EMISSIONS ARE BAD; EARLY EMISSIONS ARE WORSE (OR, LOOK BEFORE YOU LEAP)

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INTRODUCTION

The Montreal Protocol [1] has reduced halon production in developed countries almost to zero, and Article 5 (developing) countries now have agreed phase out plans. At the same time, the fire protection industry and its users have reduced unwanted emissions of extinguishing agents to a minimal level, perhaps as little as 1%. Halons have high ozone depletion potentials (ODP), and every effort should be, and will continue to be, made to avoid emissions whenever and wherever possible.

Meanwhile, attention is turning, logically enough, to the ultimate fate of the remaining agent accumulated in stockpiles, systems, and extinguishers around the world. The Science Panel of the Protocol, in its 1998 Assessment Report [2], identified elimination and destruction of halon as the most environmentally beneficial option to speed the recovery of the ozone layer. Thus, decommissioning of non-Critical* halon systems and destruction of apparently surplus halon becomes an intuitively appealing course of action. At their tenth meeting in 1998, the Parties to the Protocol reached a Decision [3] encouraging Parties to adopt such policies. Some influential governments are considering measures such as mandatory early decommissioning and destruction of any agent not specifically required to support already-identified future Critical uses.

This simplistic assessment may well be in error. **As** will be seen, the mere need to handle, transport, and store or destroy large quantities of halon, especially in a limited time, can hardly avoid leading to earlier-than-necessary emissions, perhaps augmented by deliberate illicit venting. And it is crucial to recognise that the *timing* of any release is also a key factor. Halon released now and over the next few years, while stratospheric halogen loading is at its peak and the frailty of the ozone layer at its nadir, will have a maximised impact. Bromine released into the stratosphere when the chlorine concentration there is high actually has a more damaging effect on ozone than the same release at lower chlorine concentrations. The same quantity of the same agent released in 10 or 20 years time, when the stratospheric chlorine concentration has reduced, will have a diminished *absolute* effect on ozone. In addition, the ozone layer will have recovered somewhat, and the *relative* effect of halon on a more robust ozone layer will be even less. The impact on health and the environment will therefore be significantly reduced.

Additionally, enormous skill and care will be necessary to ensure the accuracy of estimated future Critical needs before embarking on destruction programmes if the potential embarrassment of later having to apply for Essential† use production is to be avoided.

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*Throughout, the term "Critical" is used to refer to uses for which there is no technically and economically feasible alternative to halon. This is the sense defined by the Montreal Protocol in Decision VII/12.

† Throughout, the term "Essential" is used to refer to Critical uses requiring new production of halon. This is the sense defined by the Montreal Protocol in Decision IV/25.

MANDATORY DECOMMISSIONING PROGRAMMES

Decision *Xi7* of the Parties to the Montreal Protocol *[3]* concerns "halon management strategies." It requests "all Parties to develop and submit to the Ozone Secretariat [by the end of July 2000] a national or regional strategy for the management of halons. including emissions reduction and ultimate elimination of their use." It also suggests that, in doing so, "Parties should consider issues such as (a) discouraging the use of halons in new installations and equipment; (b) encouraging the use of halon substitutes and replacements acceptable from the standpoint of environment and health, taking into account their impact on the ozone layer, on climate change and any other global environmental issues; (c) *considering a target date for thr complete decommissioning of non-critical halon installations and equipment*, taking into account an assessment of the availability of halons for critical uses; and (d) *promoting appropriate measures to ensure the environmentally safe* and effective recovery, storage, management and *destruction of halons*" (authors' italics for emphasis).

Some influential governments are proposing programmes of this type. This may be in response to Decision X/7, or for other reasons, for instance to establish state control over remaining halon or to maintain the political momentum of ever-tightening environmental policy in this area. Whatever the reason, such actions raise a number of interesting issues, including the effect of mandatory decommissioning on emissions and the wisdom of destroying halons before it is *absolutely* clear that there is excess.

LIKELY EFFECT ON EMISSIONS

Fixed Systems

Halons in well-maintained fixed fire suppression systems are rarely emitted. It will have been one of the objectives of the designers of the individual items of hardware and of the systems to avoid any possibility of leakage. Adequate maintenance ensures that these standards are safeguarded. The same aim is also amongst the requirements of customers — a system that has leaked no longer provides the commodity they are purchasing: protection against fire for their people and property. Non-fire loss rates of around 1% are being achieved with current best practice for the new halocarbon agents in the UK.[†] Levels little greater than this are probably now being achieved for halon systems, since emissions resulting from activities such as testing, training, and venting of unwanted agent were virtually eliminated after the environmental impact of halons became clear. Halons in well-maintained systems are pretty safe!

When a system is decommissioned, however, halons must he handled, transported, decanted, and either stored or destroyed. Any competent fire engineering company will perform these activities as safely as possible and will keep losses to an absolute minimum — but probably not to zero. This is not only a matter of safety and engineering professionalism. Most states have legislation aimed at avoiding the discharge of hazardous substances, which, for this purpose. includes halon. But however well intentioned, competent and law-abiding those involved in the process may be, the very need to decommission large numbers of halon systems in a limited time can hardly avoid leading to earlier-than-necessary emissions.

These potential causes of emissions will of course apply. eventually, to every halon system once it reaches the end of its useful life. The important point is that a mandatory decommissioning

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[†] M. Stamp, Great Lakes Chemical Corporation, personal communication, 2000

programme will result in their occurrence sooner and in a much shorter time span. An incidental effect may be that the high level of demand for decommissioning could lead to the involvement of less experienced and possibly less competent engineers, which, in turn, may result in increased levels of emission.

Portable Extinguishers

Portable extinguishers pose some distinctive problems. Many such extinguishers are the property of large organisations including commercial enterprises, fire brigades, police forces, and the military. However, a significant number of extinguishers remain that are widely dispersed in very small individual quantities, often poorly supervised and maintained, in a wide variety of premises including domestic homes. It seems unlikely that any decommissioning programme would be successful in retrieving all these units. This is not because their owners are seeking to evade the programme requirements, but because they remain unaware of those requirements or because they do not recognise that they (or their extinguishers) are subject to them.

Illicit Venting

It is a fact sometimes unpalatable to the legislators charged with enacting programmes of this sort that compliance with their requirements is not necessarily a certainty. Owners of halon systems will already be faced with the imminent unavailability of a fire system which, they had planned, would provide cover for the useful life of the protected asset. Quite probably, they will also face the cost of replacing it. A proportion of less scrupulous owners are likely to seek to avoid the further cost of removal of the halon, and maybe of its destruction, by deliberate illicit venting, and perhaps, if challenged on the point, ascribing the discharge to a false actuation. It is widely considered amongst more cynical (or realistic?) observers that the loss mechanisms described above (Fixed Systems and Portable Extinguishers) will be augmented, perhaps extensively, by this so-called “Big Hiss.”

Experience

No official data are known to the authors on the success rates of the few halon recall programmes that have already been enacted. There has also been retrospective uncertainty regarding the size of the installed base prior to implementation of the programmes, which would have defined the hoped-for quantities to be recovered, Based on anecdotal evidence, however, it is believed that those few countries that have attempted to call in all their halon in non-Critical uses have recovered approximately 50% of the expected quantity of agent.

ESTIMATING FUTURE NEEDS BEFORE DESTROYING HALON

There are significant uncertainties regarding the quantity of stored or installed halon in existence, the rates at which it is being emitted, and the quantity required to accommodate future Critical uses. In the case of Halon 1301, these uncertainties are sufficiently great to make it difficult, if not impossible at present, to determine whether current stocks are sufficient to meet future needs or whether there is a surplus or even a shortfall. It is not the purpose of this paper to explore this area, but the wisdom is questioned — as it has been by a number of authoritative sources [e.g., 4] — of destroying halon until such a determination is possible and clearly shows a surplus. Mandatory early decommissioning accentuates this problem by throwing the entire burden of making provision for future needs, including storage of halons, on to Critical users. (Without such regulation, at least part of the halon becoming available from decommissioning at the end of the useful life of non-Critical systems goes immediately to meet contemporary Critical needs without requiring to be stored.) Both these effects increase the likelihood of later having to apply for Essential use production—embarrassing if it follows previous destruction programmes!

EFFECT OF EARLY RELEASES

QUALITATIVE EFFECTS

Both chlorine and bromine are effective in depleting stratospheric ozone (bromine significantly more so, hence the high ODPs of halons). **A** number of compounds. mainly synthetic, can carry these halogens into the stratosphere: chlorotluorocarhons (CFC), hydrochlorofluorocarbons (HCFC), carhon tetrachloride, methyl chloroform, Halons 1211, 1301 and 2402, and synthetic methyl bromide are all classed as ozone-depleting substances under the Montreal Protocol [1]. Natural releases of methyl chloride and methyl bromide [5, 6] also contribute chlorine and bromine to the stratosphere. Thus the release of a given quantity of halon will have a predictable effect on the column ozone (after allowing for the time delay, measured in years, introduced by the physical transport of the agent to the stratosphere). This is exacerbated by the synergy with chlorine monoxide, as explained below (Methodology), and this latter effect will be most pronounced now and over the next few years while the stratospheric chlorine concentration is at its maximum. The results of the Montreal Protocol [1] in reducing stratospheric chlorine concentrations will then begin to be seen, *so* lowering the absolute magnitude of the ozone reduction caused by releasing this same quantity of halon.

Meanwhile, of course, the effects of the Protocol will also start to be seen in the gradual recovery of stratospheric ozone levels accompanied by *a* proportionate reduction in irradiation in the biologically active UV-B waveband (i.e., radiation in the ultraviolet waveband from 280 to 315 nm wavelength). The biological effectiveness of UV-B irradiance can be expressed as a radiation amplification factor (RAF), which is defined as the percentage increase in a particular biological effect that would result from a 1% decrease in the column amount of atmospheric ozone at a particular latitude [7]. For many effects. the RAF is greater than unity. meaning that a given percentage decrease in ozone will result in a greater percentage increase in the effect concerned. Selected examples of biological effects whose RAF falls in defined bands are given in the following table, taken from Reference 7. It can be seen that a number of important effects have high values of RAF.

RAF *Range*	*Effects*
0-1	Cataracts; immune suppression: plant and phytoplankton photosynthesis: DNA damage in alfalfa: yellowing of plastics
1-1.5	Skin cancer in hairless mice; elastosis: photocarcinogenesis; skin oedema; corneal damage
1.5-2	Erythema: melanogenesis: inhibition of phytoplankton motility
>2	General DNA damage: mutagenicity and fibroblast killing: HIV-I activation

QUANTITATIVE EXAMPLES

Two Scenarios

It is widely known that the European Union (EU) is currently finalising a new Regulation [8], which will mandate the decommissioning of all non-Critical halon systems. This should be largely completed by the end of 2002, although a few systems may remain installed until the end of 2003. The effect of this action has been taken as an example, using the following two assumptions in turn. In the first case, *50%* of the existing European installed bases of both 1211 and 1301 are emitted as a consequence of more or less deliberate venting or innocent failure to return halons for reuse or destruction: in the second case, 10% are emitted. The remainder would be recovered and destroyed but with a further 10% loss, so that the total loss from the European banks that exist in 2000 would be *55* and 19% respectively in equal annual amounts over the period 2001 to 2004. Based on the sizes of banks projected for the year 2000 in TEAP [9], the amounts released would be 12,656 tonnes of Halon 1211 and 4574 tonnes of Halon 1301 in the first case.

The first figure of *50%* was selected as representative of the anecdotal experience of similar programmes implemented in the past and discussed above (Experience). The second, 10%, was the most optimistic result that the authors felt could conceivably be postulated, especially considering the difficulties associated with full recall of portable extinguishers, also discussed above (Portable Extinguishers). The simplifying assumption is made that ***none*** of the recovered halon is subsequently emitted clearly, as some of it will be employed in Critical uses, this is overly optimistic and, as will be seen, has important effects on the modelled results of the changes. However, the figures used are not presented as being definitive but merely indicative, and as useful starting points for the equally indicative analysis that follows.

Methodology

The calculations are based on a comparison between evolutions in time of stratospherically effective halogen concentrations with different assumptions about containment of halons. The relative ozone loss is then calculated from the change and, through an estimate of the increase in UV-B, this leads to an estimate of the long-term increase in skin cancer cases for a northern hemispherical population.

The impact of each ozone-depleting substance on the ozone layer is governed by a number of factors:

- persistence, in this case parameterised by atmospheric lifetime ranging from a year for methyl bromide to almost 2000 years for CFC-I 15 (chloropentafluoroethane)
- the quantity of chlorine or bromine in each molecule
- the effectiveness of that chlorine or bromine, which varies with the way that the compound reacts in the stratosphere. Effectiveness factors, relative to fluorotrichloromethane (CFC-I1), vary from 0.35 for HCFC-22 (chlorodifluoromethane) to 65 for methyl bromide

These parameters may be combined as described [IO] on a common accounting system where the unit is the Equivalent Effective Stratospheric Chlorine Loading (EESC). This enables projections of future contributions to ozone depletion from individual substances and groups of substances.

The absolute value of the contribution of halon releases has been adjusted for the known synergy between bromine and chlorine in ozone depletion. This arises because one step in the conversion of bromine into bromine atoms (which are the ozone active species) involves reaction of bromine monoxide (BrO) with chlorine monoxide (C_lO). The concentration of active bromine therefore depends on the C_lO concentration that, in turn, depends on the square of the total chlorine concentration [11]. For the purposes of the comparison described here, which is examining the effects of marginal differences in bromine concentration over a wide range of chlorine concentrations, the bromine effectiveness has been adjusted relative to the square of contemporary chlorine concentration.

Results

Figure 1 shows the historical and projected EESC arising from global emissions of all ozone depleting substances, with the contribution from the subjects of this work, Halons 1211 and 1301, shown separately. The basic scenario is described in detail in the SORG Report of 1999 [11]. Historical concentrations are calculated from the consumption and emissions given in the AFEAS and UNEP databases [12, 13]; future emissions are projected as if the provisions of the Montreal Protocol were followed to the letter. For the halons in the base case this means that there is no further production in the developed world and that Indian. Chinese, and Korean production matches the Montreal Protocol commitments. Halon emissions are projected at constant percentages of the unreleased banks in equipment. at rates of 12 and 4% for Halon 1211 and 1301, respectively. These rates are consistent with those in the analysis conducted by the Technical and Economic Assessment Panel [9] and give results for the historical atmospheric concentrations that are consistent with measured atmospheric concentrations [14].

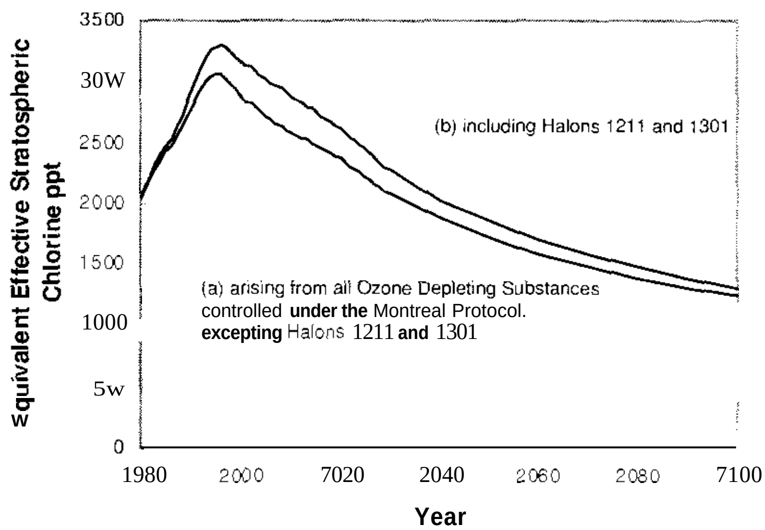

Figure 1. Stratospherically effective halogen loading throughout the 21" century.

The peak in EESC occurred in 1996 at a value of 3300 ppt (parts per trillion, 1 in 10^{12} of equivalent effective chlorine). This was a consequence of the atmospheric concentrations of CFCs beginning to stabilise as a result of the Montreal Protocol controls, coupled with a very rapid decline in the concentration of methyl chloroform driven by very low emissions. By contrast, the concentrations of halons are continuing Lo grow and are projected to maintain that growth until 2010, in the case of Halon 1301. All of the following calculations have been performed relative to the base year of 1980, as used in the 1998 Scientific Assessment of Ozone Depletion [10].

Figures 2 and 3 show the EESC contribution from global emissions of solely Halons 1211 and 1301 in the base case and for comparison with the changes to earlier emissions from Europe that are supposed under the two release scenarios (55 and 19% of the bank, respectively) described above. Due to the time delay **for** transport to the stratosphere, the increment in EESC from the European releases commences to show an effect only in 2004 and reaches a maximum in 2007.

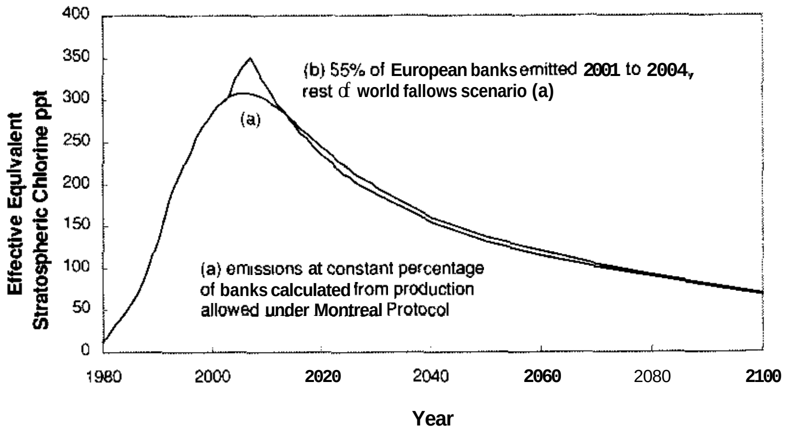

Figure 2. Stratospherically effective halogen loading from Halons 1211 and 1301 only (55% case).

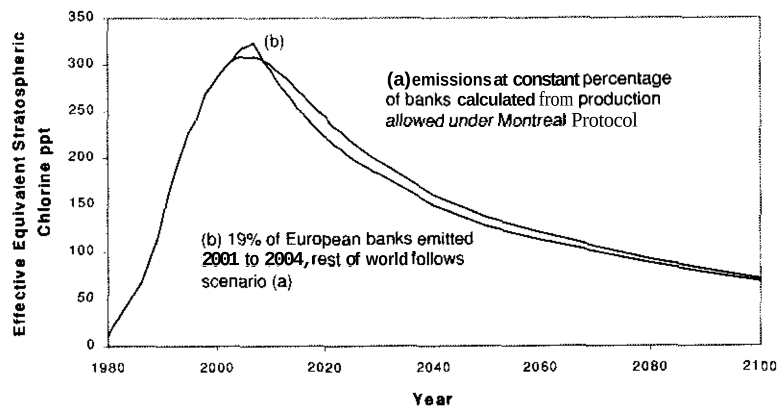

Figure 3. Stratospherically effective halogen loading from Halons 1211 and 1301 only (19% case).

In 2007, the additional EESC from European halon releases under the 55% emission scenario amounts to some 42 ppt and the rest of the ODS releases, including halon emissions elsewhere, contribute 918 ppt in that year over the 1980 baseline. According to the methodology described by Madronich and Velders [10], this additional burden on the ozone layer would cause a small additional thinning over the northern hemisphere; a loss, relative to 1980, of 3.15% would become 3.3%. Because the increase in UV for a given latitude band is proportional to the ozone loss there, the increase in UV-B in the year 2007 relative to the base case would amount to 4.6%.

Effects such as the incidence of skin cancer are consequences of cumulative change in the average incidence of UV-B which, in turn, depends on the integral of the change in EESC. The difference calculated above gives a long-term increase in integrated UV-B that reaches a maximum, relative to the integral of the base case incidence, of +0.8% in 2020 and is still +0.6% at the end of the century.

For the lower emission case, where only 19% of the European bank of halons is prematurely released. the maximum integrated UV-B occurs in 2011 at 0.16% above the base case. In this lower emission case, 81% of the European hank is not emitted; consequently there is a reduction in integrated UV-B in the long term with the UV-B integral matching the base case in 2020 and falling to about 0.4% and 0.5% lower in 2050 and 2100, respectively.

Slaper et al. [15]* have estimated that, for each 1% increase in integrated EESC over the first half of the 21st century, the incidence of skin cancer in the Netherlands population would increase by 9 cases per million inhabitants. The accumulation of increased UV-R arising from a 1% increase in EESC over the whole of the century would boost cases by 30 per million. The common skin cancers (squamous cell aiid basal cell carcinomas) are augmented by accumulated doses of UV-B. Hence the statistical incidence described by Slaper et al. [15] increases non-linearly with the length of exposure. and there are more cases for the same dose rate by the end of the 21st century.

The larger change postulated (that 55% of the European banks of Halons 1211 and 1301 is released over the period 2001 to 2004, and the rest of the banks are destroyed) would result in about 7 excess cases of skin cancer per million population over the first half of the 21st century. not just in Europe but in similar latitudes around the world. Because the material will already be in the atmosphere, there will be an irrevocable commitment for this *to* increase to 19 cases per million in the latter part of the century. The whole population of the world living outside the tropics would be affected, and the result would be many thousands of additional cases, perhaps tens of thousands.

The smaller emission case, where only 19% of the banks is emitted, still results in an increase in the potential for skin cancer in the short term (although its actual development may not occur until many years later). The increase is one case per million. In the longer term, the effects are dominated by the overly optimistic assumption that *none* of the collected halon is ever emitted. In this unlikely case, the fact that a smaller absolute amount of halon would be emitted would result in a reduction in potential cases by **3** per million in 2050 and 16 per million in 2100, relative to the base case.

This analysis has, necessarily, been confined to a single effect—skin cancers in humans. Other effects on the environment including skin cancers in other animals, erythema, cataracts, disturbances to terrestrial and aquatic ecosystems and to photosynthesis, and eye damage to penguins.? will also be accentuated and will be additive to the effect quantified here.

CONCLUSIONS

Policies of mandatory decommissioning of non-Critical halon systems aiid destruction of apparently surplus halon have been portrayed as offering clear environmental benefits. **(As** noted,

* H. Slaper, personal communication, 1999.

† According to the 1998 Assessment Report of the Effects Panel [16], whether penguins will he affected by the ozone hole is one of their *23* most frequently asked questions: eye damage is the major concern.

there may be benefits of other kinds.) Their intuitive appeal is clear, and, based on such perceptions, the Montreal Protocol has reached a Decision encouraging Parties to adopt them as a course of action. The current analysis indicates that this simplistic assessment of benefits may well be in error, and that the effect of such policies may in fact be, contrary to intuition, damaging to the environment. The wisdom of destroying halons before it is absolutely clear that there is excess is also questionable. Models and approaches similar to and including that used to reach these conclusions are available to assess the real impact of such policies. Governments and other authorities who may be contemplating mandatory decommissioning and destruction are urged to use them to evaluate carefully the impact of the courses of action open to them.

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