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Halon Options Technical Working
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U.S. Department of Commerce
Donald L. Evans, Secretary

Technology Administration
Phillip J. Bond, Under Secretary for Technology

National Institute of Standards and Technology
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ADDRESSING THE NEED FOR HALON REPLACEMENT

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This paper describes some of the factors, interactions, and dynamics of evolving halon substitute approaches and options. The viewpoint is from my experiences at the US Naval Research Laboratory (NRL) as a bench scientist, field test director, technical program manager, DoD Halon Alternatives Steering Group advisor, and US Government Representative and Technical Advisor to the United Nations Environment Program's Halons Technical Options Committee. I have been fortunate to be an interacting part of the halon replacement process at several different levels. The experiences and observations I describe are my own and do not represent official viewpoints or policies.

How did halons become so prominent in fire protection? Fire losses have long occurred. With advances in technology and mechanization the opportunity for catastrophic casualties also increased, especially when involving large quantities of liquid fuels. Around 1948 the US Army, sustaining tremendous losses in World War II, initiated a research review with Purdue University searching for very efficient, less toxic, fire extinguishants. The study, which became public later, considered approximately 60 compounds. These were mainly halogenated hydrocarbons (thereafter labeled as numbered halons). Halons 1301, 1211, 2402 and 1202 were identified (as were CF_3I and PBr_3 but both were considered likely to be more toxic). The US developed primarily halon 1301. Europe used halon 1211 but later increasingly used halon 1301 due to greater halon 1211 toxicity. Russia (and the former Soviet Union countries) employed primarily halon 2402. Here, ease of manufacture was probably a consideration.

I received a telephone call in the 1980s asking about the difficulty of replacing halons compared with replacing CFCs. I noted that the CFCs require certain thermodynamic properties to function as refrigerants while the halons require not only thermodynamic properties but also chemical properties to function as extinguishants. To add to the difficulty in finding replacements for halons, the chemistry needed to extinguish fires was very closely related to the chemistry that 'extinguishes' the ozone layer. Further, as the ozone depletion potential of halons were higher than those of CFCs by up to an order of magnitude, the replacement solutions had to have that much more depletion potential improvement. Bottom line, halons were much more difficult to replace than CFCs.

The phone call had been from the EPA to help formulate the US Government position on the Montreal Protocol. Appreciating the difficulties of replacing halons for their critical life and property protection roles, the Montreal Protocol had CFC production phase-out schedules but only undefined future halon restrictions.

Over the years, the use of halon based fire protection systems has greatly increased. Thus, when the mounting evidence on stratospheric ozone layer depletion by chlorofluorocarbons (CFCs) and halons resulted in a halon production halt, the magnitude of the problem faced in fire protection was immense. The impact was even greater with an accelerated halon production phase-out schedule. Production of halons was banned in the developed countries from January 1, 1994, two years before any other ozone-depleting substance production halt. What happened to accelerate the timetable is part of the story in this paper.

In the early 1970s prior to stratospheric ozone environmental concerns, there were already significant efforts on studying halon fire suppression. The US National Academy of Sciences held a symposium on “An Appraisal of Halogenated Fire Extinguishing Agents” in April 1972. Issues included toxicity aspects and practical applications of fire suppression for a variety of scenarios. The US Naval Research Laboratory (NRL) was active in halon laboratory and field studies as well as alternative gaseous approaches by that time. I was studying spontaneous ignition with Fred Williams when Dick Gann was hired by NRL to work on fire suppression. Dick assembled cup burner and small (1.8 m³) total flooding test facilities in addition to conducting flow tube kinetic studies. He also organized an American Chemical Society symposium on “Halogenated Fire Suppressants.” This important symposium included many technical papers delving into understanding the mechanisms of halon suppression action. The proceedings were published in 1975 as volume 16 of the ACS Symposium Series. When Dick went to NIST from NRL, I was his replacement on the halon replacement efforts.

Efforts were well underway for developing a scientific understanding of suppression and improving fire protection. NRL was actively involved in shipboard safety and survivability, and especially fire protection. Even as early as the 1970's halon related studies included smoldering combustion, kinetics, cup burner exploration, quantifying physical and chemical effects, quantifying HF and HBr from laboratory scale and full-scale extinguishments, and full-scale total flooding system evaluation and development providing the shipboard design guidance for Navy halon system implementation. Cup burner studies showed that halon 1301 works 20 % by physical action and 80 % by chemical action. The 80 % halon chemical action is split between 25 % radical scavenging by CF₃ and 55 % radical catalytic recombination by Br. The agent quantification model was later expanded as a predictive tool for suppressant requirement for new aliphatic hydrohalocarbons and complex mixtures including with physical agents varying oxygen concentrations. The reported high CF₃ suppression activity result was later used by Great Lakes Chemical Corporation to select the molecular structure of 1,1,1,2,3,3,3-heptafluoropropane as a promising candidate halon replacement to synthesize. The high HF production results foreshadowed the even greater production of HF from non-brominated replacements. The US military can be very proud of their very significant lead efforts in proper halon use, conservation and replacement programs.

The halon replacement program at NRL included a range of tasks, representative of the mix that is needed within the technical community in pursuing halon replacements. Understanding combustion suppression mechanisms and being able to suggest and confirm possible highly efficient suppressant chemicals is less than half the effort. Success only comes when acceptable agent availability, toxicity, storage, generation, dissemination and distribution in practical

systems addressing real fire threats is achieved. Science, technology, engineering, and program politics must all come together.

But this is getting ahead of the story. How did the need for a halon replacement arise? An entirely different issue was the perceived need for faster transportation. One proposed solution was to create a large fleet of high altitude supersonic transport aircraft, or SSTs. A possible problem emerged. The combustion engines from hundreds of SSTs flying high in the atmosphere would emit a tremendous quantity of nitrogen oxides. The NO_x would react with and destroy a significant amount of ozone in the stratospheric ozone layer. The stratospheric ozone layer absorbed considerable ultraviolet light from sunlight. Although some UV radiation is helpful as a germicide, a rapid change greatly increasing exposure to these energetic photons would cause health and food bio-chain problems. A significant amount of research was initiated on clean burning engines with congressional hearings probing the repercussions. In the end the SST fleet was not built, but awareness to the need for and fragility of the ozone layer was increased.

CFCs are a wonderful chemistry success story, but they would turn out to cause a serious problem. They were invented and found to be very stable with relatively low toxicities. CFCs quickly were adopted as refrigerant fluids replacing toxic sulfur dioxide and ammonia for many uses. Their production increased tremendously as refrigeration, air conditioning and other usage spread. In 1974, Mario Molina and Sherwood Roland posed an interesting question. Since CFCs were very stable, what happened to them when they were emitted by leaks or at end of system lifetime? They had been detected in the atmosphere. The concentrations in the troposphere, the lower atmosphere in which we and weather exist, corresponded to production. They must be accumulating without being destroyed. Molina and Roland proposed that CFCs crossing the tropopause into the stratosphere would be subject to photolysis by the more energetic UV radiation present at higher altitudes. The liberated chlorine atoms could then enter into catalytic cycles destroying ozone. A new serious threat to the stratospheric ozone layer emerged. Unlike the SSTs, CFCs were already in existence with increasing production.

We were aware in 1976 that the halons were at least as potent stratospheric ozone layer depleters as were the CFCs. Dr. Homer Carhart, former Director of the Navy Technology Center for Safety & Survivability at NRL, noted that if CFCs were bad, then halons with bromine, directly under chlorine in the halogen column of the periodic chart, could behave similarly. Denis Bogan, then my post-doctoral fellow, conducted approximate kinetic calculations confirming the vulnerability. Our technical response was halon replacement research. Our long-range impact evaluation was supplied by Homer. He felt that while the existing and probable future Navy halon usage was insignificant compared with the total ozone depletion magnitude, perception driven mandates would emerge in the future necessitating halon replacement. As we have seen, the science, technology, business, environmental, and political (world-wide) concerns have interacted to form our constantly evolving perceptions. The results have been increasingly restrictive requirements on halon production and use. Possessing a larger picture appreciation of total system dynamics is essential.

The potential repercussions to the stratospheric ozone layer were not appreciated. Halon usage for fire protection increased tremendously. Systems became certified. Construction codes and

insurance companies strongly encouraged their use. In perhaps most of the instances where halon was employed, it was not uniquely needed. But if you were a fire protection engineer designing a system to provide protection and you chose not to employ halon, you had a hard sell to make. You needed to spend considerable time smartly considering the needs and tailoring a system to satisfy them. You must obtain approval from the authorities having jurisdiction, convince the insurers of the adequacy of the system, and convince your sponsor the increased cost of conducting business was for his good. Does one accept significant time delays, expensive tests, and higher insurance premiums or, just install a pre-approved, one-size-fits-all, halon system.

Although the potential ozone destruction issue was known within the scientific community, the lack of a general perception of the seriousness of ozone depletion had not yet arisen. While I continued halon replacement related research, it was primarily as a low budget side project. No mandate materialized. We knew what would occur in the future, but that is far different from establishing its importance to others. Potential sponsors and decision makers have limited resources and seemingly unlimited tasks to accomplish. Less important issues are ignored until they go away – or become too important to ignore.

All during this time period, NASA had been studying the ozone layer, including satellite ozone concentration measurements. There was not much cause for excitement. The change was to emerge from the sky over Antarctica. There are peculiar circumstances around this frozen continent. The large landmass at the South Pole has winds that circle the continent, essentially isolating it from air interactions with the rest of the atmosphere. It also is very cold and in darkness almost half a year. The known ozone destroying reactions of chlorine should have caused only single digit percent reductions in ozone concentrations since a significant fraction of the chlorine is tied up in forms such as ClONO_2 and HCl that do not interact with ozone. However, sunlight would break up those species into reactive forms once antarctic winter was over. During winter the very cold air over Antarctica allowed formation of polar stratospheric clouds (PSCs). The cloud surfaces enhanced reaction rates and tied up NO_2 , which would otherwise combine with ClO to form ClONO_2 . When spring sunlight activated the chlorine species while the clouds still lingered on in the warming atmosphere, dramatic ozone depletion occurred, an unexpected phenomenon. The confluence of air currents, cold, clouds, surfaces, sunlight, and chlorine were all necessary for the formation of what became the “ozone hole.”

If there were satellite ozone measurements over the South Pole, why was the ozone hole not seen before the 1980s? Such dramatic drops in ozone concentration had not been expected. Thus, the mathematical algorithms processing the data had been programmed to ignore such large discrepancies; they must be in error. After ground based instruments reported large ozone decreases, the satellite data was reexamined. The ozone hole was ‘rediscovered’ to have had a 33 per cent concentration decrease in 1975.

There was now an area of decreased ozone with the easily grasped image of an ozone hole. Australians potentially would be among the most affected by increased UV radiation levels around Antarctica. A significant happening was when an Australian pipe fitters union supported not servicing CFC equipment. They understood CFCs cause ozone depletion and therefore cause

more UV exposure. They understood the health implications were not good. They took the only direct action they could. Their boycott got peoples' attention.

Public concern, and thus, legislative imperative, was increasing. US congressional hearings, National Academy of Science reports, and US, Canada, Norway, Sweden, and European Community actions restricting CFC usage began. A NASA plane flew into the ozone hole and dramatically provided the "smoking gun" with concentration traces showing ozone concentration dropped dramatically precisely where active chlorine species concentration abruptly rose. Definition of the problem allows taking action. If they can land a man on the moon, why can't they make a good cup of coffee? Or solve the ozone hole problem?

The idiosyncrasies of the polar ozone hole include the existence of the quasi-biennial oscillation. A result of this world atmosphere phenomena means that the ozone hole is worse in alternative years. So once every two years someone can point out that the ozone hole is much larger than it was last year and demand action. Perceptions of complex phenomena are important drivers.

British Lord Kennet said "Politics is the art of making good decisions on insufficient evidence." Laws responding to the need to take some action can be shortsighted. However, in the case of the evolving Montreal Protocol on Substances that Deplete the Ozone Layer, the politicians have done very well with a very complex issue. Occasionally, gentle urging is required as in the form of a Natural Resources Defense Council lawsuit brought against the US EPA to carry out US obligations.

It is truly difficult to supply sufficient evidence for scientists and legislators to make good decisions. What are background ozone concentration levels? What are normal fluctuations? What are the trends? Ozone depletion rates are functions of latitude, longitude, altitude, time of year, time of day, and the concentrations (at the specific location) of reactive species and the controlling chemistry and physics. For good measure, once in fifty to a hundred years there is a very large volcanic eruption that inserts massive amounts of chemicals into the stratosphere. Mt. Pinatubo in the Philippines greatly affected the world atmosphere for several years, primarily with sulphur compounds. Natural sources for chlorine and bromine also exist from the oceans and land life forms.

If stratospheric levels of chlorine and bromine due to man-made sources, after minimization of unnecessary CFC and halon releases, become less than natural chlorine and bromine sources, why impose further drastic restrictions? Because of: 1) the capability to take some action, 2) the emotional need to do something, and 3) the capability to change the situation back towards the previous status quo. How far to go is a complex societal decision. A viewpoint on the lack of need for action expressed in many parts of the world was that the ozone depletion issue was a white man's problem. Darker skinned peoples are less susceptible to skin cancer from increased UV exposure. The old colonial countries were perceived as trying to subjugate developing countries by imposing economic hardships and dislocations. They would not be allowed to raise their standards of living by utilizing established, cheaper technologies based on ozone depleting substances (ODSs).

Amazingly, despite this perception, many countries of the world came together in agreement and ratified the Montreal Protocol. This took extensive negotiations, establishing what could be established, creating constituencies, and making deals. A major 'deal' was establishing special consideration for countries with economies in transition (CEITs), with a multilateral fund (MLF) supported by developed countries to aid CEITs and less developed countries. The less developed countries were assured sponsorship for technology transfer, allowing their economies to transition to non-ozone depleting technologies according to a timetable to be better defined in the future.

The Montreal Protocol entered into force January 1, 1989. It controlled production, not use. CFC production phase-out schedule for the developed countries was defined, with halon production decreases to be dealt with later. Circumstances would continue to arise to hasten the halon phase-out schedule. A sleeper issue in the treaty, and an important consideration in evaluating approaches to the similar environmental concern of global warming, were the undefined terms for developing countries. The CFC increases allowed for China in order to give all its citizens the barest of food refrigeration capability dwarfed most countries' CFC production.

Why were there amendments and adjustments to the Montreal Protocol accelerating the phase-out times? Why were the halons singled out for an even faster phase-out schedule? There was better appreciation of the ozone depletion processes, less than hoped for results of some enactments (including clandestine production and smuggling), heightened perceptions of the seriousness of the situation engendering the need for further actions, and for the halons, the appearance of being able to easily have a large effect with a simple identifiable action.

As long as the highly visible ozone hole was far away over Antarctica, it was less compelling. But increased UV over populated northern countries gave more driving concern. Once every 10 to 20 years is there a very cold winter over the arctic. This is rare due to the absence of a large land mass and a circumpolar wind phenomenon. Polar stratospheric clouds can form and remain until late in a cold winter, perhaps until sunlight returns above the arctic circle to liberate active chlorine species and form a North Pole ozone hole. A cold winter did occur and the media did focus on the coming North Pole ozone hole. Actually the PSCs dissipated before strong sunlight appeared. There were new lower ozone concentration levels reached, but nothing comparable to the Antarctica ozone hole. However, increased pressure for more rapid global action was established.

There is a very valid rationale to be more concerned with bromine (and iodine) containing compounds. Less reactive chlorine compounds can require light activation for rapid ozone depletion. Bromine in the form of BrO has a thermodynamically allowed reaction channel that does not require activation. Consequently bromine, and thus halons, has a greatly enhanced effectiveness compared to chlorine. Even though chlorine atmospheric loadings are much greater than bromine atmospheric loadings, the magnified depletion effect makes halons a significant contributor to ozone depletion. Halons are definitely part of the problem.

Putting an exact number on potential halon damage to the ozone layer is very difficult. The effectiveness of bromine, as for chlorine, is a function of latitude, longitude, altitude, time of

year, time of day, and the concentrations (at the specific location) of reactive species and the controlling chemistry and physics. The controlling chemistry includes the interaction of bromine and chlorine cycles. There is not an independent metric for bromine. Its effectiveness depends on the concentrations of the chlorine species present at each specific location. Ozone depletion potential (ODP) is defined relative to the assigned value of 1.0 for CFC 11. Halon 1301 has an ODP of between 10 and 16, depending on the specific model and assumptions used in the calculation. Models and concentration information are continually updated. Regulation cannot function with such uncertainty. The ODP of halon 1301 was defined as 10 for purpose of legal calculations such as taxes. This is not a scientific definition, but one allowing for political operations. Where information is insufficient, decisions still need a basis.

Depending on location in the atmosphere and time, bromine can be far worse than chlorine, up to a thousand times more deleterious for ozone destruction. Policy makers grasped this greatly increased destructiveness. Halons were also a target that could be easily focused upon. CFCs are used for a variety of purposes including refrigeration, air conditioning, foam blowers, electronics manufacture, solvents, etc. There are many different applications in many different industries. Halons were determined as responsible for at least ten percent of man-caused ozone layer depletion and, simplifying consideration, it is used primarily for one purpose only, fire protection. Only methyl bromide and its agricultural use was a bigger simple sector target. That application was viewed (until more recently) as necessary and hard to replace.

To policy formulators trying to ‘repair’ the ozone hole and minimize stratospheric ozone layer depletion, there is an apparently simple approach with a big payoff. Halon phase-out has a significant clearly defined benefit and with usage in one industry with clear distribution lines, action seemed straightforward. The early phase-out of halon production became too advantageous a path to be ignored. While production minimization of all ODSs was the goal, halon production faced the earliest stoppage.

“If you are not part of the solution, you are part of the problem.” That dictum is too simplistic and harsh to apply generally. Success involves having the players have a stake in the desired outcome. Companies that manufacture halons can perhaps be involved in manufacturing replacements. Their issue is not resisting phase-out, but replacing an existing product with a new product and achieving market share. The more narrow methyl bromide sector however, did not have an in-kind replacement product. Possible solutions were emerging from completely different industries. Therefore resistance to regulation was strong. Fire protection companies could perhaps adapt to new approaches, but there is the definite possibility of undesirable change and uncertainty.

There were grave concerns in the fire protection community about the dislocations the lack of halon would cause, as well as doubts that such action was really warranted. I received many calls along the lines, “How can they take away my halon?” “Don’t they know lives and assets depend on it?” “The powers that be must give my use an exemption for continued production and availability.” As I stated as a talking head in a CNN Science Watch interview, many if not most halon usage was not absolutely necessary. Alternatives did exist. But there was some fraction of halon use for which there were not acceptable replacements that were currently technically and economically feasible. For those, including some three dimensional flammable

liquid fire threats, not having halon did mean that more lives would be lost and that assets and the capabilities they supplied would be lost. However, continuing with halon was not acceptable. The decision makers representing many governments of the world had already decided the increased threat of skin cancer and potential interference with the food chain were more critical. The calculus of the Montreal Protocol included acceptance of increased loss of lives and property from fires as a necessary cost for preserving the ozone layer's UV radiation filtration.

In 1988 I had a project to identify a halon 1301 replacement that would have a lower ODP by an order of magnitude, i.e., an ODP of 1 instead of 10. CF_2BrH became my exploratory candidate and I did find a chemical source from a firm that manufactured brominated anesthetics. At a 1988 halon alternatives conference sponsored jointly by the EPA and US Air Force, I mentioned to representatives of Great Lakes Chemical Corporation that CF_2BrH might be a chemical for their consideration. They told me they had no interest. Bob Tapscott later told me he also recommended investigating CF_2BrH around the same time. In fact Great Lakes did not want to reveal their business position of already considering production of that compound, later trade named by them as FM-100.

My heptane fuel cup burner studies showed about one third more CF_2BrH (by gas volume) was required for extinguishments compared to halon 1301. The ODP was approximated as 1, so the compound had potential to satisfy the ODP improvement mandate given me. We did medium scale (56 m^3) total flooding extinguishment tests not just on CF_2BrH itself, and also CF_2BrH as a minor component in a blend. An ODP value of 1 was acceptable for halon replacements only for a short time. Employing a mixture allowed me to meet the new replacement criteria for an ODP of 0.20, as well as reduce toxicity impact. We verified the low concentration in the mixture still retained much of the chemical catalytic bromine effectiveness as predicted by our quantifying the non-linear relative effectiveness enhancement (sometimes labeled synergism) in laboratory experiments.

Shortly thereafter however, CF_2BrH was removed from consideration as a halon replacement by a new criterion for ODP; less than 0.05. Throughout the search for halon replacements, the moving target requirements, frequently not well defined, have presented ever more stringent restrictions. ICI in the UK felt toxicity was too much a concern for CF_2BrH to be a viable solution. Further, they felt it unlikely any feasible chemically active fire suppressant would be able to pass both environmental and toxicity bars. They left this market sector. The uncertainty of moving ODP targets is not conducive to industry investment. This was especially so as CFC replacement was an easier challenge and a much larger potential market.

The fire protection community, suppliers and users, have responded admirably in working to assure fire protection while helping to also decrease the threat to the environment. Concerted efforts have been made for responsible use of halons. In addition to exploring alternative ways for providing protection, advances were made in minimizing leaks, inadvertent system discharges, testing and training. At the first "International Conference on CFC and Halon Alternatives" in 1989, I was able to state that the US Navy was able to reduce halon discharges to the atmosphere by almost 75 percent.

The “Second Conference on the fire protecting Halons and the environment” in Geneva in 1990 saw a greatly increased appreciation of the halon community issues. A variety of approaches, including videos of pyrotechnic devices from Russian efforts, were covered.

Halon alternative efforts got a real boost in 1991 with the advent of the “Halon Alternatives Technical Working Conference” held in Albuquerque, New Mexico. Bob Tapscott of NMERI served us very well in shepherding these annual conferences, called the “Halon Options Technical Working Conference” or HOTWC since 1994. This conference, with the help of Doug Mather at the University of New Mexico and the organizational support of the Next Generation Program under Dick Gann, continues to be a technology exchange mainstay for scientists, engineers, vendors and users on the many aspects of halon substitutes.

The technical community responses to address the environmental drivers have included searching for halon-like replacements and understanding halon combustion suppression. Other searches have been more broadly based on replacing the fire protection capabilities halon supplied. A serious consideration of risk analysis frequently suggested alternatives implementable without new halon replacements. In all cases, identifying a “solution” demands the frequently more difficult task of enabling proper implementation. Science without enabling technology does not address our needs. The 1995 ACS symposium “Halon Replacements: Technology and Science” explored many aspects from fundamental science through applications. As with the predecessor ACS symposium in 1975, the proceedings papers are published as ACS Symposium Series #611. A review of NRL efforts is included in the publication.

Many of the difficult to solve problems relate to protecting fuel loaded movable military platforms. The DoD can proudly claim very significant efforts with solutions applicable to many civilian applications. Many lead actions and breakthroughs came from military sponsored efforts. Our NRL efforts on clean agent replacements led to the selection of a hydrofluorocarbon as the best available solution for several specific navy ship fire threat scenarios. We have provided detailed design guidance for systems employing HFC-227ea which is being implemented aboard the LPD-17 and CVN-76, new ships that are being constructed without ODS materials aboard. However, such gaseous agent systems (including halon 1301) do not provide cooling. Also, HFC agent – fire interactions produce far more HF (5-8 times) than was produced with halon 1301. In response, we invented a hybrid gaseous agent – water spray cooling system (WSCS) (United States Patent 5,918,680, July 6, 1999) to provide cooling, minimize agent by-products, minimize reflash potential, and facilitate post-casualty compartment reentry.

Several Army representatives were present aboard the ex-USS SHADWELL, NRL’s Advanced Fire Research Vessel, during full-scale development testing. They were sufficiently impressed to advocate incorporating the WSCS technology in Army watercraft. Budgets can contain different types of funding and programs may not communicate adequately to allow approaching optimum results. The Army had very significant funding available for a limited time period for implementation but no funding for development. To date, the Army has replaced halon 1301 total flooding systems aboard 60 watercraft machinery spaces (up to 1700 m³) with the NRL patented system and our general guidance. They were not able to devote efforts to optimize the

specific operational parameters. This is definitely a halon replacement success story, but as sometimes happens in a non-ideal world, a qualified success that could be improved upon.

A key point to emphasize is that satisfactory solutions are not always capable of being optimized due to non-technical considerations. Knowing what agent can serve as a halon substitute is not the same as knowing how to properly implement an operational system, let alone taking full advantage of that capability.

Perceptions play important roles. A scientific fact is subject to evaluation and must be independently verified. A legal fact is one established in a court of law by virtue of being accepted by a Judge and jury. A fact in the public arena is a viewpoint accepted by the people. Differences in viewpoints exist with different countries having different tolerances to HCFCs, PFCs, global warming gases, and various atmospheric lifetimes. Realities within different countries can also be different. Different countries thus evolve different production and usage phase-out schedules for different compound classes. Commerce, airline, ship and military equipment movement gets complicated in this era of global interactions.

I have been privileged to serve as a US Government Representative and Consulting Expert on the Halons Technical Options Committee (HTOC), which advises the participating governments of the world on the Montreal Protocol Treaty via the United Nations Environment Program (UNEP). The experience continually reinforces the importance of the large number of factors in addition to science involved in efforts to minimize mankind caused ozone layer depletion. It is amazing how a disparate group of people with very different interests and agendas can so constructively form a productive consensus output. This has been in significant measure a tribute to the efforts of the members, especially the early co-chairs Gary Taylor and Walter Brunner.

Exposure to different situations at HTOC meetings showed me that someone else might consider a use of halon viewed by many as not important to be crucial. Being able to use automobiles well into the car's old age is important in Mexico. Being able to extinguish a car engine fire with halon 1211 allows the engine and most residual wiring to be repaired without high cost. Alternative suppressants may not allow home repairs or cause significant economic impact.

A personal computer might be regarded as expendable in some countries, but when the only PC in the town is used to run a factory, protection is vital. Water sprinklers may be perfectly adequate to deal with a fire threat, but if half the time when one turns on the water spigot and nothing comes out, sprinklers are not a viable halon alternative.

High technology countries can also have their particular needs. High-rise concrete garages in Japan cannot easily be converted to water based systems because drainage was not built in. A halon system may be only one of many viable fire protection modes, but once a facility is built around its characteristics, converting to a different system can be exceedingly difficult. Facilities with political or national prestige may also be thought to necessitate halon.

In practice, the different sovereign states determine for themselves what is truly important for their requirements. With the advent of production phase-out, signatories must follow a

procedure to request production exemptions if existing halon supplies are not available to meet needs. The HTOC is the initial evaluation point for granting production exemptions under the Montreal Protocol. I remember when the first set of approximately 20 requests for exemptions was to be dealt with. A high placed gentleman in the UNEP administration was seated next to me. He noted that sovereign nations had submitted formal requests. It would be an embarrassment if they were turned down. I politely informed him that I did not feel this was the basis for the operation of a technical committee. In the end, we did not cause any one country embarrassment. We turned down all requests based on our knowledge of halon availability. They simply did not need any new production to satisfy their needs.

Availability of existing supplies of halons 1301 and 1211 served to buffer transition to alternatives and maintain supply for remaining legacy essential uses. Russia was unique as there was no reserve of halon 2402 available in international commerce to smooth the phase-out transition. Russia was later allowed a measured decreasing production allowance by the UNEP.

India as a large developing country (Article V country under the Montreal Protocol) has progressed very far in elimination of halon dependence. Much credit is due to Mr. H. S. Kaprwan of the Indian Defence Institute of Fire Research for facilitating the effort.

China as a developing country also has an extended time period for phasing out production of halons. Their continued allowed production peaked several years ago at approximately 14,000 tons/year. Most of this production was of halon 1211 for portable extinguishers. While ozone depleting substance production worldwide had been decreasing, halon concentrations in the atmosphere were increasing. This may be due in part to the Chinese production. Also usage in limited lifetime handheld units would lead to future releases. The UN Multilateral Fund arranged for a halon and CFC production reduction program in advance of mandatory scheduling, including contributory payments of approximately \$100 million. While the cost is large, it is a very efficient use of funds for the impact achieved. The success is due in no small part to the limited number of officials who were involved. A similar attempt in a less controlled economy with strong private interest groups present would have been much more difficult.

The program for phasing out halons in China had a very dramatic success in Shanghai. Use control on halon extinguishers resulted in a very significant decrease in market demand. Local authorities then banned production and sale of halon extinguishers, as well as forbidding all halon 1211 agent and extinguishers from entering Shanghai, effective January 1, 2000. While there were possibilities of using this forward momentum for speeding up the phase-out of halons in the rest of China, program structure and bureaucratic realities provided too much status quo inertia. The World Bank-China ten-year plan had been approved with various international entities involved. Modifying the agreements for a shorter time frame could have been difficult. The current plan does not have provision for advancing payment of support funds, nor can the implementation payments continue to be made once the phase-out is completed.

Economic and political programs can develop lives of their own, not directly dependent on scientific or technical capabilities. This is a reality of the non-technical complexity of halon replacement.

Political imperatives are an important aspect of issues with commercial impact; halon replacement is no exception. One country proposed a modification to the Montreal Protocol to help achieve a faster phase-out. Three other countries cosponsored the action that appeared to be good environmental activism. The impact in the opinion of many HTOC members would have been premature destruction of halon before more accurate knowledge of the amount of existing stock for legacy essential systems was gathered. The proposal was not supported by HTOC and was later not supported by the policy makers. A side issue was that the proposing country contained a manufacturer that thought it had a near drop-in replacement. More rapid halon withdrawal would have meant business.

The focus of HTOC has changed repeatedly with the maturation of halon replacement efforts. HTOC exists to serve as a technical advisory body. With halon production halted in developed countries, some parties to the protocol prefer to initiate halon destruction. Questions are posed for reply. Sometimes parties prefer actions that may not be supportable by data available at the time. The HTOC has to be able to educate and convince others as to why such positions may not be optimum. It can be difficult to provide a convincing technical reply when a different conclusion has been reached based on other considerations. Such an interaction on a policy level is not the domain of scientific research to find halon replacements, but it is an important part of the dynamics of evolving environmental laws governing our actions. This is a true adventure for this former basic science researcher.

Were the sky parchment,
Were all reeds quills,
Were the seas and all waters ink,
Were all the world's inhabitants scribes,
It would not suffice to record the intricacies of government.

Talmud

Significant future events include the European Union legislation banning refilling of halon systems after 31 December 2002, and the required decommissioning of all systems by 31 December 2003. There will be exemptions for certain essential uses.

The cost of recycled halon is already greatly reduced with the decommissioned halon becoming available on the market. Care must always be exercised in designing a decommissioning program. If an owner's concern about being responsible for possessing an environmentally hazardous material overcomes the perceived value of the material as an asset, we may find accidental discharges and fires increasing. This is opposite to the conscientious treatment seen so far, but always a consideration.

Another significant future event will occur in 2010 when the Montreal Protocol Article 5 countries, the developing countries, must cease halon production. Many countries have acted very well. Many others can only address their needs with continued financial and technical aid. The continuation of the multilateral fund is crucial.

Obtaining real-world economically and technically feasible solutions, while looking over your shoulder as ground rules modifications gain on your efforts, has supplied us a thrilling and very challenging ride. We can be proud of many successes. The quest continues for addressing the remaining difficult challenges.

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A useful source for further information on the current status of halon replacement efforts is:

Wickham, Robert. T, *Status Of Industry Efforts To Replace Halon Fire Extinguishing Agents*, Wickham Associates, Stratham, NH: March 2002. This document can be downloaded from the web site of the U.S. Environmental Protection Agency at <http://www.epa.gov/ozone/snap/index.html>.