KEYNOTE

A Perspective on Halon Replacements and Alternatives

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presented at

The Halon Alternatives Technical
Working Conference 1993

Albuquerque, New Mexico
May 11, 1993

It is an honor to have been asked to address this conference. The staff at the Center for Global Environmental Technologies here at the NMERI have performed a vital function of technology transfer and information dissemination through these annual conferences. The apparent breadth and quality of the work reported here is reflected in the large attendance. Thank you Bob and the rest of the staff for so ably filling the need. It is a fitting tribute to the staff here at NMERI for all of the fine work you have performed in the area of halon and halon alternatives research.

Six and one-half years ago, the production of halons was to be limited to 1986 levels or approximately 50 million lb/year in 1996 by the Montreal Protocol. Six months ago, amendments to the Protocol required that the production of halon cease by the end of 1993. That is a huge regulatory policy shift occurring in a very small period of time. One of the results has been an explosion in new fire suppression concepts and technologies. **You** will be hearing about most of these new technologies in great detail over the next several days.

The goal of this introductory talk is to address the ***status*** of various halon replacements and alternatives and to examine the near-term trends and what they are likely to mean to the fire protection community.

Since much is made of the argument that in most cases, clean total flooding gaseous extinguishing systems are not needed, the issue of conventional "not-in-kind" alternatives will be addressed. For several years, the myth that pre-action sprinklers **are** a replacement for Halon 1301 total flooding systems has gained credence. Pre-action sprinkler systems are no more effective in preventing or limiting damage to the contents of a sensitive electronics space than fire walls are. This is due to a number of factors:

1. Sprinkler systems are slow to respond. Small, incipient fires originating in electronics equipment or obstructed cable bundles will generate tremendous quantities of smoke.

2. Electronics equipment is sensitive to smoke. Damage, due to the products of combustion of typical cable insulations and printed circuit boards, can and will ruin electronics gear even prior to the actuation of sprinklers. This is particularly true if the fire is slowly developing. This, by the way, happens in the case of modem polymers with good flammability characteristics exposed to small ignition sources (e.g., electric faults). This is the basis for the concern over non-thermal damage.

3. Sprinklers are ineffective in extinguishing fires in obstructed fuel arrays and in electronics cabinets. The result is that while there is no doubt the average room temperatures will not be very high the fire, even modest in size, will continue to generate smoke.

Other attributes of sprinkler system performance can be designed around. Electrical conductivity ***can*** be resolved, in some cases, by securing power to equipment prior to damage.

One particular fire test, the exact nature of which remains confidential illustrates these points.

A fire was initiated inside a partially enclosed electronics cabinet. Several "failures" in overcurrent protective systems had to be artificially induced to make this ignition occur. The fire involved printed circuit boards and wiring. Approximately two minutes after ignition, the first smoke detector operated. At approximately 30 minutes, there was less than one foot visibility in the space.. At 60 minutes after ignition, the first sprinkler head activated as flames projected through the cabinet vent openings. The sprinkler was allowed to flow for approximately 30 minutes. The fire was manually extinguished with hose streams at that time.

In this type of fire scenario, the sprinklers are of limited value in protecting the equipment in the compartment. They are, however, quite effective in ensuring that the fire does not spread rapidly beyond the initial equipment and that spaces outside the room of origin are not threatened by fire. From the standpoint of the equipment in the space, they accomplish very little. This is, of course, not necessarily true for fires originating outside the equipment.

The fire protection community has won almost religious awe of sprinkler systems. This is due to their excellent reliability record in preventing large loss fires and preventing life loss. The basic characteristics of sprinkler systems, however, make them ineffective in protecting enclosed electronics sensitive to non-thermal damage.

There are limitations to all traditional not-in-kind alternatives relative to their use as halon replacements. The use of total flooding CO_2 systems in the U.S. for protecting flammable liquids hazards particularly onboard ship has led to tragic loss of life due to accidental discharges, some in normally unoccupied areas.

Guidelines for evaluating "best and essential" uses of halons were prepared to systematically rate the characteristics of fire protection systems relative to the characteristics and requirements of the hazards they were protecting. It is not coincidental that in many hazards traditionally protected with halon total flooding systems, the highest ranked alternative was a non-ozone depleting, clean, non-toxic, total flooding, gaseous extinguishing system. These findings have been put forward and ratified repeatedly by the UNEP Halon Technical Options Committee.

This leads to another point. There have been repeated arguments made by regulators and those with a more environmental than fire protection background that such traditional alternatives were indeed available and that there was no problem with a complete phaseout of Halon 1301. This is patently not the case. The judgement was made that the perceived environmental risk of using halon outweighed the additional total cost (including inefficiency, life lost, etc.) of using traditional alternatives. This judgement was made with no quantitative judgement of the total cost. The HTOC recommended a total phaseout on the basis that sufficient banked halon or "the halon bank" a theoretical concept at the time (and largely still one) was sufficient to deal with important uses for at least a decade. There was never a judgement made that traditional not-in-kind alternatives were "as good as" or equivalent to the halons they are replacing.

This misrepresentation has been made in other places, for example, the replacement of Halon 1211 portables in "critical" defense uses. There is an interesting logical transition to the problem. If lower system cost (not total cost) alternatives existed before halon was used, who and why were they buying halon.

It is inconceivable that the Federal Government, the single largest user of halons, was spending government funds on unnecessarily expensive, unneeded materials and hardware.

Replacement of halons with traditional not-in-kind replacements represents a largely unknown cost and risk.

Halon Bank Management

As previously described the concept of a halon bank was central to the decision to accelerate phaseout schedules. While the quantity of stored and in-use halon is large, it was and is not clear that the basic idea of many users buying and selling halon will function. Based on the price uncertainty of recycled halon, we could probably use a Halon 1301 listing on the Chicago Board of Trade, trading Grade A recycled halon futures.

I see several important issues associated with the halon bank.

1. Will it work?

2. Is there a sufficiently large, but not so large demand (or supply) such that prices will stabilize, sellers will sell, and buyers buy?

3. The bank (in the U.S.) is not a commonly owned stockpile of halon; each pound belongs to someone. The assumption is that some fraction of the ownership is willing to voluntarily sell, ripping out and potentially replacing systems.

4. There is an incipient concern that certain large classes of users will attempt to 'live off the bank" and not aggressively pursue near-term alternatives.

5. The large potential dependence of certain U.S. military applications on the bank has and will cause problems with the Defense Agencies of the LDC's, where such large inventories do not exist.

The Concept of Essential Use

The last death gasp of halon production in all but the LDC's lies in the concept of "an essential use." Putting aside for the moment that it is virtually impossible to motivate at this time a single U.S. use that meets all of the criteria for a production exemption by the Amendments to the Montreal Protocol, it is easy to assert that in the limit of an assumed very, very high potential cost due to continued production of halons, there is no such thing as an essential use.

This is a logical consequence of the arguments made for both the initial production limits (in 1987) and the total production phaseout (posed in 1992). Given a sufficiently high environmental (and hence societal) cost that can be translated into dollars and lives, no application justifies continued production. It is a simple risk/benefit decision.

In order to make such judgements, one should have a reasonably good assessment of the costs on both sides of the equation. Such data and analysis do not exist in an reliable sense. Hence, it comes down to judgement and, in the end, political horsepower. The former is optional, the latter is essential.

All of those who hope to fill intermediate or longer term halon needs with "'banked" halon while waiting for second generation or beyond miracle agents should proceed with caution. It is entirely conceivable that destruction of banked halon will be required currency in the next five years. Remember, there was a five-year gap in time between a permitted production of 50 million pounds and zero production allowance.

When first confronted by the ozone depletion issue, many took it on faith that ozone depletion was a serious and immediate problem. Having worked in the area and observed the standard of "proof' required to motivate an environmental issue is generally much lower than the standard applied to almost any technical undertaking. You will hear, over the next several days, results of carefully performed research, and most likely arguments about the reliability of data to the second or third decimal place. This discussion will occur on every topic except the environmental basis motivating or associated with this conference. This has been made clear to me at least with regard to proscription against the use of high global warming chemicals as halon replacement fire extinguishants, even given the minimal usage and emission rates of even the most optimistic marketing facets for the use of the these compounds.

One of the constraints in the development of halon phaseout schedules has been the unwillingness of many in the user community to address problems associated with such a phaseout. This occurs because, to many users, fire protection use of halons is small compared to the expenditure of political capital which would be required to voice concerns. The "business" of these users is not fire protection; they are concerned about ramifications of speaking out and don't. The user community's silence is then interpreted as support for the position that these chemicals are not needed and earlier phaseout dates are not a problem.

Regulatory Issues

The EPA should be congratulated on releasing the proposed SNAP rule on halon replacements. One of the purposes of the SNAP program was to facilitate the introduction of alternatives. This goal has been partially accomplished by focusing regulatory attention in one place. This has clearly been advantageous relative to toxicity issues. While I sympathize with the impossible task of evaluating and judging acceptable fire protection measures, I regret that the EPA had to get into the fire protection engineering business.

Many aspects of the proposed rule are confusing, particularly those related to where, when, and how to install certain kinds of systems. One of the most interesting aspects of the rule is that it permits the use of chemicals at toxic concentrations in occupied areas. Such use is only permitted when the space . evacuated prior to the gas concentration reaching the NOAEL. While this is logical, it is the moral equivalent of legislating that no fires will occur. The reason that most chemical manufacturers or uses will not permit the use of a product under such conditions are the lessons learned by experience. There are enough accidental discharges during inspection testing and maintenance and other conditions, where the space will not be evacuated before the NOAEL is reached, to be of concern.

The rationale that the EPA wanted to show as many alternatives as possible is understandable. While it is not this intent of the talk to critique the proposed rule, the requirement for cross-zoned smoke detectors when using certain agents as the way to minimize unwanted discharge is interesting. This begs the issue of what to do with other detection technologies including heat detectors, analog addressable smoke detectors, air sampling and flame detectors.

The EPA should concentrate on regulating environmental and toxicity issues consistent with the bounds of legislation. They should allow the existing regulatory and standards infrastructure to deal with fire protection design, engineering, installation, maintenance, and testing of such systems.

Alternatives

One of the great positive outcomes of the halon/ozone issue has been the rate at which alternative technologies have been developed, through the regulatory prowess (or parts of it) and commercialized. The development of such technologies is a tribute to the technical process of the inventors. The non-federal regulating system, which in the case of halon total flooding system, consists of consensus design and installation standards and third party testing and approval has proceeded at as fast a pace as possible. There is a draft NFPA standard on clean agent extinguishing systems winding its way through an open consensus standards making process and due for final approval by the NFPA in January 1994. At least two total flooding chemical agents and system hardware have almost completed third party testing and approval at Underwriters Laboratories.

The classes and categories of new technology replacements include the following:

1. Chemical Replacements

   a. HFC, C_4F_{10}, C_3F_7H, CHF_3, Fe-23 (Robin (1991, 1992), Hanauska (1991), Ferreira (1992), DiNenno et al. (1992, 1993), Fernandez (1991)).

   b. HCFC, HFC, and PFC blends (Anderson (1992), Gugliemi (1992)).

   c. Possible near/moderates term second generation agents (Gann et al. (1991), Pitts et al. (1991), Tapscott et al. (1989, 1992, 1993), Skaggs (1993)).

   d. Inert gas compounds (Riley 1992), Nicholas (1993), Grindstead (1993), Scheffey et al. (1989), Nirnitz et al. (1991).

2. Water Mist Technologies

   a. Single Fluid Systems

      - generic systems utilizing industrial specialty nodes and proprietary systems including Marioff, Ultra Fog, and Baumac International (Jackman et al. (1993), Marttila (1993), Turner (1993), Hill et al. (1991, 1993), Arvindson and Ryderman (1992), Marker (1991)).

   b. Twin Fluid System

      generic (water with air/N_2/CHF_3) utilizing modified industrial spray nozzles. These generic technologies include systems designed and developed by NRCC, Naval Research Laboratory, and Hughes Associates, Inc. Several proprietary systems will also be evaluated including Securiplex (BP), Kidde-Fenwal/Gravines, and ADA Technologies (Mawhinney (1993), Spring et al. (1993), Gameiro (1993), Butz (1992), Papavergos (1991), Hills et al. (1993), Soja (1990), Cousin (1992), Wighus (1992)).

3. Combustion Generated Aerosols

   proprietary systems (Kopylov (1993), Kibert (1993), Kidde-Gravines by Spring (1993), Walter Kidde by Harrison (1993)).

4. Total Flooding Fire Dry Chemical Systems

   - generic concept (Ewing et al. (1984, 1989)).

I would like to briefly address some of the major technical and other barriers or problems posed by the proposed halon alternatives. I preface these remarks with the observation that all of these alternatives appear to have very important application not only to replacing halons, but to improving fire protection in general.

First Generation Alternatives

A variety of HFC, PFC, HCFC, and inert gas compounds are currently being commercialized. You will hear in a talk later this morning, the going technical details of various limitations and potential problems associated with these agents.

There are at least six non- or very low ozone depleting chemical alternatives under active development and testing. Several of these chemical alternatives have reached commercialization for some fire protection applications. The primary group of chemical alternatives are hydrofluorocarbons (HFCs), which have zero-ozone depletion potential. For Halon 1301 total flooding replacement agents, there are three leading HFC agent candidates: C_4F_{10}, C_3F_7H, and CHF_3. In addition, several blends of HCFC compounds have been commercially proposed. The most well tested blend, which has been publicly considered is NAF S3 (80% R22). Several other proprietary blends including Halotron have been discussed, but no test data or other details (including composition) have been made publicly available. There are additional HFC compounds that have been demonstrated to be effective, but these carry toxicity penalties without significant advantages over the HFCs described above.

All of these so called "first generation" agents are significantly less effective on a weight or storage volume basis by a factor of two to three: hence, there are significant weight penalties associated with potential aircraft use.

Of all categories of proposed alternatives, the first generation halon alternatives are the best understood. These are under active development and testing. Additional work has been reported by authors referenced in Section 3.0 of this proposal. Notable among the test results of these agents are the production of relatively high quantities of HF and COF_2 as primary decomposition products. Problems associated with mixing have also been reported (DiNenno et al. (1993), Sheinson et al. (1993), Filipczak (1993), Dierdorf (1993)).

Basic fire suppression effectiveness of these agents has been evaluated in small, intermediate, and real scale. No reported work has been done relative to smoldering, deep-seated Class A fires except for crib experiments done as part of the UL/FM approval process for C_4F_{10} and C_3F_7H. These compounds can be readily used (except for (CHF_3) in typical low pressure (36 psig) hardware. Material compatibility, nozzle design, and other engineering design issues have been resolved for some applications for these agents.

These HFC, PFC, and HCFC compounds and blends have widely varying physical properties; hence, the selection of candidates, if any, from this class would reflect optimum selection of thermodynamic and other physical properties to promote mixing, flow, etc. The basic agent weight efficiency of the first generation compounds may preclude their use as cargo compartment fire suppressants.

Of the announced alternatives and those being subjected to consensus standards making, the following alternatives appear viable relative to human safety:

PFC 410	C_4F_{10},
FM-200	C_3F_7H,
Fe-25	CHF_3, and
Inergen	N_2, Ar, CO_2.

All of these agents have space, weight, and system cost penalties relative to Halon 1301. The magnitude of these differences varies by agent. On the other hand, all are clean total flooding agents that put fires out at concentrations that won't kill you. All are zero ozone depleters (remember, that's what got us here). All agents except Inergen produce HF and COF_2 during fire suppression. The quantity and degree being highly dependent on fie sue at time of discharge and discharge time. This potential problem is readily managed in most applications.

Of the halocarbons, two are criticized for high global warming potentially and long atmospheric lifetimes. These happen to be the least toxic. This judgement appears to be unrelated to worst case expected global warming impact posed by these compounds in use. The proposed SNAP rule will limit the use. of both of these compounds. I am reminded of J.P. Morgan saying, 'There are two reasons for doing anything: a good reason and the real reason."

There has been reluctance by many users especially those with space and weight critical applications to seriously consider these alternatives, the preferred option being to utilize banked halons and wait for second generation agents.

Arguments for costs associated with additional weight are not necessarily compelling, refemng to previous comments made relative to the empirical nature of "essential uses."

Large users of halon who hope to live off the bank for the next decade are urged to seriously consider, test, and evaluate the family of chemical replacements which are at or near commercialization.

The pursuit of the Holy Grail for the so called second generation or beyond, "better than halon" replacement is being actively pursued by several laboratories. It should be continued; the important point here is that a minimal ten-year time horizon for the as yet unidentified true son of wonder gas should be assumed. If halons are truly as damaging to human health as has been put forward, it seems incredibly optimistic to believe that banked halons will be available to weight sensitive uses on the basis of cost alone.

There are two basic types of water mist suppression systems: single and dual fluid systems. Single fluid systems utilize water stored at high pressure (40-200 bar) and spray nozzles which deliver drop sizes is the 10 to 100 ㎛ diameter range. Dual systems use air, nitrous, or other gas to atomize water at a nozzle. Both types of systems have been shown to be promising fire suppression systems. It is more difficult to develop single phase systems with the proper drop size distribution, spray geometry, and momentum characteristics. This difficulty is offset by the advantage of requiring only high pressure water storage versus water and atomizer gas storage.

Water mist systems are reasonably weight efficient. The use of small diameter distribution tubing and the possible use of composite, lightweight, high-pressure storage cylinders would increase this efficiency. It may also be possible to integrate a "central storage" of agent for use in several potential fire locations (for example, cargo and passenger cabin locations). This would further increase the benefit.

The major difficulties with water mist systems are those associated with design and engineering. These problems arise from the need to distribute the mist throughout the space while gravity and agent deposition loss on surfaces deplete the concentration. The need to generate, distribute, and maintain an adequate concentration of the proper size drops. Engineering analysis and evaluation of droplet loss and fallout as well as optimum drop size ranges and concentrations can be used effectively to minimize the uncertainty and direct the experimental program.

Water mist cannot, at present, be considered as a fire suppression agent in isolation of the system, particularly the nozzle that delivers it. Wide variations in performance of mist systems have been observed. The interrelationship between fire suppression effectiveness, drop size and velocity, distribution, spray momentum, spray mixing, and water loss rates defy complete theoretical treatment at this time. Hence, near term development and evaluation will be largely empirical facilitated by theory and analysis that can be brought to bear. There is, of course, nothing wrong with this "Edisonism" approach. Many, many technological innovations have proceeded without complete theoretical analytical descriptions. There is a danger that such theoretical understanding be made a prerequisite for regulatory acceptance. Nothing could be more deadly for a new technology than to become the love object of a possessive research community.

The complex relationship between the sprinkler/mist and tire will not yield easily to generic off-the-shelf nozzle technology in many applications. Hence, proprietary hardware, particularly nozzle designs, may form the most promising near term candidates. This poses special problems for standards making and regulatory authorities.

Fine Particulate Technology

The third category of new technologies being developed and introduced are those related to fine solid particulate and aerosols. These take advantage of the well established fire suppression capability of solid particulates, with potentially reduced or eliminated collateral damage associated with traditional dry powders. A range of proprietary technologies is being offered and will be discussed later in the conference.

The use of Combustion Generated Aerosols (CGA) also termed Pyrotechnically Generated Aerosols (PGA) originated in the 1980's in the Soviet Union (Kopylov (1988, 1993)). The systems utilize a chemical reaction to generate fire solid and liquid particulate. The resultant aerosol is, in principal, distributed through the protected volume in concentrations sufficient to cause gas phase suppression. The primary suppression mechanism appears to be gas phase cooling. The use of solid particulate as a gas phase cooling mechanism is well known. It has been studied extensively for dry chemicals and powders by Hughes Associates (Ewing et al. (1984, 1989).

This technology is being pursued independently by several groups and is proprietary. Ongoing work includes efforts by Spring and Ball (1993), Kibert (1993), Harrison (1993), and Spectrex Inc. (1992).

A natural extension of both CGA and water mist technology is the possibility of using fine solid particulate as a total flooding agent using more traditional dispensing systems than the CGA/PGA technology. This would permit optimization of the particulate type, size distribution, and mixing/distribution characteristics. The resultant "total flooding fine dry chemical particulate" system may have significant advantages over previously discussed particulate technologies.

While solid particulates and chemicals have very high effectiveness/weight ratios (Persson (1992), Ewing et al. (1989)), they pose potential collateral damage problems to electronics, engines, and other sensitive equipment. In addition, the ability to distribute a particulate cloud uniformly throughout a complex geometry must be evaluated further. They have the advantage of reduced wall and surface losses, and the particle size distribution is easier to control and optimize. There are potential caking problems with very fine powders. This potential difficulty can probably be solved with coated or encapsulated particles.

Conclusions

The entire halon phaseout and replacement program hinged on two things:

1. Having seen the writing on the wall, for good or ill, the fire protection community went about the work of making it happen. This involved

   - guidance to users relative to traditional alternatives,
   - halon bank management,
   - development of alternatives,
   - standardization, and
   - third party approvals.

2. The Federal Government through regulatory and large user agencies to a large extent in active cooperation with the private sector assisted this process by
   - providing early R&D funds for independent testing and feedback to manufacturers,
   - centralizing the regulatory decision making, and
   - Government user participation in the process.

While there were and are unquestionable areas of conflict between organizations involved, I think the final judgement will be that the phaseout of Halon 1301 has been to-date accomplished as well as would be expected given the political realities it was operating under.

This issue has had positive impact in the area of fire protection, in the following areas:

1. Improved Engineering

   leakage, generic flow calculations, and better theoretical and conceptual understanding of important processes

2. Improved Hardware

3. Wide range of Alternatives Available

4. Optimized Protection Concept

5. Fire Protection Community as Model

In conclusion, in many ways this change has been positive although one must not forgot the severe economic impact it has had on manufacturers, installers, and users.

There is still a great deal of regulatory uncertainty, and Federal Government can adversely impact the introduction of alternatives by both ill-advised regulation and through its government users. The last slide summarizes a caution to all of us in the room. Facilitate the process and stay out of the way.

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