' rating plus can be safely used on fires that involve energized electrical equipment
A:B:C	#-A:#-B:C	Same as for the 'A' rating plus the 'B' rating plus can be used on energized electrical equipment.

*The '#' represents a rating number based on the size of the test fires with larger numbers indicating greater effectiveness.

Obviously, some extinguishing agents can achieve listing for all three classifications while others may be limited to two or perhaps even just one. Table 20 is an illustration of the types of extinguishers that have achieved ratings in the various classifications of fires:

Table 20: Classification of Extinguishers by Type of Agent

A	A:B	A:C	B:C	A:B:C
Water	Foam	Water mist	Dry chemical* Carbon dioxide	Dry chemical* Halon Halocarbons

* Some dry chemicals – usually sodium bicarbonate based – have no Class A extinguishing ability and thus are limited to Class B:C applications. Other dry chemicals – of the multi-purpose type usually based on ammonium phosphate – are effective on Class A fires and thus qualify for Class A:B:C ratings.

The Class A fire tests are conducted on wood cribs, wood panels and excelsior material as illustrated in Table 21. Class B fire tests are performed on square metal pans as summarized in Table 22. [39] Referring to Table 22, it can be seen that the numerical value of the B rating is 40% of the area of the fire test pan. This relationship was

[38] "Standard for Portable Fire Extinguishers – NFPA Standard 10," National Fire Protection Association, Quincy, MA: 1998.

[39] "UL Standard for Safety for Fire Extinguishers, Rating and Fire Testing of, UL 711," Fifth Edition, Underwriters Laboratories Inc., Northbrook, IL: (revised) June 2000.

established several years ago when it was determined through fire testing with novices that they could achieve extinguishment proficiency equal to 40% of that of a professional fire fighter doing the UL testing. That is, if a professional fire fighter could extinguish a fire 100 square feet in area with a given extinguisher, a novice using that same extinguisher could be expected to extinguish a fire no more than 40 square feet in area.

There is no rating for the Class C classification as the testing is limited to assuring that the agent stream is electrically non-conductive and hence safe for use around energized electrical equipment. An extinguisher with an A:B:C rating has successfully passed the fire tests for Class A fires, the fire tests for Class B fires and the electrical test required for the Class C listing.

Table 21: UL Class A Fire Test Objects

Rating	**Wood Crib Dimensions** (length x width x height) (inches)	**Wood Panel Dimensions** (width x height) (feet)	**Weight of Excelsior** (pounds)
1-A	20.0 x 20.0 x 15.0	8 x 8	6
2-A	25.6 x 25.6 x 19.5	10 x 10	12
3-A	30.8 x 30.8 x 21.0	12 x 12	18
4-A	33.4 x 33.4 x 22.5	14 x 14	24
6-A	38.4 x 38.4 x 25.5	17 x 17	36
10-A	47.5 x 47.5 x 27.5	17 x 17	Not required
20-A	62.3 x 62.3 x 36.5	Not required	Not required
30-A	74.6 x 74.6 x 36.5	Not required	Not required
40-A	87.1 x 87.1 x 36.5	Not required	Not required

Table 22: Flammable Liquid Arrangement for Class B Fire Test

Rating – Class	**Indoor or Outdoor Test**	**Pan Size** (square feet)	**Minimum Effective Discharge Time** (seconds)	**Commercial Grade Heptane Used** (gallons)
1-B	Indoor	2.5	8	3.3
2-B	Indoor	5.0	8	6.3
5-B	Indoor	12.5	8	15.5
10-B	Indoor	25.0	8	31.0
20-B	Indoor	50.0	8	65.0
30-B	Outdoor	75.0	11	95.0
40-B	Outdoor	100.0	13	125.0
60-B	Outdoor	150.0	17	190.0
80-B	Outdoor	200.0	20	250.0
120-B	Outdoor	300.0	26	375.0
160-B	Outdoor	400.0	31	500.0
240-B	Outdoor	600.0	40	750.0
320-B	Outdoor	800.0	48	1,000.0
480-B	Outdoor	1,200.0	63	1,500.0
640-B	Outdoor	1,600.0	75	2,000.0

8.1.3 End Users' Fire Protection Objectives

For the most part, the motivation to purchase hand portable fire extinguishers is for compliance with fire codes. In general, based on the type of occupancy, fire codes describe the hand portable fire extinguisher requirements in terms of (1) the rating of the extinguisher and (2) the number of extinguishers required based on the floor area of the facility and the maximum travel distance to an extinguisher.

Typical code language for the hand portable fire extinguisher requirements for a business occupancy might look like this:

> **Types of Fire Extinguishers Required -** The (blank) Fire Code requires fire extinguishers to be provided in all business occupancies to protect both the building structure and its contents. For this reason, extinguishers suitable for use on Class A, B and C fires must be provided. The minimum fire extinguisher rating acceptable for use in business occupancies is 2-A:10-B:C. Extinguishers with higher ratings may be used.
>
> **Distribution of Fire Extinguishers -** Three factors must be considered in determining the proper distribution of fire extinguishers: the floor area of the protected space; the maximum travel distance to a fire extinguisher; the location of extinguishers in relationship to normal paths of exit travel.
>
> a. In office areas, fire extinguishers with a minimum rating of 2-A:10-B:C shall be provided at the rate of one unit of "A" rating for every 3,000 square feet.
>
> b. In mercantile, service, and production areas, fire extinguishers with a minimum rating of 2-A:10-B:C shall be provided at the rate of one unit of "A" for every 1,500 square feet.
>
> c. In storage areas, fire extinguishers with a minimum rating of 4-A:40-B:C (usually 4-A:60-B:C are available) shall be provided at the rate of one unit of "A" rating for every 1,000 square feet.
>
> Extinguishers shall be located along normal paths of exit travel so that no part of the area protected is more than 75 feet from an extinguisher. Contact the Fire Department prior to occupancy for approval of number, location, and type of fire extinguishers to be installed.

From Table 20, it's clear that the end user, once required by the code to have a certain number of extinguishers with a minimum rating, has some choices. For an A:B:C extinguisher, he can use either (1) a halon 1211 unit, (2) an extinguisher with one of the new halocarbon agents or (3) a dry chemical extinguisher. In some jurisdictions, the end user will be allowed to meet the code requirements by using two extinguishers located side-by-side, a water extinguisher to meet the Class A requirement and a carbon dioxide extinguisher to deal with the B:C fires.

8.1.4 Product Features Necessary to Meet the Objectives

It is at this point that the end user is faced with making trade-offs between effectiveness of the extinguisher, cleanliness of the agent and cost of the extinguisher. Tradeoffs are necessary because, on an equal size basis, …..

- the clean agent extinguishers are the most expensive, …..
- the clean agent extinguishers have the lowest fire ratings, …..
- the dry chemical (not-very-clean) extinguishers cost the least and …..
- the dry chemical extinguishers have the highest fire ratings.

8.2 *Options for Prospective Owners of Portable Extinguishers*

End-users who 15 years ago would have purchased halon 1211 portable extinguishers to protect their facilities or equipment have three clear options today:

1. Use an "in-kind" halon 1211 alternative such as one of the new halocarbon agents or …..
2. Use two extinguishers to do the job done by the halon 1211 unit using water for Class A fires and carbon dioxide for Class B fires and those around electrically energized equipment or …..
3. Use a multipurpose dry chemical extinguisher where the agent residue can be tolerated.

8.2.1 Gaseous Agents for Portable Extinguishers

The list is shorter for replacements for halon 1211, with 7 gaseous agents on the SNAP list as shown in Table 23.

Table 23: Gaseous Alternatives to Halon 1211 [40]

Generic Name	Trade Name	Group	Chemical Composition
HCFC Blend B	Halotron I	HCFC+ Blend	Blend of $CHCl_2CF_3$, CF_4 and argon
HCFC Blend E	NAF P-IV	HCFC+ Blend	Blend of $CHCl_2CF_3$, CF_3CHF_2 and $C_{10}H_{16}$
HCFC-124	FE-24	HCFC	$CHClFCF_3$
HFC-236fa	FE-36	HFC	$CF_3CH_2CF_3$
HFC-227ea	FM-200	HFC	CF_3CHFCF_3
FC-5-1-14	CEA-614	PFC	C_6F_{14}

As with the agents for systems, not all of the gaseous alternatives on the SNAP list for streaming applications have achieved commercialization and, in fact, one (FC-5-1-14) has been discontinued by its manufacturer.

Table 24: Gaseous Streaming Agents - Progress Toward Commercialization

Generic Name	Trade Name	Step 1 EPA SNAP List	Step 2 NFPA Standard	Step 3 Component Listing	Step 4 Listing in a Portable Extinguisher
HCFC Blend B	Halotron I	X	X	X	X
HCFC Blend E	NAF P-IV	X			
HCFC-124	FE-24	X			
HFC-236fa	FE-36	X	X	X	X
HFC-227ea	FM-200	X	X	X	
FC-5-1-14	CEA-614	X	X	X	X

Table 24 is an illustration of the current status of the gaseous agents for portable fire extinguishers with the shaded boxes indicating the step has been achieved for the particular agent. With the discontinuance of FC-5-1-14, the only two remaining

[40] Technical Note#1, Revision 2, Halons Technical Options Committee, United Nations Environment Programme, available from Taylor/Wagner, Inc., 3072 – 5th Line, Innisfil, ON L95 4P7, Canada: March 1999.

halocarbon streaming agents used in hand portable extinguishers in the US are shown in bold type in Table 23, HCFC Blend B (Halotron I) and HFC-236fa (FE-36).

8.2.2 Other Agents for Portable Extinguishers

8.2.2.1 Dry Chemical

Conventional dry chemical extinguishers are available in two types: (1) ordinary dry chemicals, usually formulations based on sodium bicarbonate, are suitable for fires involving flammable liquids and gases; (2) multipurpose – also known as ABC - dry chemicals, usually formulations of ammonium phosphate, are suitable for use on fires of ordinary combustibles such as wood, paper and fabrics and fires involving flammable liquids and gases. Both ordinary and multipurpose dry chemicals may be safely used on fires where electrical circuits are present.

On a per pound basis, dry chemicals are the most effective fire extinguishing agents ever commercialized. The main shortcoming of the dry chemical agents is the fine, powdery residue left after discharge of the extinguisher. This residue, consisting of particles ranging down into sub-micron diameter, is difficult if not impossible to clean up. Dry chemicals should not be used around sensitive equipment and are best limited to use in areas where the residue is not an issue.

8.2.2.2 Carbon Dioxide

Carbon dioxide is, relatively speaking, a poor extinguishing agent when compared to the halons and dry chemicals. However, it has two advantages – one over each of its competitors. Compared to dry chemical, carbon dioxide is clean. Compared to halon and the new halocarbon alternatives, carbon dioxide is cheap. The agent and its extinguishers are unable to achieve a UL listing for Class A fires, thus its listings with UL are limited to B:C type fires.

As pointed out earlier, carbon dioxide extinguishers have achieved new prominence as half of a cost effective alternative to halon 1211 portable extinguishers. This is when the carbon dioxide extinguisher is deployed together with a 2-1/2 gallon water extinguisher to achieve the intent of the code requirements for 2-A:10-B:C rated extinguishers in jurisdictions that allow this approach.

8.3 Effectiveness Comparisons of Portable Extinguishers

The most equitable way to measure the fire extinguishing effectiveness of a portable extinguisher is to compare the ratings of different types of extinguishers with similar agent quantities (by weight). There are two ways of looking at this: (1) comparing halon 1211 to carbon dioxide and dry chemical and (2) comparing halon 1211 to the two commercialized halocarbon alternatives, HFC-236fa and HCFC Blend B.

8.3.1 Halon 1211, Carbon Dioxide and Dry Chemical Extinguishers

Table 25 is an illustration of the relative effectiveness of one manufacturer's ABC dry chemical extinguishers when compared to that manufacturer's now discontinued halon 1211 units. Included in the table are three carbon dioxide extinguishers. These fire ratings are typical of all manufacturers of hand portable extinguishers with these agents.

Table 25: Relative Effectiveness of Halon 1211, Carbon Dioxide and Dry Chemical Extinguishers[41]

Halon 1211*		Carbon Dioxide		ABC Dry Chemical	
Agent Charge	Rating	Agent Charge	Rating	Agent Charge	Rating
2.5	5-B:C			2.5	1-A:10-B:C
5.0	10-B:C	5.0	5-B:C	5.0	2-A:10-B:C
9.0	1-A:10-B:C	10.0	10-B:C	10.0	10-A:60-B:C
14.0	2-A:40-B:C	15.0	10-B:C	20.0	20-A:120-B:C

* The halon 1211 ratings are from Ansul Sentry extinguishers prior to the halt of production of these units.

In reviewing the table, it's clear that from a B:C rating standpoint, a 2.5 pounds ABC dry chemical extinguisher is as effective as a halon 1211 unit with 5 pounds of agent or a carbon dioxide extinguisher with 10 pounds of agent. From the standpoint of a Class A rating, an ABC dry chemical extinguisher with 2.5 pounds of agent has the same rating as a halon 1211 extinguisher with 9 pounds of agent. The carbon dioxide extinguishers are incapable of achieving any sort of Class A rating.

While the ABC dry chemical extinguishers are more effective than halon 1211 and carbon dioxide extinguishers, their use is limited to applications where an agent residue after extinguishment is not a significant problem.

8.3.2 Halon 1211 versus Halocarbon Alternatives

When comparing the fire ratings of the halon 1211 extinguishers to those of similar sizes using HFC-236fa and HCFC Blend B, the ratings illustrated in Table 26 indicate that the agents are in the same range of effectiveness. That is, a halon 1211 unit with 9 pounds of agent has the same rating as an HFC-236fa unit with 9.5 pounds of agent which has the same rating as an HCFC Blend B extinguisher with 11 pounds of agent.

When comparing the information in Table 26 for the next larger extinguisher units, it would suggest that halon 1211 is quite a bit more effective than the new halocarbon alternatives on Class B fires but with about the same effectiveness across the board on Class A fires.

Table 26: Relative Effectiveness of Halon 1211, HFC-236fa and HCFC Blend B Extinguishers

Halon 1211		HFC-236fa		HCFC Blend B	
Agent Charge	Rating	Agent Charge	Rating	Agent Charge	Rating
2.5	5-B:C	2.5	2-B	2.5	2-B
5.0	10-B:C	4.8	5-B	5.0	5-B
9.0	1-A:10-B:C	9.5	1-A:10-B:C	11.0	1-A:10-B:C
14.0	2-A:40-B:C	13.3	2-A:10-B:C	12.5	2-A:10-B:C

[41] "Fire Protection Equipment Directory," Underwriters Laboratories Inc., Northbrook, IL: December 2000.

8.4 Cost Comparisons for Portable Extinguishers

Earlier it was pointed out that in addition to the cleanliness and effectiveness of the extinguisher, a parameter that everyone takes into consideration is the relative cost of the various extinguishers. The information in Table 27 is an illustration of these costs to an end user for a range of extinguishers.

Table 27: Cost Comparisons for Portable Extinguishers

Type	Agent Charge	Fire Rating	Price Range** ($)	Average Selling Price*** ($)
Halon 1211*	9.0 pounds	1-A:10-B:C	145 – 180	163
Halon 1211*	14.0 pounds	2-A:10-B:C	195 – 250	223
ABC Dry Chemical	**5.0 pounds**	**3-A:40-B:C**	**25 – 35**	**30**
HFC-236fa	9.5 pounds	1-A:10-B:C	270 – 385	328
HFC-236fa	**13.3 pounds**	**2-A:10-B:C**	**360 – 625**	**493**
HCFC Blend B	11.0 pounds	1-A:10-B:C	235 – 300	268
HCFC Blend B	**12.5 pounds**	**2-A:10-B:C**	**350 – 480**	**415**
Carbon Dioxide	**10.0 pounds**	**10-B:C**	**140 – 210**	**175**
Carbon Dioxide	15.0 pounds	10-B:C	160 – 250	205
Water	**2-1/2 gallons**	**2-A**	**55 – 70**	**63**
Water Mist	2-1/2 gallons	2-A:C	105 – 150	128

*The halon 1211 price information is from 1993 before the halt of production of new halon 1211.
**The price range reflects the differences in selling prices offered customers who buy one extinguisher at a time (high price) versus contractors that buy hundreds at a time (low price) for a new building.
***The average selling price in the table is merely the mean of the two numbers in the range without regard to the distribution within the range.

From a fire code standpoint, the most commonly specified extinguisher is one with a 2-A:10-B:C rating. Referring to the units in bold type in Table 27, end users have a choice of using the 5 pounds ABC dry chemical unit for an average end user cost of $30 each, the 13.3 pounds HFC-236fa unit for $483, the 12.5 pounds HCFC Blend B unit for $415 or employing both a 10 pounds carbon dioxide unit and a 2-1/2 gallons water extinguisher with a combined average end user cost of $238. This is compared to a cost of $223 for an equivalent rated halon 1211 unit prior to 1994 when they were still being manufactured.

History has shown that a large portion of the market place was willing to pay a cost multiple over 7 times to get a clean agent halon 1211 unit versus a not very clean dry chemical extinguisher ($223/30=7.43). With the two new halocarbon agents, that cost multiple is in the range of 13 to 16 and it's becoming obvious in the market place that most people are just not willing to pay that premium.

Industry consensus is the hope that the market for halocarbon type clean agent extinguishers will grow to approximately 20% of the previous halon 1211 market size. The other 80% of the unit demand will be filled by (1) dry chemical extinguishers where a clean agent is not ***absolutely*** required or (2) by carbon dioxide units where a clean agent is required.

8.5 The Transition to Alternatives

In general, the adaptation to alternatives to halon 1211 has proceeded quite well with most market segments fairly well adjusting to the new (halocarbons) and the old (carbon dioxide, water, dry chemical) alternatives. There's no suggestion – even anecdotal – that the level of protection afforded by the alternatives is creating a further risk to loss of life or property from fire.

What is likely to happen is an increase in damage to surroundings (sensitive equipment) as some people reject the very expensive halocarbon alternatives and try to get by with the use of dry chemical extinguishers in areas demanding cleanliness. However, this appears to be a matter of education and given enough time applications requiring clean agent extinguishers will be served by that type and those areas that can tolerate the agent residue will be served by dry chemical extinguishers.

What will not happen will be a repeat of the somewhat frivolous employment of the halocarbon extinguishers into areas where cleanliness is not an absolute necessity. Much of this went on with halon 1211 where the end users were not discriminating enough in the use of that type of agent. It is expected that the high cost of the halon alternatives will continue and will assure that they are used only where they are needed.

The commercial aviation segment is not adapting too well to the idea of employing alternatives for its on board halon 1211 hand portable extinguishers. The FAA and the International Aircraft Systems Fire Protection Working Group (IASFPWG) have worked for years to develop the minimum performance standards [42] for handheld extinguishers to replace the halon 1211 units. While the industry is being encouraged by both the FAA and the EPA to do the right thing from the standpoint of the environment, the belief in the industry is that as long as halon 1211 is available the aircraft operators and manufacturers will not willingly move to non-ozone depleting alternatives. At this stage, it's apparent that all alternative agents being considered will end up with an extinguisher (1) weighing more, (2) taking up more space and (3) costing more than the halon 1211 units. In the chronically economically troubled commercial aviation segment, any one of those three reasons would appear to be enough to keep the initiative from moving ahead.

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[42] "Minimum Performance Standards For Handheld Fire Extinguishers As A Replacement For Halon 1211 On CivilianTransport Aircraft." FAA Draft, Revised April 2000.

Appendix A - Peer Reviewers' Statements

March 12, 2002

Ms. Bella A. Maranion
Program Analyst
Alternatives and Emissions Reduction Branch
Global Programs Division, Office of Atmospheric Programs
Office of Air and Radiation
U.S. Environmental Protection Agency
1200 Pennsylvania Avenue, N.W. (mailstop 6205J)
Washington, DC 20460-0001

Dear Ms. Maranion:

I have reviewed the final draft dated March 6, 2002, of the report by Bob Wickham entitled "Status of Industry Efforts to Replace Halon Fire Extinguishing Agents." I concur with the report.

The report is very thorough and well written. It reflects a great deal of research into relevant facts and background information. I believe that all findings and conclusions are well substantiated.

Thank you for the opportunity to serve as a peer reviewer.

Sincerely,

(by email)

Robert L. Darwin, P.E.
Senior Engineer
Hughes Associates, Inc.
3610 Commerce Drive
Baltimore, MD 21227

David V. Catchpole

12831 Huffman Circle
Anchorage
Alaska 99516
Telephone: (907) 868-3911
Facsimile: (907) 868-3911
E-mail: dcatchpole@gci.net

March 16, 2002

Ms. Bella A. Maranion, Program Analyst
Alternatives and Emissions Reduction Branch
Global Programs Division, Office of Atmospheric Programs
Office of Air and Radiation
U.S. Environmental Protection Agency
1200 Pennsylvania Avenue, N.W. (mailstop 6205J)
Washington, DC 20460-0001

Dear Bella:

Reference: Status Of Industry Efforts To Replace Halon Fire Extinguishing Agents

Thank you for the opportunity to review and comment on the referenced document. My comments are as follows:

In general I found this report to be a well-written and balanced assessment of the current situation regarding efforts to replace halon extinguishing agents in the USA. The report is clear and informative and the author obviously thoroughly researched a difficult subject matter. I believe that the report will be a useful reference document.

Once again, thank you for the opportunity to review this report, and I look forward to seeing the final version.

Sincerely,

(by email)

Dave Catchpole

harrington group
Engineering Firesafety Solutions

Jeff L. Harrington, P.E.

James M. Rucci, Jr., P.E

March 15, 2002

Ms. Bella Maranion
US Environmental Protection Agency
1200 Pennsylvania Avenue, NW
(Mailcode 6205J)
Washington, DC 20460

Re: Halon Industry Report
Peer Review Comments

HGI # NFPA2001:

Dear Bella:

I have had a chance to review the report entitled "Status of Industry Efforts to Replace Halon Fire Extinguishing Agents" written by Bob Wickham and would like to share my impressions with you.

First let me emphasize that the world of halon and halon replacements is a broad one. My expertise is relevant to certain portions of this world, but certainly not all of it.

I agree with Bob's central conclusions. I feel his report is extremely thorough and comprehensive. It appears to address all of the important aspects of this broad subject. He addresses all issues clearly and concisely, without sugar coating or putting a spin on certain issues that the industry may not be so proud of. This was refreshing to see.

From my limited perspective, this report seems to be well researched, unbiased, thorough and comprehensive.

Sincerely,

Harrington Group, Inc.

Jeff L. Harrington
President

3055 Breckinridge Blvd. / Suite 310 / Duluth, GA 30096-7562 / (770) 564-3505 / (770) 564-3509 Fax
www.hgi-fire.com
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