REVIEW OF THE USE OF CARBON DIOXIDE TOTAL FLOODING FIRE EXTINGUISHING SYSTEMS

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August 8, 2003

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Preface

In March 2002 the Military Sealift Command (MSC) had a fatal accident[1] involving a carbon dioxide total flooding fire extinguishing systems on its ship CAPE HORN.[2] This followed another carbon dioxide total flooding fatal accident on a MSC sister ship, CAPE DIAMOND, in 1993.[3] Each of those accidents caused the deaths of two persons.

The time has come to re-examine the practice of using carbon dioxide total flooding systems in normally occupied spaces. This report considers the use of these types of systems in both the industrial and marine markets. Due to the considerable increase in the use of carbon dioxide systems over other available systems in the marine sector, this report makes a special focus on the use of these types of systems in manned machinery spaces on merchant ships.

In the preparation of this report, I was able to interview over 70 people who have specific knowledge and often times strong opinions on the subject of the use of carbon dioxide total flooding systems. The contributions of these experts 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.

During the peer review process, several additional subjects were suggested. These included a discussion of mandatory discharge testing for carbon dioxide systems, assessments of reliability of carbon dioxide systems and the consideration of employing detection and alarm systems only in lieu of carbon dioxide systems. These subjects were considered beyond the scope of this report and are not included.

Five peer reviews were received and four were in agreement with the report. One reviewer had reservations regarding nuanced language or emphasis but did dispute the process of arriving at conclusions in the report without the performance of a very broad-based risk-benefit analysis. In response to this minority view, the report has been changed to reflect the reviewer's concerns regarding emphasis.

The minority reviewer's comments on risk-benefit focused on the point that there are both reasonable and unreasonable exposures to injury or death and that an expansive risk benefit analysis should be performed to establish which is the case for carbon dioxide total flooding systems compared to other industrial equipment use. This comment was rejected and the following explanation[4] for that rejection was provided to the minority reviewer:

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[1] Cole, William, "Suffocation Likely In Ship's Two Fire Deaths," *Honolulu Advertiser,* April 3, 2002.

[2] The CAPE HORN is owned by the United States as part of the Ready Reserve Force, a fleet of more than 90 vessels capable of transporting on short notice military cargo, fuel, equipment, munitions, and other supplies in support of military forces. These ships are under the operational control of the United States Navy's Military Sealift Command.

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

[4] Letter from Ms. Bella Maranion to the minority reviewer, United States Environmental Protection Agency, Washington, DC: July 14, 2003.

> “In most risk benefit analyses, both the risk and the benefit accrue to the same party. In all of your examples of “drive a car rather than use public transportation, live in a high rise building rather than a single level house, purchase and store various poison chemicals in the household, ….” the beneficiary of the risk has been the risk-taker him/herself.
>
> In the case of carbon dioxide systems, the beneficiary of the risk and the risk taker are nearly always different parties. The decision to employ carbon dioxide systems is never made by those who are ultimately exposed to the danger of death or injury. Instead it is made by the owner or owner’s representative and it is to the owner that the benefit of a cost savings accrues. In this case, it is the workers or other persons exposed to the possibility of an accidental discharge of the carbon dioxide system who assume the risk.
>
> This is why it is a public safety issue. We have one segment of society (owners, owners’ representatives, etc.) making decisions to use carbon dioxide systems in instances that needlessly expose an entirely different group of people. Thus I am afraid that the only conclusion a risk-benefit analysis would reach is that – from a public safety standpoint – the balance between the risk and the benefit lies heavily or even entirely on the risk side.”

Several manufacturers provided engineering and cost information on their agents and systems that served as the basis for the comparisons of alternatives in this report. I would like to acknowledge the following manufacturers for their input, without which the comparisons could not have been made:

- 3M Performance Chemicals, St. Paul, Minnesota
- Ansul Fire Protection, Marinette, Wisconsin
- Dupont Fluoroproducts, Wilmington, Delaware
- Fogtec Fire Protection, Hamburg, Germany
- Great Lakes Chemical Corporation, West Lafayette, Indiana
- Kidde-Fenwal, Inc., Ashland, Massachusetts
- Marioff Corporation Oy, Vantaa, Finland

Most of all, I would like to thank the peer reviewers who spent countless hours on this report. I appreciate the time they took to review and comment on the report and the nearly unanimous support of the contents and conclusions:

- David V. Catchpole of Petrotechnical Resources Alaska[5]
- Robert Darwin, P.E. of Hughes Associates, Inc.
- Jeffrey L. Harrington, P.E. of the Harrington Group, Inc.
- Normal W. Lemley, P.E. of the Center for Maritime Leadership, Inc.
- Thomas Wysocki of Guardian Services, Inc.

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[5] In addition, I would like to acknowledge the contribution of two of Mr. Catchpole’s associates in the peer review process. Richard Coates of BP and Niall Ramsden of Resource Protection International provided valuable input and I appreciate their efforts as well.

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1 Introduction

In 2000, the US Environmental Protection Agency (EPA) published a report[6] on the risks of carbon dioxide systems which enumerated many of the injuries and deaths associated with carbon dioxide total flooding extinguishing systems used in industrial and marine fire protection applications. That same report made special note of the fact that the marine industry had the most injuries and fatalities from these systems.

The deployment of new carbon dioxide systems began to decline with the increase in commercial acceptance[7] of halon 1301 systems in the early 1970s. Over the next two decades, halon 1301 became the system of choice for many industrial fire protection applications and for new ships and boats. One important reason was that the halon 1301 systems cost less than carbon dioxide systems. In addition to cost, halon 1301, at the concentrations used for effective extinguishment, was not lethal to persons in the protected spaces.

In the late 1980s and early 1990s, the problem of depletion of the stratospheric ozone layer was recognized, the Montreal Protocol was ratified, and the Clean Air Act in the U.S. required the production phase-out of halons, a potent ozone-depletor. Many in the fire protection industry thought this situation did not pose a problem as a whole portfolio of alternatives was available ranging from halocarbons, inert gases, water mist and aerosol extinguishing agent systems. The industry focused its efforts on both commercialization of the alternatives and developing the necessary standards and test protocols to provide guidelines for the safe use of the new agents.

To support the U.S. transition away from halons, the US EPA developed the SNAP[8] list which served as a vehicle to provide guidance to the public about the human health and environmental effects of the alternative total flooding agents and any conditions for use such as suitability for use in normally occupied or limited to use in normally unoccupied spaces.[9] The distinction between the two is rather conservative, but those agents that failed to achieve the approval for use in normally occupied spaces invariably ended up on the trash pile of abandoned agents.

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

[7] "Guide to Fixed Fire Fighting Equipment Aboard Merchant Vessels, Change 1: Halon Systems," Navigation and Vessel Inspection Circular NVIC 6-72, U.S. Coast Guard, Washington, DC: August 22, 1972.

[8] "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. 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.

[9] The NFPA Glossary of Terms (available at http://www.nfpa.org/PDF/definitions.pdf?src=nfpa) defines "occupiable area," "occupiable story" and "unoccupied building." However, those terms are used individually in three different standards (NFPA 72, 101B and 1124 respectively), so a clear differentiation is not obvious. The draft standard for aerosol extinguishing systems (proposed NFPA 2010) has provided the following side-by-side definitions: *Normally Occupied*: An area or space where, under normal circumstances, persons are present. *Normally Unoccupied*: An area or space not normally occupied by people but which may be entered occasionally for brief periods. *Unoccupiable*: An area or space which cannot be occupied due to dimensional or other physical constraints.

Little did we know at that time that one of the agents that would play a significant role as a halon alternative would be carbon dioxide. Carbon dioxide is in fact on the SNAP list as a suitable alternative to halons in total flooding applications. Unlike other agents that may have “use conditions” or “narrowed use limits” attached, there are no restrictions on carbon dioxide. However, the EPA obviously does recognize the dangers of the use of carbon dioxide when they published the previously cited report on its risks and specifically pointed out …..

> “Appropriate precautions must be taken before switching to carbon dioxide systems and with this report EPA attempts to raise awareness and promote the responsible use of carbon dioxide fire suppression systems.”

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 advisability of the use of carbon dioxide total flooding systems in normally occupied spaces. This report considers the use of carbon dioxide systems in the industrial and marine markets with a special focus on the growing use in this latter market.

Specific goals of the report are:

- Provide an overview of past and current experience with carbon dioxide total flooding systems with a focus on the life safety aspects of their use.
- Outline the relevant regulations and standards that provide guidance on the safe employment of carbon dioxide total flooding systems.
- Develop comparisons of carbon dioxide with other halon alternatives to include consideration of system weight, system space requirements and system costs.
- Provide a discussion of issues related to changes in use conditions for carbon dioxide total flooding systems.
- Provide specific recommendations on the need for use conditions, if any, and the nature of those use conditions.

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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 and systems – including carbon dioxide and the alternatives to carbon dioxide.

Table 1 is an illustration of the affiliations and the number of interviewees who were consulted for their views on the subject of the use of carbon dioxide systems.

Table 1: Interviewees for this Report

Affiliation of Interviewee	Number of Interviewees in this Category
Architect or Engineering Firm	8
Associations & Societies	13
End User	16
Federal Regulator	10
Fire Extinguishing Agent Manufacturer	6
Fire Extinguishing Systems Installer	3
Fire Extinguishing Systems Manufacturer	11
Fire and Accident Statisticians	6
Insurance Industry	3
TOTAL	76

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4 Conclusions

4.1 Personnel Safety

- The number of injuries and deaths from carbon dioxide total flooding systems are well known. The obvious proliferation of total flooding carbon dioxide systems at rates heretofore unseen in the marine market will certainly result in a directly proportional increase in injuries and deaths from this agent.
- When viewed individually, the reported accidents involving carbon dioxide total flooding systems could each be rationalized as unfortunate but somehow unrelated events. However, looking at the record of carbon dioxide systems in total, (even with incomplete information) it is difficult to accept that enough is being done to protect the public.
- With the exception of the US EPA and the US Coast Guard, there is not another standards making organization or regulatory body, nationally or internationally, that has done anything of substance to reduce the incidents of death and injury caused by carbon dioxide systems.
- It is technically indefensible that standards and regulatory organizations employ rigorous review standards to assure that the new halon alternatives (including halocarbons, inert gases and aerosols) are safely employed in normally occupied spaces while seemingly relegating a lower level of scrutiny to the use of carbon dioxide systems <u>at lethal</u> <u>concentrations</u> in spaces where personnel may be exposed.
- The fundamental fact remains that carbon dioxide is inherently lethal – accidental discharges of carbon dioxide total flooding systems can kill <u>and have killed</u>.

4.2 Performance

- Unquestionably, the advent of total flooding systems in general (halons, carbon dioxide, halocarbons, inert gases, aerosols, and water mist) have truly benefited society by saving untold numbers of lives and property over the last half century and continuing to perform this service today.
- Contrary to widely held beliefs within the industry that carbon dioxide systems are unique and cannot be replaced by other systems, the facts are that there are several extinguishing agent systems that perform as well as or better than carbon dioxide in the most frequent applications.
- In the absence of carbon dioxide, no technical reason exists to forestall testing of many of the already commercialized alternatives to service those few applications where carbon dioxide today seems to be the exclusive solution in some industrial applications.

4.3 Training

- As the most frequent cause of accidental discharges of carbon dioxide systems involve maintenance activities on or around the carbon dioxide systems, training for maintenance and service people must be emphasized and consistently employed to stress the dangers of these systems.

- At the same time, training does not seem to be a high priority for many of these organizations as funding for this type of activity is difficult to secure, especially when compared to all the other discretionary spending needs of an organization.
- In the marine sector, training is an especially difficult issue due to continuing concern being expressed, and not just by unions, about the effect of the reduction in crew sizes and the resultant reduction in the combined knowledge and expertise of the crews.

4.4 Cost

- The cost of the alternatives compared to carbon dioxide systems are a real barrier to acceptance. The most cost-effective alternative systems range between 55% to 65% more than the cost of carbon dioxide systems. Other alternative systems cost as much as 130%+ more than the carbon dioxide systems.
- The cost difference between the carbon dioxide systems and the alternatives is exacerbated by the fact that carbon dioxide systems cost anywhere between 100% and 180% more than halon 1301 systems which carbon dioxide is replacing in the marine sector.

4.5 Alternatives

- The choice of a fire suppression flooding system is based on several factors. In the case of carbon dioxide systems, cost apparently eclipses all other considerations to the detriment of sound safety and performance decisions.
- In the marine sector, the shipowners, classification societies, shipyards, architects and regulators report there are (1) too many alternatives for them to sort through, (2) too much negative information being spread about competitive products and (3) too little energy by the fire protection industry to provide what the marine sector needs: <u>a safe, cost-effective replacement for halons and, by default, carbon dioxide systems</u>.
- The review of the new alternatives incorporates the latest scientific knowledge and technological expertise on safe human exposure, environmental effects and system performance to determine appropriate applications and restrictions on applications of these systems. The same rigor has not been applied to carbon dioxide systems.

4.6 Technology

- The output of research and development efforts to provide alternatives to halon 1301, and by inference carbon dioxide, have met the safety, fire protection and environmental goals but have completely missed the cost goals for the majority of users, especially in the marine sector.
- The level of effort going into developing alternatives technologies to carbon dioxide and halon 1301 must be intensified, both in the search for new chemical based agents and/or the development of more cost-effective agent storage and delivery systems for naturally occurring agents such as water and inert gases.

4.7 Use Controls

- The notion of use controls on carbon dioxide total flooding systems would receive the support of some and opposition from many. There are also significant numbers of those who are undecided or have not expressed an interest in the subject.
- Those who would oppose use controls generally have an economic stake in the matter. As a group they dislike carbon dioxide systems, but they have an even greater dislike for the costs of the alternative systems. For many, the opposition would disappear with a solution to the cost problem.

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5 Recommendations

5.1 Use Conditions

Based on historical data of use and current industry practices and priorities, carbon dioxide total flooding systems should be subjected to the same use limitations imposed on the agents contained in NFPA Standard 2001[10], ISO Standard 14520[11] and IMO MSC Circular 848.[12]

These standards incorporate the most current information and scientific knowledge on safe human exposure, environmental impacts and system design and performance as recognized in the various sectors of use in the fire protection industry. These standards and regulations define current industry practices to assure the highest level of safety for the use of fire suppression agents.

To adopt a consistent level of safety, the following restriction should be placed on the use of carbon dioxide systems in all standards and regulations:

> Carbon dioxide total flooding systems shall not be used in normally occupied areas.

5.2 Approach

While the EPA's options are numerous, ranging from public education up through direct regulation, it is recommended that the EPA support the adoption of the suggested use restriction through the consensus standards' making process of the National Fire Protection Association (NFPA).

The EPA has demonstrated, through its direct participation in several NFPA technical committees, that the agency works well within the framework of this standards making organization to support the work of these committees related to issues of environmental protection and public safety. The introduction of this subject has been made with a proposal to NFPA that NFPA 12[13] be modified to prohibit the use of carbon dioxide total flooding systems in spaces that are normally occupied. (See Appendix H).

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

[11] "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.

[12] "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.

[13] "NFPA 12 - Standard on Carbon Dioxide Extinguishing Systems – 2000 Edition," National Fire Protection Association, Quincy, MA February 2000.

6 Background

6.1 History of Carbon Dioxide Fire Extinguishing Systems

Carbon dioxide systems have been in use since the early 1900's and in the late 1920's work began on the first NFPA standard describing the use of these systems. From that point until the late 1960's, carbon dioxide was for all practical purposes the only gaseous extinguishing agent in wide commercial use. It was during that time period that society apparently became accustomed to the notion that employing a fire extinguishing system with inherent serious life safety consequences was nothing more than a trade-off and well worth the risk in light of the fire protection benefits derived.

In the early 1970's carbon dioxide total flooding systems somewhat fell from favor with the introduction of the halons, and specifically halon 1301 systems. Halon 1301, with its inherent life safety characteristics coupled with the fact that the new systems were less expensive than high pressure carbon dioxide systems, virtually left carbon dioxide fewer and fewer places to be applied. During the period of the early 1970's until the late 1980's, the use of carbon dioxide systems was relegated to applications where (1) halon 1301 was clearly inappropriate or where (2) the promoters of halon 1301 chose not to market that agent. The most obvious of these were local application systems, an area never seriously pursued with halon 1301; applications with a deep seated Class A fire potential, like shipboard cargo holds; and applications where decomposition of halon 1301 would be problematical, like in ovens. Another area virtually reserved for carbon dioxide in that time frame were applications than needed so much agent that refrigerated, bulk storage, low pressure carbon dioxide systems were the economical choice.

In general, a good rule of thumb was if you are going to experience a lot of system discharges, it was wiser to invest in a carbon dioxide system where the cost of recharge was much less that that of a halon 1301 system. Otherwise, if the fire extinguishing system was employed to protect high value hazards with a low probability of fire, the lower initial cost, safer halon 1301 system became the preferred selection.

With the 1994 production and import ban on newly produced halons and even with the introduction of new halon alternatives, we have seen an increase in the use of carbon dioxide fire extinguishing systems, especially in the marine market. The resurgence in the use of carbon dioxide in the marine market is very visible since shipbuilding is a huge market for fire protection systems and the procurements and buying preferences are apparent. In other markets, such as industrial and commercial, changes in carbon dioxide system preferences and usage is not that obvious.

6.2 Carbon Dioxide Performance in Marine Systems

In trying to quantify the historical performance of carbon dioxide systems, it was found that statistics are just not available. However, it was possible to derive a sense of the performance by looking at the marine market and searching the Lloyd's List casualty archive[14] for shipboard engine room incidents of fire involving carbon dioxide systems.

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[14] The Archive is a source for marine casualty information on the web. It contains complete record of all reports in Lloyd's List Casualty Page since January 1991. The search engine offers a number of tools to work across the full text of the casualty database and can be accessed at http://www.lloydscasualty.com

The search covered the period from January 1991 through November 2002 and identified 56 articles describing the same number of fire incidents within the scope of the search parameters. Some of the articles were better than others with respect to providing meaningful information. Table 2 is an illustration of the information derived from the articles. Appendix A contains an expanded table summarizing the individual incidents.

Table 2: Search Results Shipboard Engine Room Fires and Carbon Dioxide Systems
(January 1991 through November 2002)

System Performance	Number of Incidents	Comments
Successful	39	The carbon dioxide system successfully extinguished the engine room fire.
Unclear	5	The articles mentioned that the carbon dioxide system was employed but never described the outcome
Irrelevant	4	While these articles were picked up in the search, the systems involved were actually water mist and halon, halon and foam and halon alone, all of which operated successfully.
Unacceptable	8	The performance of the carbon dioxide system was unacceptable either because it was not able to be discharged or the system failed to extinguish the fire once it was discharged.

In reviewing the information in Table 2, unless the Lloyd's List casualty archive misses most or even many of the engine room fires and related carbon dioxide system releases, 56 discharges of engine room systems over a period of 12 years is less than five per year.

6.3 Health Risk

During the research for this study it was surprising to find how many people were misinformed about the range and extent of adverse health effects of exposure to large concentrations of carbon dioxide. Many believe that the cause of injury and death was a simple matter of hypoxia (reduced oxygen) similar to what one would expect with an inert gas (nitrogen, argon or blends of the same). In fact, carbon dioxide is anything but inert. It is toxic and it causes injuries and death by interfering with the functions of the central nervous system.

6.4 Adverse Health Effect

Table 3 illustrates the progressive adverse health effects from exposure to increasing levels or ranges of carbon dioxide. Since most carbon dioxide total flooding systems are designed to produce concentrations ranging upwards from 34%, it is clear that carbon dioxide is lethal far below the concentrations employed in total flooding fire extinguishing systems.

Table 3: Acute Health Effects of High Concentrations of Carbon Dioxide[15]
(With Increasing Exposure Levels of Carbon Dioxide)

Concentration (% Carbon Dioxide/Air)	Time	Effects
2%	Several hours	Headache, dyspnea upon mild exertion.
3%	1 hour	Dilation of cerebral blood vessels, increased pulmonary ventilation, and increased oxygen delivery to the tissues.
4 – 5%	Within a few minutes	Mild headache, sweating and dyspnea at rest.
6%	1 – 2 minutes <16 minutes Several hours	Hearing and visual disturbances Headache and dyspnea Tremors
7 – 10%	Few minutes 1.5 minutes – 1 hour	Unconsciousness or near unconsciousness. Headache, increased heart rate, shortness of breath, dizziness, sweating, rapid breathing.
10 - 15%	1+ minute	Dizziness, drowsiness, severe muscle twitching and unconsciousness.
17 – 30%	< 1 minute	Loss of controlled and purposeful activity, unconsciousness, convulsions, coma and death.

6.5 *Accident Record*

The accident record of carbon dioxide systems through 1999 is fairly well documented in the US EPA report previously cited. However, in that report, the following cautionary statement was made about the completeness of the data, which clearly implies that there are more - rather than fewer - accidents than those reported ….

> "Although a comprehensive review was performed, it should be noted that data developed through this process may be incomplete because: 1) additional sources of data may be difficult to uncover (e.g., international incidents), 2) records are incomplete, 3) agencies are not required to report, 4) anecdotal information is sketchy and difficult to verify, and 5) fire-related deaths due to CO2 are generally not well documented."

In any case, the EPA report describes a total of 62 incidents resulting in 119 injuries and 152 fatalities broken out into two time periods as shown in Table 4. It is probably not useful to compare the post 1975 values with those of pre-1975 as the information, at best, can be considered "incomplete" and "very incomplete," respectively.

Table 4: Death And Injury Incidence Reports[16]
(Associated With Carbon Dioxide Total Flooding Fire Extinguishing Systems)

Period	Incidents	Deaths	Injured
Pre 1975	11	47	7
1975 – 1999	51	72	145
Total	**62**	**119**	**152**

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

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

Of the 51 incidents during the period of 1975 through 1999, there was enough information on 35 incidents to broadly categorize their causes or circumstances. Table 5 is an illustration of the general circumstances surrounding these accidents, clearly illustrating that maintenance activities – either on the system or in the vicinity of the system – are most associated with these incidences of system discharges.

Table 5: Causes of Injuries and Deaths Associated with Carbon Dioxide Discharges[17]
(1975 - 1999)

Type Discharge	Circumstances	Incidents	Deaths	Injured
Accidental	During Maintenance on the CO2 System	9	8	10
	During Maintenance near the CO2 System	8	19	19
	During Testing	1	2	6
	During Fire Situation	2	10	7
	Faulty Component or Installation	2	4	13
	Operator Error	2	1	4
	False Alarm	2	1	15
Intentional	During Testing or Training	3	2	2
	During Fire Situation	5	15	8
	False Alarm	1	2	1
	Total	**35**	**64**	**85**

6.6 *Recent Accidents*

In the preparation of this report, many inquiries were made to identify additional carbon dioxide total flooding system incidents resulting in death or injury. The same observations as made in the EPA report are made here, about the difficulty of identifying and confirming accidents from official sources. Further, in the US, it seems that there is a significant lag in time between the date of an incident and the time that it appears in an official data base managed by OSHA, the USCG or some other agency.

Notwithstanding that, Table 6 is a listing of several additional accidents that have occurred in North America since the publication of the EPA report.

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

Table 6: Additional Death And Injury Incidents in the US and Mexico
(Associated With Carbon Dioxide Total Flooding Fire Extinguishing Systems)

Event Date	Source	Deaths	Injuries	Summary
07/27/2000	OSHA Technical Information Bulletin 12/22/2001	1	0	"…. an employee of a securities firm died from CO2 intoxication. The employee was inside the vault with the vault door closed and locked. When the employee pulled a manual fire alarm actuation device that was located inside the vault space, it activated the warning alarm and the total flooding CO2 system."
02/20/2002	Mr. Donald Murray Ansul 03/31/2003	2	multiple	A carbon dioxide system prematurely connected and manually discharged in error by workers aboard a ship at the Mexican Navy Shipyard in Salina Cruz Oaxaca Mexico. The engine room was occupied at the time by many workers as ship was being overhauled.
03/31/2002	Honolulu Advertiser 04/03/2002	2	0	Two civilian crew members died on the 750-foot Ready Reserve Force ship Cape Horn from apparent suffocation when a fire was put out in the engine room, officials said. "The possibility is that it may have been as a result of a fire suppression system ….. The suppression systems replace oxygen with carbon dioxide to smother a fire."
01/19/2003	Associated Press 01/31/2003	2	0	"A couple found dead aboard their docked 58-foot yacht apparently suffocated when a fire suppression system was accidentally set off, using up all the oxygen in the yacht. Marine experts have determined that John Robertson, a leg amputee who wasn't wearing his prosthesis, fell and grabbed a wire that triggered the carbon dioxide powered fire - suppression system. Andreija was overcome by lack of oxygen when she probably tried to rescue her 260-pound husband. The couple was cleaning the yacht's engine room and had begun painting it when the accident happened, police said."

A request to many contacts around the world to document accidents with injuries and / or deaths from total flooding carbon dioxide systems resulted in input only from associates in Japan. In its 2000 report, the US EPA had listed 7 accidents resulting in 4 deaths and 14 injuries in Japan. The recent request for any new or additional information produced a report of another 4 accidents in Japan resulting in 3 deaths and 11 injuries. That information is illustrated in Table 7.

With his report of the accidents, Mr. Matsuo Ishiyama[18] made the following comment which would suggest that there are many more accidents that fortunately did not result in deaths or injuries:

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[18] Matsuo Ishiyama is an advisor to Nohmi Bosai Ltd., a leading fire detection, controls and extinguishing systems manufacturer in Japan. He is also an advisor to the Japan Fire Extinguishing Systems Manufacturer's Association and is a member of the Halons Technical Options Committee (HTOC) of the United Nations Environment Programme (UNEP).

> "I also think more accidents have occurred than this, but we have no specific knowledge of them. Mr. Yamada[19] told me that he has a record of 28 additional accidents without casualties for the same period of time. And, he presumed that there should be at least a total of 100 accidents in Japan in the same period."

Table 7: Additional Death And Injury Incidents in Japan

(Associated With Carbon Dioxide Total Flooding Fire Extinguishing Systems)

Event Date	Source	Deaths	Injuries	Summary
05/08/1997	Mr. Nobuo Yamada Koatsu Co. 04/03/2003	0	4	4 company employees were injured from CO2 intoxication while they were working inside the coating booth. The cause of the accidental discharge was reported as a short circuit of the actuation line of the CO2 system installed, due to the old and deteriorated system's wiring
10/07/1998	Koatsu Co. & JFESMA[20] 04/03/2003	0	7	7 repair workers were injured from CO2 intoxication while they were working inside of the transformer substation. A worker inadvertently cut off the fire detector's wiring during the repair work of the substation ceiling, which caused the CO2 system actuation and gas discharge.
07/05/2001	Mr. Matsuo Ishiyama Nohmi Bosai 04/03/2003	1	0	In a self-operation type car parking garage building, one person who did not see the other man was still inside of the car within the lift of the garage, was going to operate the lift to take his car out. Then, he saw the man there and rushed to try to stop the lift operation. All in a fluster, he pushed the actuation button of the CO2 system by mistake. The man inside of the lift was killed from CO2 intoxication.
01/22/2003	Koatsu Co. & JFESMA 04/03/2003	1	0	A maintenance company worker was killed from CO2 intoxication during the maintenance work of CO2 system in the car parking garage of an apartment house. This system was designed to actuate automatically when two detectors of different types were placed under operation. The worker did not shut off the actuation valve and placed both detectors in operation for testing the fire detectors performance. The discharged CO2 killed the worker who failed in evacuation.

While the United States and Japan are the #1 and #2 ranked industrialized nations in the world, it would be extremely improbable that those two countries, together with Mexico, are the only countries to have had accidents with carbon dioxide extinguishing systems in recent years. Thus, once again, it must be pointed out that the reporting is incomplete and the probability that there are additional deaths and injuries from total flooding systems is approaching certainty.

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[19] Mr. Nobuo Yamada is the Technical Director of Koatsu Co. Ltd. and is a member of the Japanese delegation to the Equipment for Fire Protection and Fire-Fighting Committee of the International Standards Organization.

[20] Japan Fire Extinguishing Systems Manufacturer's Association.

6.7 *Accident Focus and Reporting*

There are two notable carbon dioxide accidents that have been described in official government documents. The first is the accidental discharge of the carbon dioxide system at the Idaho National Engineering and Testing Environmental Laboratory (INEEL) on which a series of reports,[21] were written by the Department of Energy and / or its contractor Lockheed-Martin. That accident resulted in 1 death and 13 injuries.

The second is an OSHA technical bulletin describing the accident involving an employee who was killed by a carbon dioxide system discharge while trapped inside a locked bank vault (see Table 6). Appendix B contains a copy of this bulletin.

The documents in the public domain on both of these accidents have the following similarities:

- neither asks the question of why a carbon dioxide system was selected over other available systems to protect the occupancy in the first place, …..
- both seem overly focused on comparing the system design and installation with the requirements of existing carbon dioxide system standards and regulations including those of NFPA and OSHA and …..
- neither addresses the question of whether or not the extensive requirements of those standards and regulations, which are being used as benchmarks for assessing appropriate or inappropriate applications, are themselves adequate from the standpoint of public safety.

An interesting point was made in an article[22] on the INEEL accident in the publication of the Society of Fire Protection Engineers which, when speaking of the safety problems presented by carbon dioxide systems, encouraged designers to factor in the dangers presented by the system itself if all does not go as planned:

> "Several lessons can be learned from this accident. In particular, designers must examine personnel safety in the context of possible special extinguishing system failure modes as well as the protection of the facility from attack by fire."

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[21] "Supplemental Response to the Type A Accident Investigation Board Report of the July 28, 1998, Fatality and Multiple Injuries Resulting from Release of Carbon Dioxide at Building 648, Test Reactor Area, Idaho National Engineering and Environmental Laboratory," INEEL/EXT-99-00282, Lockheed Martin Idaho Technologies Company, Contract DE-AC07-94ID13223, April 1999. This and four other reports on this accident are available for viewing or downloading from the Department of Energy website http://www.id.doe.gov/doeid/foia/archive.htm

[22] Hurley, Morgan J., P.E. and Bisker, James G., P.E., "Carbon Dioxide Systems Accident," Fire Protection Engineering, Issue No. 12, Society of Fire Protection Engineers, Bethesda, MD: Fall 2001 available at http://www.pentoncmg.com/sfpe/articles/Hurley-%20FAll%202001.pdf

7 Types of Carbon Dioxide Extinguishing Systems

Carbon dioxide systems can best be categorized by agent storage configurations and methods of applications.

7.1 Agent Storage Configurations

There are two configurations for storing the agent in carbon dioxide systems: either high pressure or low pressure storage. The type of storage container does not have a bearing on the relative safety of the agent. It does have an effect on the economics of a system, especially in large systems protecting multiple hazards where the low pressure, and lower cost, approach is often preferred. Descriptions of these two agent storage configurations are available in many documents, including the *NFPA Fire Protection Handbook*.[23]

7.2 Methods of Application

There are two common methods for applying carbon dioxide extinguishing agent: (1) total flooding and (2) local application. The method of application does have an effect on the relative safety of the system. While injury and death are always possible with either method if people become exposed to the agent in high concentrations, the popular belief is that escape from the vicinity of a local application system discharge is more likely than escape from an enclosed space during or after a total flooding system discharge.

7.2.1 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) sufficient 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.

Total flooding is the most common system application of carbon dioxide in the marine sector with the protection of machinery spaces, machinery space control rooms, cargo pump rooms and dry cargo spaces. Total flooding is also done in many industrial applications such as diesel generator rooms, cable spreading rooms, electrical switchgear rooms and similar spaces. Carbon dioxide total flooding systems are sometimes used to protect the sub-floor spaces in computer or computer like facilities.

7.2.2 Local Application

In local application, the agent is applied directly onto a fire or into the region of a fire. This is perhaps the most significant use of carbon dioxide as the techniques and guidelines for applying other gaseous agents in this manner simply have not been developed. Local application carbon dioxide systems are used in numerous industrial applications including aluminum rolling mills, printing presses, dip tanks, quench tanks and similar applications.

There are two different techniques used to design local application systems …..

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[23] “Carbon Dioxide and Application Systems,” *Fire Protection Handbook*, Nineteenth Edition, Volume II, National Fire Protection Association, Quincy, MA 2003.

Rate-by-Area Method - The area method of system design is used where the fire hazard consists primarily of flat surfaces or low-level objects associated with horizontal surfaces. In these applications, nozzles are usually located in one plane either in a tank-side or overhead configuration. The agent is applied within flow rate and area coverage limitations established in listing and approval testing programs.

Rate-by-Volume Method - The volume method of system design is used where the fire hazard consists of three-dimensional irregular objects that cannot be easily reduced to equivalent surface areas. In this case, the system is designed on the basis of an assumed enclosure surrounding the three dimensional hazard. The agent is applied to meet a minimum proscribed flow rate density (kilograms per second per cubic meter of assumed volume) and within the flow rate and area coverage limitations established in listing and approval testing programs.

7.3 Mechanism of Extinguishment

The extinguishing mechanism of carbon dioxide is primarily dilution of the oxygen content of the atmosphere surrounding a hazard to a point where that atmosphere will no longer support combustion. Under certain applications, the available cooling effect is also helpful especially where carbon dioxide is applied directly on the burning material.

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8 Applications

The EPA report described the broad market applications for carbon dioxide systems covering uses for both total flooding and local application systems. Some of the points made in that report are:

- Carbon dioxide continues to be used in many applications for the extinguishment of flammable liquid fires, gas fires, electrically energized fires and, to a lesser degree, fires involving ordinary cellulosic materials such as paper and cloth.
- Carbon dioxide can effectively suppress fires of most materials with the exception of active metals, metal hydrides and materials containing their own oxygen source, such as cellulose nitrate.
- The use of carbon dioxide is limited primarily by the factors influencing its method of application and its intrinsic health hazards.
- Carbon dioxide is used internationally in marine applications in engine rooms, paint lockers, vehicle transport areas on cargo vessels, and in flammable liquid storage areas.
- Carbon dioxide fire suppression systems are currently being used by the U.S. Navy and in commercial shipping applications.[24]
- The steel and aluminum industries also rely heavily on carbon dioxide fire protection. In the aluminum industry, for example, the rolling mill process requires the use of kerosene-like lubricants and coolants. Fires are prevalent in this application, occurring on the average of 1 per week in the typical aluminum plant.

In order to more clearly deal with the matter, the markets served by carbon dioxide systems can be segmented into:

- Marine market
- Industrial market

NFPA 12[25] advises that carbon dioxide fire-extinguishing systems are useful when an inert electrically nonconductive medium is essential or desirable, where cleanup of other media presents a problem or where carbon dioxide systems are more economical to install than systems using other media. According to the standard, the types of hazards and equipment that carbon dioxide systems can satisfactorily protect include flammable liquid materials, electrical hazards such as transformers, switches, circuit breakers, rotating equipment, and electronic equipment, engines utilizing gasoline and other flammable liquid fuels, ordinary combustibles such as paper, wood, and textiles and hazardous solids.

In looking at the industrial market, there does not appear to be a significant growth in the use of carbon dioxide systems which compete with the new alternative agents to fill the role once played by halon 1301 systems for protection of normally occupied spaces.

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[24] While it is true the US Navy has carbon dioxide systems on existing combatant and sealift type ships, attention is called to paragraph 8.1.2 where it is clear that over ten years ago the Navy adopted a “no new carbon dioxide systems” approach in combatant and, more recently, new construction sealift vessels.

[25] “NFPA 12 - Standard on Carbon Dioxide Extinguishing Systems – 2000 Edition,” National Fire Protection Association, Quincy, MA February 2000.

On the other hand, the marine market has experienced a considerable increase in the use of carbon dioxide systems over other available systems to protect normally occupied machinery spaces. It is therefore that segment that will receive most of the attention in this report.

8.1 Marine Market

The marine market is a large user of carbon dioxide systems and that use has been increasing with the halt of production of halon 1301. Table 8 is an illustration of the more common applications of carbon dioxide total flooding systems in marine applications.

Table 8: Marine Applications for Carbon Dioxide Total Flooding Systems

Application / Risk	Normally Occupied	Normally Unoccupied	Accessible
Main Machinery Spaces (engine rooms)	Yes		
Auxiliary Machinery Spaces (bow thruster, generator rooms)		Yes	Yes
Paint and Flammable Liquid Storage Lockers		Yes	Yes
Cargo Pump Rooms		Yes	Yes
Cargo Holds		Yes	Yes
Vehicle Spaces		Yes	Yes
Incinerators		Yes	No

As shown in Table 8, most of the applications are in normally unoccupied spaces but, of those, most would also have people accessing the space for service, maintenance, loading, unloading or other purposes.

Table 9 is an illustration of the agents that are in use today which achieve the same technical level of performance as the carbon dioxide systems for the marine applications. The alternatives shown in Table 9 are not in any order of preference as there is a significant difference between USCG and international requirements where some agent systems are permitted and others are not, thus making ranking quite difficult.

Table 9: Alternatives to Marine Carbon Dioxide Total Flooding Systems
(Alternatives listed in alphabetical order)

Application / Risk	Alternatives
Main Machinery Spaces (engine rooms)	Halocarbon, Inert Gas, Water Mist
Auxiliary Machinery Spaces (bow thruster, generator rooms)	Halocarbon, Inert Gas, Water Mist
Paint and Flammable Liquid Storage Lockers	Halocarbon, Inert Gas, Water Mist
Cargo Pump Rooms	Halocarbon, Inert Gas, Water Mist
Cargo Holds	Water Spray
Vehicle Spaces	Foam/Water
Incinerators	Water Mist

While it may be interesting to review all these different spaces on the ships now being protected by carbon dioxide, the number one priority must be the examination of the spaces that are normally occupied by people. Those are the main machinery spaces. In discussions with the delegates to the International Maritime Organization Fire Protection

Sub-Committee[26] there was general agreement that the order of preference of systems for the protection of machinery spaces on SOLAS regulated ships is …..

- Carbon dioxide systems
- High expansion foam systems
- Water mist or spray systems
- Halocarbon systems
- Inert gas systems

The listing of the preferences on SOLAS ships is, with the exception of water mist, in ascending order of system cost with carbon dioxide being the least expensive, high expansion foam next, etc. It will be shown later in this report (section 11) that water mist systems are generally the most expensive alternatives to carbon dioxide at small volumes but become the least expensive at larger volumes, perhaps accounting for the ranking of that type system in the middle of the list of preferred systems.

However, the order of preference on US flag commercial vessels is somewhat different since the USCG has not approved any water mist, water spray or high expansion foam systems for total flooding protection of machinery spaces. Thus, in the US, the current preferences are in this order which, as will be shown later in section 11, is in ascending order of system cost[27] …..

- Carbon dioxide
- Halocarbon systems (specifically FM-200)[28]
- Inert gas systems (specifically Inergen)

The USCG is supportive of the use of water mist systems for the protection of machinery spaces even though it has yet to approve any for that application. This is apparent from a supplemental notice of proposed rulemaking[29] for towing vessels which, when defining acceptable systems expected to be mandated by the rule, states:

> *"Fixed Fire-Extinguishing System* means a carbon-dioxide system that satisfies 46 CFR subpart 76.15; a manually-operated clean-agent system that satisfies NFPA 2001 and is approved by the Commandant; or a manually-operated water-mist system that satisfies NFPA 750 and is approved by the Commandant."

In addition, there is some limited movement away from carbon dioxide systems in unoccupied spaces on cargo ships where the USCG has recently approved the

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[26] 47th Session of the Fire Protection Sub-Committee, International Maritime Organization, London, UK: February 10-14, 2003.

[27] See Table 13 for a listing of the number and types of systems being installed on the merchant ships under construction in the US at this time. While the list does not include any Inergen systems at this time, that type of system has been installed on ships in the past and will likely be installed on ships in the future.

[28] Table 24 provides a correlation between generic and trade names of the various alternatives. To facilitate recognition, the more commonly used trade names are used throughout the report.

[29] "Fire-Suppression Systems and Voyage Planning for Towing Vessels," 33 CFR Part 164 and 46 CFR Parts 25 and 27, DEPARTMENT OF TRANSPORTATION, Coast Guard, [USCG 2000–6931], Federal Register / Vol. 65, No. 217 / 66941, Wednesday, November 8, 2000.

substitution of a water spray system together with boundary cooling for the protection of multi-purpose spaces aboard a new Military Sealift Command ship.[30]

In discussing the matter of system preferences with IMO delegates, some believe that the use of carbon dioxide systems tends to fall off in smaller vessels where agent storage container space and weight of the system become more of an issue. The estimate for the smaller ships is that 7 out of 10 are using carbon dioxide systems; however, as will be shown later, the US information shows over 8 out of 10 new commercial ships being built today are being fitted with carbon dioxide systems.

8.1.1 International Marine Market

Table 10: Top 20 Merchant Fleets of the World[31]

(Vessels 100 Gross Tons and Greater; Average Age in Years)

Flag of Registry	Cargo Carrying Ships		Ships of Miscellaneous Activities		Total Ships	
	Number	Average Age	Number	Average Age	Number	Average Age
Japan	4,321	13	3,137	16	7,458	14
Panama	5,353	16	894	27	6,247	18
United States	422	28	5,658	24	6,080	24
Russia	1,897	24	3,046	22	4,943	23
China	2,338	23	988	22	3,326	22
Korea (South)	1,015	19	1,517	27	2,532	24
Singapore	1,027	14	741	10	1,768	12
Greece	1,317	23	231	32	1,548	24
Liberia	1,440	13	95	25	1,535	13
United Kingdom	514	19	1,011	23	1,525	21
Italy	857	21	629	25	1,486	23
Malta	1,309	19	41	25	1,350	19
Bahamas	1,181	16	16	20	1,348	17
Cyprus	1,205	17	120	18	1,325	17
St. Vincent	869	25	435	23	1,304	24
Germany	529	18	328	24	857	21
Hong Kong	715	14	51	11	766	13
Norway	630	17	92	14	722	17
Denmark	357	17	96	22	453	18
Marshall Islands	348	12	80	22	428	14
All Other Flags	19,012		23,148		42,009	
Total All Flags	**46,656**	**20**	**42,354**		**89,010**	**22**

Four sets of data are helpful in putting the size of the international marine market into perspective …..

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[30] Robert Darwin, Hughes Associates, Inc., "Performance-Based Sprinkling for T-Ship Ordnance Holds," Workshop on Fire Suppression Technologies, Mobile, AL, February 24-27, 2003, available at http://www.haifire.com/presentations.html

[31] "2001 World Fleet Statistics," Table 1A, Lloyd's Register-Fairplay Ltd., Lombard House, 3 Princess Way, Redhill RH1 1UP, United Kingdom: May 2003.

- the size and make up of the top 20 merchant fleets of the world,
- the age profile of the world merchant fleet,
- the annual net change in the world merchant fleet size and
- the order book for new ships for the world merchant fleet.

Table 10 is a listing of the number of ships over 100 gross tons (GT) registered under the flag of each of the top 20 merchant fleets of the world. The vessels are listed in two broad categories used by merchant vessel statisticians: cargo carrying ships and ships of miscellaneous activities.

Table 11 is a profile of the age of the world fleet once again by type and the percentage of each type in one of four age groups.

Table 11: Age Profile of the World Merchant Fleet Greater than 100 Gross Tons[32]
(Based on Number of Vessels over 100 Gross Tons on December 31, 2002)

Type of Vessel	0 – 4 Years	5 – 14 Years	15 – 24 Years	25+ Years
Dry Cargo	4.3%	21.7%	29.5%	44.5%
Container	23.0%	48.0%	20.4%	8.6%
Tanker	10.5%	29.4%	28.5%	31.6%
Bulker	13.9%	30.5%	34.1%	21.5%
RO-RO	9.7%	22.7%	28.6%	39.0%
Passenger	8.3%	32.0%	24.4%	35.3%
Offshore	10.2%	9.4%	39.8%	40.6%
Miscellaneous	6.2%	19.2%	27.7%	46.9%
Total	**7.9%**	**23.0%**	**28.8%**	**40.3%**

Table 12 is an illustration of the net changes in the world merchant fleet vessel count due to losses, disposals and additions through new construction. 821 ships have either been scrapped (734 disposals) or lost at sea (87 losses) and 1,529 new ships have been added to the fleet during 2002. The disposed ships had an average age of 27.7 years. Referring back to Table 11, it is interesting to note the large percentage of the fleet that is older than 25 years and thus candidates for replacement.

Table 12: Annual 2002 Net Change in the World Merchant Fleet Count[33]
(Based on Number of Vessels over 100 Gross Tons on December 31, 2002)

Type of Vessel	Losses	Disposals	New	Ending Balance	Net Change
Dry Cargo	32	175	134	18,384	-73
Container	0	41	200	2,918	159
Tanker	6	205	307	11,127	96
Bulker	7	124	224	6,487	93
RO-RO	9	27	84	4,575	48
Passenger	2	7	52	3,165	43
Offshore	2	2	101	3,397	97
Miscellaneous	29	153	437	38,957	255
Total	**87**	**734**	**1,539**	**89,010**	**718**

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[32] "2001 World Fleet Statistics," Table 6, Lloyd's Register-Fairplay Ltd., United Kingdom: May 2003.

[33] "2001 World Fleet Statistics," Lloyd's Register-Fairplay Ltd., United Kingdom: May 2003.

Table 13 is an illustration of the ships on order, both world wide and with US shipyards. The table applies only to ships greater than 299 GT[34] and the units for this table are numbers of ships.

Table 13: World Commercial Ship Order Book[35]
(Number of Vessels over 299 Gross Tons on Order on February 28, 2003)

Type of Vessel	Ships on Order World Wide	Ships on Order US Shipyards
Dry Cargo	235	5
Container	314	4
Tanker	930	7
Bulker	434	
Ro/Ro	87	4
Passenger	175	29
Offshore	239	41
Miscellaneous	324	37
Total	**2,738**	**127**

On February 28, 2003, there were 127 commercial vessels of all types with a market value of more than $3.1 billion under construction in American shipyards. Included in that total are a number of double-hulled tankers and tank barges that meet the requirements of The Oil Pollution Act of 1990 (OPA90), and a new generation of roll-on/roll-off cargo carriers that incorporate the latest in environmental safeguards.[36]

Of the ships on order with US shipyards in Table 13, 109 have delivery dates in 2003, 7 in 2004, 8 in 2005 and 3 in 2006. Thus, 86% of the current backlog of ships under construction in US shipyards are scheduled for shipment in 2003.

On a worldwide basis, Lloyd's Fairplay[37] indicates 1,741 vessels are scheduled for delivery in 2003 out of the backlog of 2,738 ships in Table 13, representing 64% of the backlog.

It is estimated by Det Norske Veritas[38], the Norwegian ship classification society, that "over 90% of the new DNV classified ships recently constructed have carbon dioxide systems protecting their engine rooms." That would suggest nearly 1,566 new ships are being delivered this year with carbon dioxide extinguishing systems in their manned machinery spaces.

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[34] The 299 gross tons ship size appears to be the demarcation line above which there is a multitude of information available on fleet sizes, construction and other important statistics about the merchant shipping industry. The information on vessels below 299 gross tons is less plentiful and difficult to correlate with the information on vessels of 299 gross tons and over.

[35] "Newbuildings Order Table," *Fairplay Solutions*, Issue No. 78, Lloyd's Register – Fairplay, Ltd., London, UK: March 2003.

[36] "Current Commercial Shipbuilding Contracts," Marine Log, March 27, 2003 available at http://www.coltoncompany.com/shipbldg/contracts/orderscommercial.htm.

[37] "Newbuildings Order Table," *Fairplay Solutions*, Issue No. 78, Lloyd's Register – Fairplay, Ltd., London, UK: March 2003.

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

8.1.2 United States Marine Market

a. Commercial Ships

Of the 127 commercial vessels under construction in US yards, 106 are being equipped with carbon dioxide systems and 12 with FM-200 systems. The systems on the 9 other vessels could not be identified.

Table 14: Engine Room Protection on US Commercial Ships Under Construction[39,40]

Type of Vessel	Number Under Construction	Carbon Dioxide System	FM-200 System	Unidentified
Dry Cargo	5	5		
Container	4	4		
Tanker	7	7		
Bulker				
Ro/Ro	4	4		
Passenger	29	22	6	1
Offshore	41	41		
Miscellaneous	37	23	6	8
Total	**127**	**106**	**12**	**9**

It would appear from the information in Table 14 that the use of carbon dioxide systems in new commercial ships being constructed in the US is in the vicinity of 8 out of 10, even though most of the commercial ships constructed in this country are considered small to medium size. Some of the small and medium sized commercial vessels (passenger ferries, fire boats, etc.) are beginning to use FM-200 when the space and weight savings (when compared to carbon dioxide systems) are made apparent to the architect, engineers and owners.

b. Military Ships

Table 15 is an illustration of major military vessel projects now under construction.

The US military (both the US Navy and the US Army) have moved away from carbon dioxide systems and are using FM-200 systems and/or water mist systems on their new ships. While neither department has a written policy prohibiting the use of carbon dioxide systems on new ships, the exclusion of carbon dioxide systems on new ships out of safety concerns has been the practice of each department for over 10 years. However, the US Coast Guard continues to employ carbon dioxide systems on buoy tenders and coastal patrol boats that were designed before the approval of other halon alternatives.

After the last fatal accident involving a carbon dioxide system discharge on a US Navy combat ship (USS Sumter accident at Little Creek Amphibious Base on July 30, 1992)[41]

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[39] "Current Commercial Shipbuilding Contracts," Marine Log, March 27, 2003 available at http://www.coltoncompany.com/shipbldg/contracts/orderscommercial.htm.

[40] The identification of the types of extinguishing systems employed on the list of ships in this table was made through individual consultation with the marine sales managers of Ansul and Kidde-Fenwal, the two major manufacturers of fire extinguishing systems for marine applications.

[41] Three sailors were performing planned maintenance on a CO_2 system in a paint locker when the system discharged. Two died and one was seriously injured.

the Navy took immediate remedial action to prevent similar accidents. They surveyed every carbon dioxide system in the fleet and then developed and implemented a correction plan involving three significant modifications to all systems in paint lockers and similar spaces that heretofore had not been equipped with time delays:

- time delays were installed on all systems together with pre-discharge alarms,
- protective caging was built around carbon dioxide cylinder control heads and
- doors were modified to swing outward and provided with kick-out panels

In addition, the maintenance procedures were modified. Rescue parties -with all members equipped with self contained breathing apparatus - stand by outside the space where maintenance on the carbon dioxide system is being performed and are ready to execute an immediate rescue in the event of an accidental system discharge.

Table 15: Sampling of Major Military and USCG Vessel Projects[42]

Project	Ships	System
CVN-76 and CVN-77 Aircraft Carriers	2 ships	FM-200 systems in lieu of halon systems normally fitted to aircraft carriers. In spaces over 5,000 ft^3 NRL WSCS[43] system used together with FM-200.
LPD-17 Class Amphibious Assault Ships	12 ships	All 5 machinery spaces employ water mist systems; FM-200 to protect other spaces normally protected with halon 1301.
T-AKE Military Sealift Command Ammunition / Dry Cargo Ships	12 ships	FM-200 systems for machinery space protection plus water spray and boundary protection for multipurpose spaces in lieu of carbon dioxide systems
US Army Watercraft Halon Retrofit Project	60 vessels	Retrofit from halon 1301 to FM-200 systems together with NRL WSCS system.
US Army LSV (Army Logistics Support Vessels) Program	3 vessels	FM-200 systems to replace carbon dioxide systems for machinery space protection
USCG WLB's Oceangoing Buoy Tenders	5 ships	Carbon dioxide systems (no approved clean agent alternative systems available when ships were designed)
USCG CPB Coastal Patrol Boats	13 ships	Carbon dioxide systems

Both the US Navy and the Army still have ships equipped with carbon dioxide systems.

- In the Army's case, it is actually removing the carbon dioxide systems from many of its ships and replacing those systems with FM-200 together with a water spray cooling system in some cases.
- In the Navy, no new carbon dioxide systems have been installed in combatant ships since the SUMTER accident over 10 years ago. The Navy is not replacing the carbon dioxide systems on ships already equipped with those systems.
- In the U.S. Navy's Military Sealift Command (MSC), many of its vessels use carbon dioxide both for the protection of the cargo compartments and machinery spaces. However, with its latest ship series under construction, the T-AKE

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[42] "Current Commercial Shipbuilding Contracts," Marine Log, March 27, 2003 available at http://www.coltoncompany.com/shipbldg/contracts/ordersgovernment.htm.

[43] The Water Spray Cooling System (WSCS), invented and patented by Naval Research Laboratory, was designed to enhance the performance of gaseous total flooding fire suppression agents by providing compartment cooling and reducing HF.

ammunition / dry cargo ships (see Table 15) the MSC has chosen FM-200 systems for the machinery spaces and is using overhead and bulkhead water spray systems for the ammunition cargo spaces.

The MSC has had some unfortunate experiences with carbon dioxide including …..

- two incidents resulting in 2 fatalities each, the first on the CAPE DIAMOND in 1993 and the second on the CAPE HORN in 2002 and …..
- a serious incident on another MSC ship, the SSG EDWARD A. CARTER, JR, which had a fire in its engine room while being loaded with (a net explosive weight of) 5 million pounds of Class 1 explosives. The fire got out of control, the crew was unable to operate the total flooding carbon dioxide system and the fire had to be extinguished by shore based and fire boat resources. There were 2 fatalities, neither directly related to the carbon dioxide system. The USCG report[44] was critical of the configuration of the carbon dioxide system, the fact that it needed electrical power to open a discharge valve, the poor level of crew training and readiness and the actions of the ship's officers.

However, the MSC is not using carbon dioxide on its newly constructed ships. With the new T/AKE class under construction, the machinery spaces will be protected with a halocarbon (FM-200) system designed to the requirements of IMO MSC Circular 848[45] together with a local application water system designed to the requirements of IMO MSC Circular 913.[46]

8.2 Industrial Market

The industrial market continues to be a large user of carbon dioxide systems. A survey of manufacturers identified the five risks in Table 16 as the most frequently encountered industrial applications for carbon dioxide total flooding systems.

As shown in Table 16, most of the applications are in normally unoccupied spaces but, of those, most would also have people accessing the space for service, maintenance or other purposes.

In many of the applications, it is clear that other agents could do the job as well as, if not better than, carbon dioxide. For example, in the case of generator housings and enclosures, halocarbons and water mist systems are both available and, in the case of water mist, systems specifically approved for this application. Table 17 is an illustration of the agents that could achieve the same technical level of performance as the carbon dioxide systems for four of the five top applications. In this illustration, the responders to the survey were asked to list their preferences for the top three alternatives to carbon

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[44] "Report of the Investigation into the Circumstances Surrounding the Engine Room Fire on Board the M/V SSG EDWARD A. CARTER, JR. While Moored at Military Ocean Terminal, Sunny Point, N.C., on July 14, 2001 with the Loss of Two Lives," Headquarters, United States Coast Guard, Washington, DC: September 30, 2002 available at http://www.uscg.mil/hq/g-m/moa/casualty.htm

[45] "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.

[46] "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.

dioxide in the listed applications, thus resulting in the ranking of choices shown in Table 17.

Table 16: Top Industrial Applications for Carbon Dioxide Total Flooding Systems

Application / Risk	Normally Occupied	Normally Unoccupied	Accessible
Generator Housings / Enclosures		Yes	Yes
Flammable Liquid Storage (chemicals, paints, mix rooms)	Yes[47]	Yes	Yes
Electrical Cabinets (controls, switchgear)		Yes	
Exhaust Systems (ducts / dust collectors / bag houses)		Yes	
Misc. Mfg. Enclosures (ovens, vaults, pits, heat treating, etc)		Yes	Yes

Table 17: Alternatives to Carbon Dioxide Total Flooding Systems

Application / Risk	First Choice	Second Choice	Third Choice
Generator Housings / Enclosures	Halocarbon	Watermist	Inert Gas
Flammable Liquid Storage (chemicals, paints, mix rooms)	Foam	Inert Gas	Halocarbon
Electrical Cabinets (controls, switchgear)	Halocarbon	Inert Gas	Watermist
Exhaust Systems (ducts / dust collectors / bag houses)	N/A	N/A	N/A
Misc. Mfg. Enclosures (ovens, vaults, pits, heat treating, etc)	Inert Gas	Dry Chemical	Watermist

In that same survey, it was asked why would there be a preference for carbon dioxide over the alternatives. The following are the most often mentioned carbon dioxide attributes that – when taken collectively – serve as the basis for a bias toward carbon dioxide systems in the industrial applications in Table 17:

- Cost (up-front investment, maintenance/service and recharge)
- Best extinguishing media for risk or only practical agent
- Specialized design requirements (i.e. extended discharge, selector valves, piping/design flexibility and main/reserve)
- Clean agent (no damage, minimum cleanup, productivity downtime, non-corrosive, non-conductive, etc.)
- Deep seated fire capability
- Previous fire history
- Proven fire capability
- Globally available
- Insurance or authority having jurisdiction (AHJ) requirement (i.e. code compliance, mandate, etc.)

It is clear that these attributes are not exclusive to carbon dioxide:

- Depending on the risk, any one of the alternatives could be declared the best

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[47] Paint mix rooms are generally considered normally occupied spaces whereas most other flammable liquid storage rooms are considered normally unoccupied.

- Inert gases and halocarbons and to some extent water mist can be considered clean agents
- Deep seated fires can be handled with water
- Previous fire history and proven fire capability are able to be demonstrated with the other agents (perhaps not all the way back to 1929, though), and
- Global availability is certainly not a problem for inert gases and water.

However, the two attributes that are difficult for other agents to match when compared to carbon dioxide systems are cost and AHJ preferences. Cost will be addressed later in this report.

AHJ preferences are extremely difficult to overcome and are the single most significant reason for the long times experienced to bring a new product or technology to commercial reality in the fire protection market. However, this is not altogether a negative attribute to ensure a very thorough review process when dealing in the business of protecting lives and property.

Finally, in the survey the respondents were asked to identify any applications where they felt carbon dioxide total flooding systems are the only appropriate solution. The following five applications were identified:

- Large industrial pits
- Industrial ovens
- Machining centers / equipment
- Electrical transformers
- Class “A” deep seated fire hazards (wherever water is unsuitable)

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9 Standards and Regulations

Nationally and internationally there are several organizations that provide guidance on the safe application of carbon dioxide systems. These include:

- U.S. Environmental Protection Agency (EPA)
- U.S. Coast Guard (USCG)
- National Fire Protection Association (NFPA)
- Occupational Safety and Health Administration (OSHA)
- International Standards Organization (ISO)
- International Maritime Organization (IMO)

At this time, the regulations or standards of all of these organizations permit the use of carbon dioxide total flooding fire extinguishing systems in normally occupied spaces. Some of the standards and regulations of the above organizations are linked to others, either by direct reference or by the simple fact that the same people are working on the requirements in several different organizations. For example ….

- consistent with federal policy, the USCG is trying, when appropriate, to use references to NFPA consensus standards as its requirements for marine fire extinguishing systems, …..
- NFPA 2001 directly references the US EPA SNAP list as an acceptance requirement for agents to be included in that standard, …..
- IMO has begun the practice of adopting by reference some ISO documents whenever there seems to be a close fit, …..
- the US EPA directly references OSHA and NFPA standards in its SNAP list, …..
- USCG personnel, together with many US members of the NFPA technical committees and EPA personnel constitute the US delegation to the IMO fire protection sub-committee and …..
- many members of NFPA technical committees form the US delegations to ISO technical committees for fire extinguishing systems.

9.1 U.S. Environmental Protection Agency

Under Title VI of the Clean Air Act (CAA)[48], EPA's Global Programs Division is responsible for several programs that protect the stratospheric ozone layer.

Under Section 612 of the Clean Air Act, EPA has been charged with developing a program for evaluating alternatives to ozone-depleting substances. EPA refers to this as the Significant New Alternatives Policy (SNAP) program. The major provisions of section 612 that direct the EPA to assess human health and environmental impacts of the halon alternatives are:

- Rulemaking - Section 612(c) requires EPA to promulgate rules making it unlawful to replace any class I or class II substance with any substitute that the Administrator determines may present adverse effects to human health or the environment where the Administrator has identified an alternative that (1)

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[48] The provisions of the Clean Air Act can be accessed at http://www.epa.gov/oar/caa/contents.html

reduces the overall risk to human health and the environment, and (2) is currently or potentially available.

- Listing of Unacceptable/Acceptable Substitutes - Section 612(c) also requires EPA to publish a list of the substitutes unacceptable for specific uses. EPA must publish a corresponding list of acceptable alternatives for specific uses.
- Updates/Changes to Determinations - Section 612 also authorizes EPA to initiate changes to the SNAP determinations independent of any petitions or notifications received. These amendments can be based on new data on either additional substitutes or on characteristics of substitutes previously reviewed.

Substitutes are reviewed on the basis of ozone depletion potential, global warming potential, toxicity, flammability and exposure potential. EPA describes its approach to reviewing substitutes for ozone-depleting substances in the SNAP Final Rule[49]. The SNAP lists of acceptable and unacceptable substitutes are updated several times each year. The current version of the SNAP list covering total flooding extinguishing agent systems[50] addresses the use of total flooding carbon dioxide systems. In 1994, EPA listed carbon dioxide systems as acceptable under SNAP but did not conduct a risk assessment. EPA, in its listing, deferred to OSHA which had already promulgated regulations for use of carbon dioxide total flooding fire suppression systems. At this time, the SNAP list identifies carbon dioxide as an acceptable substitute for halon 1301 with the comment that the "System design must adhere to OSHA 1910.162(b)(5)[51] and NFPA Standard 12."[52] The full text of the referenced OSHA paragraph is …..

> 1910.162(b)(5) The employer shall provide a distinctive pre-discharge employee alarm capable of being perceived above ambient light or noise levels when agent design concentrations exceed the maximum safe level for employee exposure. A pre-discharge employee alarm for alerting employees before system discharge shall be provided on Halon 1211 and carbon dioxide systems with a design concentration of 4 percent or greater and for Halon 1301 systems with a design concentration of 10 percent or greater. The pre-discharge employee alarm shall provide employees time to safely exit the discharge area prior to system discharge.

The requirements of NFPA Standard 12 are discussed in paragraph 9.3.

9.2 U.S. Coast Guard

The United States Coast Guard regulations address two subjects: (1) where carbon dioxide systems (or their equivalents) are required and (2) how those systems should be designed and installed.

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[49] "Final Rule - Protection of Stratospheric Ozone," 40 CFR Parts 9 and 82, [FRL-4839-7], RIN 2060-AD48, Vol. 59 No. 53 Friday, March 18, 1994 p 13044 (Rule), Environmental Protection Agency (EPA), Washington, DC available at http://www.epa.gov/ozone/snap/regs/59fr13044.html

[50] "Substitutes for Halon 1301 as a Total Flooding Agent," Significant New Alternatives Policy (SNAP) Program, Environmental Protection Agency (EPA), Washington, DC available at http://www.epa.gov/ozone/snap/fire/lists/flood.html

[51] "Fixed Extinguishing Systems, Gaseous Agent," 29 CFR 1910, Occupational Safety and Health Standards, Subpart L, Fire Protection, Standard Number 1910.162, Occupational Safety and Health Administration, Washington, DC available at http://www.osha.gov/comp-links.html

[52] "NFPA 12 - Standard on Carbon Dioxide Extinguishing Systems," National Fire Protection Association, Quincy, MA: February 2000.

The USCG regulations are contained in Title 46 – Shipping of the Code of Federal Regulations. The regulations for carbon dioxide systems are contained in several different sub-chapters of Title 46 organized along the lines of the several classes of ships and vessels covered. Table 18 is an illustration of the relevant documents describing the requirements of carbon dioxide systems for several of the more important vessel types.

The requirements from one class of vessel to another do not vary significantly, except that the treatment of carbon dioxide systems in Sub-Chapters D, H and I is quite dated, even to the extent of discussing special exemptions for ships built before 1952. The treatment of carbon dioxide systems and the equivalents in Sub-Chapters K and T are, relatively speaking, more recent and probably reflect the current thinking of the USCG with respect to gaseous extinguishing system requirements for all the different types of vessels.

Table 18: USCG Regulations for Carbon Dioxide Fire Extinguishing Systems[53]

Sub-Chapter	Topic	Sub-Part	Title	Paragraph
C	Uninspected Vessels	Part 25 Subpart 25.30	Fire Extinguishing Equipment	§ 25.30-15
C	Commercial Fishing Vessels	Part 28 Subpart D	Fixed Gas Fire Extinguishing Systems	§ 28.320
D	Tank Vessels	Part 34 Subpart 34.15	Carbon Dioxide Extinguishing Systems	§ 34.15-1
H	Passenger Vessels (>100 gross tons)	Part 76 Subpart 76.15	Carbon Dioxide Extinguishing Systems	§ 76.15-1
I	Cargo Vessels	Part 95 Subpart 95.15	Carbon Dioxide Extinguishing Systems	§ 95.15-1
I-A	Mobile Offshore Drilling Units	Part 108 Subpart D	Carbon Dioxide Systems	§ 108.431
K	Passenger Vessels (<100 gross tons) (>150 passengers)	Part 118 Subpart D	Fixed Fire Extinguishing and Detecting Systems	§ 118.400
L	Offshore Supply Vessels	Part 132 Subpart C	Miscellaneous	§ 132.310
R	Public Nautical School Ships	Part 167 Subpart 167.45	Steam, carbon dioxide, and halon fire extinguishing systems	§ 167.45-1
R	Civilian Nautical School Vessels	Part 169 Subpart 169.50	Fixed extinguishing system	§ 169.564
T	Small Passenger Vessels (<100 gross tons) (<150 passengers)	Part 181 Subpart D	Fixed Fire Extinguishing and Detecting Systems	§ 181.400
U	Oceanographic Research Vessels	Part 193 Subpart 193.15	Carbon Dioxide Extinguishing Systems	§ 193.15-1

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[53] The referenced USCG regulations are available at http://www.uscg.mil/hq/g-m/MSE4/reg.htm

For all practical purposes, there are two requirements in the USCG regulations that are specifically designed to prevent the exposure of personnel to a discharge of carbon dioxide. Table 19 is an illustration of the two requirements and the objective of each.

Table 19: USCG Safety Provisions for Carbon Dioxide Fire Extinguishing Systems[54]

Requirement	Objective
181.410(b)(2) Except for a normally unoccupied space of less than 170 cubic meters (6000 cubic feet), release of an extinguishing agent into a space must require two distinct operations.	Mandates that all systems protecting normally occupied spaces must be manually (as opposed to automatically) operated and that two distinct actions must be taken by a person before a system can be made to discharge. This is intended to preclude an accidental discharge through a single action of an individual.
181.410(b)(9) A system protecting a manned space must be fitted with an approved time delay and alarm arranged to require the alarm to sound for at least 20 seconds or the time necessary to escape from the space, whichever is greater, before the agent is released into the space. Alarms must be conspicuously and centrally located. The alarm must be powered by the extinguishing agent.	Mandates a pre-discharge alarm that warns occupants of a protected space that a discharge of agent into the space is imminent. Also mandates a time delay which prevents the release of the agent into the occupied space until a pre-determined suitable time has lapsed allowing all the occupants to evacuate the space.

With all the marine accidents involving carbon dioxide systems, it is clear that something else is needed in addition to these two requirements to assure the safety of the people who might be exposed to a system discharge. In fact, the USCG concluded this some time ago and published a navigation and vessel inspection circular (NVIC) specifically addressing carbon dioxide fire extinguishing system safety.[55] This NVIC is an excellent document, not just for the marine industry but for other market segments that use these systems.

The NVIC, which is only an advisory document intended to guide USCG inspectors and thus not mandatory, deals with (1) health hazards of carbon dioxide, (2) system design considerations and (3) safety considerations. In reviewing the accidents in the earlier EPA report on carbon dioxide systems, it is clear that in virtually every case someone did something that was unexpected or ill advised. Many of those accidents took place when the system was being serviced. The following is an excerpt from the safety considerations in the NVIC. These safety considerations attempt to convey to others certain lessons that have too often been learned the hard way with the loss of life.

> "4. SAFETY CONSIDERATIONS. Whenever carbon dioxide systems are taken out of service for testing or recharge, strict safety precautions must be followed to prevent the possibility that individuals performing or witnessing the activities are placed at risk. The following paragraphs offer general safety recommendations to avoid accidental exposure to personnel. <u>Because each carbon dioxide system is engineered for the particular vessel on which it is installed, it is difficult to envision all possible safety risks</u>. This guide provides general information that should be considered and applied on a case-by-case basis. (*Emphasis added*)

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[54] "Fixed Fire Extinguishing and Detecting Systems - Small Passenger Vessels," 46 CFR 181, Subpart D, United States Coast Guard, Washington, DC available at http://www.uscg.mil/hq/g-m/MSE4/reg.htm

[55] "Carbon Dioxide Fire Extinguishing System Safety," Navigation And Vessel Inspection Circular No. 9-00, COMDTPUB P16700.4, NVIC 9-00, United States Coast Guard, Washington, DC: March 17,2000 available at http://www.uscg.mil/hq/g-m/nvic/9_00/n9-00.pdf

- Most accidents related to the testing or recharge of installed carbon dioxide systems are attributable to personnel errors. It is therefore critical that all persons working on the system must be fully knowledgeable in its operation and repair.
- If the system protects multiple spaces, be aware of the possibility of split discharges.
- All personnel must be evacuated from the protected spaces while any service, however minimal, is performed.
- Establish and implement a plan to prevent personnel entry into the protected spaces until testing is completed and the spaces have been ventilated and determined to be safe for human occupancy.
- Before beginning, determine that a means of communication is available to summon help if it is needed. Confirm that the means of communication is operable and effective throughout the areas where personnel will be stationed.
- Provide ready access to self-contained breathing apparatus.
- Determine what shipboard equipment will be disabled or operated if the system discharges.
- Before beginning, evaluate the location of the agent storage room and plan an escape route.
- The overall condition of the system should be evaluated before beginning any work.
- Protect exposed high pressure cylinder valves.
- Disconnect all high-pressure cylinders from the manifold if the system distribution piping is to be pressure tested, or if an actuation test will be performed.
- On low-pressure systems, verify that the tank shutoff valve is closed during testing.
- Verify that all control heads are correctly re-installed after the work is completed.
- Verify that all stop valve or selector valve remote release controls are connected to the proper valves.
- If an accidental release occurs, immediately evacuate and do not re-enter the spaces affected until they have been ventilated and tested for an adequate oxygen concentration.”

9.3 National Fire Protection Association

The National Fire Protection Association develops, publishes, and disseminates consensus codes and standards intended to minimize the possibility and effects of fire and other risks. Virtually every building, process, service, design, and installation in society today is affected by NFPA documents. More than 300 NFPA codes and standards are used around the world.

Among these, there are two standards dealing with gaseous extinguishing agent systems that approach the matter of personnel safety quite differently. These are …..

- NFPA 12 Standard on Carbon Dioxide Extinguishing Systems[56]
- NFPA 2001 Standard on Clean Agent Fire Extinguishing Systems[57]

9.3.1 NFPA 12

NFPA Standard 12 was first published in 1929 and has been updated a total of 25 times since that first version. Today, the standard lists the following as its scope and purpose:

> **1-1* Scope.** This standard contains minimum requirements for carbon dioxide fire extinguishing systems. It includes only the necessary essentials to make the standard workable in the hands of those skilled in this field. (*Emphasis added*)
>
> **1-2 Purpose.**
>
> **1-2.1** This standard is prepared for the use and guidance of those charged with the purchasing, designing, installing, testing, inspecting, approving, listing, operating, or maintaining of carbon dioxide fire extinguishing systems, in order that such equipment will function as intended throughout its life. Nothing in this standard is intended to restrict new technologies or alternate arrangements, provided the level of safety prescribed by the standard is not lowered.
>
> **1-2.2** Only those with the proper training and experience shall design, install, inspect, and maintain this equipment.

Appendix C is an excerpt of the requirements and related explanatory material regarding hazards to personnel and system requirements. These include …..

- A discussion of hazards to personnel including suffocation, reduced visibility during and after the discharge period, the migration of carbon dioxide into adjacent places outside of the protected space, the fact that personnel could be trapped in or enter into an atmosphere made hazardous by a carbon dioxide discharge and the need to ensure prompt evacuation and rescue of trapped personnel.
- The standard goes to great lengths to describe the placement of warning signs ...
  - in every protected space
  - at every entrance to protected space
  - in every nearby space where carbon dioxide can accumulate to hazardous levels
  - outside each entrance to carbon dioxide storage rooms
  - at every location where manual operation of the system can occur.
- The standard describes system design requiring the provision of audible and visual predischarge alarms and time delays of sufficient duration to allow for

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[56] "NFPA 12 - Standard on Carbon Dioxide Extinguishing Systems – 2000 Edition," National Fire Protection Association, Quincy, MA: February 2000.

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

evacuation under worst-case conditions. However, it also permits the time delay to be bypassed under certain circumstances.

- A new requirement in the 2000 version of the standard is the provision of a "lockout" mechanism <u>when persons not familiar with the systems and their operation are present</u> in a protected space. Examples of situations that could require lock-out of a total flooding system are when persons are so located where they cannot easily exit the protected space within the system's time delay period. The requirements of the lockout are very specific and do not include electrical or electronic switching to accomplish this:

  > **1-3.7 Lock-Out.** A manually operated valve in the discharge pipe between the nozzles and the supply, which can be locked in the closed position to prevent flow of carbon dioxide to the protected area.

- Personnel training is required to include all persons that can at any time enter a space protected by carbon dioxide, warning them of the hazards involved, given an alarm signal and provided with safe evacuation procedures. The training requires making people aware that the discharge of carbon dioxide can cause eye injury, ear injury, or even falls due to loss of balance upon the impingement of the high velocity discharging gas.

9.3.2 <u>NFPA 2001</u>

NFPA 2001 covers systems using clean alternatives to halons, principally halocarbon and inert gas agents at this time. NFPA 2001 was first published in 1994 and has been updated twice since that first version. Of the two NFPA standards (12 and 2001), NFPA 2001 has clearly had more effort put into addressing system safety. Today, the standard lists the following as its scope and purpose:

> **1-1 Scope.** This standard contains minimum requirements for total flooding clean agent fire extinguishing systems. It does not cover fire extinguishing systems that use carbon dioxide or water as the primary extinguishing media, which are addressed by other NFPA documents.
>
> **1-2 Purpose.**
>
> **1-2.1** The agents in this standard were introduced in response to international restrictions on the production of certain halon fire extinguishing agents under the Montreal Protocol signed September 16, 1987, as amended. This standard is prepared for the use and guidance of those charged with purchasing, designing, installing, testing, inspecting, approving, listing, operating, and maintaining engineered or pre-engineered clean agent extinguishing systems, so that such equipment will function as intended throughout its life. Nothing in this standard is intended to restrict new technologies or alternate arrangements provided the level of safety prescribed by this standard is not lowered.
>
> **1-2.2** No standard can be promulgated that will provide all the necessary criteria for the implementation of a total flooding clean agent fire extinguishing system. Technology in this area is under constant development, and this will be reflected in revisions to this standard. The user of this standard must recognize the complexity of clean agent fire extinguishing systems. Therefore, the designer is cautioned that the standard is not a design handbook. The standard does not do away with

> the need for the engineer or for competent engineering judgment. It is intended that a designer capable of applying a more complete and rigorous analysis to special or unusual problems shall have latitude in the development of such designs. In such cases, the designer is responsible for demonstrating the validity of the approach. or uninsulated live electrical components not at ground potential.

Appendix D is an excerpt of the requirements and related explanatory material regarding hazards to personnel redischarge alarms, time delays and maximum safe exposure limits. From the safety standpoint, NFPA 2001 differs from NFPA 12 in three fairly significant ways.

- No agent can be included in the NFPA 2001 standard until it has been through an environmental and safety review in a manner equivalent to the process used by the U.S. Environmental Protection Agency's (EPA) SNAP Program.

  > **1-6.1* Hazards to Personnel.**
  >
  > **1-6.1.1*** Any agent that is to be recognized by this standard or proposed for inclusion in this standard shall first be evaluated in a manner equivalent to the process used by the U.S. Environmental Protection Agency's (EPA) SNAP Program.

- NFPA 2001 requires a predischarge alarm and a time delay on <u>all</u> systems (with one exception), even on systems where the agent is used at concentrations well below levels approaching a safety concern.

  > **2-3.5.6 Time Delays.**
  >
  > **2-3.5.6.1*** For clean agent extinguishing systems, a pre-discharge alarm and time delay, sufficient to allow personnel evacuation prior to discharge, shall be provided. For hazard areas subject to fast growth fires, where the provision of a time delay would seriously increase the threat to life and property, a time delay shall be permitted to be eliminated.
  >
  > **2-3.5.6.2** Time delays shall be used only for personnel evacuation or to prepare the hazard area for discharge.
  >
  > **2-3.5.6.3** Time delays shall not be used as a means of confirming operation of a detection device before automatic actuation occurs.

- Similarly, NFPA 2001 displays a healthy skepticism about the reliability of predischarge alarms and time delays by mandating that agents be used at concentrations below their demonstrated safe exposure limits <u>in the event the predischarge alarm and/or time delays fail to operate properly</u>. First, the requirements for halocarbon agents …..

  > **1-6.1.2* Halocarbon Agents.**
  >
  > **1-6.1.2.1** Any unnecessary exposure to halocarbon clean agents, even at NOAEL concentrations, and halocarbon decomposition products shall be avoided. The requirement for pre-discharge alarms and time delays are intended to prevent human exposure to agents. The following additional provisions shall apply in order to account for failure of these safeguards: …..

  ….. and then the requirements for inert gas systems …..

> **1-6.1.3* Inert Gas Clean Agents.** Unnecessary exposure to inert gas agent systems resulting in low oxygen atmospheres shall be avoided. The requirement for pre-discharge alarms and time delays is intended to prevent human exposure to agents. The following additional provisions shall apply in order to account for failure of these safeguards: …..

….. where both then go on to describe the maximum safe exposure limits for the various halocarbons and inert gases (see Appendix D).

9.4 Occupational Safety and Health Administration

An excerpt from the OSHA regulations describing the general requirements for fixed extinguishing systems (29 CFR **1910.160)** together with the specific requirements for gaseous extinguishing systems (29 CFR **1910.162)** are at Appendix E.

The general requirements include the employer's responsibility to

- provide effective safeguards to warn employees against entry into discharge areas;
- post hazard warning or caution signs;
- assure that fixed systems are inspected annually;
- assure that the weight and pressure of refillable containers is checked at least semi-annually;
- provide an emergency action plan;
- provide a pre-discharge alarm and time delay;

The specific requirements for fixed gaseous systems include the employer's responsibility to

- assure that the concentration of gaseous agents is maintained;
- assure that employees are not exposed;
- assure that no unprotected employees enter the area during agent discharge.

9.5 International Standards Organization

ISO Standard 6183[58] for carbon dioxide fire extinguishing systems was first published in 1990 and has not been revised since. The following as its scope:

> **Scope**
>
> This International Standard lays down requirements for the design and installation of fixed carbon dioxide fire-extinguishing systems for use on premises. The requirements are not valid for extinguishing systems on ships, in aircraft, on vehicles and mobile fire appliances or for below ground systems in the mining industry, nor are they valid for carbon dioxide pre-inerting systems.

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[58] "Fire Protection Equipment - Carbon Dioxide Extinguishing Systems for Use on Premises - Design and Installation," International Standard ISO 6183 : 1990 (E), International Standards Organization, First edition, July 1990.

Appendix F is an excerpt of the requirements and related explanatory material regarding safety requirements, including ….

- exit routes
- warning and instruction and direction signs
- alarms
- outward swinging self-closing doors
- self-contained breathing equipment
- personnel training
- ventilation of the areas after extinguishing the fire

The standard has specific requirements for …..

- precautions for low-lying parts of protected areas.
- precautions during maintenance work.

9.6 International Maritime Organization

The requirements for carbon dioxide systems that are employed on ships on international voyages fall under the regulations promulgated under the International Convention for the Safety of Life at Sea, 1974, an international ship safety treaty, also referred to as SOLAS. Those requirements are detailed in the Fire Systems Safety Code (FSS Code)[59] which has the following stated purpose:

> "The purpose of this Code is to provide international standards of specific engineering specifications for fire safety systems required by chapter II-2 of the International Convention for the Safety of Life at Sea, 1974, as amended."

An excerpt from this Code pertaining to the safety requirements for carbon dioxide systems is shown at Appendix G. In general, though, the requirements are rather simple, covering the following:

- A requirement to prevent inadvertent release of the agent into the space together with guidelines about routing piping for the systems through accommodations or passenger spaces.
- A requirement for a predischarge alarm and time delay of at least 20 seconds to permit personnel evacuation from "ro-ro spaces and other spaces in which personnel normally work or to which they have access." Conventional cargo spaces and "small spaces" are exempted from these requirements.
- A requirement that the controls for of any fixed gas fire-extinguishing system have clear instructions relating to the operation of the system having regard to the safety of personnel.
- The requirement that all systems must be manually operated. That is, automatic release of the fire-extinguishing system is not permitted.
- Plus the requirement that carbon dioxide systems must have two separate controls, one control for opening the valve of the piping which conveys the gas

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[59] "International Code for Fire Safety Systems, Chapter 5, Fixed Gas Fire Extinguishing Systems," International Maritime Organization, 4 Albert Embankment, London SE1 7SR, England: July 2002.

into the protected space and a second control for opening the valve on the agent storage containers.

Concern over the use of carbon dioxide systems has been expressed at the 47th meeting of the IMO Fire Protection Sub-Committee in February 2003 where three documents were submitted on this subject.

- First, a report[60] by the Correspondence Group on Performance Testing and Approval Standards for Fire Safety Systems that described specific tasks for a working group to accomplish. The following is a verbatim excerpt from that report and attention is called to point .9:

  ".4 Fixed gas fire-extinguishing systems
  Consider revising MSC/Circ.848 for fixed gas fire-extinguishing systems, including inert gases required by regulation II-2/10.4.1.1.1 and 10.9.1.1 to:
  .1 add the PBPK model for toxicity;
  .2 add component manufacturing standards;
  .3 define a standard cup burner test;
  .4 identify necessary changes for testing of inert gases;
  .5 decide on the need for a minimum vent opening;
  .6 harmonize the minimum fire size with MSC/Circ. 668;
  .7 correlate the volume of the test enclosure with the actual engine room volume;
  .8 decide if a fire exposure test should be required for agent storage containers and control system components located inside the protected space; and
  .9 decide if carbon dioxide should be prohibited in occupied spaces."

- Second, a paper[61] submitted by Denmark, called for changes to the requirements for carbon dioxide systems to improve their safety performance. The Danish proposal included this statement:

  > "4 It should also be noted that CO2 systems are still being released by accident so the safety of the personnel in the concerned spaces should have high priority in the Sub-Committee's consideration of this matter. "

- Third, a paper[62] submitted by the United States transmitting for the information of IMO delegations a copy of the Merchant Shipping Case Study excerpt from the 2002 Assessment Report[63] of the UNEP Halons Technical Options Committee. The following excerpt addresses the use of carbon dioxide systems in shipboard machinery spaces:

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[60] "Report of the Correspondence Group on Performance Testing and Approval Standards for Safety Systems," Document FP 47/8, International Maritime Organization, 4 Albert Embankment, London SE1 7SR, England: November 2002.

[61] "Proposal for Amending the International Code for Fire Safety Systems," Document FP 47/8/1, Submitted by Denmark, International Maritime Organization, 4 Albert Embankment, London SE1 7SR, England: November 2002.

[62] "Availability of Halons Used on Board Ships," Document FP 47/INF.5, Submitted by the United States, International Maritime Organization, 4 Albert Embankment, London SE1 7SR, England: November 2002.

[63] "2002 Assessment Report of the Halons Technical Options Committee," ISBN 92-807-2286-7, Ozone Secretariat, United Nations Environment Program, Nairobi, Kenya: March 2003.

“But a recent survey has illustrated that 9 out of 10 new ships use carbon dioxide systems for the protection of the machinery space. While systems using the new halon alternatives are safer than carbon dioxide in terms of personnel exposure to the agents, they are all more expensive than carbon dioxide systems, thus accounting for the new popularity of carbon dioxide. Irrespective of the safety devices and measures employed with total flooding carbon dioxide systems, the history of deaths and injuries caused by these systems is ample evidence that their wholesale employment will likely produce higher rates of deaths and injuries than we are currently experiencing. This regression to carbon dioxide systems has alarmed many health and safety officials. On the basis of the growing life safety concerns, it is likely there will be efforts to effect a ban on the use of carbon dioxide total flooding systems in normally occupied spaces, including shipboard machinery spaces.”

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10 Alternatives

Many feel that the increased usage of carbon dioxide total flooding systems, especially in the marine market, is the direct result of our inability to produce a cost effective alternative to halon 1301. 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. However, it became apparent that some compromises were necessary in order to accept the alternatives to halons that were ultimately developed. Table 20 is an illustration of some of the agent characteristics the industry felt were important, the level expected and what was actually achieved.

Table 20: 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

Had all the expectations in Table 20 been achieved, many believe that carbon dioxide total flooding systems would be a thing of the past. Unfortunately, by failing to achieve all the expectations, especially the matter of cost, the employment of carbon dioxide systems has proliferated.

10.1 General

From a technical standpoint, there are several types of systems that can perform comparably if not better than carbon dioxide in total flooding applications:

- Halocarbon gaseous extinguishing systems
- Inert gas extinguishing systems
- Water mist extinguishing systems

In addition, under certain circumstances, there are additional alternative systems that might be appropriate, including:

- Aerosol extinguishing systems
- Preaction water sprinkler systems
- Ordinary water sprinkler systems
- Low, medium and high expansion foam systems
- Dry chemical systems

In the marine market, IMO has developed guidelines for the approval of systems considered equivalent to carbon dioxide systems for the protection of machinery spaces.

Three separate guidelines deal with water mist,[64] halocarbon or inert gas[65] and aerosol systems.[66]

The US EPA funded an earlier report[67] addressing the development and market acceptance of several alternatives to halons. The information in that report dealt with the long path to commercialization, the status of various agents along that path, a comparison of environmental properties of the agents and a quick look at some of the relative costs.

From a total flooding system standpoint, that report concluded that there has been commercial acceptance of two types of agents …..

- gaseous agents including halocarbons and inert gas agents and …..
- water mist extinguishing systems …..

….. and that while aerosol extinguishing systems present some potential, those types of agents have not yet achieved any significant level of acceptance, especially in the US.

10.2 Gaseous Extinguishing Agents for Fixed Systems

From the gaseous extinguishing agents standpoint, the report also pointed out that some of the agents that had been incorporated into national and international standards[68,69] never really achieved commercial success and others are already on a phase-out schedule (e.g. the HCFC's). Thus many of those agents are probably beyond consideration as suitable alternatives to halons, carbon dioxide or anything else. In the end, the agents in Table 21 can be considered viable gaseous alternatives to compete with carbon dioxide in many applications. While accepted for the next editions but not yet included in the current cited standards, a new halocarbon agent, identified as FK-5-1-12, or 3M Novec 1230 Fire Protection Fluid, has been listed as acceptable by EPA's SNAP program,[70] so it too is included in Table 21.

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[64] "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.

[65] "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.

[66] "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, International Maritime Organization, London: June 2001.

[67] Wickham, Robert. T, "Status Of Industry Efforts To Replace Halon Fire Extinguishing Agents," Wickham Associates, Stratham, NH: March 2002 available at http://www.epa.gov/ozone/snap/index.html

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

[69] "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.

[70] "Protection of Stratospheric Ozone: Notice 17 for Significant New Alternatives Policy Program," 40 CFR Part 82, Environmental Protection Agency, [FRL–7425–6], Federal Register / Vol. 67, No. 245 / 77927, Friday, December 20, 2002.

Table 21: Gaseous Alternatives to Carbon Dioxide for Total Flooding Systems

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
FK-5-1-12	Novec 1230	FK	$CF_3CF_2C(O)CF(CF_3)_2$
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

10.3 Water Mist Systems

To many, water is perceived as a tremendous fire extinguishing agent. It is readily available, inexpensive and 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 collateral damage often associated with higher flow rate water systems.

Water mist has made in-roads into 3 major market applications, two of which have heretofore been served by carbon dioxide systems: the protection of turbine and diesel powered machinery, the protection of machinery spaces aboard ships and as an alternative to water sprinkler systems aboard passenger ships. There are accepted test protocols (Factory Mutual Research[71] for the turbines and IMO[72,73,74] for shipboard) for these market applications and those who have their systems successfully tested have achieved the right to participate.

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[71] "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.

[72] "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.

[73] "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.

[74] "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.

While water mist shows a lot of promise, it is having a difficult time capitalizing on its utility in the marine market. There it has become apparent that water mist tends to work well as a total flooding agent in extinguishing large fires but has difficulties extinguishing small fires in large spaces, a requirement that is built into the IMO test protocol. At this time, those manufacturers who have successfully tested their water mist systems to the IMO test protocol have done so by employing very expensive techniques or additional agents and hardware that are considered by many to be unnecessary for the types of fires for which a fixed system is intended. The additional costs embodied in the water mist systems by this total extinguishment of the small fire requirement is what makes the difference between water mist systems being very competitive and being the most costly, as will be shown later in the report.

IMO has a working group studying this situation and that group is considering proposals that suggest an overhaul to the test methods and approval guidelines. Should IMO change its water mist requirements to something more flexible regarding the small fires in large spaces, it will make a significant difference in the cost and thus market acceptance of water mist systems going forward.

10.4 Other Types of Agents for Fixed Systems

In addition to the gaseous agents listed in Table 20 and the water mist systems, there are several other types of agents being promoted as halon replacements in fixed systems, including inert gas generators and aerosols. These systems, when developed further, may become viable alternatives for applications now largely served by carbon dioxide total flooding systems.

10.4.1 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." There is work underway to adapt this technology to industrial and marine applications.

10.4.2 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 has formed a technical committee on "Aerosol Extinguishing Technology"[75] which will develop a standard to provide the guidance for appropriate application of these systems. As illustrated in Table 22, several other standards making organizations are in the process of developing or have completed their guidelines for the use of these types of agents.

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[75] The technical committee member list is available at http://www.nfpa.org/PDF/ComList.pdf?src=nfpa

Table 22: 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.
National Fire Protection Association	"(Draft) Standard For Aerosol Fire Extinguishing Systems," Proposed NFPA 2010 (under development).
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) Condensed Aerosol Extinguishing Systems. Part 2: Design, Installation and Maintenance of Condensed Aerosol Extinguishing Systems.;" CEN/TC 191/WG 6/TG 2 N 6rev, 10 March 2003.

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11 Comparisons of Alternatives

11.1 General

Several studies have weighed and ranked the “desirability” of one agent system over another. Most of these studies have been in search of a replacement for halon 1301.

Many of these studies take an approach of …..

- identifying several desirable or undesirable attributes of an extinguishing system , then …..
- assigning weights to those attributes to make some more important than others, then …..
- assigning a numerical value to each of these attributes for each of the different as some sort of grade and then…..
- performing the mathematics to arrive at what would seem to be a scientifically sound best choice.

The difficulty with this type of approach is that not everyone agrees on the relevant attributes, few agree on the weighting of those attributes and almost no one agrees on the grades that are assigned to individual agents.

11.2 Types of Comparisons

From a practical standpoint, it is probably best to categorize individual system attributes into three types …..

- those where it is sufficient to say the individual system is either adequate or inadequate, …...
- those that represent different value to different people (i.e. preferences) and thus do not lend themselves to generalizations and …..
- those that lend themselves to quantification and are useful as a basis for comparison of alternatives.

11.2.1 <u>Adequate or Inadequate</u>

On the first point, all of the alternatives to carbon dioxide listed in Table 20, together with water mist, are…..

- recognized as total flooding fire extinguishing agents by several authoritative sources, …..
- included on the US EPA SNAP list with no use conditions, …..
- employed at concentrations below that considered harmful to humans, …..
- leave little or no agent residue, …..
- generally operate throughout the same temperature range as carbon dioxide and …..
- have a number of other common attributes for adequacy.

11.2.2 Preferences

On the second point, there are numerous characteristics of the various agent systems that may make profound differences to some users, but certainly not all. Some examples are …..

- water mist systems can be brought into action faster than a gaseous system, thus reducing fire damage, since it is not necessary with the water mist systems to close openings and shut down ventilation before the start of discharge, …..
- water mist and inert gas agents have more attractive environmental properties than the halocarbons and some of the halocarbons have more attractive environmental properties than other halocarbons, …..
- the gaseous systems are usually limited to a single discharge of agent whereas most water mist systems have an unlimited water supply in land based operations and at least 30 minutes of potable water discharge plus after that an unlimited amount of sea water for marine applications, …..
- some halocarbons are considered safer than others depending on how close the use concentrations come to the point where adverse health effects may be experienced, …..
- halocarbon agents tend to extinguish fires more rapidly than the longer discharging carbon dioxide, inert gas or water mist systems and …..
- in high energy fire situations, the halocarbons can experience decomposition, thus creating hydrofluoric acid (HF) whereas decomposition of the agent is not an issue with carbon dioxide, the inert gases nor water mist.

11.2.3 Quantifiable Comparisons

Finally, on the third point, the quantifiable areas of differentiation are best illustrated by selecting several applications (hazard sizes), selecting a common set of performance goals (internationally accepted IMO fire system requirements for Category A machinery spaces), designing a series of systems to achieve those goals and then comparing those systems with respect to …..

- space required by the main equipment (footprint and volume), …..
- weight of the main equipment and …..
- cost.

It must be acknowledged that there are several elements of cost, including, at least, …..

- Equipment provided by the systems manufacturer
- Materials provided by the installer
- Labor provided by the installer
- Profit at every level on the avenue to the customer
- Maintenance, recharge and servicing costs over the system's life.

Only one element of cost is included in this report and that is the cost of the equipment provided by the system manufacturer at the level the manufacturer sells the equipment. While this approach does not give the complete end user cost, it certainly ranks the different systems with respect to the initial cost. Within the range of systems covered by the report, it is generally accepted that a system that costs twice as much as another at the manufacturers level will likely cost somewhere in the vicinity of twice as much at the end-user level.

The IMO requirements were selected as they are the only quantifiable guidelines that apply to carbon dioxide systems, halocarbon systems, inert gas systems and water mist systems applied to a common application, in this case a Category A machinery space. For the most part, the space, weight and cost information for the gaseous systems (carbon dioxide, halocarbons and inert gases) translate quite well from marine to industrial applications for hazards of like volumes. The marine water mist systems, however, do not translate well to industrial applications. Thus, the space, weight and cost comparison information for the water mist systems in paragraph 11.3 is limited to marine systems since considerably smaller, less costly water mist systems would be the norm for most industrial applications.

11.3 Space, Weight and Cost Comparisons

Several fire systems manufacturers were requested to design and estimate the price of their systems to protect 4 different size spaces to the IMO SOLAS requirements. Table 23 is an illustration of the appropriate IMO documents describing the requirements for the different types of systems.

Table 23: IMO Requirements for Machinery Space Total Flooding Systems

Agent Type	**IMO Documents**
Carbon dioxide	"International Code for Fire Safety Systems, Chapter 5, Fixed Gas Fire Extinguishing Systems," *Carbon Dioxide, paragraph 2.,* International Maritime Organization, 4 Albert Embankment, London SE1 7SR, England.
Halocarbon or inert gas	"International Code for Fire Safety Systems, Chapter 5, Fixed Gas Fire Extinguishing Systems," *Equivalent Fixed Gas Fire-Extinguishing Systems For Machinery Spaces And Cargo Pump Rooms, paragraph 2.5,* and "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," (MSC/Circ.848), International Maritime Organization, 4 Albert Embankment, London SE1 7SR, England.
Water mist	"International Code for Fire Safety Systems, Chapter 7 - Fixed Pressure Water-Spraying and Water-Mist Fire-Extinguishing Systems," *Equivalent Water-Mist Fire-Extinguishing Systems, paragraph 2.2*, and "Alternative Arrangements for Halon Fire-Extinguishing Systems in Machinery Spaces and Pump-Rooms," (MSC/Circ.668) and the "Revised Test Method For Equivalent Water-Based Fire-Extinguishing Systems for Machinery Spaces of Category A and Cargo Pump-Rooms," (MSC/Circ.728), International Maritime Organization, 4 Albert Embankment, London SE1 7SR, England.

Table 24 is an illustration of the spaces selected, all of which had a net volume of 85% of the gross volume to account for machinery or other un-moveable objects. The design temperature was set at 0°C.

From a weight and space estimate standpoint, the manufacturers were asked to include only the agent storage containers (for the gaseous agents) and the main machinery for the water mist systems (pumps, cylinders and skid mounted controls). They were asked to disregard the weight and space for any supply or distribution piping and supports and, in the case of water mist systems, report the weight of the 30 minutes potable water supply separately from the system weight.

Table 24: Protected Space Characteristics

Nominal Space	Length	Width	Height	Gross Volume	Machinery	Net Volume
m^3	m	m	m	m^3	m^3	m^3
500	10.00	10.00	5.00	500	75	425
1,000	12.00	16.50	5.00	990	149	842
3,000	20.00	25.00	6.00	3,000	450	2,550
5,000	24.00	29.00	7.00	4,872	731	4,141

From a cost estimate standpoint, the manufacturers of gaseous systems were all asked to use a pricing level that represents their average selling price to distributors or installers. The pricing …..

- should include agent, agent storage containers, actuators, brackets, discharge and actuation hoses, check valves, stop valves and controls, time delay, manual operated stations, predischarge alarms, pilot cylinders and controls ex works not including packing and freight and …..
- should not include agent distribution piping and fittings, pipe supports and hangers, actuation tubing and fittings, electrical cables and junction boxes or labor to install.

The manufacturers of water mist systems were all asked to use a pricing level that represents their average selling price to distributors. The pricing …..

- should include pump units, water and nitrogen cylinder banks (for 1st minute of water supply), spray heads, section valves and other devices factory fabricated and skid mounted and …..
- should not include feed water pipes, low pressure piping, electrical cables and junction boxes or labor to install.

Table 25 is an illustration of the design concentrations and temperatures used for each of the gaseous systems. While certainly not considered an alternative to carbon dioxide, data was generated for a series of halon 1301 systems to illustrate the cost and performance appeal those types of systems surely had in the 1960's through the 1980's when halon 1301 systems were the preferred method of protecting normally occupied machinery spaces aboard ships. For that comparison, present day halocarbon system hardware was used as the basis for cost, weight and space data. A halon 1301 agent cost of $7.70 per kilogram was used which represents the pricing of the agent before the production halt.[76]

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[76] In introducing halon 1301 systems into the comparison, a choice had to be made about the type of system hardware to use in the make up of the space and weight estimates for this type of system. New halon 1301 systems have, for all practical purposes, been out of production since the early 1990s. Since the modern day halocarbon hardware is for the most part descended from halon hardware, the use of the same vintage hardware for both halocarbons and halon 1301 seemed the least problematical from the point of avoiding introducing unnecessary variables. The choice of using an historical agent price was necessary as the current price of reclaimed halon 1301 in some parts of the world has gone negative as system owners are being faced with agent destruction costs when halon 1301 systems are removed from service. Thus, the use of an agent cost common before the production ban coupled with the modern equipment cost, weight and space requirements provides the most useful derived system information for comparisons with the other systems.

Table 25: Design Parameters for the Gaseous Agent Systems[77]

Generic Name	Trade Name	Concentration	Temperature
HFC-23	FE-13	19.5%	0°C
HFC-227ea	FM-200	8.7%	0°C
FK-5-1-12	Novec 1230	5.5%	0°C
IG-541	Inergen	40.0%	0°C
Carbon dioxide	-	~34%[78]	NA
Halon 1301	-	*6.0%*	*0°C*

11.3.1 System Design Results

Tables 26 through 29 illustrate the space and weight requirements for the agent storage cylinders for the gaseous systems and the pump units, water and nitrogen cylinder banks (for 1st minute of water supply), section valves and other devices factory fabricated and skid mounted.

In that regard, the following notes apply to the tables:

a. For the gaseous agents, agent weight is the net weight of the agent and is included in the total weight of the system. For water mist, the agent weight is for the dedicated potable water supply to provide 30 minutes discharge and is not included in the system total weight.

b. Footprint is the area of a square or rectangle circumscribing the agent cylinder bank for the gas systems and the pump skid, water and nitrogen cylinders and other equipment for the water mist system.

c. Cube is the footprint multiplied by the height of the cylinders measured to the top of the valves for gaseous systems and to the top of the uppermost component on the pump or cylinder skids for the water mist systems.

d. Total weight in the case of the gas systems is the weight of the agent storage containers and contents. For the water mist system total weight includes the pump skid, water and nitrogen cylinders and other equipment but does not include the potable water supply. Neither include the weight of piping, hangers, etc.

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[77] The concentrations for the halocarbons and inert gases are based on the net volume of the protected space per IMO requirements. The agent quantities for carbon dioxide and for halon 1301 are based on the gross volume of the protected space, also per IMO requirements.

[78] The SOLAS regulations for carbon dioxide systems do not use the term "concentration" but instead require a volume of free carbon dioxide gas equal to either 35% (if including the casing) or 40% (if excluding the casing) of the gross volume of the protected space. The regulation requires the agent quantity calculation be performed assuming the free specific volume of carbon dioxide is 0.56 m^3/kg. For the purposes of the study estimates, the 40% value was used which provides a residual agent concentration in the vicinity of 34% when taking into consideration the normal loss of agent from the space during discharge.

Table 26: System Design Results for 500 m^3 Systems

Agent	**Agent Weight** (Note a)	**Cylinder Volume**	**Number of Cylinders**	**Footprint** (Note b)	**Cube** (Note c)	**Total Weight** (Note d)
	Kilograms	Liters	Each	m^2	m^3	kg
Halon 1301	*216*	*246*	*1*	*0.3*	*0.5*	*400*
Carbon dioxide	364	68	8	0.6	0.9	1,000
FE-13	425	68	9	0.6	1.0	1,200
FM-200	319	368	1	0.4	0.7	600
Novec 1230	373	368	1	0.4	0.7	600
Inergen	320	82	19	1.3	2.7	2,000
Water Mist	9,000			3.8	6.9	2,900

Table 27: System Design Results for 1,000 m^3 Systems

Agent	**Agent Weight** (Note a)	**Cylinder Volume**	**Number of Cylinders**	**Footprint** (Note b)	**Cube** (Note c)	**Total Weight** (Note d)
	Kilograms	Liters	Each	m^2	m^3	kg
Halon 1301	*432*	*246*	*2*	*0.6*	*0.9*	*800*
Carbon dioxide	727	68	16	1.1	1.9	2,100
FE-13	856	68	17	1.2	1.8	2,300
FM-200	632	368	2	0.7	1.4	1,100
Novec 1230	738	368	2	0.7	1.4	1,200
Inergen	624	82	37	2.9	5.8	4,400
Water Mist	17,500			6.1	11.0	5,700

Table 28: System Design Results for 3,000 m^3 Systems

Agent	**Agent Weight** (Note a)	**Cylinder Volume**	**Number of Cylinders**	**Footprint** (Note b)	**Cube** (Note c)	**Total Weight** (Note d)
	Kilograms	Liters	Each	m^2	m^3	kg
Halon 1301	*1,300*	*246*	*5*	*1.6*	*2.3*	*2,100*
Carbon dioxide	2,182	68	48	3.4	5.5	6,300
FE-13	2,556	68	49	3.5	5.2	6,700
FM-200	1,915	368	5	1.9	3.6	3,100
Novec 1230	2,235	368	6	2.2	4.3	3,600
Inergen	1,888	82	112	8.7	17.5	13,200
Water Mist	20,400			17.6	27.2	16,200

Table 29: System Design Results for 5,000 m^3 Systems

Agent	**Agent Weight** (Note a)	**Cylinder Volume**	**Number of Cylinders**	**Footprint** (Note b)	**Cube** (Note c)	**Total Weight** (Note d)
	Kilograms	Liters	Each	m^2	m^3	kg
Halon 1301	*2,160*	*246*	*9*	*2.8*	*4.2*	*3,600*
Carbon dioxide	3,591	68	79	5.6	9.1	10,300
FE-13	4,277	68	82	5.8	8.7	11,200
FM-200	3,110	368	8	3.0	5.8	4,900
Novec 1230	3,630	368	9	3.4	6.5	5,700
Inergen	3,036	82	182	14.2	28.5	21,500
Water Mist	32,000			20.7	38.9	22,400

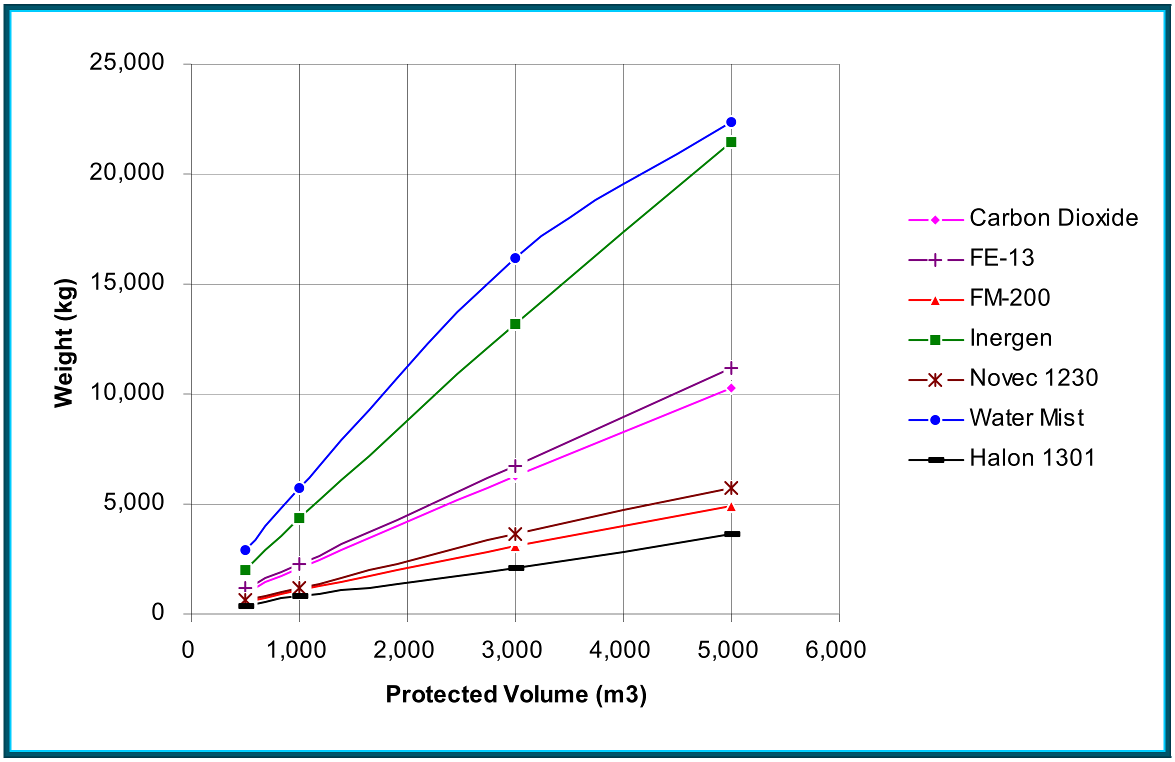
11.3.2 System Weight Comparisons

Table 30 is a tabular comparison of the weights of the systems over the range of volumes from 500 m^3 through 5,000 m^3 in terms of percentage additional weight over a halon 1301 system. Figure 1 is graphical presentation of total system weights for the 4 volumes from Tables 26 through 29. Ignoring the halon 1301, it is clear that the FM-200 system is the most weight efficient while the water mist and Inergen systems are 3 times the weight of the FM-200 systems. Carbon dioxide and FE-13 equipment weights are nearly identical and Novec 1230 systems are between the FM-200 and carbon dioxide weights.

Table 30: % Weight Comparisons of Systems in 500 – 5,000 m^3 Range of Volumes
(percentage additional weight when compared to a halon 1301 system)

Agent	500 m^3	1,000 m^3	3,000 m^3	5,000 m^3
Halon 1301	0%	0%	0%	0%
Carbon dioxide	150%	163%	200%	186%
FE-13	200%	188%	219%	211%
FM-200	50%	38%	48%	36%
Novec 1230	50%	50%	71%	58%
Inergen	400%	450%	529%	497%
Water Mist	625%	613%	671%	522%

Figure 1: System Weight Comparisons



11.3.3 System Footprint Comparisons

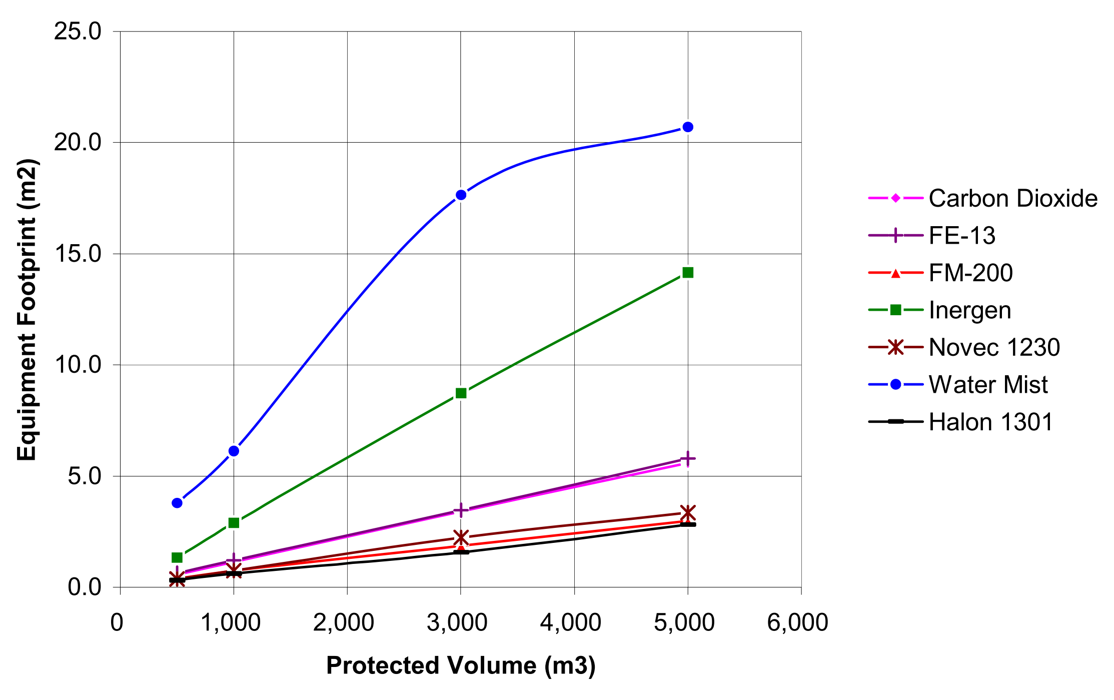
Table 31 is a tabular comparison of the footprint or floor / deck space occupied by the agent storage containers for the gaseous systems and the pumping machinery and accessories for the water mist systems in terms of percentage additional floor area over that required by a halon 1301 system. Figure 2 is a graphical presentation of the actual footprint or floor / deck area occupied over the 4 volumes. In this case, both the FM-200 and Novec 1230 agent storage cylinder arrangements are less than that required for carbon dioxide with FE-13 requirements fairly similar to carbon dioxide.

The Inergen and water mist system floor area requirements are significantly more than the requirements for the halocarbon or carbon dioxide systems.

Table 31: % Footprint Comparisons of Systems in 500 – 5,000 m^3 Range of Volumes
(percentage additional floor space when compared to a halon 1301 system)

Agent	500 m^3	1,000 m^3	3,000 m^3	5,000 m^3
Halon 1301	0%	0%	0%	0%
Carbon dioxide	84%	82%	118%	99%
FE-13	105%	94%	122%	107%
FM-200	20%	20%	19%	6%
Novec 1230	20%	20%	43%	19%
Inergen	327%	365%	459%	404%
Water Mist	1,119%	889%	1,030%	636%

Figure 2: System Footprint Comparisons



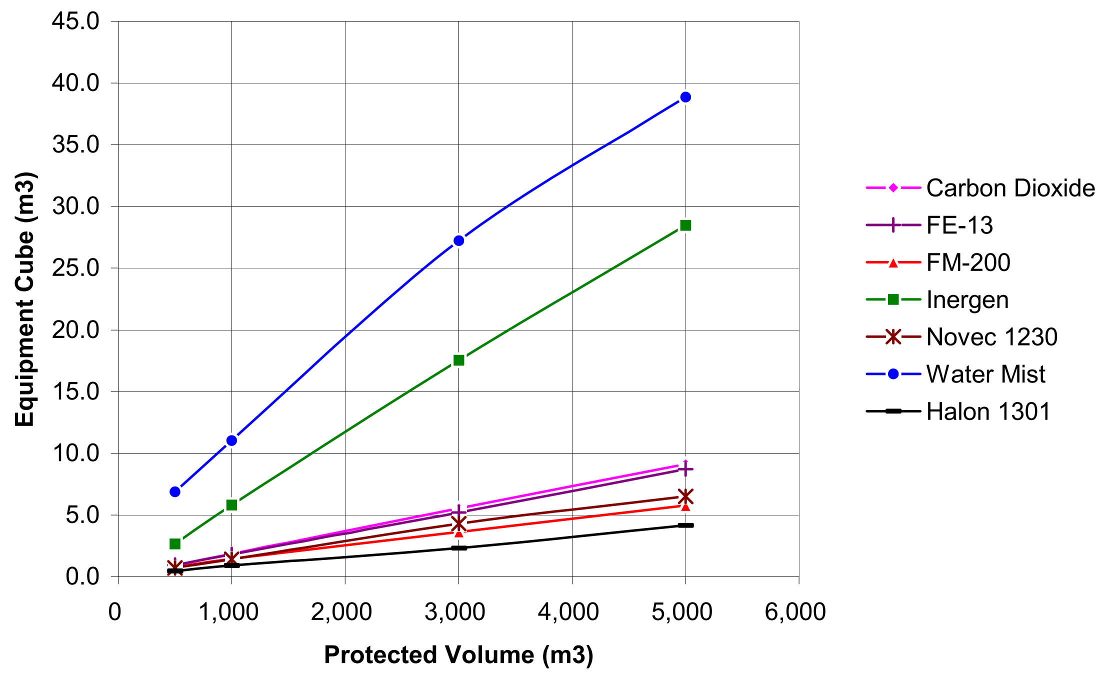
11.3.4 System Cube Comparisons

Table 32 is a tabular comparison of the volume or cubic space occupied by the agent storage containers for the gaseous systems and the pumping machinery and accessories for the water mist systems in terms of percentage additional cubic space over that required by a halon 1301 system. Figure 3 is graphical presentation of the actual volume or cubic space occupied by the systems over the 4 volumes. In this case, the cubic space requirements track quite close the footprint requirements of the various systems.

Table 32: % Cube Comparisons of Systems in 500 – 5,000 m³ Range of Volumes
(percentage additional cubic space when compared to a halon 1301 system)

Agent	500 m³	1,000 m³	3,000 m³	5,000 m³
Halon 1301	0%	0%	0%	0%
Carbon dioxide	100%	101%	140%	119%
FE-13	108%	96%	125%	109%
FM-200	57%	57%	56%	39%
Novec 1230	57%	57%	87%	56%
Inergen	478%	529%	659%	585%
Water Mist	1,398%	1,098%	1,079%	834%

Figure 3: System Cube Comparisons



11.3.5 Cost Comparisons

Table 33 is an illustration of the comparative costs of the carbon dioxide, halocarbon, inert gas and water mist systems over the range of volumes from 500 m³ through 5,000 m³. Figure 4 is a graphical presentation of the same information. The halon 1301 costs[79] are hypothetical and for reference only.

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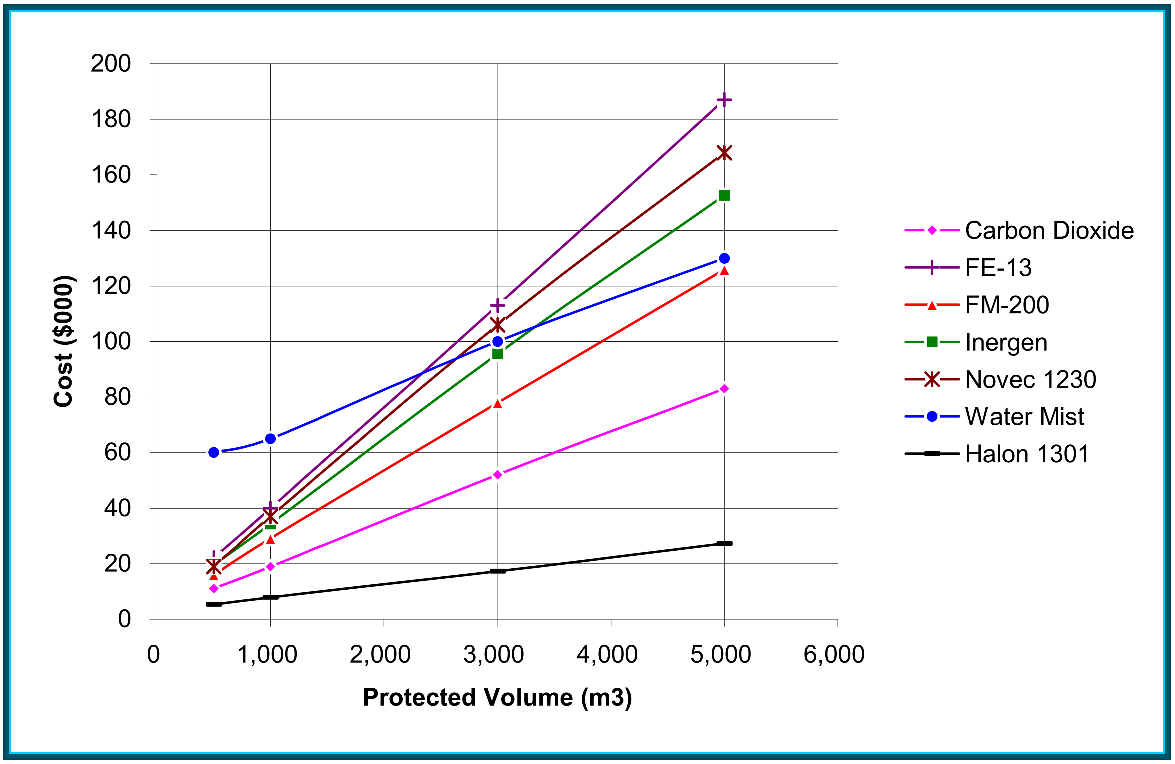
[79] The halon 1301 system costs were derived using present day halocarbon system hardware and an agent cost of $7.70 per kilogram which represents the pricing of the agent from the system manufacturer at sometime before the halon production halt.

Table 33: $ Cost Comparisons of Systems in 500 – 5,000 m^3 Range of Volumes

Agent	500 m^3	1,000 m^3	3,000 m^3	5,000 m^3
	$	$	$	$
Halon 1301	*5,300*	*7,900*	*17,300*	*27,300*
Carbon dioxide	11,000	19,000	52,000	83,000
FE-13	22,000	40,000	113,000	187,000
FM-200	16,000	29,000	78,000	126,000
Novec 1230	19,000	37,000	106,000	168,000
Inergen	20,000	34,000	95,000	153,000
Water Mist	60,000	65,000	100,000	130,000

Figure 4: $ Cost Comparisons of Systems in the 500 - 5,000 m^3 Range of Volumes



Another way of looking at the cost comparisons is from a percentage standpoint, using halon 1301 systems in the 4 spaces as the base. Table 34 is an illustration of the “cost penalties” the alternative systems carry in terms of percentage over the cost of a halon 1301 system.

Table 34 illustrates the scaling effect on costs where, at 500 m^3, FM-200 appears to be the most cost effective alternative to carbon dioxide and water mist the least. Then, at 5,000 m^3, water mist appears to be the most cost effective alternative to carbon dioxide having moved up the ranks from last to first place over the range of volumes.

Table 34: % Cost Comparisons of Systems in 500 – 5,000 m^3 Range of Volumes
(percentage additional cost when compared to a halon 1301 system)

Agent	500 m^3	1,000 m^3	3,000 m^3	5,000 m^3
Halon 1301	0%	0%	0%	0%
Carbon dioxide	108%	140%	200%	204%
FE-13	315%	406%	553%	585%
FM-200	202%	267%	351%	361%
Novec 1230	259%	368%	513%	515%
Inergen	277%	330%	449%	460%
Water Mist	1,032%	723%	478%	376%

To put this whole cost matter into perspective, those who had historically used halon 1301 total flooding systems, who now use carbon dioxide systems for those same applications and who are now faced with the prospect of changing to newer alternatives, have experienced ….

- a system cost increase ranging from 100%+ to 180%+ to move from the safety of halon 1301 systems to carbon dioxide systems and …..
- a further increase in the range of 55% to 65% over the carbon dioxide system costs to move from the use of carbon dioxide systems to the safety of the most cost effective of the alternatives.

The cost comparisons in Tables 33 and 34 show …..

- why the marine industry – in the 1970s - was so supportive of accepting halon 1301 systems instead of the then current standard carbon dioxide systems and …..
- why, with the production halt on halon 1301, the preference shifted right back to carbon dioxide and not to one of the new alternatives.

Clearly, relative cost has to be the largest single objection to the selection of any of the available alternatives over carbon dioxide systems, especially in the marine sector.

11.3.6 Cost Comparison Exceptions

In dealing with the system costs, one cannot always directly compare a system against another without taking some other relevant matters into consideration. There are three instances where some fairly significant changes in costs can take place: The first is when selector valves are employed to deal with multiple hazards with the same agent supply, the second when the system approaches a size where bulk storage of the agent supply is appropriate and the third when many of the system components are used for both local application and total flooding purposes.

a. Selector Valve Systems

Carbon dioxide, water and inert gas systems are often configured with selector valve arrangements to use the same agent supply (or pumping capacity in the case of water mist) to protect multiple hazards. In those cases, economics truly favor these multiple hazard capable systems as the cost of the agent supply (or pumping capacity) can be amortized over several applications. The halocarbon agent systems have some selector valve capability but with the maximum 10 seconds system discharge time it is often impossible to use the same agent supply for serve multiple hazards unless they are very close together.

In the case of carbon dioxide systems:

- In land based systems a shared agent supply is often the case in aluminum or steel rolling mills where the carbon dioxide supply serves two purposes: providing agent for the local application system for the rolling machines and agent for the total flooding of normally unoccupied cellars or vaults that contain machinery to support the mill. The agent supply is sized for the largest requirement and delivered to one or the other application through a selector valve arrangement. The assumption here is that only one of the applications would require agent at any given time.
- In marine applications, dry cargo and vehicle carrying ships are required to have a total flooding carbon dioxide system to protect the cargo compartment or vehicle spaces. That agent requirement tends to exceed the amount of agent required for the engine room. So, once again, it is permitted to use the same agent supply to serve both the cargo and machinery spaces.

b. Bulk Storage Systems

In both land based and marine systems, at some point in agent weight it becomes more economical to move from high pressure cylinder storage to low pressure bulk storage systems. All of the comparisons made here have been limited to high pressure carbon dioxide systems.

c. Combined Use Systems

In the case of marine systems, in addition to the total flooding system in the machinery spaces, SOLAS regulations now require a local application water system protecting the individual pieces of hazardous machinery. Much of the same equipment used for a total flooding water mist system may be shared with the local application water system. Table 35 is an illustration of this matter, where the economic benefits of multi-use systems are apparent. (Note: in this example the 500 m^3 total flooding system has the capacity to supply the local application system without the addition of any more pumping capacity).

Table 35: Equipment Costs of Incorporating IMO MSC/Circ. 913 System

Nominal Space	Water Mist Total Flooding System (only)	Local Application System (only)	Water Mist Total Flooding and Water Local Application System Combined	Incremental Cost for Local Application System
m3	$	$	$	$
500	60,000	8,000	60,000	0
1,000	65,000	30,000	75,000	10,000
3,000	100,000	32,000	110,000	10,000
5,000	130,000	32,000	140,000	10,000

11.3.7 Overall Comparisons and Ranking

Table 36 is a compilation of the simple averages of each of the values from Tables 30, 31, 32 and 33 for the percentage weight, footprint, cube and cost comparisons respectively. These values serve to approximate the average for each type of system in each measured category over the 4 volumes of 500, 1,000, 3,000 and 5,000 m^3.

Table 36: % Comparisons of Average Values over the 500 to 5,000 m^3 Range
(Percentage when compared to averages for halon 1301 systems)

Agent	Weight	Footprint	Cube	Cost
Halon 1301	0%	0%	0%	0%
Carbon dioxide	175%	96%	115%	163%
FE-13	204%	107%	110%	465%
FM-200	43%	16%	52%	295%
Novec 1230	57%	26%	64%	414%
Inergen	469%	389%	563%	379%
Water Mist	608%	919%	1,102%	652%

Table 37 is merely a ranking of each type of system against the others in each measured category (weight, footprint, cube and cost) from 1 through 7. If one were to assume that …..

- weight, footprint, cube and cost are the only measurable characteristics that matter and …..
- each of those characteristics was of equal importance, …..

….. then the ranking of the systems in Table 37 would illustrate the order of preference with the hypothetical halon 1301 being the most preferred and water mist the least preferred.

Table 37: Ranking of Average Values over the 500 to 5,000 m^3 Range of Volumes
(Relative ranking in each category)

Agent	Weight	Footprint	Cube	Cost
	ranking	ranking	ranking	ranking
Halon 1301	1	1	1	1
Carbon dioxide	4	4	5	2
FE-13	5	5	4	4
FM-200	2	2	2	3
Novec 1230	3	3	3	6
Inergen	6	6	6	5
Water Mist	7	7	7	7

However, as described in paragraph 11.2.2, there are other characteristics that do not easily lend themselves to quantification and may well individually or collectively serve as the basis for system selection. Some of these other characteristics include …..

- water mist systems can be brought into action faster than a gaseous system, thus reducing fire damage, since it is not necessary with the water mist systems to close openings and shut down ventilation before the start of discharge, …..

- water mist and inert gas agents have more attractive environmental properties than the halocarbons and some of the halocarbons have more attractive environmental properties than other halocarbons, …..
- the gaseous systems usually are limited to a single discharge of agent whereas most water mist systems have an unlimited water supply in land based operations and at least 30 minutes of potable water discharge plus after that an unlimited amount of sea water for marine applications, …..
- some halocarbons are considered safer than others depending on how close the use concentrations come to the point where adverse health effects may be experienced, …..
- halocarbon agents tend to extinguish fires more rapidly than the longer discharging carbon dioxide, inert gas or water mist systems and …..
- in high energy fire situations, the halocarbons can experience decomposition, thus creating hydrofluoric acid (HF) whereas decomposition of the agent is not an issue with carbon dioxide, the inert gases nor water mist.

In reviewing the rankings in Table 36, the only advantage carbon dioxide appears to have over any of the alternatives is cost with several other agents offering significant savings in weight and space when compared to carbon dioxide.

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12 Perceived Issues

In the process of interviewing people knowledgeable on the subject of the use of carbon dioxide total flooding systems in normally occupied spaces, it is obvious that viewpoints spanned the full range of positions available on the issue from,

- carbon dioxide total flooding systems are an essential tool for the fire protection community and nothing should be done to limit their use, to
- use controls are long past due and we must stop this practice of using carbon dioxide systems in normally occupied spaces.

In this section we will try to identify the main issues and present, where possible, both supporting and opposing views to action on carbon dioxide total flooding systems.

There are 6 topics that continued to be touched on during the interviews with divergent opinions on each …..

- Personnel Safety
- Performance
- Training
- Cost and Availability
- Alternatives
- Technology

12.1 Personnel Safety

The issue with safety is not a question of whether or not carbon dioxide can cause injury or death at the concentrations used in total flooding systems. Everyone agrees the agent is nearly instantly lethal at those concentrations. The issue is whether or not the safeguards built into the systems - coupled with the requirements of standards and regulations – are adequate to assure safety to those who work around, visit or transit areas fitted with carbon dioxide systems. In this regard, there are two views ….

12.1.1 Safe enough

There is a strong belief among many that a properly designed, properly serviced total flooding carbon dioxide system can be safely employed in a normally occupied space if the system is equipped with a suitable predischarge alarm and time delay, if there is an adequate evacuation plan and if all who can be exposed to the discharge of the system are adequately trained to act and respond properly.

The view here is that there have “not been that many” accidents, injuries and deaths that would warrant considering changing the rules to unnecessarily further limit personnel exposure. Also, before even thinking about use controls, one must weigh the good that protection with a carbon dioxide system provides society against the few injuries and deaths attributable to those systems.

This group points to the new provision of the “lock out” device in the 2000 version of NFPA 12 as an example of the proactive measures being taken by industry and the consensus standards process to further enhance the safety of these systems. Further, the view is that there is little more that can or should be done to make these already safe systems safer.

12.1.2 Unsafe under any conditions

The opposing view is that carbon dioxide total flooding systems are unsafe under any conditions. The record of accidents and deaths is a testament to this and an indictment of all who promote, design, install, regulate or buy these systems for use in normally occupied spaces.

This group takes issue with and considers flippant approach presented by promoters that simply more changes to existing "safeguards" can make these systems significantly safer. Further, this group feels the industry and its trade associations have done a poor job of adequately advising the public about the safety risks related to carbon dioxide systems. They pointed out an industry association publication which extols the merits of carbon dioxide systems without one word about the safety risks inherent in these systems.[80]

Both the US Navy and the US Army have stopped the practice of installing new carbon dioxide systems out of concern for the safety of some of the finest trained people in the world. So why is it that we - in the civilian sector - think it is appropriate to use these systems around people who are often unaware about the risks presented? This is especially true in the marine sector where the issue of inadequate crew training is the subject of continuous debate.

Finally, how is it that two NFPA standards, 12 and 2001, have such diverging views on what is and what isn't safe? The inconsistency between these two standards, with respect to the requirements for personnel safety, is both illogical and impossible to defend.

12.2 Performance

The issue of performance centers on whether one perceives or does not perceive carbon dioxide to be a unique, irreplaceable system. …..

12.2.1 Carbon dioxide is unique

One view holds that the attributes and performance of carbon dioxide systems are unique when compared to other systems employing alternatives. This view asserts that there are no other agents that can protect such a wide range of applications, and any action to limit the use of carbon dioxide would put numerous lives and unmeasurable property value at risk in the event of a fire. The design flexibility with selector valves and central storage are not available with the halocarbons; neither inert gas nor the halocarbons are very effective on deep seated class A fires and none of the alternatives can be used in local application modes.

12.2.2 Other agents can do the same

The other view is that, while carbon dioxide may well be unique and no single other agent replace it in all (its) applications, there is an entire portfolio of other agent systems that collectively can perform as well as and often times better than carbon dioxide in most plausible total flooding applications. Inert gas and water mist systems can employ selector valves as readily as carbon dioxide and water is the most effective agent on deep seated class A fires. From a technical standpoint, it is difficult to envision any carbon dioxide total flooding system application that could not be readily handled by other agent systems. Water mist is displacing carbon dioxide in the protection of turbine

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[80] "Why Carbon Dioxide (CO2) in Fire Suppression Systems?" at http://www.fssa.net/library-r.shtml and http://www.nafed.org/library/whyCO2.cfm

enclosures and diesel generators. The only area of weakness for alternatives is in local application, which really is not the subject as the issue is the safe use of total flooding systems.

12.3 Training

In looking at this question of the safety of carbon dioxide systems, the thought was presented by several that increased training might reduce the accident rate. Once again, there are different views on this …..

12.3.1 Training is the answer

One view is that many of the accidents described in the earlier EPA report on carbon dioxide systems could have easily been avoided by more training on installation, maintenance and service practices. Some suggested a certification program for installers and servicing companies to make sure those who work around these systems are properly qualified. Over time, the core group of people who were proficient with carbon dioxide systems have retired or gone on to different things at all levels in the industry from the manufacturers to the distributors to the installing and servicing companies to the end user. So today we have new players without a lot of experience. If we train them, the accident rate will drop.

12.3.2 Training is a good idea, but not the answer

The other view is that training is always a good idea, but the repeated mentions of training highlights a disturbing reality. If the lack of training is considered a significant cause of our carbon dioxide related accidents, what do we think our accident experience is going to be like going forward as we retire additional experienced people and end up with fewer trained people? Is the industry willing to make the investments necessary to consistently support and conduct the proper training at all levels on these systems?

12.4 Cost and Availability

Virtually everyone agrees that the major attractions of carbon dioxide systems are low cost and high availability. While there is agreement here, there are different views on the value of low cost, high availability.

12.4.1 Low cost is great

One view is that carbon dioxide systems are the best deal around as the halocarbon and inert gas systems can cost twice as much for a new system. Further, the recharge costs of a carbon dioxide system are inconsequential when compared to the halocarbons. What is equally important though are some of the hidden costs in dealing with the alternatives. Carbon dioxide is a known entity and everyone understands the rules for the design and installation and acceptance of these systems. That's not the case with the alternatives because they are new and some of the requirements may still be open to conflicting interpretations. This is especially true in the shipbuilding industry where there are numerous influences on a project ranging from the owner, the architect, the shipyard, the classification society, the USCG, etc. Questions on the alternatives at any of these levels very easily translate into delays in ship construction.

12.4.2 You get what you pay for

The other view is that the costs of the carbon dioxide systems are so low that some of the essential support that should be bundled with the system are deliberately eliminated from the scope so one can bid a competitive price. When a product settles to a commodity level – as carbon dioxide systems have in many instances – then it is in no one's short term economic interests to incur additional costs supporting that line. It has been a learning experience with the systems using alternatives, but it was that way with halon 1301 in the late 1960's and many made it through that era quite successfully.

Speaking of hidden costs, those system manufacturers, distributors, installers or owners who have been found responsible, even partially, in an accidental death or injury with a carbon dioxide system will never forget either the experience or the cost. Many feel that the profit earned or money saved by selling or buying carbon dioxide systems – when safer alternatives are available – is inconsequential when compared to the potential liability costs associated with even partial responsibility for a single injury or death.

12.5 Alternatives

In considering alternatives to carbon dioxide, those who really do not want to consider them have a long list of reasons, some right on target and the others quite unlikely. Those on the other side of the issue acknowledge many of these reasons and address them ……

12.5.1 Alternatives have problems

One side of this issue feels that the alternatives are really troublesome. First of all, there are too many of them and most people do not have the time or inclination to sort them out. This is compounded by the competitive spirit of self promoting product information which often include less than subtle negative connotations of competitors' products. As a result, after talking to all the promoters, the end user is completely conversant in all the negative attributes of all alternatives.

In addition, there are several specific concerns, such as inert gas and halocarbon systems can kill too if not designed right. There is a concern about the halocarbons and the environment and concerns about halocarbons and decomposition. Also, many mentioned that the alternatives are not as proven as carbon dioxide.

12.5.2 Sure, but don't rule them out

The other side feels this type of criticism of the alternatives is just a replay of what went on in the late 1960's and early 1970's when the forces of carbon dioxide met those of halon 1301 in the battle of the market place. In that instance, however, there was only one alternative, and the collective halon 1301 forces prevailed. This side wishes there were fewer alternatives too. As time marches on, that will be the case as some alternatives have already emerged as leaders and others have failed or are headed in that direction.

The focus on possible, but implausible, safety issues with the inert gases and halocarbons is not credible. The comment about the alternatives not being as proven as an agent that has been in commercial use since 1929 was acknowledged as probably true, but irrelevant.

12.6 Technology

Some feel the reason we find ourselves insisting that carbon dioxide continues to be essential is because we have had only limited success on the technology front. As there is no obvious way to reach the goal of a cost effective replacement for carbon dioxide systems, why even start down that path? Further, who needs it – we have carbon dioxide!

While manufacturers and government organizations have done much work to develop chemical alternatives to halons, everything brought to market to date is so expensive that some have lost hope of finding a cost effective replacement for either halon 1301 or carbon dioxide (with the carbon dioxide presumably being an easier economic target). On the equipment manufacturers side, with a few exceptions, the approach has been limited to putting the new (very expensive) agents into existing hardware, re-labeling it and going to market.

Some have mentioned goals like ……

- continue the work on chemical agent development and find one able to (safely) compete on an installed cost basis with carbon dioxide total flooding systems, ..
- focus development efforts on more cost effective agent storage and delivery systems for really inexpensive agents like water and inert gases or …...
- do both.

This is an area that needs a renewed effort on the part of all stakeholders.

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Appendix A – Search Results – Engine Room Fires

Date	Waters	Type Vessel	Vessel Name	Outcome
21-Oct-02	Sweden	Dry cargo	Flinterzee	Fire extinguished with engine room carbon dioxide system
03-Sep-02	UK	Ro/Ro	Norsea	Fire extinguished with engine room carbon dioxide system
02-Apr-02	UK	Ro/Ro	Atlantic Osprey	Fire extinguished after flooding engine room with carbon dioxide
10-Dec-01	Mozambique	Container	Camille	**Unclear**. Carbon dioxide released; no outcome reported.
14-Nov-01	Spain	Passenger	Arkona	The fire was later extinguished using carbon dioxide
14-Jul-01	US	Container	Staff Sgt Edward A. Carter Jr.	**Unacceptable**. Crew unable to activate carbon dioxide system; 2 fatalities; fire extinguished by shore side assistance.
26-Jun-01	Canada	Bulk	Canadian Transport	Fire extinguished with engine room carbon dioxide system plus shoreside assistance
20-Jun-01	Bermuda	Passenger	Nordic Empress	**Irrelevant**. Fire extinguished with water mist and halon system
18-May-01	UK	MV	Hansa Parijs	Fire extinguished with engine room carbon dioxide system
06-Apr-01	UK	Motor Vehicle	Autofreighter	Fire extinguished with engine room carbon dioxide system
10-Jul-00	Ireland	Dry cargo	Inisheer	**Unclear**. Extinguishers; system not used
23-Jun-00	UK	Tug	Lady Constance	Fire extinguished with engine room carbon dioxide system
20-Mar-00	Atlantic	Bulk	Judith Litrico	Fire extinguished with engine room carbon dioxide system
22-Jan-00	UK	Tug	Toisa Gryphon	**Irrelevant**. Fire extinguished with engine room halon system
25-Sep-99	Germany	Ro/Ro	Donnington	Fire extinguished with engine room carbon dioxide system
19-Sep-99	US	Passenger	Tropicale	**Irrelevant**. Fire extinguished with engine room halon system assisted by water and foam
07-Jan-99	UK	MV	Anagel Fidelity	Fire was extinguished by carbon dioxide.
17-Sep-98	Indonesia	Container	P&O Nedlloyd Brisbane	Fire extinguished with engine room carbon dioxide system
29-Aug-98	Greece	MV	Lady Maria T	Fire extinguished with engine room carbon dioxide system
22-Jun-98	UK	Dry cargo	Paris	Fire extinguished with engine room carbon dioxide system
05-Jun-98	UK	Container	Canmar Endeavor	Fire extinguished with engine room carbon dioxide system and boundary cooling
30-Mar-98	Spain	Tanker	Concorde	Fire extinguished with engine room carbon dioxide system
17-Dec-97	Atlantic	Reefer	Honolulu	Fire extinguished with engine room carbon dioxide system
29-Nov-97	Denmark	Ferry	Mie Mols	Fire extinguished with engine room carbon dioxide system
12-Nov-97	US	Tug	Lawrence L	**Unacceptable**. Carbon dioxide system failed to extinguish; fire extinguished with shore side help

Date	Waters	Type Vessel	Vessel Name	Outcome
20-Oct-97	UK	Reefer	Bolivar	**Unacceptable**. Carbon dioxide system depleted and fighting fire with water. Outcome not reported.
10-May-97	UK	MV	Danica Sunrise	Fire extinguished with engine room carbon dioxide system
21-Apr-97	Angola	Container	Maditerranea	Fire extinguished with engine room carbon dioxide system
06-Jan-97	Canada	Tanker	Le Saule	Fire extinguished with engine room carbon dioxide system
06-Jan-97	UK	Ferry	Achieve	Fire extinguished with engine room carbon dioxide system
03-Jan-97	UK	Ferry	Achieve	Fire on board Achieve smothered using vessel's carbon dioxide system
06-Aug-96	Puerto Rico	Ro/Ro	Kent Atlantic	Fire extinguished with engine room carbon dioxide system
11-May-96	Bahamas	Passenger	Discovery	**Unclear**. Fire extinguishing efforts unclear but fire could not be put out by ship crew but had to be put out with shore side assistance.
08-Feb-96	Canada	Fishing	Judith Suzanne	**Unacceptable**. Carbon dioxide system diminished when crew open door prematurely. Crew not trained in firefighting.
24-Jan-96	Bangladesh	MV	Banglar Robi	Fire extinguished with engine room carbon dioxide system
30-Oct-95	US	Ferry	Billikin	**Unacceptable**. Carbon dioxide unable to extinguish fire. Salvor brought in to extinguish the blaze.
07-Sep-95	UK	MV	Jan-Willem	**Unclear**. Fire out but report did not say how.
18-May-95	Singapore	Container	Planeta	**Unclear**. Sent message "cannot reach CO2 equipment" then 3 hours later reported fire was under control; outcome unclear.
23-Jan-95	US	Container	POL America	Fire extinguished with engine room carbon dioxide system
04-Dec-94	Italy	Bulk	Khudozhnik Toidze	Fire extinguished with engine room carbon dioxide system and shore brigades
17-Oct-94	UK	Bulk	Risnes	**Irrelevant**. Fire extinguished with engine room halon system
26-Jul-94	US	Bulk	Forum Chemist	Fire extinguished with engine room carbon dioxide system
07-Jun-94	Saudi Arabia	Tanker	Nejmat el Petrol XXII	Fire extinguished with pump room carbon dioxide system
02-Jun-94	Libya	Tanker	Esso Demetia	Fire extinguished with engine room carbon dioxide system
13-Dec-93	UK	Ro/Ro	Norman Commodore	**Unacceptable**. Fire still burning 8 hours after release of engine room carbon dioxide system; no outcome reported.
01-Dec-93	Mombosa	MV	Marita Leonhardt	Fire extinguished with engine room carbon dioxide system
27-May-93	UK	Fishing	Calvados	**Unacceptable**. Crew initially tried fighting fire with carbon dioxide system but was forced to abandon vessel due to smoke
14-Apr-93	New Zealand	MV	Capitaine Tasman	Fire extinguished with engine room carbon dioxide system

Date	Waters	Type Vessel	Vessel Name	Outcome
05-Aug-92	Greece	Container	Norasia Attica	Fire extinguished with engine room carbon dioxide system
02-Jul-92	China	Bulk	Berge Charlotte	**Unacceptable**. Carbon dioxide discharged without success. Fire controlled by cooling with seawater.
16-Jan-92	Atlantic	Reefer	Geestbay	Fire extinguished with engine room carbon dioxide system
27-Nov-91	UK	Ferry	Morning Sun	Fire extinguished with engine room carbon dioxide system
19-Sep-91	Canada	Bulk	Docevirgo	Fire extinguished with engine room carbon dioxide system
05-Aug-91	St. Lucia	Reefer	Geestcape	Fire extinguished with engine room carbon dioxide system
01-Aug-91	Thailand	MV	Jutha Malee	Fire extinguished with engine room carbon dioxide system
08-Jun-91	Nigeria	Container	Boringia	Fire extinguished with engine room carbon dioxide system

Appendix B – OSHA Technical Bulletin

Technical Information Bulletin

U.S. Department of Labor
Occupational Safety and Health Administration

Total Flooding Carbon Dioxide (CO_2) Fire Extinguishing System

TIB 01-12-22

Purpose

This Technical Information Bulletin informs users of total flooding carbon dioxide (CO_2) fire-extinguishing systems of a condition that poses a serious hazard to employees.

Background

The New York Regional Office brought to the attention of the Directorate of Technical Support the potential hazards of carbon dioxide intoxication for employees inside a vault protected by a total flooding CO_2 fire-extinguishing system. The Manhattan Area Office investigated an accident in which an employee of a securities firm died from CO intoxication. The employee was inside the vault with the vault door closed and locked. When the employee pulled a manual fire alarm actuation device that was located inside the vault space, it activated the warning alarm and the total flooding CO_2 system.

Description of the Accident

An account administrator at a securities firm was working overtime in a section of a vault. At 7:10 p.m., security personnel closed and locked the vault. The employee was working in a section of the vault accessible only with a swipe card. The security guard did not have a swipe card and did not access that area of the vault, but instead looked through a small window and apparently did not see the employee. The employee discovered that the vault was locked shortly thereafter. There was a phone in the vault, and the employee apparently tried unsuccessfully to call for help. At about 7:35 p.m., the employee pulled a manual fire alarm system actuation device. In addition to sounding an alarm, the device instantly activated a total flooding CO_2 fire-extinguishing system. Activation of the CO_2 system created an atmosphere immediately dangerous to life and health inside the locked vault. Using self-contained breathing apparatus (SCBA), firefighters recovered the employee's body. The cause of death, as ruled by the medical examiner, was accidental CO_2 intoxication.

Accident Investigation

OSHA's accident investigation revealed violations of OSHA's means of egress and fire protection standards, including 29 *CFR* 1910.36 (b)(1), 1910.160(b)(5), 1910.160(c)(1), and 1910.160(c)(3). The

The Occupational Safety and Health Administration's (OSHA's) Directorate of Technical Support issues Technical Information Bulletins (TIBs) to provide information about occupational hazards and/or to provide information about noteworthy, innovative, or specialized procedures, practices, and research that relate to occupational safety and health. These bulletins are not standards or regulations and they create no independent legal obligations. They are advisory in nature, informational in content, and are intended to assist employers in providing a safe and healthful workplace.

Further information about this bulletin may be obtained by contacting OSHA's Directorate of Technical Support at 202-693-2095.

National Fire Protection Association (NFPA) standard on carbon dioxide extinguishing systems (NFPA-12, 2000) also addresses these conditions.

The investigation found that the extinguishing system was interlocked with the vault door. The system would only discharge if the door was shut. The manual pull station was located inside the vault. Pulling the device with the door open sounds the alarm; however, no CO_2 is discharged until the vault door is closed. There were no warning signs at the entrance to the vault indicating the hazard of the total flooding CO_2 system. There also was no label on the pull station to indicate that once activated, there would be a discharge of total flooding CO_2 into the vault and to describe the resultant hazard to personnel.

The employer explained that the system's configuration was intended to permit employees to pull the manual actuation device, exit the vault, and close the door behind them. The employer further explained that the pull station was installed inside the space to prevent employees from activating the system while others were in the vault. However, if the manual station is pulled when the door is already shut, as was the case in this accident, there is an immediate discharge of the CO_2.

The NFPA-12, 2000 standard requires that the normal manual controls for the CO_2 system actuation be located for easy accessibility at all times, including the time of fire. It does not specify whether the location should be inside or outside of the protected space. The 18th edition of the NFPA Fire Protection Handbook requires that the manual controls be located to avoid confusion, and they must be clearly labeled with safe operating procedures. However, it also contains schematics for a total flooding CO_2 system that depict the manual actuation device outside of the protected space and next to the entrance.

During the rescue operation, a problem arose when the fire department needed quick access to the vault space. Firefighters were unable to execute a rescue until a securities firm employee was able to open the vault door.

Conclusions

The employer did not meet the requirements of 29 *CFR* 1910.160 and NFPA-12 standards that require: a warning be posted at the entrance to the vault space, as well as inside the vault, regarding the function of the total flooding CO_2 system and its hazards to personnel; warning signs be posted at the manual actuation station to warn employees about the hazards associated with the total flooding CO_2 system; employees who work inside vault spaces be trained with respect to the potential hazard in the protected spaces and the proper safety precautions to be observed before manually actuating the system. Further, the employer did not provide an emergency action plan in accordance with 29 *CFR* 1910.38, and did not provide a pre-discharge employee alarm in accordance with 29 *CFR* 1910.160 that complies with 29 *CFR* 1910.165. Finally, NFPA-12, 2000 requires, in part, that means be provided for the "*prompt rescue of any trapped personnel.*" The employer failed to meet this requirement.

Recommendations

- Fixed CO_2 extinguishing systems should be installed and maintained in accordance with NFPA-12, 2000 standards.
- Equip the pull station device, installed inside a vault, with a control circuit to ensure that actuating the pull station will initiate activation of the CO_2 fire-extinguishing system only if the vault door is open at the time of actuation and that no discharge of CO_2 will occur until the vault door is subsequently closed. In addition, the control circuit should disable the manual pull station from activating the extinguishing system if the vault door is already closed.
- Ensure that employees have safe and readily available means of evacuation. In unique situations, such as those associated with vaults, alternative protective means such as an emergency intercom system, sign-in log, video or manual-surveillance, and a procedure to ensure that all other employees have cleared all vault spaces before actuating the alarm and fire-extinguishing system and before closing the vault doors, should be communicated, implemented, and followed.

- Post emergency numbers near vault and enclosed space telephones.
- Install signs at the entrance to and inside the protected space indicating the presence of extinguishing systems which can present CO_2 intoxication and suffocation hazards to employees.
- Properly mark/label pull stations and other actuation devices to indicate their function and the potential hazard to personnel.
- Insure that total flooding systems have a pre-discharge alarm which provides employees with sufficient time to safely exit the space.
- Train all employees with respect to: the type of systems installed in the workplace, the hazards involved, proper activation in case of emergency, and the correct response to audible and visual pre-discharge alarms. Provide training for non-English speaking employees in languages understood by the affected employees and other individuals that may be exposed to the hazard.
- Provide a system or device that can be secured in the closed position to prevent accidental or deliberate discharge when persons not familiar with the system (outside vendors and contractors) and its operation are present in a protected space.
- 29 *CFR* 1910.160(b)(6) requires annual inspection to check that the system is maintained in good operating condition. We also recommend inspection of the system for compliance with NFPA and OSHA requirements.

If the total flooding CO_2 extinguishing systems are installed by employers to meet a particular OSHA standard, employers must:

- comply with provisions of 29 *CFR* 1910.162, *Fixed extinguishing systems, gaseous agent;*
- comply with provisions of 29 *CFR* 1910.160, *Fixed extinguishing systems, general.* Among the requirements in this standard is the obligation in Paragraph 29 *CFR* 1910.160 (b)(17) that requires employers to, "*provide and assure the use of PPE needed for immediate rescue.*" Employers will need to designate and train individuals how to properly wear an SCBA and perform rescue.

Additional Information

- NFPA-12, Section 1-6, Personnel Safety, contains requirements to protect personnel.
- NFPA-12, Appendix A-1-6, "The steps and safeguards necessary to prevent injury or death to personnel in areas whose atmospheres will be made hazardous by the discharge of carbon dioxide ...." is not a part of the requirements of NFPA-12. It is presented for informational purposes only. However, the appendix includes provisions which can be used to safeguard personnel and prevent injury or death.
- U.S. Environmental Protection Agency report, "*Carbon Dioxide as a Fire Suppressant: Examining the Risks,*" contains valuable information for raising awareness and promoting the responsible use of CO_2 fire suppression systems. See http://www.epa.gov.

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Appendix C - Excerpt from NFPA Standard 12

Standard	Related Appendix Material
1-6* Personnel Safety.	**A-1-6** The steps and safeguards necessary to prevent injury or death to personnel in areas whose atmospheres will be made hazardous by the discharge of carbon dioxide can include the following provisions: (1) Adequate aisleways and routes of exit and keeping them clear at all times (2) Necessary additional or emergency lighting, or both, and directional signs to ensure quick, safe evacuation (3) Alarms within such areas that will operate immediately upon activation of the system on detection of the fire, with the discharge of the carbon dioxide and the activation of automatic door closures delayed for sufficient time to evacuate the area before discharge begins (4) Only outward swinging, self-closing doors at exits from hazardous areas, and, where such doors are latched, provision of panic hardware (5) Continuous alarms at entrances to such areas until atmosphere has been restored to normal (6) Odor, which is added to the carbon dioxide so that hazardous atmospheres in such areas can be recognized (7) Warning and instruction signs at entrances to and inside such areas (8) Prompt discovery and rescue of persons rendered unconscious in such areas (This can be accomplished by having such areas searched by trained personnel equipped with proper breathing equipment immediately after carbon dioxide discharge stops. Those persons rendered unconscious by carbon dioxide can be restored without permanent injury by artificial respiration, if removed quickly from the hazardous atmosphere. Self-contained breathing equipment and personnel trained in its use, and in rescue practices including artificial respiration, should be readily available.) (9) Instruction and drills of all personnel within or in the vicinity of such areas, including maintenance or construction people who can be brought into the area, to ensure their correct action when carbon dioxide protective equipment operates (10) Means for prompt ventilation of such areas (Forced ventilation will often be necessary. Care should be taken to really dissipate hazardous atmospheres and not merely move them to another location. Carbon dioxide is heavier than air.) (11) Other steps and safeguards that are necessary to prevent injury or death as indicated by a careful study of each particular situation

Standard	Related Appendix Material
1-6.1 Hazards to Personnel. The discharge of carbon dioxide in fire-extinguishing concentration creates serious hazards to personnel, such as suffocation and reduced visibility during and after the discharge period. Consideration shall be given to the possibility of carbon dioxide drifting and settling into adjacent places outside of the protected space *(see 1-6.1.1)*. Consideration shall also be given to where the carbon dioxide can migrate or collect in the event of a discharge from a safety relief device of a storage container.	
1-6.1.1* In any use of carbon dioxide, consideration shall be given to the possibility that personnel could be trapped in or enter into an atmosphere made hazardous by a carbon dioxide discharge. Suitable safeguards shall be provided to ensure prompt evacuation, to prevent entry into such atmospheres, and to provide means for prompt rescue of any trapped personnel. Personnel training shall be provided. Predischarge alarms shall be provided except as noted in 1-8.1(c) and 1-8.3.5.	**A-1-6.1.1** It is recommended that self-contained breathing apparatus be provided for rescue purposes.
1-6.1.2 The following represent typical signs.	
1-6.1.2.1 Appropriate warning signs shall be affixed in a conspicuous location.	
(1) Typical sign in every protected space WARNING CARBON DIOXIDE GAS WHEN ALARM OPERATES VACATE IMMEDIATELY	
(2) Typical sign at every entrance to protected space WARNING CARBON DIOXIDE GAS WHEN ALARM OPERATES DO NOT ENTER UNTIL VENTILATED	
(3) Typical sign in every nearby space where carbon dioxide can accumulate to hazardous levels **CAUTION** CARBON DIOXIDE DISCHARGE INTO A NEARBY SPACE CAN COLLECT HERE. WHEN ALARM OPERATES VACATE IMMEDIATELY	

Standard	Related Appendix Material
(4) Typical sign outside each entrance to carbon dioxide storage rooms **CAUTION** CARBON DIOXIDE GAS VENTILATE THE AREA BEFORE ENTERING. A HIGH CARBON DIOXIDE GAS CONCENTRATION CAN OCCUR IN THIS AREA AND CAN CAUSE SUFFOCATION	
1-6.1.2.2 Appropriate warning signs shall be placed at every location where manual operation of the system can occur. A typical sign at each manual actuation station is as follows: **WARNING** ACTUATION OF THIS DEVICE WILL CAUSE CARBON DIOXIDE TO DISCHARGE. BEFORE ACTUATING, BE SURE PERSONNEL ARE CLEAR OF THE AREA	
1-6.1.3 All persons that can at any time enter a space protected by carbon dioxide shall be warned of the hazards involved, given an alarm signal, and provided with safe evacuation procedures. *(See 1-8.5.)*	
1-6.1.4 The predischarge warning signal shall provide a time delay of sufficient duration to allow for evacuation under worst-case conditions, except as noted in 1-8.1(c) and 1-8.3.5. Dry runs shall be made to determine the minimum time needed for persons to evacuate the hazard area, allowing time to identify the warning signal.	
1-6.1.5 Audible and visual predischarge signals shall be provided, except as noted in 1-8.1(c) and 1-8.3.5.	
1-6.1.6 All personnel shall be informed that discharge of carbon dioxide gas from either high- or low-pressure systems directly at a person will endanger the person's safety by causing eye injury, ear injury, or even falls due to loss of balance upon the impingement of the high velocity discharging gas. Contact with carbon dioxide in the form of dry ice can cause frostbite.	

Standard	Related Appendix Material
1-6.1.7* To prevent accidental or deliberate discharge, a "lock-out" shall be provided when persons not familiar with the systems and their operation are present in a protected space. Local application systems shall be locked out when persons are present in locations where discharge of the system will endanger them, and they will be unable to proceed to a safe location within the time-delay period for the system. When protection is to be maintained during the lock-out period, a person(s) shall be assigned as a "fire watch" with suitable portable or semiportable fire-fighting equipment or means to restore protection. The fire watch shall have a communication link to a constantly monitored location. Authorities responsible for continuity of fire protection shall be notified of lockout and subsequent restoration of the system.	**A-1-6.1.7** Examples of situations that could require lock-out of a total flooding system are when persons are present in the spaces on ladders or scaffolds or working so they are physically under or inside equipment. If the location of persons is where they cannot easily exit the protected space within the system's time delay period, the system should be locked out.
1-6.1.8* Safe handling procedures shall be followed when transporting system cylinders.	**A-1-6.1.8** Cylinder outlets should be fitted with safety covers or anti-recoil devices whenever the cylinder is not connected to the system piping.
1-8 Detection, Actuation, and Control.	
1-8.1 Systems shall be classified as automatic or manual in accordance with the following methods of actuation.	
(a) *Automatic Operation.* Operation that does not require any human action.	
(b) *Normal Manual Operation.* Operation of the system requiring human action where the location of the device used to cause operation makes it easily accessible at all times to the hazard *(see 1-8.3.4)*. Operation of one control shall be all that is required to bring about the full operation of the system.	
(c) **Emergency Manual Operation.* Operation of the system by human means where the device used to cause operation is fully mechanical in nature and is located at or near the device being controlled. A fully mechanical device can incorporate the use of system pressure to complete operation of the device. *(See 1-8.3.5.)*	

Standard	Related Appendix Material
1-8.3.5* All valves controlling the release and distribution of carbon dioxide shall be provided with an emergency manual control. This shall not apply to slave high-pressure cylinders. The emergency means shall be easily accessible and located close to the valves controlled. Determination shall be made as to whether a time delay and predischarge alarm for emergency manual control are required based on the nature of the hazard and safety requirements. Where there is no time delay or predischarge alarm with emergency manual method of actuation, it shall be ascertained that the hazard area and adjoining areas where carbon dioxide can accumulate are clear of all personnel prior to operation of this device. These devices shall be clearly marked to indicate this concept with a warning placard.	

Appendix D - Excerpt from NFPA Standard 2001

Standard	Related Appendix Material
1-6 Safety. **1-6.1* Hazards to Personnel** 1-6.1.1 * Any agent that is to be recognized by this standard or proposed for inclusion in this standard shall first be evaluated in a manner equivalent to the process used by the U.S. Envi-ronmental Protection Agency's (EPA) SNAP Program.	**A-1-6.1** Potential hazards to be considered for individual systems are the following: (a) *Noise.* Discharge of a system can cause noise loud enough to be startling but ordinarily insufficient to cause traumatic injury. (b) *Turbulence.* High-velocity discharge from nozzles could be sufficient to dislodge substantial objects directly in the path. System discharge can cause enough general turbulence in the enclosures to move unsecured paper and light objects. (c) *Cold Temperature.* Direct contact with the vaporizing liquid being discharged from a system will have a strong chilling effect on objects and can cause frostbite burns to the skin. The liquid phase vaporizes rapidly when mixed with air and thus limits the hazard to the immediate vicinity of the discharge point. In humid atmospheres, minor reduction in visibility can occur for a brief period due to the condensation of water vapor. **A-1-6.1.1** The discharge of clean agent systems to extinguish a fire could create a hazard to personnel from the natural form of the clean agent or from the products of decomposition that result from exposure of the agent to the fire or hot surfaces. Unnecessary exposure of personnel either to the natural agent or to the decomposition products should be avoided. The SNAP Program was originally outlined in 59*FR* 13044.
1-6.1.2* Halocarbon Agents. 1-6.1.2.1 Any unnecessary exposure to halocarbon clean agents, even at NOAEL concentrations, and halocarbon decomposition products shall be avoided. The requirement for pre-discharge alarms and time delays are intended to pre-vent human exposure to agents. The following additional pro-visions shall apply in order to account for failure of these safeguards: (a) Halocarbon systems for spaces that are normally occupied and designed to concentrations up to the NOAEL *(see Table 1-6.1.2.1(a))* shall be permitted. (b) Halocarbon systems for spaces that are normally occupied and designed to concentrations above the NOAEL and up to the LOAEL *(see Table 1-6.1.2.1(a)),* shall be permitted, given that means be provided to limit exposure to no longer than the time specified in Tables 1-6.1.2.1 (b) through 1-6.1.2.1 (e) cor-responding to the given design concentration.	**A-1-6.1.2** Table A-1-6.1.2(a) provides information on the toxicological effects of halocarbon agents covered by this standard. The NOAEL is the highest concentration at which no adverse physiological or toxicological effect has been observed. The LOAEL is the lowest concentration at which an adverse physiological or toxicological effect has been observed. An appropriate protocol measures the effect in a stepwise manner such that the interval between the LOAEL and NOAEL is sufficiently small to be acceptable to the competent regulatory authority. The EPA includes in its SNAP evaluation this aspect (of the rigor) of the test protocol. ………. Continued >>>>>

Standard

(c) In spaces that are not normally occupied and protected by a halocarbon system designed to concentrations above the LOAEL *(see Table 1-6.1.2.1(a)),* and where personnel could possibly be exposed, means shall be provided to limit exposure times using Tables 1-6.1.2.1 (b) through 1-6.1.2.1 (e).

(d) In the absence of the information needed to fulfill the conditions listed in 1-6.1.2.1 (a) through 1-6.1.2.1(c), the fol-lowing provisions shall apply:

(1) Where egress takes longer than 30 seconds but less than 1 minute, the halocarbon agent shall not be used in a concentration exceeding its LOAEL.

(2) Concentrations exceeding the LOAEL are permitted only in areas not normally occupied by personnel provided that any personnel in the area can escape within 30 seconds. No unprotected personnel shall enter the area during agent discharge.

Table 1-6.1.2.1(a) Information for Halocarbon Clean Agents

(%)	LOAEL Agent	NOAEL (%)
FC-3-1-10	40	>40
HCFC Blend A	10.0	>10.0
HCFC-124	1.0	2.5
HFC-125	7.5	10.0
HFC-227ea	9.0	10.5
HFC-23	50	>50
HFC-236fa	10	15

………. Continued >>>>>

Related Appendix Material

Table A-1-6.1.2 (a) Toxicity Information for Halocarbon Clean Agents

Agent	LC_{50} or ALC (%)	NOAEL (%)	LOAEL (%)
FC-2-1-8	>81	30	>30
FC-3-1-10	>80	40	>40
FIC-13I1	>12.8	0.2	0.4
HCFC Blend A	64	10.0	>10.0
HCFC-124	23-29	1.0	2.5
HFC-125	>70	7.5	10.0
HFC-227ea	>80	9.0	10.5
HFC-23	>65	50	>50
HFC-236fa	>18.9	10	15

Notes:

1. LC50 is the concentration lethal to 50 percent of a rat population during a 4-hour exposure. The ALC is the approximate lethal concentration.
2. The cardiac sensitization levels are based on the observance or non-observance of serious heart arrhythmias in a dog. The usual protocol is a 5-minute exposure followed by a challenge with epinephrine.
3. High concentration values are determined with the addition of oxygen to prevent asphyxiation.

For halocarbons covered in this standard, the NOAEL and LOAEL are based on the toxicological effect known as cardiac sensitization. Cardiac sensitization occurs when a chemical causes an increased sensitivity of the heart to adrenaline, a naturally occurring substance produced by the body during times of stress, leading to the sudden onset of irregular heart beats and possibly heart attack. Cardiac sensitization is measured in dogs after they have been exposed to a halocarbon agent for 5 minutes. At the 5-minute time period, an external dose of adrenaline (epinephrine) is administered and an effect is recorded, if the dog experiences cardiac sensitization. The cardiac sensitization potential as measured in dogs is a highly conservative indicator of the potential in humans. The conservative nature of the cardiac sensitization test stems from several factors, the two most pertinent are as follows:

(1) Very high doses of adrenaline are given to the dogs during the testing procedure (doses are more than 10 times higher than the highest levels secreted by humans under maximum stress.

(2) Four to ten times more halocarbon is required to cause cardiac sensitization in the absence of externally administered adrenaline, even in artificially created situations of stress or fright in the dog test.

Because the cardiac sensitization potential is measured in dogs, a means of providing human relevance to the concentration at which this cardiac sensitization occurs (LOAEL) has been established through the use of physiologically

Standard

Table 1-6.1.2.1(b) Time for Safe Human Exposure at Stated Concentrations for HFC-125

HFC-125 Concentration		
% v/v	ppm	Human Exposure Time (minutes)
7.5	75,000	5.00
8.0	80,000	5.00
8.5	85,000	5.00
9.0	90,000	5.00
9.5	95,000	5.00
10.0	100,000	5.00
10.5	105,000	5.00
11.0	110,000	5.00
11.5	115,000	5.00
12.0	120,000	1.67
12.5	125,000	0.59
13.0	130,000	0.54
13.5	135,000	0.49

Notes:

1. Data derived from the EPA-approved and peer-reviewed physiologically based pharmacokinetic (PBPK) model or its equivalent.
2. Based on LOAEL of 10.0 percent in dogs.

Table 1-6.1.2.1 (c) Time for Safe Human Exposure at Stated Concentrations for HFC-227ea

HFC-227ea Concentration		
% v/v	ppm	Human Exposure Time (minutes)
9.0	90,000	5.00
9.5	95,000	5.00
10.0	100,000	5.00
10.5	105,000	5.00
11.0	110,000	1.13
11.5	115,000	0.60
12.0	120,000	0.49

Notes:

1. Data derived from the EPA-approved and peer-reviewed PBPK model or its equivalent.
2. Based on LOAEL of 10.5 percent in dogs.

………. Continued >>>>>

Related Appendix Material

based pharmacokinetic (PBPK) modeling.

A PBPK model is a computerized tool that describes time-related aspects of a chemical's distribution in a biological system. The PBPK model mathematically describes the uptake of the halocarbon into the body and the subsequent distribution of the halocarbon to the areas of the body where adverse effects can occur. For example, the model describes the breathing rate and uptake of the halocarbon from the exposure atmosphere into the lungs. From there, the model uses the blood flow bathing the lungs to describe the movement of the halocarbon from the lung space into the arterial blood that directly feeds the heart and vital organs of the body.

It is the ability of the model to describe the halocarbon concentration in human arterial blood that provides it primary utility in relating the dog cardiac sensitization test results to a human who is unintentionally exposed to the halocarbon. The concentration of halocarbon in the dog arterial blood at the time the cardiac sensitization event occurs (5-minute exposure) is the critical arterial blood concentration, and this blood parameter is the link to the human system. Once this critical arterial blood concentration has been measured in dogs, the EPA-approved PBPK model simulates how long it will take the human arterial blood concentration to reach the critical arterial blood concentration (as determined in the dog test) during human inhalation of any particular concentration of the halocarbon agent. As long as the simulated human arterial concentration remains below the critical arterial blood concentration, the exposure is considered safe. Inhaled halo-carbon concentrations that produce human arterial blood concentrations equal to or greater than the critical arterial blood concentration are considered unsafe because they represent inhaled concentration that potentially yield arterial blood concentrations where cardiac sensitization events occur in the dog test. Using these critical arterial blood concentrations of halocarbons as the ceiling for allowable human arterial concentrations, any number of halocarbon exposure scenarios can be evaluated using this modeling approach.

For example, in the dog cardiac sensitization test on Halon 1301, a measured dog arterial blood concentration of 25.7 mg/l is measured at the effect concentration (LOAEL) of 7.5 percent after a 5-minute exposure to Halon 1301 and an external intravenous adrenaline injection.

Standard

1-6.1.3* Inert Gas Clean Agents. Unnecessary exposure to inert gas agent systems resulting in low oxygen atmospheres shall be avoided. The requirement for pre-discharge alarms and time delays is intended to prevent human exposure to agents. The following additional provisions shall apply in order to account for failure of these safeguards:

(a) Inert gas systems designed to concentrations below 43 percent (corresponding to an oxygen concentration of 12 percent, sea level equivalent of oxygen) shall be permitted, given the following:

(1) The space is normally occupied.
(2) Means are provided to limit exposure to no longer than 5 minutes.
(b) Inert gas systems designed to concentrations between 43 and 52 percent (corresponding to between 12 and 10 percent oxygen, sea level equivalent of oxygen) shall be permitted, given the following:

(1) The space is normally unoccupied.
(2) Means are provided to limit exposure to no longer than 3 minutes.
(c) Inert gas systems designed to concentrations between 52 and 62 (corresponding to between 10 and 8 percent oxygen, sea level equivalent of oxygen) shall be permitted given the following:

(1) The space is normally unoccupied.
(2) Where personnel could possibly be exposed, means are provided to limit the exposure
(d) Inert gas systems designed to concentrations above 62 percent (corresponding to 8 percent oxygen or below, sea level equivalent of oxygen), shall only be used in unoccupied areas where personnel are not exposed to such oxygen depletion. *(See 3-5.3.3 for atmospheric correction factors.)*

1-6.1.4 Safety Requirements

1-6.1.4.1 * Suitable safeguards shall be provided to ensure prompt evacuation of and prevent entry into hazardous atmospheres and also to provide means for prompt rescue of any trapped personnel. Safety items such as personnel training, warning signs, discharge alarms, self-contained breathing apparatus (SCBA), evacuation plans, and fire drills shall be considered.

1-6.1.4.2* Consideration shall be given to the possibility of a clean agent migrating to adjacent areas outside of the protected space.

Related Appendix Material

A-1-6.1.3 Table A-1-6.1.3 provides information on physiological effects of inert gas agents covered by this standard. The health concern for inert gas clean agents is asphyxiation due to the lowered oxygen levels. With inert gas agents, an oxygen concentration of no less than 12 percent (sea level equivalent) is required for normally occupied areas. This corresponds to an agent concentration of no more than 43 percent.

Table A-1-6.1.3 Physiological Effects for Inert Gas Agents

Agent	No Effect Level* (%)	Low Effect Level* (%)
IG-01	43	52
IG-100	43	52
IG-55	43	52
IG-541	43	52

*Based on physiological effects in humans in hypoxic atmospheres. These values are the functional equivalents of NOAEL and LOAEL values and correspond to 12-percent minimum oxygen for the No Effect Level and 10-percent minimum oxygen for the Low Effect Level.

IG-541 uses carbon dioxide to promote breathing characteristics intended to sustain life in the oxygen-deficient environment for protection of personnel. Care should be used not to design inert gas-type systems for normally occupied areas using design concentrations higher than that specified in the system manufacturer's listed design manual for the hazard being protected.

Inert gas agents do not decompose measurably in extinguishing a fire. As such, toxic or corrosive decomposition products are not found. However, heat and breakdown products of the fire itself can still be substantial and could make the area untenable for human occupancy.

Appendix E - Excerpt from OSHA Regulations

Regulations (Standards - 29 CFR)
Fixed extinguishing systems, general. - 1910.160
Subpart L - Fire Protection
Standard 1910.160 - Fixed extinguishing systems, general

1910.160(a)
Scope and application.

1910.160(a)(1)
This section applies to all fixed extinguishing systems installed to meet a particular OSHA standard except for automatic sprinkler systems which are covered by 1910.159.

1910.160(a)(2)
This section also applies to fixed systems not installed to meet a particular OSHA standard, but which, by means of their operation, may expose employees to possible injury, death, or adverse health consequences caused by the extinguishing agent. Such systems are only subject to the requirements of paragraphs (b)(4) through (b)(7) and (c) of this section.

1910.160(a)(3)
Systems otherwise covered in paragraph (a)(2) of this section which are installed in areas with no employee exposure are exempted from the requirements of this section.

1910.160(b)
General requirements.

1910.160(b)(1)
Fixed extinguishing system components and agents shall be designed and approved for use on the specific fire hazards they are expected to control or extinguish.

1910.160(b)(2)
If for any reason a fixed extinguishing system becomes inoperable, the employer shall notify employees and take the necessary temporary precautions to assure their safety until the system is restored to operating order. Any defects or impairments shall be properly corrected by trained personnel.

1910.160(b)(3)
The employer shall provide a distinctive alarm or signaling system which complies with 1910.165 and is capable of being perceived above ambient noise or light levels, on all extinguishing systems in those portions of the workplace covered by the extinguishing system to indicate when the extinguishing system is discharging. Discharge alarms are not required on systems where discharge is immediately recognizable.

1910.160(b)(4)
The employer shall provide effective safeguards to warn employees against entry into discharge areas where the atmosphere remains hazardous to employee safety or health.

1910.160(b)(5)
The employer shall post hazard warning or caution signs at the entrance to, and inside of, areas protected by fixed extinguishing systems which use agents in concentrations known to be hazardous to employee safety and health.

1910.160(b)(6)

The employer shall assure that fixed systems are inspected annually by a person knowledgeable in the design and function of the system to assure that the system is maintained in good operating condition.

1910.160(b)(7)
The employer shall assure that the weight and pressure of refillable containers is checked at least semi-annually. If the container shows a loss in net content or weight of more than 5 percent, or a loss in pressure of more than 10 percent, it shall be subjected to maintenance.

1910.160(b)(8)
The employer shall assure that factory charged nonrefillable containers which have no means of pressure indication are weighed at least semi-annually. If a container shows a loss in net weight or more than 5 percent it shall be replaced.

1910.160(b)(9)
The employer shall assure that inspection and maintenance dates are recorded on the container, on a tag attached to the container, or in a central location. A record of the last semi-annual check shall be maintained until the container is checked again or for the life of the container, whichever is less.

1910.160(b)(10)
The employer shall train employees designated to inspect, maintain, operate, or repair fixed extinguishing systems and annually review their training to keep them up-to-date in the functions they are to perform.

1910.160(b)(11)
The employer shall not use chlorobromomethane or carbon tetrachloride as an extinguishing agent where employees may be exposed.

1910.160(b)(12)
The employer shall assure that systems installed in the presence of corrosive atmospheres are constructed of non-corrosive material or otherwise protected against corrosion.

1910.160(b)(13)
Automatic detection equipment shall be approved, installed and maintained in accordance with 1910.164.

1910.160(b)(14)
The employer shall assure that all systems designed for and installed in areas with climatic extremes shall operate effectively at the expected extreme temperatures.

1910.160(b)(15)
The employer shall assure that at least one manual station is provided for discharge activation of each fixed extinguishing system.

1910.160(b)(16)
The employer shall assure that manual operating devices are identified as to the hazard against which they will provide protection.

1910.160(b)(17)
The employer shall provide and assure the use of the personal protective equipment needed for immediate rescue of employees trapped in hazardous atmospheres created by an agent discharge.

1910.160(c)
Total flooding systems with potential health and safety hazards to employees.

1910.160(c)(1)
The employer shall provide an emergency action plan in accordance with 1910.38 for each area within a workplace that is protected by a total flooding system which provides agent concentrations exceeding the maximum safe levels set forth in paragraphs (b)(5) and (b)(6) of 1910.162.

1910.160(c)(2)
Systems installed in areas where employees cannot enter during or after the system's operation are exempt from the requirements of paragraph (c) of this section.

1910.160(c)(3)
On all total flooding systems the employer shall provide a pre-discharge employee alarm which complies with 1910.165, and is capable of being perceived above ambient light or noise levels before the system discharges, which will give employees time to safely exit from the discharge area prior to system discharge.

1910.160(c)(4)
The employer shall provide automatic actuation of total flooding systems by means of an approved fire detection device installed and interconnected with a pre-discharge employee alarm system to give employees time to safely exit from the discharge area prior to system discharge.
[45 FR 60711, Sept. 12, 1980]
<break>(Not included: Fixed extinguishing systems, dry chemical. - 1910.161)

<break>

Regulations (Standards - 29 CFR)
Fixed extinguishing systems, gaseous agent. - 1910.162
Subpart L - Fire Protection
Standard 1910.162 - Fixed extinguishing systems, gaseous agent

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1910.162(a)
Scope and application -

1910.162(a)(1)
Scope. This section applies to all fixed extinguishing systems, using a gas as the extinguishing agent, installed to meet a particular OSHA standard. These systems shall also comply with 1910.160. In some cases, the gas may be in a liquid state during storage.

1910.162(a)(2)
Application. The requirements of paragraphs (b)(2) and (b)(4) through (b)(6) shall apply only to total flooding systems.

1910.162(b)
Specific requirements.

1910.162(b)(1)
Agents used for initial supply and replenishment shall be of the type approved for the system's application. Carbon dioxide obtained by dry ice conversion to liquid is not acceptable unless it is processed to remove excess water and oil.

1910.162(b)(2)
Except during overhaul, the employer shall assure that the designed concentration of gaseous agents is maintained until the fire has been extinguished or is under control.

1910.162(b)(3)
The employer shall assure that employees are not exposed to toxic levels of gaseous agent or its decomposition products.

1910.162(b)(4)
The employer shall assure that the designed extinguishing concentration is reached within 30 seconds of initial discharge except for Halon systems which must achieve design concentration within 10 seconds.

1910.162(b)(5)
The employer shall provide a distinctive pre-discharge employee alarm capable of being perceived above ambient light or noise levels when agent design concentrations exceed the maximum safe level for employee exposure. A pre-discharge employee alarm for alerting employees before system discharge shall be provided on Halon 1211 and carbon dioxide systems with a design concentration of 4 percent or greater and for Halon 1301 systems with a design concentration of 10 percent or greater. The pre-discharge employee alarm shall provide employees time to safely exit the discharge area prior to system discharge.

1910.162(b)(6)

1910.162(b)(6)(i)
Where egress from an area cannot be accomplished within one minute, the employer shall not use Halon 1301 in concentrations greater than 7 percent.

1910.162(b)(6)(ii)
Where egress takes greater than 30 seconds but less than one minute, the employer shall not use Halon 1301 in a concentration greater than 10 percent.

1910.162(b)(6)(iii)
Halon 1301 concentrations greater than 10 percent are only permitted in areas not normally occupied by employees provided that any employee in the area can escape within 30 seconds. The employer shall assure that no unprotected employees enter the area during agent discharge.
[45 FR 60712, Sept. 12, 1980; 46 FR 24557, May 1, 1981]

Appendix F - Excerpt from ISO Standard 6183

5 Safety requirements

In any proposed use of carbon dioxide extinguishing systems where there is a possibility that people may be trapped in or enter into the protected area, suitable safeguards shall be pro vided to ensure prompt evacuation of the area, to restrict entry into the area after discharge, except where necessary to provide means for prompt rescue of any trapped personnel. Such safety aspects as personnel training, warning signs, discharge alarms, and breaching apparatus shall be considered. The following requirements shall be taken into account:

a) Provision of exit routes which shall be kept clear at all times and the provision of adequate direction signs;

b) Provision of alarms within such areas that are distinctive from all other alarm signals and that will operate immediately upon detection of the fire and release of the carbon dioxide (see clause 6);

c) Provision of only outward swinging self-closing doors which shall be openable from the inside even when locked from the outside;

d) Provision of continuous visual and audible alarms entrances, until the atmosphere has been made safe;

e) Provision for adding an odour to the carbon dioxide so that hazardous atmospheres may be recognized;

f) Provision of warning and instruction signs at entrances;

g) Provision of self-contained breathing equipment and personnel trained in its use;

h) Provision of a means of ventilating the areas after extinguishing the fire;

6 Warning alarms

An audible alarm shall be provided on all total flooding systems, and on local flooding systems where dispersal of the carbon dioxide from the system into the room would give a concentration of more than 5 %. The alarm shall sound during any delay period between fire detection and discharge and throughout the discharge.

The sound intensity of the alarm described in 5 b) shall be such that it will be heard above the average local noise level; where this is abnormally high, visual indication shall also be provided.

Alarm devices shall be supplied from an energy source sufficient to allow continuous Operation of the warning alarm for a minimum of 30 min.

NOTE - Alarms may not be necessary for local application systems, unless the quantity of carbon dioxide discharged relative to the room volume is capable of producing a concentration in excess of 5 %.

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10 Precautions for low-lying parts of protected areas

Where it is possible for carbon dioxide gas to collect in pits, wells, shaft bottoms or other low-lying areas, consideration shall be given to adding an odoriferous substance to the carbon dioxide, and/or to providing additional ventilation systems to remove the carbon dioxide after discharge.

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11 Safety signs

For all total flooding systems, and those local application systems which may cause critical concentrations, a warning notice shall be displayed on the inside and outside of every door to the protected area.

The notice shall warn that, in case of alarm or discharge of carbon dioxide, personnel should leave the room immediately and not enter again before the room has been thoroughly ventilated because of the danger of suffocation.

12 Precautions during maintenance work

On automatic total flooding systems, protecting normally unoccupied rooms, provision shall be made for the prevention of automatic discharge during periods of entry by personnel where they may not be able to leave the room during any delay period (sec clause 6).

NOTE - This precaution is not usually necessary for local application systems but should be provided where hazardous concentrations may be produced in any area which may be occupied.

Appendix G - Excerpt from IMO FSS Code

CHAPTER 5 - FIXED GAS FIRE-EXTINGUISHING SYSTEMS

1 Application

This chapter details the specifications for fixed gas fire-extinguishing systems as required by chapter II-2 of the Convention.

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2 Engineering specifications

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2.1.3 System control requirements

2.1.3.1 The necessary pipes for conveying fire-extinguishing medium into the protected spaces shall be provided with control valves so marked as to indicate clearly the spaces to which the pipes are led. Suitable provision shall be made to prevent inadvertent release of the medium into the space. Where a cargo space fitted with a gas fire-extinguishing system is used as a passenger space, the gas connection shall be blanked during such use. The pipes may pass through accommodations providing that they are of substantial thickness and that their tightness is verified with a pressure test, after their installation, at a pressure head not less than 5 N/mm^2. In addition, pipes passing through accommodation areas shall be joined only by welding and shall not be fitted with drains or other openings within such spaces. The pipes shall not pass through refrigerated spaces.

2.1.3.2 Means shall be provided for automatically giving audible warning of the release of fire-extinguishing medium into any ro-ro spaces and other spaces in which personnel normally work or to which they have access. The pre-discharge alarm shall be automatically activated (e.g., by opening of the release cabinet door). The alarm shall operate for the length of time needed to evacuate the space, but in no case less than 20 s before the medium is released. Conventional cargo spaces and small spaces (such as compressor rooms, paint lockers, etc.) with only a local release need not be provided with such an alarm.

2.1.3.3 The means of control of any fixed gas fire-extinguishing system shall be readily accessible, simple to operate and shall be grouped together in as few locations as possible at positions not likely to be cut off by a fire in a protected space. At each location there shall be clear instructions relating to the operation of the system having regard to the safety of personnel.

2.1.3.4 Automatic release of fire-extinguishing medium shall not be permitted, except as permitted by the Administration.

2.2 Carbon dioxide systems

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2.2.2 Controls

Carbon dioxide systems shall comply with the following requirements:

- **.1** two separate controls shall be provided for releasing carbon dioxide into a protected space and to ensure the activation of the alarm. One control shall be used for opening the valve of the piping which conveys the gas into the protected space and a second control shall be used to discharge the gas from its storage containers; and
- **.2** the two controls shall be located inside a release box clearly identified for the particular space. If the box containing the controls is to be locked, a key to the box shall be in a break-glass-type enclosure conspicuously located adjacent to the box.

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2.5 Equivalent fixed gas fire-extinguishing systems for machinery spaces and cargo pump rooms

Fixed gas fire-extinguishing systems equivalent to those specified in paragraphs 2.2 to 2.4 shall be approved by the Administration based on the guidelines developed by the Organization.[81]

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[81] Refer to the 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 (MSC/Circ.848).

Appendix H – Proposal for NFPA 12

NFPA Technical Committee Document Proposal Form

NOTE: All Proposals Must Be Received By 5:00 P.M. EST/EDST On The Published Proposal Closing Date.

For further information on the standards-making process, please contact Codes and Standards Administration at 617-984-7249

For technical assistance, please call NFPA at 617-770-3000

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Date June 20, 2003 **Name** Robert T. Wickham, P.E. **Tel. No.** 603-772-3229

Company Wickham Associates

Street Address 9 Winding Brook Drive **City** Stratham **State** NH **Zip** 03885

Please Indicate Organization Represented (if any) N/A

1. **a) NFPA Document Title** Standard on Carbon Dioxide Extinguishing Systems
   b) NFPA No. & Edition NFPA 12 - 2000 **c) Section/Paragraph** 1-6

2. **Proposal recommends: (check one)** ☒ new text ☐ revised text ☐ deleted text

3. **Proposal** *(include proposed new or revised wording, or identification of wording to be deleted):* (Note: Proposed text should be in legislative format: i.e., use underscore to denote wording to be inserted (inserted wording) and strike-through to denote wording to be deleted (~~deleted wording~~).

Carbon dioxide total flooding systems shall not be used in normally occupied areas.

4. **Statement of Problem and Substantiation for Proposal:** (Note: State the problem that will be resolved by your recommendation; give the specific reason for your proposal including copies of tests, research papers, fire experience, etc. If more than 200 words, it may be abstracted for publication.)

The proliferation of carbon dioxide total flooding systems used in normally occupied spaces and the continuing incidences of deaths and injuries caused by the accidental discharge of these systems are very serious concerns. Fire suppression systems should not be the cause of deaths especially in the event of accidental system discharges. (See reverse for continuation …..).

5. ☒ **This Proposal is original material.** (Note: Original material is considered to be the submitter's own idea based on or as a result of his/her own experience, thought, or research and, to the best of his/her knowledge, is not copied from another source.)

☐ **This Proposal is not original material, its source (if known) is as follows:**

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Signature (Required) Robert T. Wickham

PLEASE USE SEPARATE FORM FOR EACH PROPOSAL • NFPA Fax: (617) 770-3500

Mail to: Secretary, Standards Council, National Fire Protection Association
1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269

NFPA Technical Committee Document Proposal Form

Continuation Sheet

Date: June 20, 2003
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1 a) NFPA Document Title: Standard on Carbon Dioxide Extinguishing Systems
1 b) NFPA No. & Edition: NFPA 12-2000
1 c) Section / Paragraph: 1-6 / 1-6.1

3. Proposal: Carbon dioxide total flooding systems shall not be used in normally occupied areas.

4. Statement of Problem and Substantiation for Proposal: The proliferation of carbon dioxide total flooding systems used in normally occupied spaces and the continuing incidences of deaths and injuries caused by the accidental discharge of these systems are very serious concerns. Fire suppression systems should not be the cause of deaths especially in the event of accidental system discharges. Prohibiting the use of carbon dioxide total flooding systems in normally occupied spaces addresses this direct threat to public health and safety.

The US EPA report ("Carbon Dioxide as a Fire Suppressant: Examining the Risks," Report EPA430-R-00-002, United States Environmental Protection Agency, Washington, DC: February 2000.) clearly documents the accident record of carbon dioxide systems.

Two copies of that report are enclosed and additional copies can be downloaded from the US EPA web-site at http://www.epa.gov/ozone/snap/fire/co2/co2report.pdf .