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Open-ended Working Group of the Parties to the Montreal Protocol to integrate the four reports of the Assessment Panels into one synthesis report and to make recommendations on amendments to the Montreal Protol.

NAIROBI

28 August - 5 September 1989

DRAFT SYNTHESIS REPORT

25 July 1989

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DRAFT UNEP INTEGRATED REPORT

1.0 INTRODUCTION

The Montreal Protocol on Substances that Deplete the Ozone Layer entered into force on 1 January 1989. Article 6 of the Protocol: Assessment and Review of Control Measures requires that

> "Beginning in 1990, and at least every four years thereafter, the Parties shall assess the control measures provided for in Article 2 on the basis of available scientific, environmental, technical, and economic information. At least one year before each assessment, the Parties shall convene appropriate panels of experts qualified in the fields mentioned and determine the composition and terms of reference of any such panels. Within one year of being convened, the panels will report their conclusions, through the Secretariat, to the Parties."

On 17-18 October 1988, at The Hague, Netherlands, in compliance with Article 6 and in anticipation of the coming into force of the Protocol, an Ad Hoc Working Group of Legal and Technical Experts for the Harmonization of Data on Production, Imports, and Exports of Substances that Deplete the Ozone Layer established four review panels and outlined their terms of reference and timetables for completing reviews of available scientific, environmental, technical, and economic information. This process was approved by the Parties to the Protocol at their first meeting in Helsinki, Finland on 2 - 5 May 1989. The Parties also confirmed UNEP as the Secretariat for the Vienna Convention for the Protection of the Ozone Layer and its Montreal Protocol.

The reports of the assessment panels contain the main conclusions reached by the review panels and represent the judgement of several hundred experts of appropriate disciplines and selected from developed and developing countries. The reports of each of the four panels incorporated an extensive peer-review process in their original language (English). They will be published and distributed by UNEP in the latter part of 1989. Copies will be made available to Parties to the Vienna Convention and Montreal Protocol; all other member states of the United Nations; and to interested organizations, institutions, and individuals worldwide.

The panel reports were chaired as follows:

- The report of the Ozone Scientific Assessment Panel, chaired by Dr. Robert Watson and Dr. Daniel Albritton (on the behalf of the United States of America). 136 scientists from 25 countries contributed to the preparation and review of the report (87 scientists from 15 countries prepared the report, and 78 scientists from 23 countries participated in the peer review process).

- The report of the Environmental Effects Panel chaired by Dr. Jan van der Leun (on the behalf of The Netherlands) and Dr. Manfred Tevini (on the behalf of the Federal Republic of Germany). 48 scientists from 17 countries participated in the preparation and peer review of the report (20 scientists from 8 countries prepared the report, and 28 scientists from 12 countries peer reviewed the report).

- The report of the Technology Review Panel chaired by Mr. Victor Buxton (on the behalf of Canada) and Dr. Stephen Andersen (on the behalf of the United States of America). 110 experts from 22 countries prepared the report. An even greater number, involving experts from additional countries, participated in the peer review process.

- The report of the Economic Assessment Panel chaired by Mr. George Strongylis (on the behalf of the European Economic Community), and co-chaired by Dr. Stephen Andersen and Mr. John Hoffman (on behalf of the United States of America). 24 experts from 12 countries prepared the report that was peer reviewed by 25 experts from 18 countries.

The Technology Review Panel Report is a summary of five detailed Technical Options Reports prepared by international subcommittees of sector specific experts. The five technical reports are:

- *Refrigeration, Air Conditioning and Heat Pumps, chaired by Dr. Lambert Kuijpers (The Netherlands),*
- *Rigid and Flexible Foams, chaired by Ms. Jean Lupinacci (USA),*
- *Electronic, Degreasing and Dry Cleaning Solvents, chaired by Dr Stephen Andersen (USA),*
- *Aerosols, Sterilants and Miscellaneous Uses of CFCs, chaired by Mrs. Ingrid Kökeritz (Sweden), and*
- *Halon Fire Extinguishing Agents, chaired by Mr. Gary Taylor (Canada).*

This document is a summary of the key findings of the four Panel reports (science, effects, technology, and economics) and will be used as a background document by a working group of Parties convened for that purpose in Nairobi, Kenya from 28 August to 5 September 1989. This draft document will have been circulated by UNEP, in one language, about six weeks before the meeting. This summary is expected to provide an easy reference for the Parties to facilitate their review of the adequacy of control measures for substances that deplete the ozone layer, as required by the Montreal Protocol. That review meeting is scheduled to take place at the Second Meeting of the Parties in June 1990.

2.0 ASSESSMENT SUMMARIES

The major findings of the four assessment reports are summarized in the following subsections.

2.1 Scientific Assessment of Stratospheric Ozone

Recent Findings

Remarkable progress has been made in stratospheric ozone science in the past few years. There have been highly significant advances in the understanding of the impact of human activities on the Earth's protective ozone layer. Since the Montreal Protocol was signed, there have been four major findings that each heighten the concern that chlorine- and bromine-containing chemicals can lead to a significant depletion of stratospheric ozone:

- Antarctic Ozone Hole: The weight of scientific evidence strongly indicates that chlorinated (largely man-made) and brominated chemicals are primarily responsible for the recently discovered substantial decreases of stratospheric ozone over Antarctica in springtime.

- Perturbed Arctic Chemistry: While at present there is no measurable ozone loss over the Arctic comparable to that over the Antarctic, the same potentially ozone-destroying processes have been identified in the Arctic stratosphere. The degree of any future ozone depletion will likely depend on the particular meteorology of each Arctic winter and future atmospheric levels of chlorine and bromine.

- Long-Term Ozone Decreases: The analysis of the total-column ozone data from ground-based Dobson instruments show measurable downward trends from 1969 to 1988 of 3 to 5% (i.e., 1.8 - 2.7% per decade) in the northern hemisphere (30 to 64°N latitudes) in the winter months that cannot be attributed to known natural processes.

- Model Limitations: These findings have led to the recognition of major gaps in theoretical models used for assessment studies. Assessment models do not simulate adequately polar stratospheric cloud (PSC) chemistry or polar meteorology. The impact of these shortcomings for the prediction of ozone layer depletion at lower latitudes is uncertain.

These and other findings are based upon the results from several major ground-based and aircraft field campaigns in the polar regions, a reanalysis of ground-based ozone data from the past thirty one years, a reanalysis of satellite ozone and PSC data, laboratory studies of gas-phase and surface-induced chemical processes, and model simulations incorporating these new laboratory data and observations.

Other Important Scientific Findings:

- Table 1 shows calculated values of the Ozone Depleting Potentials (ODP) and Global Warming Potentials (GWP) for the CFCs and halons currently included in the Montreal Protocol, carbon tetrachloride (CCl_4), methyl chloroform (CH_3CCl_3), and potential HCFC and HFC substitutes. In general, the ODPs and GWPs of the potential substitutes are significantly lower than those of the controlled substances because of their shorter atmospheric residence times.

Implications

The findings and conclusions from the intensive and extensive ozone research over the past few years have several major implications as input to public policy regarding restrictions on man-made substances that lead to stratospheric ozone depletion:

- The scientific basis for the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer was the theoretical prediction that, should CFC and halon abundances continue to grow for the next few decades, there would eventually be substantial ozone layer depletion. *The research of the last few years has demonstrated that actual ozone loss due to man-made chlorine (i.e., CFCs) and bromine has already occurred, i.e., the Antarctic ozone hole.*

- Even if the control measures of the Montreal Protocol were to be implemented by all nations, today's atmospheric abundance of chlorine [about 3 parts per billion by volume (ppbv)] will at least double to triple during the next century. *Assuming that the atmospheric abundance of chlorine reaches about 9 ppbv by about 2050, ozone depletions of 0 - 4% in the tropics and 4 - 12% at high latitudes would be predicted, even without including the effects of heterogeneous chemical processes known to occur in polar regions.*

- The surface-induced, PSC-induced chemical reactions that cause the ozone depletion in Antarctica and that also occur in the Arctic represent additional ozone-depleting processes that were not included in the stratospheric ozone assessment models that were used to guide the Montreal Protocol. Recent laboratory studies suggest that similar reactions involving chlorine compounds may occur on sulfate particles present at lower latitudes, which could be particularly important immediately after a volcanic eruption. *Hence, future global ozone layer depletions could well be larger than originally predicted.*

- Large-scale ozone depletions in Antarctica appeared to have started in the late 1970s and were initiated by atmospheric chlorine abundance of about 1.5 - 2 ppbv, compared to today's level of about 3 ppbv. *To return the Antarctic ozone layer to levels approaching its natural state, and hence to avoid the possible ozone dilution effect that the Antarctic ozone hole could have at other latitudes, one of a limited number of approaches to reduce the atmospheric abundance of chlorine and bromine is a complete phaseout of all fully halogenated CFCs, halons, carbon tetrachloride, and methyl chloroform, as well as careful considerations of the HCFC substitutes. Otherwise, the Antarctic ozone hole is expected to recur seasonally, provided the present meteorological conditions continue.*

2.2 Environmental Effects

With depletion of the ozone layer, the intensity of the UV-B radiation reaching the ground increases and the wavelength composition is shifted to shorter wavelengths. Most effects of ultraviolet radiation depend strongly on the wavelength, with the largest impacts associated with the shorter wavelengths.

UV-B radiation is known to have a multitude of effects on humans, animals, plants, and materials. Most of these effects are damaging. The knowledge required for quantitative predictions of the effects, however, is available only for a few of these damages. For others, the qualitative understanding of the effect gives reason for concern, but the degree of the impact cannot be quantified at present.

Human Health

Exposure to increased UV-B radiation can cause suppression of the body's immune system, which might lead to an increase in the occurrence or severity of infectious diseases and a possible decrease in the effectiveness of vaccination programmes.

Enhanced levels of UV-B radiation can lead to increased damage to the eyes, especially cataracts, which are estimated to increase by 0.6% per 1% total column ozone depletion. Therefore, during the coming decades, each 1% ozone depletion is predicted to lead to a worldwide increase of 100,000 blind persons due to UV-B induced cataracts, other things being equal (e.g., availability of medical care, age distribution, etc.) Damage to the eyes and possible increases in incidence or severity of infectious diseases would be serious, particularly for people in tropical and subtropical areas.

Nonmelanoma skin cancer will increase with any long-term increase of the UV-B radiation, without a threshold value. The percentage increases will not be one-to-one: every 1% decrease of total column ozone will result in a 3% rise of the incidence of non-melanoma skin cancer. There is concern that an increase of the more-dangerous cutaneous melanoma could also occur. Skin cancer would effect mainly people with little protective pigment in their skin, such as white caucasians.

Terrestrial Plants

Of the plant species investigated, about half were found to be sensitive to enhanced UV-B radiation, the impact being that plants typically having reduced growth and smaller leaves. In some cases, these plants also show changes in their chemical composition, which can affect food quality and the availability of mineral nutrients. Within species, varieties have different UV-sensitivities, as demonstrated in soybeans. In certain economically important varieties, increased UV-B reduces food yield by up to 25% for exposures simulating 25% total column ozone depletion. Even small decreases in food production from UV-B effects on agriculture would significantly affect people in areas where food shortages occur even now, which are mainly developing countries.

Aquatic Ecosystems

Increased UV-B irradiance has been shown to have a negative influence on aquatic organisms, especially small ones such as phytoplankton, zooplankton, larval crabs and shrimp, and juvenile fish. Because many of these small organisms are at the base of the marine food web, increased UV-B exposure may have a negative influence on the productivity of fisheries. Many developing nations are primarily dependent on fisheries for protein.

Increased exposure to UV-B radiation could lead to decreased nitrogen assimilation by prokaryotic microorganisms and, thereby, to a possible nitrogen deficiency for rice paddies. The potential loss in yield has not yet been quantified.

Since phytoplankton fix carbon dioxide in photosynthesis, damage to phytoplankton by increased UV-B radiation would indirectly contribute to the predicted global warming induced by greenhouse gases.

Tropospheric Air Quality

Enhanced levels of surface UV radiation could cause increased atmospheric abundances of several chemically reactive compounds, notably ozone, hydrogen peroxide, and acids. It is also possible that the atmospheric abundance of particulates could be enhanced. This would aggravate the environmental pollution problems already present in many urban areas and some rural regions today.

Materials Damage

Exposure to UV radiation is a significant cause of degradation of many materials, particularly plastics that are used outdoors. The impact is mainly economic. The increased damage will be most severe in tropical locations, where the degradation may be enhanced by high ambient temperatures and sunshine levels. Developing countries in these areas are particularly susceptible to such impacts because of the growing use of plastics in building.

Key Areas of Uncertainty

The key areas of uncertainty are in the following areas:

- Quantification of the primary effects on food production and quality, on forestry, and natural ecosystems. Even with the present limited level of quantification, it is clear that some of these effects could pose significant environmental threats.
- Development of biotechnology for replacement of sensitive crops, especially in tropical areas.
- Clarification and quantification of influences on human health, especially the immune system, and occurrences of melanomas and cataracts.

2.3 Technology Review

Based on the current state of technological development, it is possible to phase-down use of the five CFCs controlled under the Montreal Protocol by 95-98% by the year 2000. The remaining demand after the year 2000 would be from refrigeration and air conditioning (principally automotive) systems that were designed to use CFCs and are still in service (and not amenable to near "drop in" substitutes) and other minor uses (e.g., inhalant drugs). These remaining uses are expected to be eliminated within 5-10 years thereafter. Figure 1 shows the technically feasible phase-down projections for any year for each of the major use categories. This graph assumes that HFCs and HCFCs currently under testing will be environmentally acceptable and commercially available. Several large chemical companies have begun construction of plants for new HFCs and HCFCs with confidence from early toxicology testing, but final test results will not be complete for two or more years. The key conclusions from the technology assessment are:

- The refrigeration, air conditioning, and heat pump sector represents 25% of global consumption of the controlled CFCs, of which 5-8% is used for food preservation, 1% being domestic refrigeration. Based on a 30% annual growth rate in the manufacture of domestic refrigerators, the demand from developing countries (including India and the Peoples' Republic of China) for CFC-12 at the year 2000 will represent less than 2% annually of the 1986 CFC consumption levels. It is necessary to distinguish between new and existing equipment. New designs using alternative refrigerants are possible in many, but not all subsectors now, but existing equipment will have to be upgraded and replaced slowly, with full substitution taking up to 15-20 years. One major problem is that automotive air conditioning represents a large use of CFCs and some automobiles produced before a switch to new environmentally acceptable refrigerants will be in use well after the year 2000.

- 25% of the world's CFCs are used in foam production. It is technically feasible to reduce consumption by 60-70% by 1993 with a virtual phase out by 1995. These reductions are dependent to a large degree on the availability of new HCFCs.

- CFC-113 solvent use in electronic, precision, metal, and dry cleaning represents about 16% of the global consumption of the controlled CFCs. There is no single universal substitute for all CFC-113 solvent uses, but rather a myriad of options. The most predominant use is in the electronics subsector. All CFC-113 solvent uses can be phased out by the year 2000. The CFC-113 phase out is only partially dependent on the availability of HCFCs, due to the large variety of non-HCFC alternatives including: product and process substitutes, water cleaning, no-clean technologies, hydrocarbons (e.g., terpenes, alcohol, and white spirits), etc.

- Sufficient technical options exist now to phase out CFC use as aerosol propellants, with the exceptions being some medical products and other minor uses. CFC-12 use in sterilization can be substantially reduced using existing alternatives and can be phased out by 1995 in developed countries and somewhat later in developing countries. In food freezing applications, substitution is technically feasible and cryogenic techniques (liquid nitrogen) are commercially available.

- Based on industry growth projections at the year 2000, HCFCs are estimated to capture up to 30% of the current CFC market. An additional 10% of demand could be captured by HFCs with the remaining 60% of demand satisfied by product and process substitutes. The use of HCFCs will be essential in achieving early reductions and eventual phase-out of CFCs.

- There are currently no substitute chemicals with equivalent characteristics to halons, but halons are not essential in many of their current uses. Confining halons to essential use and maximizing conservation and management of the bank (halons stored or in existing equipment) could reduce consumption by 50-60% by 1997. Unless new substitutes are developed, a phasedown of 60 - 80% may leave the choice of continuing to use halons in only the most essential areas with the resultant adverse impact on the ozone layer or to proceed with a phase-out and accept an increased fire risk.

- Technology is currently available to capture, recycle, and destroy CFCs and halons; however, more cost effective techniques are currently under development.

A virtual phase-out of the five controlled CFCs, methyl chloroform production and use, and carbon tetrachloride emissions (allowing production as a chemical feedstock) by the year 2000 is technically feasible, since substitutes currently exist for most of their uses. A complete phase-out requires that substitutes currently available or under development are environmentally acceptable and are made commercially available throughout the world.

2.4 Economic Implications

A review of the Protocol measures requires an appraisal of the costs of substitution of CFCs and halons and the benefits of avoiding ozone depletion.

North America, Europe, and Japan are responsible for approximately 80% of the total consumption of controlled chemicals. The per capita consumption in developed economies is in many cases more than ten times the per capita consumption in most developing countries. Economic implications have to be considered in the context of developed and developing economies separately.

Economic/Environmental Benefits of Reduced CFC/halon Use.

Reducing the use of CFCs and halons could have enormous beneficial impacts on human health and the environment in both developed and developing countries. The current state of scientific knowledge makes it very difficult to quantify the magnitude of many of these impacts. Nevertheless, the scientific evidence is mounting that predicted stratospheric ozone depletion will cause increased levels of skin cancers, cataracts, immune suppression, and other human health impacts, plus additional effects on plants and animals, among others. Many factors associated with proper valuation procedures vary from one region of the world to another and between people alive today and generations to come. These issues make it inherently difficult, if not impossible, to assign a monetary value to the harmful impacts avoided as a result of reduced CFC and halon use.

This difficulty in economic quantification does not change the basic conclusion of the economics panel that, on a global basis, the monetary value of the benefits of safeguarding the ozone layer is undoubtedly much greater than the costs of CFC and halon reductions. However, developing countries are less able to pay the costs of reducing or phasing out CFCs and halons and may have other, more immediate concerns such as food supply and economic development. Given the fact that a global CFC reduction is essential for the protection of the ozone layer, diffusion of CFC and halon replacement technology, including recovery and recycling, is necessary and is in the interest of both developed and developing countries alike.

The Costs of Technical Substitution

The costs of reducing or eliminating CFCs and halons depend on a variety of factors including capital costs, research and development costs, operational costs (such as energy and labour costs), and safety and toxicity risks. Differences in national development and in the extent of development of CFC and halon producing and using industries result in large differences in transition costs for each country. Consequently, global cost estimates are difficult to make with reasonable accuracy.

The development of new options for replacing CFCs and halons is progressing very rapidly. An analysis performed today based on current technology may overestimate the costs of reductions in use.

Many technical options require initial capital investments, but ultimately are less expensive to operate or offer improvements in product quality. The first 50% reduction in the global use of CFCs will require modest new capital investment, will incurr little or no net cost, will result in some buisness disruption, and will require very little capital abandonment. This relatively easy step will be accomplished through reduction in the use of CFCs in the manufacture of flexible foams and as aerosol propellants, the more efficient use of CFCs as solvents, and by reductions in many other applications. Cost estimates for the remaining reductions - mainly in the fields of refrigeration, air conditioning, rigid foam, solvents, and fire protection - vary widely and depend on the availability of near drop-in substitutes, costs of re-engineering equipment and products, and the price and the energy efficiency of the substitutes.

The time-path for phasing out some CFCs can substantially affect costs. A very rapid transition (much less than 10 years) would result in substantially higher costs due to capital abandonment. Individual governments and industries face significant opportunities to save money and improve energy efficiency if the best reduction strategy is chosen. Furthermore, higher energy efficiency would reduce greenhouse gas emissions for an equivalent energy demand.

Technology Transfer.

Developing countries have special needs and concerns as part of a global effort to protect stratospheric ozone. These concerns include: (1) the cost of CFC supply, (2) the cost of new chemical substitutes, (3) the cost of imported products made now with CFCs and, that later will be made with new alternatives, (4) the cost of access to new technology, and (5) maintenance of trade with parties to the protocol in products made with or containing CFCs and halons.

- Even low-use developing countries will want to adopt new technologies that cost about the same or less than the old CFC technologies. For example, the potential cost savings from more energy efficient refrigerators may be more important in developing countries where income is low and energy costs are high. All countries can avoid new capital investment that would make them more dependent on CFCs and would result in later costs from abandonment of CFC capital when they begin their phase-down.

- Developing nation members of the Protocol need to be able to purchase CFCs for important needs such as food preservation until the alternatives are available. These countries may be able to purchase allowable quantities of CFCs at reasonable prices as production capacity becomes surplus in developed countries due to the CFC phase-down. New investment in CFC production technology is now imprudent since there may not be time to depreciate the new capital and since ample supplies of CFCs may be available at low prices as developed countries phase-down production. Some coordination may be necessary to assure a reliable reasonable price and supply. A low-cost adequate supply to developing countries that are Parties to the Protocol can avoid the cost of investment in old CFC technology.

- The new chemical substitutes (HFCs and HCFCs) are estimated to initially cost two to five times the cost of CFCs due to the increased cost of chemical ingredients, manufacturing costs, and profits. In some cases, the new chemicals may provide cost-offsetting advantages such as improvements in energy efficiency or other product performance. However, developing countries may need development assistance including capital grants and other technology transfer to afford these new chemicals. Countries that now produce CFCs including China, South Korea, Brazil, India, etc. may decide to become producers of some of the new chemicals. UNEP should carefully monitor this situation as new chemicals become available, mostly after 1993.

- To the extent that new products (refrigerators, electronics, etc.) cost more due to increases in research-and-development, capital investment, chemical ingredients, and other costs; countries that import these products may need supplementary technical assistance or financial aid.

Currently, the lack of technical knowledge and financial resources of developing countries inhibits the adoption of certain CFC/halon replacement technologies and the definition and implemention of the best national options for the transition to CFC-free technologies.

Some CFC replacement technologies will be adopted in the usual course of economic growth, but at a slow rate. Development assistance will be required in most cases. Funding is needed for the transfer of technology during the transition period because currently available resources are already strained as a result of the world debt problem and the dire economic situation of many countries. Examples of methods of raising funds for financial assistance vary from charging for CFC use to contributing a small percentage of GNP. Financial assistance can be either bilateral or as a contribution to an intermediate fund.

3.0 OPTIONS

Options for controlling the emissions of chlorine containing chemicals. The following section presents five possible options for controlling chlorine containing chemicals. For each option, there is a brief description of (i) how the atmosphere is predicted to respond in terms of chlorine loading and stratospheric ozone depletion (polar and globally) by the year 2050, (ii) environmental effects, (iii) technical feasibility, and (iv) economic costs. Figure 2 presents the total chlorine concentrations in the stratosphere from 1986 through 2100 that would result from each of these five possible options for controlling chlorine containing chemicals. In each of the following options a number of assumptions have been made. These include, (i) 100% global participation, (ii) an average annual growth in goods and services that currently use CFCs of 3% between 1986 and 2050 and constant thereafter, (iii) an increase in methyl chloroform and HCFC-22 emissions of 3% between 1986 and 2050 and constant thereafter, and (iv) no growth in the emissions of carbon tetrachloride. This last assumption may be optimistic given that the atmospheric abundance of carbon tetrachloride has recently been increasing at about 1% per year.

Options for controlling the emissions of halons. For the purposes of discussing these options it was assumed that the halons currently covered by the Montreal Protocol were treated in a manner consistent with the CFCs, i.e., the CFC phase-out was accompanied by a halon phase-out.

Environmental consequences. There is a general lack of quantitative information available for most of the environmental effects discussed in Section 2.2. Therefore, specific quantified projections of the magnitude of the effects to be predicted for each of the different options discussed below is unwarranted. However, two human health impacts that can be quantified are, (i) that for every 1% decrease in total column ozone there would be a 3% increase in the incidence of non-melanoma skin cancer, and (ii) that for every 1% decrease in total column ozone there would be a 0.6% increase in the incidence of cataracts. These relationships apply to all of the predicted ozone changes in the options discussed below.

Model predictions of ozone depletion. There are two key points to be noted about the model calculations of ozone depletion; (i) none of the models considered the effects of ice crystal chemistry, which could increase the estimates of ozone depletion, at least in polar regions, and (ii) the model results shown for each of the five options, except option 1, do not include the effect of temperature feedback. Increasing abundances of atmospheric carbon dioxide decrease stratospheric temperatures, which, in turn, lead to a decrease in the destruction of ozone through temperature feedback. While there are still open questions regarding the quantitative treatment of the influence of CO_2 (temperature feedback), those models that do not include the CO_2 effect are almost certainly overestimating the magnitude of ozone depletion by chlorine- and bromine-containing chemicals compared to models neglecting temperature feedback (the results shown in option 1 demonstate the magnitude of this effect).

3.1 Current Montreal Protocol (Figure 2, option 1)

Science: As seen in Figure 2, the total chlorine loading of the atmosphere is expected to increase to about 8 ppbv by the year 2050 (triple today's level) and about 10 ppbv by the end of the next century. An increase from 2.7 ppbv to about 8 ppbv of total chlorine is predicted to lead to an additional total column ozone depletion of 1 to 3.5 % in the tropics and 7 to 11 % at high latitudes. These models did not take into account the impact of increasing atmospheric abundances of carbon dioxide. For models that did include the effect of carbon dioxide, predicted column ozone reductions were somewhat less, i.e., 0 to 1.5% in the tropics and from 3.5 to 7% at high latitudes in late winter. None of these models considered the effects of ice crystal chemistry, which could increase the estimates of ozone depletion, at least in polar regions. Higher ozone layer depletions would occur after the year 2050 as atmospheric chlorine abundances increase. The Antarctic ozone hole would be expected to be comparable or worse than at present, and significant Arctic ozone losses would become more likely.

Technology: There is a large choice of product, chemical, and process control systems available to accomplish much more than a 50% reduction in CFCs and a freeze in halons, even with no new substitute chemicals.

Economics: The economic benefits of the Montreal Protocol in developed and developing countries include reduced loss of life from cancer, health improvement, and the associated savings in medical costs. There are also benefits of increased worker productivity and longevity. In addition, there are savings stemming from longer product life of UV-sensitive plastics and other materials exposed to sunlight. Fewer losses in agricultural and marine productivity--with possibly far greater changes in some regions than others--are particularly important economic factors in developing countries where food price increases would have to be at the expense of other essential spending.

(a) *Developed Countries*: A 50% reduction in production and use of CFCs and a freeze in halon production and use will require modest new capital investment, will incur little or no net cost, will result in some disruption, and will require very little capital abandonment. User industries will have to adjust to a reduced supply of CFCs, but relatively modest amounts of new capitol investment will be required and capital redundance is not expected to be particularly significant. Aerosols, foam, solvent, automobile air conditioning, and other sectors will be most affected. Which industries will be most affected in any country will depend on how reductions in consumption are implemented, for example, by voluntary agreements, market forces, or national regulation. There is a substantial opportunity for cost savings from international and national industrial cooperation. The use of CFCs in foam insulation and refrigeration could preserve current energy efficiency. Equal fire protection can be provided at similar costs if industry reduces fire risk and the consequences of fires through architectural design, fire-resistant construction, lower flammable loads in high-value areas and by backup of computer systems and records.

(b) *Developing Countries*: Special provisions of the Montreal Protocol allow low-use, developing countries to increase annual CFC consumption as much as 0.3 kilograms per capita for up to ten years. However, these countries will naturally want to adopt new technologies that cost about the same or less than the old CFC technologies. All countries can avoid new capital investment that would make them more dependent on CFCs and would result in later costs from abandonment of CFC capital when they begin their 50% phase-down. For example, new investment in CFC production technology is imprudent since there may not be time to depreciate the new capital and since ample supplies of CFCs may be available at lower prices as developed countries phase-down production. In most CFC applications substantial reductions are possible with technical options that require some initial capital investment, but actually save money in the long run by reduced operating costs and by improved product quality. However, investment funds must be available for the transfer of these technologies to developing countries including the funds for the purchase of new capital. Some of these funds can be repaid from the operating cost savings of the new investment and from costs that are recovered from export sales, but some investment will need to be grants from developed countries.

3.2 CFC Phaseout, no controls on methyl chloroform (50% substitution of CFCs with HCFCs with an average ODP of 0.05) (Figure 2, option 2)

Science: Atmospheric chlorine abundances in the year 2050 would be 1.8 ppbv lower than option 1, i.e. about 6 ppbv, or twice today's level, increasing to about 7 ppbv by the end of the century. An increase from 2.7 ppbv to about 6 ppbv of total chlorine is predicted to lead to an ozone depletion of 1 to 2.5% near the equator and 4 to 6% at high latitudes (without considering the effects of ice crystal chemistry, which could increase these estimates, at least in polar regions). As in option 1, the Antarctic ozone depletion would be expected to comparable or worse than at present, and significant Arctic ozone losses would become more likely.

Technology: 95-98% phase-out of use possible by the year 2000 based on today's knowledge and total phase out within 5 - 10 years thereafter. The commercialization of chemicals currently under test would allow a phase-out by the year 2000. In this case, drop-in substitutes are needed for in-use equipment and substitutes are needed for medical products. The existing capital stock of refrigeration and air conditioning can be serviced from recycled CFCs if aggressive recycling programs recover CFCs during servicing and from decommissioned equipment and from equipment where the CFCs are replaced by near "drop-in" chemical blends. A phase-out of CFCs is dependent on the availability of HCFCs, particularly for rigid insulating foam, refrigeration / air conditioning, and medical / hospital sectors.

Economics: (a) *Developed countries.* Capital investment for a complete phase-out will be higher than for the current Montreal Protocol. The net cost of the first 50% reduction can be made with existing technical options at little or no net cost but investment is necessary. Additional cost-effective technologies will be developed prior to the year 2000 if a phase-out is scheduled. The marginal cost of final reductions may be very expensive. There will be significant business disruption with increasing costs of final phase-out unless new technologies are developed in time. Major product substitution is likely in the foam sectors. Product substitutes are currently available at similar cost but require some redesign and changes in construction practices to accommodate thicker insulating materials. Capital abandonment will be higher than under the current Protocol. Substantial research and development is needed to avoid unacceptable losses in energy efficiency.

(b) *Developing countries:* Very ambitious technology transfer is necessary to developing countries including financing of capital to use new chemical alternatives, the retrofit of existing capital equipment to minimize CFC emissions, and for recycling and recovery. Countries qualifying for special use provisions will also want new cost-saving technology as soon as it is available.

3.3 CFC Phaseout, freeze on methyl chloroform (50% substitution of CFCs by HCFCs with an average ODP of 0.05) (Figure 2, option 3)

Science: Freezing methyl chloroform at its 1986 levels, in conjunction with a CFC phaseout, would lead to an atmospheric abundance of chlorine in the year 2050 of about 4.5 ppbv, or one and one half today's level, then staying constant throughout the rest of the century. An increase from 3 ppbv to 4.5 ppbv of total chlorine is predicted to lead to little change in total column ozone in the tropics and a decrease of up to 4% at high latitudes (without considering the effects of ice crystal chemistry, which could increase these estimates, at least in polar regions). The Antarctic ozone layer depletion would be expected to remain similar to that of today, with Arctic ozone losses becoming somewhat more likely.

Technology: Comments relating to scenario 2 also apply to CFCs in scenario 3. Substitutes currently exist that would permit an almost total phase-out of methyl chloroform. Therefore, a freeze should pose few insurmountable problems. Methyl chloroform is a low cost effective solvent. Methyl chloroform is widely used, with varying workplace precautions, in most regions of the world. Concern for the ozone layer has already stimulated the development of alternatives that clean as well or better than CFC-113. These alternatives include aqueous, terpene and alcohol cleaners. These alternatives to CFC-113 are also alternatives for methyl chloroform in most uses.

Economics: This option has the same economic implications as option 2 above plus the following additional implications.

(a) *Developed countries.* Based on analysis in the Electronic, Degreasing, and Dry Cleaning Solvents report and the Technology panel report, a freeze in CCl_4 emissions in countries where it is already prohibited due to toxicity will have no economic effect. In other countries a freeze in CCl_4 emissions and a freeze in methyl chloroform production and use would provide increased benefits of ozone protection and benefits resulting from reduced health and environmental exposure to CCl_4. The economic benefits of increased product durability and performance, particularly in electronics, are far more valuable than small changes in cleaning cost that are an inconsequential part of final product cost. Some alternatives such as aqueous and terpene cleaning alternatives require moderate capital investment but new HCFC solvents are near "drop-in" replacements. Costs of cleaning are an extremely small part of final product cost except in the case of dry cleaning. Use of methyl chloroform is more important to small solvent users in both developed and developing countries because it is low cost and relatively safe to use. Little if any capital abandonment is necessary if HCFCs are commercialized promptly and no new investment is made in CFC solvent equipment.

(b) *Developing Countries.* New low-cost/no-cost solvent alternatives will allow a freeze in CCl_4 and methyl chloroform at low net cost world-wide if technology is promptly transferred to developing countries. Methyl chloroform will be less economically important when technologies are transferred to developing countries. Increased technical assistance and investment funds are necessary for investment in the new technologies.

3.4 CFC Phaseout, Phaseout of both carbon tetrachloride and methyl chloroform (50% substitution of CFCs by HCFCs with an average ODP of 0.05) (Figure 2, option 4)

Science: Phaseout of both carbon tetrachloride and methyl chloroform in conjunction with a CFC phaseout would lead to an atmospheric abundance of chlorine in the year 2050 of about 3.5 ppbv, or slightly above today's level, then staying constant throughout the rest of the century. An increase from 3 ppbv to 3.5 ppbv of total chlorine is predicted to lead to little change in total column ozone in the tropics and decreases limited to about 3% at high latitudes (without considering the effects of ice crystal chemistry, which could increase these estimates, at least in polar regions). The Antarctic ozone depletion would be expected to be unchanged, but additional significant Arctic ozone losses would be expected to be small. Thus, this scenario describes keeping approximately the status quo with regard to the present state of the ozone layer.

Technology: Substitutes exist for almost all methyl chloroform solvent uses, with the exception of a few uses such as methyl chloroform in waterborne adhesive products. Phaseout of CCl_4 should be based on emissions, not consumption, because CCl_4 is needed as feedstock for the production of HCFCs. Substitutes exist for current uses of CCl_4 other than as a feedstock chemical.

Economics: This option is the same as options 2 and 3 above, plus additional human health advantages from the CCl_4 reductions. CCl_4 use as a solvent is prohibited in many countries because it is a highly toxic and carcinogenic. CCl_4 can be safely used as an economically important chemical feedstock that is transformed during chemical production and therefore need not be regulated in feedstock uses that have no emissions. The United States, Europe, and Japan already limit CCl_4 use in non-feedstock applications to 3-9% of total production. Additional research will be necessary to understand minor uses and to develop alternatives and substitutes. New capital investment is moderate since existing capital can be used by some new alternatives. Capital abandonment will be minimal because many solvent machines will be replaced in the normal course of business. Increased technology transfer is necessary in developing countries, including financing of additional capital investment to use new alternatives and substitutes. More economic analysis on CCl_4 and methyl chloroform should be conducted in the near future.

3.5 CFC Phaseout, Phaseout of both carbon tetrachloride and methyl chloroform, (20% substitution of CFCs by HCFCs with an average ODP of 0.02) (Figure 2, option 5)

Science: Phaseout of both carbon tetrachloride and methyl chloroform in conjunction with a CFC phaseout, but with HCFC substitution being limited to 20% with an average ODP of 0.02 would lead to an atmospheric abundance of chlorine in the year 2050 slightly less than today's level. The Antarctic ozone depletion would be expected to be unchanged, and significant Arctic ozone losses would be expected to be somewhat less likely than today. Eventually, with this scenario (beyond the year 2100) the atmospheric abundance of chlorine would drop below about 2 ppbv and ozone in Antarctica may be expected to return to normal (all other things being equal, e.g. climate). Although no model calculations were performed using this scenario, it is likely that all models would predict an increase in global total column ozone beyond the middle of the next century due to the effects of the increasing atmospheric abundances of carbon dioxide and methane.

Technology: All of previous comments apply. HCFCs are needed for phasing-out CFCs before the year 2000. HCFCs such as HCFC-22, -124, -142b, are ingredients in the proposed high energy efficiency refrigerant blends. HCFC-22 is already commercialized as an energy efficient refrigerant in small and medium sized air conditioning systems and some refrigeration equipment. Emission controls for the existing and new future equipment may be desirable; these should be realizable taking into account the experience obtained in emission controls for CFC refrigeration equipment. In the short term, HCFCs are the only candidates for the highest quality rigid foam insulation (energy efficient) in applications such as refrigerators where thickness cannot be easily increased to provide equivalent insulation. In the long-term, vacuum insulation may provide greater insulation value, and instead of HCFCs, new HFC refrigerants such as HFC-134a and HFC-152a might be blended for use in certain refrigeration equipment.

Economics: This option has the same economic implications as options 2, 3, and 4 above plus it has a higher risk of increases in energy use if alternative insulation of equivalent value is not used, if insulating foam made without HCFCs ages more rapidly, or if the choice of refrigerants not including HCFC ingredients results in lower energy efficiency. Higher energy use has implications for resource use, pollution, climate change, national costs, and consumer prices. However, HCFCs may not be essential in these uses if more energy efficient alternatives are developed that are not dependent on HCFCs. It may not be economically or technically feasible to phase-out CFCs while providing some products such as medical aerosols and low pressure, non-flammable ethylene oxide sterilization if HCFCs are not available.

4.0 REPORTING AND SYSTEMATIC OBSERVATION REQUIREMENTS

Reporting and systematic observations of all chlorine and bromine containing chemicals that can contribute to the chlorine and bromine loading of the stratosphere (hence potential stratospheric ozone depletion), or to the predicted global warming, is strongly recommended. This should include all fully halogenated CFCs currently not included in the Montreal Protocol, as well as carbon tetrachloride, methyl chloroform, the proposed hydrochlorofluorocarbons (HCFC), and hydrofluorocarbons (HFCs) substitute chemicals. Reporting and systematic observation requirements for these chemicals should be similar to those required for the substances currently controlled by the Montreal Protocol, which should meet the needs of the scientific community to evaluate the environmental impacts of these chemicals.

A "monitoring" network that could evaluate the global abundances and trends of the HCFCs and HFCs would require more stations than the current network that is used to monitor the long-lived CFCs. This is because the atmospheric distributions of the HCFCs and HFCs will exhibit greater variability since their atmospheric lifetimes are shorter than those of the CFCs. A quantitative evaluation of the impact of atmospheric chlorine and bromine on the stratosphere could be achieved if a sub-set of the stations in this network also monitored the chemical composition and physical structure of the stratosphere.

5.0 CONCLUSIONS

Ozone depletion is a global problem. It is caused by those nations producing and emitting CFCs, halons, and other chlorine- and bromine-containing chemicals into the Earth's atmosphere. Ozone depletion increases the amount of harmful ultraviolet radiation reaching the Earth's surface and, among other things, can result in adverse consequences for human health and may cause a reduction in food production. While the largest ozone depletions are predicted to occur at high latitudes in the both hemispheres, enhanced levels of ultraviolet radiation will have adverse affects on people from all nations, independent of geographical position, i.e., northern or southern hemisphere, or economic status, i.e., developed or developing. While peoples with lightly pigmented skins are most susceptible to melanoma and non-melanoma skin cancer, all peoples are susceptible to contracting eye disorders and a suppression of the immune response system. Unfortunately, those people with inadequate health services are placed at the greatest risk, i.e., some of the developing countries. Agricultural and fisheries productivities could decrease because of enhanced levels of ultraviolet radiation, and again those people most likely to be affected live where shortages of food now exist.

Developed/Developing Nations Partnership Needed. The current and historic use of CFCs, halons, and other chlorine and bromine containing chemicals in developed nations is the primary cause of this problem. However, it is clear that protection of the ozone layer will require a full partnership between developed countries that have caused the problem and those in developing countries who would now like to improve their standard of living by using these chemicals for uses such as refrigeration.

Current Montreal Protocol. The total chlorine and bromine loadings of the atmosphere are predicted to approximately triple by the year 2050 and lead to total column ozone depletions of 0 to 3.5 % in the tropics and 3.5 to 11 % at high latitudes (without consideration of the effects of surface induced chemistry, which could increase these estimates, at least in polar regions). The Antarctic ozone depletion would be expected to be comparable or worse than at present and significant Arctic ozone losses would become more likely. Significant adverse human health consequences would be expected.

Stabilizing atmospheric chlorine and bromine. Stabilizing atmospheric chlorine and bromine to today's levels can be achieved through a phase-out of the CFCs, carbon tetrachloride, methyl chloroform and the halons. If the total chlorine and bromine loading of the atmosphere is stabilized, the Antarctic ozone hole would recur seasonally for the forseeable future, but no additional significant ozone depletion would be expected either in the Arctic or globally. Indeed, if the stabilized chlorine and bromine levels are accompanied by increased atmospheric abundances of carbon dioxide and methane then ozone increases might even be expected. This assumes that increases in carbon dioxide and methane will not significantly decrease the temperature of the lower polar stratosphere and change polar meteorology and PSC abundances.

Antarctic Ozone "Hole". The Antarctic ozone hole will not disappear until the atmospheric abundance of chlorine is reduced to the levels of the early 1970's: 1.5 - 2 ppbv. In addition, the atmospheric abundance of bromine should be reduced below today's level. This could be achieved by a complete phase-out of the fully halogenated CFCs, halons, carbon tetrachloride, and methyl chloroform, and careful consideration of what emission rates of the HCFCs are acceptable. Even if all anthropogenic sources of atmospheric chlorine were to be eliminated today, the time taken for the abundance of atmospheric chlorine to be reduced below 2 ppbv would be many decades, hence the Antarctic ozone hole will recur seasonally for a long time to come.

Long Atmospheric Recovery Times. Once chemicals, such as the chlorofluorocarbons with long atmospheric lifetimes, are emitted into the atmosphere, the time for the atmosphere to fully recover is many decades to centuries. Compliance (100% participation by all nations), broad scope (inclusion of chemicals such as carbon tetrachloride and methyl chloroform), and stringency (a complete phaseout of these chemicals) are of paramount importance in protecting the ozone layer. Almost any level of non compliance or reduction in the scope and stringency below a complete phase-out of CFCs, methyl chloroform, and carbon tetrachloride would effectively eliminate the possibility of reducing the atmospheric abundance of chlorine below today's level. It should be noted, however, that timing is also important. For every year that fully halogenated chlorofluorocarbons are emitted into the atmosphere at the present rate it will take about an additional five years for the abundance of atmospheric chlorine to be reduced below 2 ppbv. Therefore, the sooner the fully halogenated CFCs are phased out of production the "quicker" the Antarctic ozone hole might recover. In contrast, the atmospheric loading of chlorine from chemicals with shorter atmospheric lifetimes, such as the HCFCs and methyl chloroform, decreases much quicker once their emissions into the atmosphere are terminated, which underscores the potential value of the HCFCs as substitutes.

CFC Phase Out Technically Feasible. A virtual phase out of the five controlled CFCs, methyl chloroform production and use, and carbon tetrachloride emissions (allowing production as a chemical feedstock) by the year 2000 is technically feasible, since substitutes currently exist for virtually all of their uses. A complete phase-out requires that substitutes currently available or under development are made commercially available throughout the world.

High Economic Costs with Rapid Phase-outs. A rapid phase-out of some CFCs over a period much less than 10 years will substantially increase costs due to abandonment of capital investment in CFC producing and using technologies and by the rush to change technologies. Major sectors including the foam industry, would lose market to product alternatives resulting in job losses in some areas and gains in others. The costs of technology transfer and capital investment in developing countries would also increase substantially if reduction schedules under the special provisions of the Protocol are also shortened. A rush to market selected technologies that were more expensive to buy or operate would also increase the costs in developed and developing countries. For example, a faster phase-out schedule may not allow time to develop more energy efficient domestic refrigerators. This could increase product cost without off- setting decreases in electricity costs and would have global climate implications from increased CO_2 emissions.

Table 1. Range of Ozone Depletion Potentials (ODPs) and halocarbon Global Warming Potentials (GWPs).

Species	ODPs		GWPs**
	This Assessment	Montreal Protocol	This Assessment
CFC-11	1.0	1.0	1.0
CFC-12	0.9 - 1.0	1.0	2.8 - 3.4
CFC-113	0.8 - 0.9	0.8	1.3 - 1.4
CFC-114	0.6 - 0.8	1.0	3.7 - 4.1
CFC-115	0.3 - 0.5	0.6	7.4 - 7.6
HCFC-22	0.04 - 0.06		0.32 - 0.37
HCFC-123	0.013 - 0.022		0.017 - 0.020
HCFC-124	0.016 - 0.024		0.092 - 0.10
HFC-125	0		0.51 - 0.65
HFC-134a	0		0.24 - 0.29
HCFC-141b	0.07 - 0.11		0.084 - 0.097
HCFC-142b	0.05 - 0.06		0.34 - 0.39
HFC-143a	0		0.72 - 0.76
HFC-152a	0		0.026 - 0.033
CCl_4	1.0 - 1.2		0.34 - 0.35
CH_3CCl_3	0.10 - 0.16		0.022 - 0.026
halon 1301*	7.8 - 13.2	10.0	
halon 1211*	2.2 - 3.0	3.0	
halon 2402*	5.0 - 6.2	to be determined	

* The ODPs for the halons are sensitive to the atmospheric abundance of chlorine. The values shown in the table are for present day conditions (i.e. a chlorine abundance of about 3 ppbv). The ODPs for the halons increase at higher chlorine abundances .

** The halocarbon GWPs are all normalized to a value of unity for CFC-11. An equally valid alternate set of values can be obtained by normalization to CFC-12 (this was done in the Technology Assessment report). Normalization to CFC-12 requires dividing all the GWP values shown in the table by 3.1(the average value for the GWP for CFC-12). The benefit gained by substitution of a CFC with an HCFC (or an HFC) is computed by ratioing the GWP values of the HCFC (or HFC) to the CFC.

Figure 1

Technically Feasible Phasedown Projections for Major CFC Use Categories

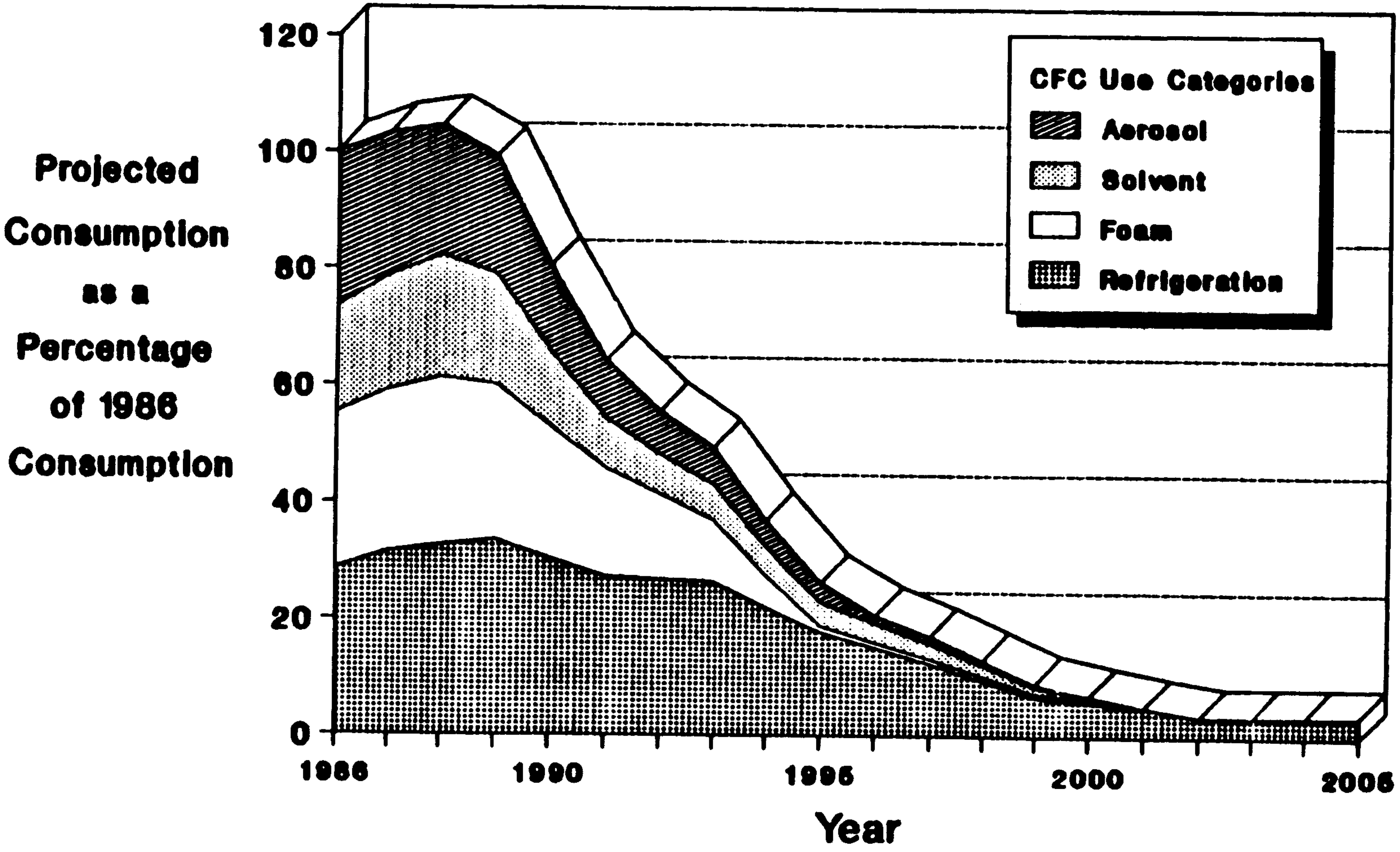
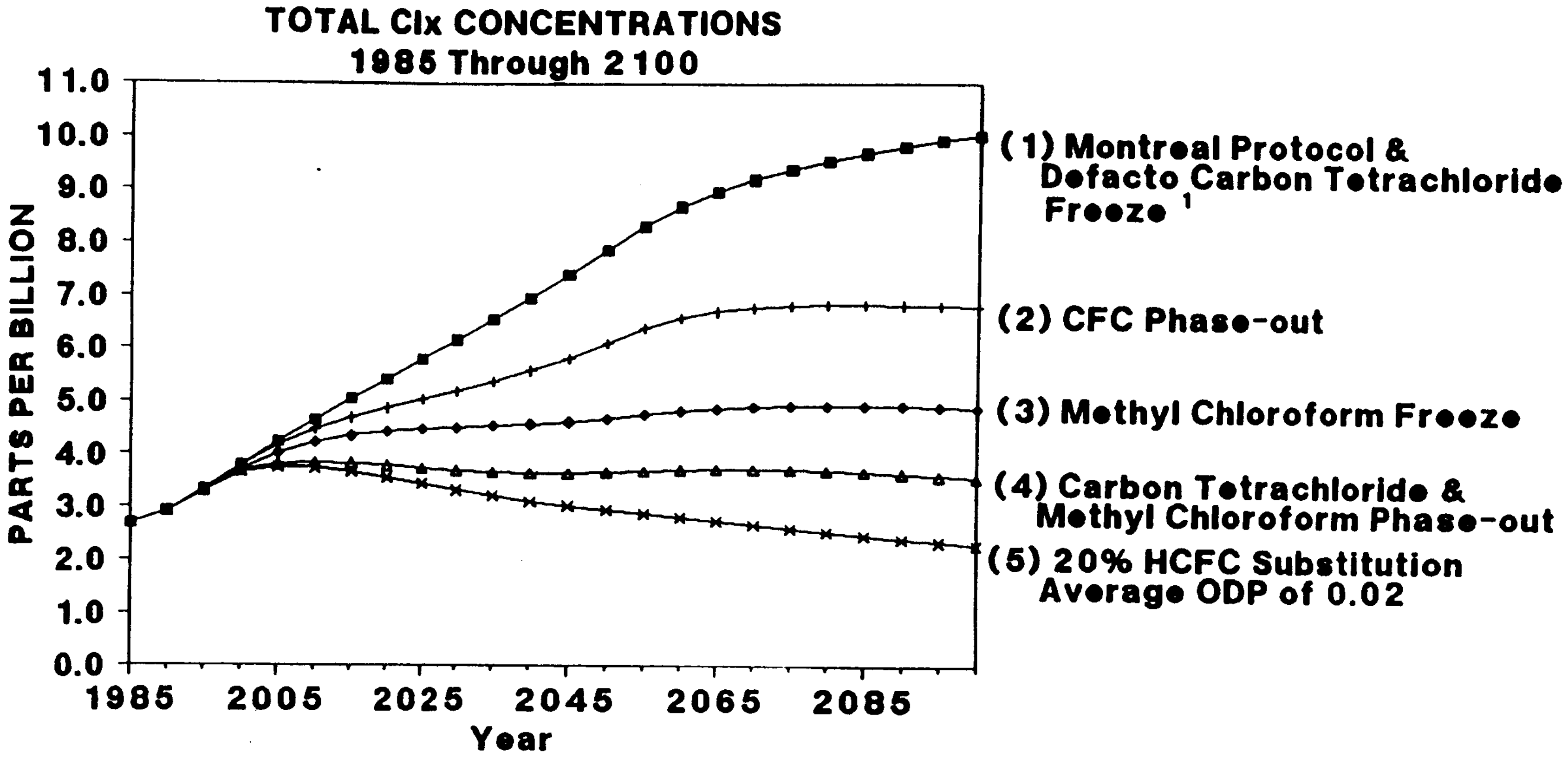


Figure 2

ATMOSPHERIC CHLORINE CONCENTRATIONS WITH DIFFERENT CHEMICAL CONTROL OPTIONS



Assumptions:

- 2000 Phase-out of Fully Halogenated CFCs (Except Curve 1)
- HCFCs Capture 50% of What CFC Market Would Have Been Without Regulation (Except Curve 1); Assumed Annual Average Growth Rates for Fully Halogenated CFCs, Baseline HCFC-22 (non-substitute) and Methyl Chloroform are Approximately 3% for the Period 1986 to 2050, After 2050 Use is Assumed to be Constant.
- Average ODP of Substitutes is 0.05 (Except Curve 5)
- 100% Global Participation

Notes:

[1] While possibilities exist for an increase in carbon tetrachloride use, such growth is unlikely given the awareness of carbon tetrachloride's potential contribution to stratospheric ozone depletion.