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Sixth meeting
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# SYNTHESIS

of the reports of the

OZONE SCIENTIFIC ASSESSMENT PANEL

ENVIRONMENTAL EFFECTS ASSESSMENT PANEL

TECHNOLOGY AND ECONOMIC ASSESSMENT PANEL

Prepared by the Assessment Chairs, for
the Parties to the Montreal Protocol

November 1991

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*Contents*

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## I. INTRODUCTION

1. 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."

2. The second meeting of the Parties, which took place in London in June 1990, asked the Secretariat to reconvene the assessment panels, as stipulated in Article 6, and outlined their terms of reference and timetables for completing assessments of available scientific, environmental, technological and economic information. In particular, the Parties requested that the Scientific Assessment Panel include an evaluation of the Ozone-Depleting Potentials (ODPs) and Global Warming Potentials (GWPs) of substitutes; the ODPs of "other halons" that might be produced in significant quantities; the impact on the ozone layer of revised control measures; and the impact on the ozone layer of engine emissions from high-altitude aircraft, rockets and space shuttles. The Parties also requested that the Technology and Economic Panels assess the earliest technically feasible dates and the costs for reductions and total phase-out of 1,1,1-trichloroethane (methylchloroform); evaluate the need for transitional substances in specific applications; estimate the quantity of controlled substances needed by developing countries and their availability; and compare toxicity, flammability, energy efficiency and safety considerations of chemical substitutes, as well as their availability.

3. At the Third Meeting of the Parties in Nairobi in June 1991, the merged Technology and Economic Panel was requested to produce a list of full and complete trade names of substances, including mixtures by November 1991; to evaluate the implications, possibilities, and difficulties, in particular for developing countries, of an earlier phase-out of controlled substances, for example by 1997; to identify the areas where transitional substances are required to facilitate the earliest possible phase-out of controlled substances and the quantities of transitional substances required; and to identify those transitional substances with the lowest ODPs required for those areas with, if possible, a feasible timetable for their elimination.

4. The reports of the assessment panels represent the judgement of several hundred experts of appropriate disciplines from close to fifty developed and developing countries [1]. The reports of each of the three panels incorporated an extensive peer-review process in their original language (English). They

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Australia, Austria, Bahamas, Belgium, Benin, Brazil, Canada, Chile, China, Columbia, Czechoslovakia, Denmark, Ecuador, Egypt, France, Germany, Greece, India, Indonesia, Iran, Ireland, Italy, Japan, Jordan, Kenya, Liechtenstein, Malaysia, Mexico, Netherlands, New Zealand, Nigeria, Norway, Papua New Guinea, Republic of Korea, Saudi Arabia, Singapore, South Africa, Sweden, Switzerland, Thailand, Trinidad and Tobago, Tunisia, Uganda, USSR, United Kingdom, United States of America, Venezuela, and Yugoslavia.

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will be published and distributed by UNEP in late 1991/early 1992. Copies will be made available to Parties to the Vienna Convention and Montreal Protocol; all other member states of the United Nations; and to relevant international organizations. They could also be available to interested institutions and individuals upon request.

5. The panels were organized as follows:

- *The Ozone Scientific Assessment Panel*, chaired by Dr. Robert Watson and Dr. Daniel Albritton (United States of America). Seventy-nine scientists from 28 countries contributed to the preparation and review of the report (61 scientists from 24 countries prepared the report and 57 scientists from 28 countries participated in the peer-review process).

- *The Report of the Environmental Effects Assessment Panel*, chaired by Dr. Jan van der Leun (Netherlands) and Dr. Manfred Tevini (Germany). Fifty-eight scientists from 22 countries participated in the preparation and peer-review of the report (22 scientists from 9 countries prepared the report and 36 scientists from 18 countries peer reviewed the report).

- *The Technology and Economic Assessment Panel*, chaired by Dr. Stephen Andersen (United States of America) and Mr. Steve Lee-Bapty (United Kingdom). Two hundred and forty experts from 38 countries prepared the report. Hundreds of expert advisors and peer reviewers from additional countries participated in the peer-review process. The Technology and Economic Review Panel report is a summary of six detailed technical and economic options reports prepared by international subcommittees of sector-specific experts. These subcommittees were, respectively, (i) Refrigeration, Air Conditioning and Heat Pumps, chaired by Dr. L. Kuijpers (The Netherlands), Dr. H. Haukas (Norway), Mr. P. Vodianitskaia (Brazil) and Mr. J. Kanyua (Kenya); (ii) Rigid and Flexible Foams, chaired by Ms. J. Lupinacci (USA) and Mr. P. Vieira (Brazil); (iii) Solvents, Coatings, and Adhesives, chaired by Dr. S. Andersen (USA) and Mr. J. Corona (Mexico); (iv) Aerosols, Sterilants and Miscellaneous Uses of CFCs, chaired by Ms. A. Hinwood (Australia) and Mr. J. Pons Pons (Venezuela); (v) Halon Fire Extinguishing Agents, chaired by Mr. G.Taylor (Canada) and Major T. Morehouse (USA); and (vi) Economics, chaired by Dr. R. Van Slooten (UK) and Ms. M. Holmes-Hanek (Bahamas).

6. This document is a synthesis, prepared by the assessment panel chairs, of the key findings of the three panel reports. The executive summaries of the three assessments are included in the Appendix to this report. The present synthesis will be used as a background document by the Open-ended Working Group of the Parties, which will meet in Nairobi from 6-15 April 1992 to evaluate the need to amend the control measures of the Montreal Protocol as revised in London in June 1990. This document will be circulated by UNEP, in all official United Nations languages, about two months before the Meeting. This synthesis is intended to provide scientific, technical and economic guidance as the Parties review the adequacy of control measures for substances that deplete the ozone layer. That review is scheduled to take place at the Fourth Meeting of the Parties in Copenhagen in November 1992.

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## II. ASSESSMENT SUMMARIES

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

### A. *Scientific assessment of stratospheric ozone*

*Recent major scientific findings*

8. Over the past few years, there have been highly significant advances in understanding the impact of human activities on the Earth's stratospheric ozone layer and the influence of changes in chemical composition on the radiative balance of the climate system.

*Larger global ozone decreases observed*

9. Ground-based and satellite observations continue to show decreases of total column ozone in winter in the northern hemisphere. For the first time, there is evidence of significant decreases during spring and summer in both the northern and southern hemispheres at middle and high latitudes (about 3.5 per cent at 45°N in summer for the period 1979-1991), as well as during the southern hemisphere winter. No trends in ozone have been observed in the tropics. The downward trends were larger during the 1980s than in the 1970s by approximately a 2 per cent loss per decade. The observed ozone decreases have occurred predominantly in the lower stratosphere.

*Antarctic ozone losses continue*

10. Serious Antarctic ozone holes have continued to occur and, in four of the past five years, have been deep and extensive in area. This contrasts with the situation of the mid-1980s, when the depth and area of the ozone hole exhibited a quasi-biennial modulation. Large increases in surface ultraviolet radiation have been observed in Antarctica during periods of low ozone. While in the Arctic no extensive ozone losses have occurred that are comparable to those observed in the Antarctic, localized Arctic ozone losses have been observed in winter concurrent with observations of elevated levels of reactive chlorine.

*Observed ozone losses due to industrial halocarbons*

11. Recent laboratory research and an extended interpretation of field measurements have strengthened the evidence that the Antarctic ozone hole is primarily due to chemicals containing chlorine and bromine. In addition, the weight of evidence suggests that the observed middle- and high-latitude ozone losses are largely due to chlorine and bromine.

*Impact of supersonic aircraft re-evaluated*

12. Earlier independent assessments of the impact of a projected fleet of supersonic aircraft on stratospheric ozone predicted that ozone loss increases with the amount of nitrogen oxides emitted. These models used gas-phase chemistry and assessed ozone loss for the case of 500 aircraft flying at Mach 2.4 between 17-20 km with an annual fuel use of 7 x $10^{10}$ kg/yr. The annual average loss of column ozone at middle latitudes in the northern hemisphere is predicted to be 2-6 per cent. For a comparable fleet operated at Mach 3.2 between 21-24 km, the comparable column ozone losses are 7-12 per cent. However, recent evidence has shown that reactions on sulfate aerosols can

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change the partitioning of nitrogen oxides. Two model studies incorporating this heterogeneous chemistry have recently re-examined the Mach 2.4 case and found substantially less ozone change (-0.5-+0.5 per cent). The implications of this finding need to be examined in detail.

*No significant impact of shuttles and rockets on ozone layer*

13. The increase in the abundance of stratospheric chlorine from one projection of U.S. annual launches of nine space shuttles and six Titan rockets is calculated to be less than 0.25 per cent of the annual stratospheric chlorine source from halocarbons in the present-day atmosphere (with maximum increases of 0.01 ppbv in the middle and upper stratosphere in the northern middle and high latitudes). The Total Ozone Mapping Spectrometer (TOMS) ozone record shows no detectable changes in column ozone immediately following each of several launches of the U.S. space shuttle.

*Ozone depletion and global warming potentials (ODPs and GWPs) re-assessed*

14. A new semi-empirical, observation-based method of calculating ODPs has better quantified the role of polar processes in this index (values shown in Table 1). In addition, the direct GWPs for tropospheric, well-mixed, radiatively active species have been recalculated. However, because of the incomplete understanding of tropospheric chemical processes, the indirect GWPs of methane and other shorter-lived gases have not been quantified reliably. In fact, the concept of a GWP may prove inapplicable for the very short-lived, inhomogeneously mixed gases, such as the nitrogen oxides. Hence, many of the indirect GWPs reported in 1990 by the Intergovernmental Panel on Climate Change (IPCC) are likely to be incorrect. Furthermore, the radiative cooling introduced by the lower stratospheric ozone loss may offset the radiative warming of the ozone-depleting chemicals. Therefore, their GWPs may be significantly less than estimated earlier and, because the effect cannot at present be quantified reliably, Table 1 does not list values of GWPs.

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Table 1

| *Substance* | ODP | | |
|---|---|---|---|
| | *This * Assessment* | *1989 Assessment* | *Montreal Protocol stipulations* |
| *CFCs* | | | |
| CFC-11 | 1.0 | 1.0 | 1.0 |
| CFC-12 | 1.0 | 0.9-1.0 | 1.0 |
| CFC-113 | 1.07 | 0.8-0.9 | 0.8 |
| CFC-114 | 0.8 | 0.6-0.8 | 1.0 |
| CFC-115 | 0.5 | 0.3-0.5 | 0.6 |
| $CCl_4$ | 1.08 | 1.0-1.2 | |
| 1,1,1-trichlorethane | 0.12 | 0.1-0.16 | |
| *HCFCs and HFCs* | | | |
| HCFC-22 | 0.055 | 0.04-0.06 | |
| HCFC-123 | 0.02 | 0.013-0.022 | |
| HCFC-124 | 0.022 | 0.016-0.024 | |
| HFC-125 | 0 | 0 | |
| HFC-134a | 0 | 0 | |
| HCFC-141b | 0.11 | 0.07-0.11 | |
| HCFC-142b | 0.065 | 0.05-0.06 | |
| HFC-143a | 0 | 0 | |
| HFC-152a | 0 | 0 | |
| HCFC-225CA | 0.025 | - | |
| HCFC-225CB | 0.033 | - | |
| $CH_3Br$ | 0.6 | - | |
| *Halons *** | | | |
| H-1301 | ~16 | 10.0 | |
| H-1211 | ~4 | 3.0 | |
| H-1202 | ~1.25 | | |
| H-2402 | ~7 | | |
| H-1201 | ~1.4 | | |
| H-2401 | ~0.25 | | |
| H-2311 | ~0.14 | | |

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* These values are based on a new semi-empirical, observation-based method of calculating ODPs, which has better quantified the role of polar processes in this index.

** These values are more uncertain than those for the chlorine containing chemicals.

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*Implications for Policy Formulations*

15. The findings and conclusions of the research of the past few years have several major implications for policy decisions regarding human-influenced substances that lead to stratospheric ozone depletion and to changes in the radiative forcing of the climate system.

*Future levels of ozone depletion*

16. Even if the control measures of the amended Montreal Protocol (London, 1990) were to be implemented by all nations, the current abundance of stratospheric chlorine (3.3-3.5 ppbv) is estimated to increase during the next several years, reaching a peak of about 4.1 ppbv around the turn of the century. With these increases, the additional middle-latitude ozone losses during the 1990s are expected to be comparable to those observed during the 1980s. Hence, by the year 2000 ozone depletions are expected to be about 6 per cent in summer and about 10 per cent in winter. In addition, there is the possibility of incurring widespread losses in the Arctic. Reducing these expected and possible ozone losses requires further limitations on the emissions of compounds that contain chlorine and bromine.

*Approaches to limiting future levels of global ozone depletion*

17. Lowering the peak and hastening the subsequent decline of global chlorine and bromine levels can be accomplished in a variety of ways, including an accelerated phase-out of controlled substances and limitations on currently uncontrolled halocarbons. Example scenarios are presented in Section III.

*Elimination of the Antarctic ozone hole*

18. The phase-out schedule of the London amendments to the Montreal Protocol, if fully complied with by all nations *and* if there are no continued uses of HCFCs, affords the opportunity to return to stratospheric chlorine abundances of 2 ppbv sometime between the middle and the end of the next century. This is the level at which the Antarctic ozone hole appeared in the late 1970s and hence is about the level that is thought to be necessary (other conditions assumed constant, including bromine loading) to eliminate the ozone hole. Such levels could never have been reached under the provisions of the original 1987 Protocol.

*Uncertain greenhouse role of CFCs*

19. The weight of evidence suggests that a large part of the observed lower stratospheric decrease in ozone is the result of CFC emissions. Furthermore, the radiative impact of this ozone decrease may have largely offset the predicted direct radiative perturbations, at middle to high latitudes, due to the CFCs' increases over the last decade. Hence, even the sign of the overall radiative effect of CFC increases on the climate system over the last decade is uncertain.

## B. *Environmental effects assessment of ozone depletion*

20. Research on the effects of ozone depletion has yielded several new and important results since the 1989 assessment. However, there has been less progress than would have been possible if available research capacity were adequately funded and if additional research were undertaken to resolve the uncertainties of potentially important effects.

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*Factors influencing UV-B radiation*

21. Because stratospheric ozone is the dominant factor limiting the penetration of solar UV-B radiation to the Earth's surface, a decrease of stratospheric ozone will, other things being equal, lead to increased UV-B radiation. This radiation, however, is also limited by tropospheric ozone, aerosols and clouds. During the past decades pollution has increased the influence of the latter factors.

*Increase of UV-B radiation*

22. Clearcut increases of UV-B radiation were observed in the Antarctic region in conjunction with periods of intense ozone depletion. The relationship between the observed decrease of ozone and increase of UV-B radiation was consistent with theoretical predictions. Most UV-B measurements at middle latitudes have been carried out in industrialized areas where pollution levels have increased. This is probably the reason why the observed trends in UV-B radiation showed a decrease while stratospheric ozone was also decreasing. However, there is no guarantee that these factors will continue to work in this manner, especially as efforts to reduce pollution are under way. Climate change may also alter cloudiness in certain areas, thus influencing the ozone-layer related increases of UV-B radiation.

*Non-melanoma skin cancer will increase*

23. The best quantitative predictions of the effect of ozone depletion are for increases in skin cancer. Non-melanoma skin cancer depends on the UV dose accumulated over a lifetime. New experimental data show that this type of skin cancer is caused not only by UV-B radiation, but also to some extent by UV-A radiation, which is hardly influenced by atmospheric ozone. This makes the incidence of non-melanoma skin cancers less sensitive to ozone depletion than was reported in the 1989 assessment. By the year 2000, ozone depletions between 5 and 10 per cent are predicted for mid-latitudes in summer. According to present data, a sustained 10 per cent loss of ozone would lead to an increase in the incidence of these skin cancers by 26 per cent.

*Melanomas more likely to increase*

24. Recent research results strengthen the theory that UV-B radiation plays a role in the formation of melanomas. This underscores the concern that increased UV-B radiation may lead to increased incidence of this serious type of skin cancer.

*More blindness*

25. Eye problems are expected to be at least as great as those discussed in the 1989 assessment. New investigations implicate UV-B radiation in more forms of cataract, a leading cause of blindness in the world. A 1 per cent decrease of ozone, other things being equal, would lead to between 100,000 and 150,000 additional cases of cataract-induced blindness world-wide.

*More infectious diseases possible*

26. Recent research confirms that UV-B radiation has profound influences on the immune system in humans as well as in experimental animals. There is concern that changes in the immune system might lead to an increase of infectious diseases. Unlike the protection against sun burn, skin pigmentation does not protect the body against changes in its immune system.

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*World food supply may be adversely influenced*

27. UV-B radiation, even at present levels, has a detrimental effect on many plants and aquatic organisms. This raises the concern that enhanced UV-B radiation may have a negative effect on world food production. The relationships between damage to individual organisms and the productivity of agriculture and fisheries are extremely complex. The available scientific data are far from sufficient to make quantitative predictions in these areas.

*Possible shifts in biodiversity*

28. A more negative effect of enhanced UV-B radiation on some species than on others may shift the competitive balance in natural ecosystems. This may lead to a loss of species, but the data are insufficient for specific predictions.

*Other impacts*

29. The 1991 assessment discusses many more impacts, such as adverse effects on animal health, on tropospheric air quality, and on materials. Another impact assessed is the link with climate change, such as a decrease of the uptake of carbon dioxide in the oceans if phytoplankton are reduced by UV-B radiation, thereby increasing atmospheric carbon dioxide concentrations.

### C. *Technology and economic assessment*

30. The Technology and Economic assessment considers the available technologies for the elimination of ozone-depleting substances and the economic consequences of their early adoption. Since the 1989 assessment, greater progress than had been predicted has been made in developing and adopting substitute chemicals and alternative technologies.

*World-wide CFC consumption is now 40 per cent below 1986 levels*

31. At this rate, developed country consumption[1] will be reduced by 50 per cent in 1992 - a three-year advance on the requirements of the amended Protocol. Major reductions have been made by using hydrocarbons as aerosol propellants and as blowing agents for flexible foams. Solvent users are turning to aqueous and semi-aqueous systems, "no-clean" technologies, alcohol, and other solvents. Refrigeration and air conditioning sectors are recovering and recycling CFC refrigerants and increasing the use of HCFCs and ammonia. Insulating foams have a lower CFC content with little energy penalty. Although halon consumption continued to rise until 1988, the total used in 1990 was less than in 1986, and use has fallen rapidly during 1991 through major reductions in training, testing and accidental discharges, as well as the adoption of alternative methods of fire protection in new facilities.

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[1] The Montreal Protocol defines consumption as production plus imports minus export and therefore does not limit the use of recycled material. It is in this sense that the word consumption is used throughout this report.

*Further progress in eliminating use of controlled substances is imminent*

32. The conversion of aerosol filling to hydrocarbons continues in developing and developed countries, as does the application of non ozone-depleting technologies to replace CFC-113 and 1,1,1-trichloroethane solvents. Commercialization of HFC-134a automotive air conditioning occurred in 1991 and its uses in domestic refrigeration will commence in 1992. In developed countries commercialization should be completed for new equipment by 1995. Technologies to retrofit existing air conditioning and refrigeration equipment with HFCs, as well as with various blends, are undergoing intensive development and field-testing. CFC use in foams can be eliminated once HCFC replacements are fully available. Given the assurance of the HCFC supply, this goal can be achieved by 1994-1995. Successful management of the bank of halons in existing equipment can satisfy essential halon needs for decades o come. The limited use of carbon tetrachloride in non feedstock applicatio can be virtually eliminated by 1995.

*It is technically feasible to virtually phase out controlled substances in developed countries by 1995-1997*

33. This, however, depends on the extent of recycling and technical feasibility of equipment retrofit, on the availability of HCFC and HFC replacements and on their toxicological and environmental acceptability, on a regulatory system which allows profitable investment in their production, on vigorous and effective management of the halon bank, and on the very rapid dissemination and adoption of technologies for the replacement of 1,1,1-trichloroethane by its many thousands of small users.

*The timetable for elimination of controlled substances in some small but important uses is not certain*

34. There are low-volume, high-value applications for which the availability of replacements by 1995, or indeed 1997, is uncertain. Metered dose inhalers for the application of medicines constitute a clear example, but there are others such as the cleaning of some precision equipment. Small emissions of CFCs, 1,1,1-trichloroethane, and carbon tetrachloride in feedstock applications are also unavoidable. Due to the rapid development of technology, the 1991 Assessment is unable to list the essential applications for which no alternatives will be available at any specified time. The Halon Technical Options Committee has listed criteria for judging what halon uses are essential. The judicious use of halon banked in existing equipment is likely to eliminate the need for production for such essential uses in the foreseeable future.

*The selection of technologies to replace the use of controlled substances should be made to minimize energy consumption as well as ozone depletion*

35. The energy efficiency of foams and refrigeration equipment has a greater influence on climate change than the emission of particular substances used in those applications, especially in view of current uncertainty over the total global warming impacts of CFC and HCFC emissions.

*As in the 1989 assessment, there are insufficient data to undertake a detailed benefit/cost analysis, but more stringent controls are justified now than in 1989*

36. Estimates of the costs of eliminating consumption of the controlled substances are generally lower than in 1989, due to the rapid pace of technological development. At the same time, the benefits of

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early action increase as the evidence and scientific understanding of ozone-depletion processes develops, and it becomes clear that problem is more serious than previously thought. This implies that a balance between costs and benefits can be achieved with a more rapid phase-out of controlled substances than was the case at the time of the last assessment. Many high-volume uses of controlled substances can be reduced or eliminated at a net saving in costs. These include uses in aerosols, flexible and packaging foams, some solvent cleaning applications and fire-fighting equipment, and the recovery and recycling of halons and refrigerants.

*In air conditioning and refrigeration the cost of accelerating the phase-out schedule could be considerable*

37. This is not easily quantified, but moving the CFC phase-out from 2000 to 1997 could cost several billion US dollars - disproportionately more if the phase-out schedule is further accelerated. These are costs for the transition itself, arising from the need to replace or retrofit existing equipment; future costs for new refrigerants will be a minor proportion of equipment costs. Specific replacement refrigerants have higher potential energy use. However, refrigerator manufacturers have reported that optimized technologies using replacement refrigerants have equal or better energy efficiency. Recycling can mitigate the need to retrofit, but the amount of refrigerant available from such sources will be insufficient in those developed countries that depend significantly on building and vehicle air conditioning, cold storage and food processing.

## D. *Developing countries*

*Developing countries each face different circumstances*

38. The implications of an earlier phase-out of controlled substances in developing countries vary with the circumstances of a country, the different substitutes and alternatives to ozone-depleting substances, and the ownership and competitive situations of different companies and government enterprises.

*Many developing countries are already taking effective steps to substantially cut their consumption of ozone-depleting substances*

39. Several countries have legislated against the use of CFCs in aerosols. China, for example, has an extensive programme of research into refrigeration alternatives, while Mexico has announced that with adequate financing it will follow the same phase-out schedule as developed countries. Countries whose industry is subject to international competition in their domestic or export markets have a particular incentive to adopt state-of-the-art technology, which increasingly avoids the use of ozone-depleting substances. Developing countries with existing manufacturing capacity for controlled substances need to consider the opportunities for using them as feedstock or to develop multi-purpose plants to produce HCFC-22.

*The Multilateral Fund is vital for the early elimination of controlled substances in developing countries*

40. Many substantial uses of controlled substances can be cut or reduced at little or no additional cost and often with cost savings. Technologies for aerosols, flexible and packaging foams, some solvent cleaning processes, some fire-fighting applications, and the recovery and recycling of refrigerant and halons are relatively mature and can be adopted quickly by developing countries with confidence that they are modern, cost-effective, and environmentally acceptable. Other options, however, imply greater costs or

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are expected to undergo further development over the next few years. In replacement refrigerants, the premature retirement of equipment, and the manufacture of rigid insulating polyurethane foams, developing countries will need to balance the environmental and competitive advantages of early transition against the increased costs and business risks associated with the phase-out. The role of the Multilateral Fund will be crucial in encouraging early transition to alternative technologies in all sectors. Parties will need to consider the implications for the Multilateral Fund of the Protocol as a two-stage process: initially a move away from the controlled substances and subsequently a move away from the transitional substances that will replace them.

### *Most barriers to the early elimination of controlled substances are administrative and informational rather than technical or economic*

41. Not only is the dissemination of new technologies relatively straightforward where companies are subsidiaries of multinational concerns, but it is also assisted where they participate in international markets. The dissemination of information and the transfer and adoption of new technologies over the whole range of companies and countries are major challenges for the Parties and the implementing agencies. Information-sharing procedures and clarity in the operation of the Fund are particularly important.

### *An earlier phase-out in developing countries is feasible and cost effective*

42. If the challenges of information exchange and technology transfer are met, it will be possible, as well as less costly, for developing countries to choose to eliminate all production and consumption of controlled substances within five to eight years of developed countries rather than taking the full 10 years allowed under the Protocol.

## III. OPTIONS FOR LIMITING FUTURE LEVELS OF GLOBAL OZONE DEPLETION

43. This section examines a number of options to limit the atmospheric levels of chlorine and bromine.

### A. *Approaches to limit atmospheric levels of chlorine and bromine*

44. Five options for reducing the atmospheric levels of chlorine and bromine, hence reducing the amount of ozone depletion and the risk of adverse environmental impacts from ultraviolet radiation, are discussed. A detailed description of each of the scenarios shown in Table 2 and Figure 1 is presented below in sections 1 (a) to 1 (e). The technical and economic feasibility of each option is evaluated. Options represent possible successive steps of increasingly reduced emissions beyond the current requirements (baseline scenario). Figure 1 shows the atmospheric levels of chlorine for each option, and that each option discussed below can significantly reduce either peak chlorine loading or, even more importantly, the integral of Cl>3 ppbv.

45. While Table 2 only shows atmospheric levels of chlorine, it is possible to equate reductions in atmospheric levels of bromine, accomplished by reductions in halon emissions, to equivalent atmospheric reductions in chlorine. Stratospheric bromine is 30-120 times more efficient than stratospheric chlorine in destroying ozone on a per atom basis. Therefore, 1 pptv of stratospheric bromine is equivalent to 0.03-0.12 ppbv of stratospheric chlorine.

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46. Table 2 shows:

(a) *Peak chlorine*: This is the maximum value of the stratospheric chlorine loading, which, within the range of these scenarios, is predicted to occur around the year 2000.

Table 2

*Scenarios for reducing chlorine emissions*

| Scenario | Peak Cl (ppbv) | Year at 3 ppbv | Year at 2 ppbv | Integral (Cl>3 ppbv) |
|---|---|---|---|---|
| Baseline | 4.12 ppbv | 2037 | 2066 | 31.4 ppbv-yr |
| Option 1 | 3.92 | 2031 | 2059 | 20.7 |
| Option 2 | 4.07 | 2037 | 2065 | 28.8 |
| Option 3 | 3.87 | 2031 | 2059 | 18.1 |
| Option 4 | 3.87 | 2018 | 2052 | 14.9 |
| Option 5 | 3.87 | 2016 | 2050 | 13.8 |

(b) *Year at 3 ppbv*: This is the year at which the stratospheric chlorine loading returns to 3 ppbv, which was the abundance of chlorine in about 1985- the middle of the decade for which the first ozone depletions were observed at middle latitudes in spring and summer. Thus it is a reference point in global ozone changes.

(c) *Year at 2 ppbv*: This is the year at which the stratospheric chlorine loading returns to 2 ppbv, which is the abundance occurring in about 1975. At 2 ppbv the first ozone depletions were observed at middle latitudes in winter and in Antarctica. Thus, it is another important reference point.

(d) *Integral (Cl>3 ppbv)*: This is the accumulated chlorine abundance above the level of 3 ppbv, which is a measure of ozone depletion over the next several decades. For example, each 0.1 ppbv of chlorine above 3 ppbv results approximately in an additional column ozone decrease of about 0.75 per cent in winter and 0.5 per cent in summer at middle latitudes. This accumulated loss is a measure of the chronic effects of the enhanced ultraviolet radiation caused by the ozone depletion. For example, over an extended period, a 10 per cent reduction in ozone corresponds to a 26 per cent increase in the incidence of non-melanoma skin cancer.

### 1. *Baseline Case*

47. *Scenario description*: This baseline case is the best estimate of chlorine- and bromine-containing emissions, assuming full adherence to the control measures of the London Amendments to the Montreal Protocol. It assumes compliance with a 2040 phase-out of HCFCs called for in the London Resolution, but no restriction on the level of their consumption.prior to 2020:

(i) *Chlorofluorocarbons*: 50 per cent reduction in 1995; 85 per cent in 1997; 100 per cent in 2000;

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(ii) *Carbon tetrachloride:* 85 per cent reduction in 1995; 100 per cent in 2000;

(iii) *1,1,1-trichloroethane:* 30 per cent reduction in 1995; 70 per cent in 2000; 100 per cent in 2005;

(iv) *Halons:* 50 per cent reduction in 1995, 100 per cent in 2000;

(v) *HCFC-22:* 3 per cent per year growth from 1991 to 2020, then reduced to zero by 2040;

(vi) *10 per cent substitution of HCFC-A* (HCFC-A has a two-year lifetime, one chlorine, and an ODP of 0.013) and 30 per cent substitution of HCFC-B (HCFC-B has a 20-year lifetime, one chlorine, and an ODP of 0.13) starting in 1997, with 3 per cent per year growth until 2020, then reduced to zero by 2040; and

(vii) A *10-year grace period for developing countries with an assumed consumption of 10 per cent of total global emissions in 1991.*

### 2. Option 1: Accelerated phase-out of CFCs, $CCl_4$ and halons

48. *Scenario description:* All control measures for CFCs, $CCl_4$, and halons are accelerated by three years relative to the baseline case.

49. Table 2 shows that a three-year acceleration in the phase-out of CFCs, $CCl_4$, and halons will result in a decrease of the peak chlorine loading by 0.20 ppbv and that the integral has been reduced by 34 per cent (10.7 ppbv-yr). In addition, the accelerated phase-out of the halons results in a decreased peak bromine loading of about 1 pptv, which is equivalent to a decrease in peak chlorine loading of 0.03 to 0.12 ppbv.

50. In developed countries it is technically feasible to reduce and phase-out consumption of CFCs, halons, and carbon tetrachloride on a schedule three years earlier than the current control dates. In fact, world-wide CFC consumption is already 40 per cent below 1986 levels, and at this rate, developed country consumption will be cut by 50 per cent by 1992 - three years ahead of the Protocol schedule. However, with a 1997 phase-out there remains the possibility that exemptions may be needed for small important uses.

51. Although two-thirds to three-fourths of the phase-out can be completed with technologies currently available, new chemicals now under final development are required for the final phase-out. A final phase-out of controlled substances requires that the risk analyses conclude that at least some combination of HCFC-123, HCFC-124, HCFC-141b, HCFC-225, and HFC-134a can be used for refrigeration, air conditioning, insulating foam, and for some aerosol, sterilization and minor solvent uses; that these HCFCs and HFC are environmentally acceptable; and that they are commercially available in adequate quantities. This phase-out will also require increased near-term use of currently available HCFC-22, HCFC-142b, and HFC-152a.

52. A 1997 CFC phase-out for refrigeration and air conditioning could cost several billion dollars more than a phase-out in 2000 because of early retirement of capital. A phase-out before 1997 is technically feasible, but would cost dis-proportionately more. Whether or not early capital retirement is necessary will depend on the success of recycling and recovery at the time of disposal and on developing simple retrofit technology. A 1997 halon phase-out

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is contingent on the use of recycled halons as the prime supply for essential uses. Bank management must begin immediately and increased efforts are needed to develop transitional and replacement fire-extinguishing agents.

### 3. Option 2: Accelerated phase-out of 1,1,1-trichloroethane

53. *Scenario description*: The change relative to the baseline case is that the emissions of 1,1,1-trichloroethane are reduced by 30 per cent in 1992 and 100 per cent in 1996.

54. Table 2 shows that an acceleration in the phase-out of 1,1,1-trichloroethane will result in a decrease of the peak chlorine loading by 0.05 ppbv and that the integral has been reduced by about 8 per cent (2.6 ppbv-yr).

55. A 30 per cent 1,1,1-trichloroethane reduction in 1992 is technically and economically feasible and will probably occur as a result of voluntary conservation and recycling initiatives by industry.

56. It is technically feasible to phase out virtually all use of 1,1,1-trichloroethane in developed countries by 1996[3] but there may be small, important uses where no environmentally acceptable alternatives or substitutes are available. A 1996 phase-out is contingent on world-wide technical cooperation. This cooperation has already been demonstrated in international efforts to eliminate CFC-113 solvents in the electronics industry.

### 4. Option 3: Accelerated phase-out of CFCs, $CCl_4$, halons, and 1,1,1-trichloroethane

57. *Scenario description*: This option is the combination of options 1 and 2, i.e., an accelerated phase-out of all currently controlled substances.

58. Table 2 shows that the combination of options 1 and 2 will result in a decrease of the peak chlorine loading by 0.25 ppbv and that the integral has been reduced by 42 per cent (13.3 ppbv-yr). In addition, as stated in option 1, the accelerated phase-out of the halons will result in an equivalent decrease in peak chlorine loading of 0.03 to 0.12 ppbv.

59. The technology implications of this option have already been discussed above under options 1 and 2.

### 5. Option 4: Accelerated phase-out of CFCs, $CCl_4$, halons, 1,1,1-trichloroethane, and limited use of HCFCs

60. *Scenario description*: The changes relative to option 3 involve limitations on the use of HCFCs A, B, and 22: (i) HCFC-22 emissions growing at 3 per cent per year until 2000, and then phased-out by 2020; and (ii) 10 per cent substitution of HCFC-A and 20 per cent substitution of HCFC-B replacing CFCs in 1994, with 3 per cent per year growth until 2010, then phased-out by 2030.

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[3] The Solvents, Coatings and Adhesives Technical Options Committee estimated that developed countries that are already limiting the use of controlled solvents can phase-out in 1992-1994 and that other developed countries and developing countries with partners can phase-out in 1995-2000.

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61. By comparing options 3 and 4 in Table 2 it can be seen that reduced emissions of HCFCs will result in no additional reduction of peak chlorine loading, but the integral is reduced by about 10 per cent (3.2 ppbv-yr). Therefore, the total effect of option 4 is to reduce peak chlorine loading by 0.22 ppbv and the integral by 53 per cent (16.5 ppbv-yr).

62. HCFCs are necessary for the near-term phase-out of CFCs in refrigeration, insulating foams and possibly limited applications in solvents, sterilants, and other small uses, but they are not necessary for many other applications. In some applications there is a choice of several HCFCs with a significant range of ODPs.

63. The minimum length of time needed to use a new HCFC is influenced by: (i) the fact that chemicals will be produced only if plant investment can be recovered; (ii) the costs users incur for transition into and out of HCFC use; and (iii) the requirement of HCFC for service during the useful life of the equipment. Refrigeration has a long service life and therefore requires HCFC for service. Foam production and solvent operations require less time and cost to change to new chemicals.

64. The phase-out of HCFC transitional substances beginning in 2010 and completed by 2030 should allow ample time for finding and shifting to alternatives. Early decisions would avoid the sale of equipment dependent on transitional substances within 15 or 20 years of the final phase-out and thus avoid costs of retrofit or early retirement.

65. It is technically feasible to limit HCFCs according to the London Resolution and with little economic impact. The challenge to Parties is to encourage essential substitution while limiting unnecessary uses.

### 6. Option 5: Accelerated Phase-out of CFCs, $CCl_4$, halons, 1,1,1-trichloroethane, limited use of HCFCs, and the grace period from 10 years to five years for developing countries

66. *Scenario description*: The change relative to option 4 is that the 10-year grace period for developing countries is reduced to five years.

67. Comparing options 4 and 5 in Table 2 shows the impact of reducing the 10-year grace period for developing countries to five years. There is little or no impact on peak chlorine loading, but the integral is reduced by 3.5 per cent (1.1 ppbv-yr). The cumulative effect of option 5 is a decrease in peak chlorine loading of 0.25 ppbv and a reduction in the integral of 56 per cent (17.6 ppbv-yr).

68. With adequate financing and technical assistance, it is technically and economically feasible to phase-out controlled substances in developing countries on an accelerated schedule. But if the phase-out is to be successful in developing countries, it is critical that technologies be available, that supporting technical assistance and training be provided, and that adequate financial assistance be forthcoming.

69. There may remain some uses that require five to eight years more than those in developed countries to generate the information, training and infrastructure necessary to eliminate the controlled substance; in other instances developing countries may need recycling and retrofit to preserve the useful life of capital now dependent on CFCs.

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70. Most developing countries have low levels of halon consumption and banked halon. Developing countries can avoid production of halons for essential uses if excess recycled halon can be supplied from countries with large banks.

B. *Additional approaches to limit atmospheric levels of bromine*

1. *Elimination of halons prior to 1997*

71. The Halon Technical Options Committee did not explicitly consider a halon phase-out earlier than 1997. However, the report provides estimates of the size of the halon bank based on production phase-out in 1995, 1997 and 2000. The existing bank of halon 1211 may be sufficient to maintain equipment that remains in service and provide small quantities for most essential applications into the next century. The existing bank of halon 1301 may be adequate to maintain systems that remain in service for up to 45 years after production ceases and to supply most essential new applications (no more than 10 per cent of 1986 level of installations) for up to 30 years after production ceases. Halon bank management has not been demonstrated, but military and civilian users are moving in that direction. Production of halon for essential uses under the terms of the Protocol may be necessary in the future if halon banks are depleted and if no environmentally acceptable alternatives and substitutes are available. Cooperation of the fire protection community will continue to be essential.

2. *Controls on methyl bromide*

72. The relative importance of natural versus anthropogenic sources of methyl bromide is uncertain. However, if anthropogenic sources of methyl bromide are significant and their emissions can be reduced, then each 10 per cent reduction in methyl bromide would rapidly result in a decrease in stratospheric bromine of 1.5 pptv, which is equivalent to a reduction in chlorine of 0.045 to 0.18 ppbv. Therefore, each 10 per cent reduction in methyl bromide emissions is comparable to a three-year acceleration of the schedule of phase-out of halons (1 pptv of bromine) or a three-year acceleration of the scheduled phase out of the CFCs and $CCl_4$ (0.16 ppbv of chlorine).

73. No detailed analysis of the sources of consumption of methyl bromide or the alternatives and substitutes has been undertaken by the Technical and Economic Assessment Panel. However, methyl bromide is believed to be used in uncertain quantities as a broad spectrum pesticide (insecticide, acaricide, rodenticide, fungicide, miticide, and herbicide). It is also used for chemical processing and organic synthesis; some may be considered as feedstock uses.

74. Many of the pesticide uses of methyl bromide are for ornamental, turf, and luxury food crops, particularly when plants are intensively cultivated in such as artificial structures as glass houses and mushroom houses. Although there is a variety of non-chemical controls and chemical substitutes for pesticide applications, there may be some uses for which no alternative as yet exists.

## IV. CONCLUSIONS

*Additional ozone depletion expected during the next decade*

75. Significant stratospheric ozone decreases have been observed in middle and high latitudes in both hemispheres in winter, spring, and summer. The weight of evidence suggests that these decreases are largely due to chlorine

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and bromine. Therefore, additional middle latitude ozone losses during the 1990s are expected as the atmospheric levels of chlorine and bromine continue to increase. By the year 2000 mid-latitude ozone depletions are expected to be about 6 per cent in summer and about 10 per cent in winter. Limiting further ozone loss will require additional controls on ozone-depleting substances.

*Many adverse effects on humans, animals and plants expected*

76. New data on the environmental effects of ozone depletion confirm the conclusions of the 1989 assessment. One quantified effect is that a sustain 10 per cent depletion of ozone would result in a 26 per cent increase in the incidence of non-melanoma skin cancer. However, a much greater research effort is needed to understand and quantify the implications of ozone depletion for food production, forestry, and natural ecosystems; for human health, especially the immune system, melanomas, and cataracts; and for biota during the Antarctic springtime ozone depletion.

*Significant reductions in atmospheric chlorine and bromine levels feasible*

77. Significant reductions in peak chlorine and bromine loading, and the integral (Cl>3 ppbv), can be reached through a number of individual actions, including an acceleration of the phase-out of CFCs, $CCl_4$, halons, 1,1,1-trichloroethane; limited use of HCFCs; and a reduction in the 10-year lag for developing countries to five years. In addition, further reductions in bromine levels may be possible if there are significant anthropogenic emissions of methyl bromide that can be controlled. Adoption of all the options discussed in this document would reduce the integral, a measure of ozone depletion and the chronic effects of enhanced UV-B effects, by about 50 per cent.

*Phase-out feasible by 1995-1997*

78. World-wide CFC production has fallen 40 per cent since 1986 and halon consumption has now begun to fall. It is technically feasible to eliminate virtually all consumption of controlled substances in developed countries by 1995-1997, if commercial quantities of transitional substances are available. The judicious use of halons banked in existing equipment can eliminate any need for production of these substances, including that for essential uses, in the foreseeable future.

*Phase-out costs falling*

79. As a result of rapid development of technology, the costs of eliminating controlled substances are lower than estimated in 1989 and will decline further. The cost of early retirement or retrofit of refrigeration and air conditioning equipment may be considerable, but can be mitigated by recovery and recycling and if simple retrofit technology is employed.

*Developing countries can accelerate phase-out*

80. Developing countries can phase-out controlled substances in many applications quickly if information, training, infrastructure and financing are adequately developed. Other applications may require up to five to eight years longer than in developed countries. International technical cooperation and the functions of the Multilateral Fund are essential for rapid phase-out in developing countries.

# V. APPENDIX

## A. *Executive summary of the scientific assessment of stratospheric ozone*

### 1. *Recent major scientific findings*

81. Over the past few years, there have been highly significant advances in the understanding of the impact of human activities on the Earth's stratospheric ozone layer and the influence of changes in chemical composition on the radiative balance of the climate system. Specifically, since the last international scientific review in 1989, there have been five major advances:

- Global ozone decreases: Ground-based and satellite observations continue to show decreases of total column ozone in winter in the northern hemisphere. For the first time, there is evidence of significant decreases in spring and summer in both the northern and southern hemispheres at middle and high latitudes, as well as during the southern winter. No trends in ozone have been observed in the tropics. These downward trends were greater during the 1980s than during the 1970s. The observed ozone decreases have occurred predominantly in the lower stratosphere.

- Polar ozone: Strong Antarctic ozone holes have continued to occur and, during four of the past five years, have been deep and extensive in area. This contrasts with the situation of the mid-1980s, during which the depth and area of the ozone hole exhibited a quasi-biennial modulation. Large increases in surface ultraviolet radiation have been observed in Antarctica during periods of low ozone. While no extensive ozone losses comparable to those observed in the Antarctic have occurred in the Arctic, localized Arctic ozone losses have been observed in winter, concurrent with observations of elevated levels of reactive chlorine.

- Ozone and industrial halocarbons: Recent laboratory research and re-interpretation of field measurements have strengthened the evidence that the Antarctic ozone hole is primarily due to chemicals that contain chlorine and bromine. In addition, the weight of evidence suggests that the observed middle- and high-latitude ozone losses are largely due to chlorine and bromine. Therefore, as the atmospheric abundances of chlorine and bromine increase in the future, significant additional losses of ozone are expected at the middle latitudes and in the Arctic.

- Ozone/Climate Relations: For the first time, the observed global lower-stratospheric ozone depletions have been used to calculate the changes in the radiative balance of the atmosphere. The results indicate that, over the last decade, the observed ozone depletions would have tended to cool the lower stratosphere at middle and high latitudes. Temperature data suggest that some cooling has indeed taken place there. The observed lower-stratospheric ozone changes and calculated temperature changes would have caused a decrease in the radiative forcing of the surface-troposphere system in the middle- to high-latitudes that is larger in magnitude than that predicted for the CFC increases over the last decade. In addition, the ozone depletion may indeed have offset a significant fraction of the radiative forcing due to increases of all greenhouse gases over the past decade.

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Ozone Depletion and Global Warming Potentials (ODPs and GWPs): A new semi-empirical, observation-based method of calculating ODPs has better quantified the role of polar processes in this index. In addition, the direct GWPs for tropospheric, well-mixed, radiatively active substances have been recalculated. However, because of the incomplete understanding of tropospheric chemical processes, the indirect GWP of methane has not, at present, been quantified reliably. Furthermore, the concept of a GWP may prove inapplicable for the very short-lived, inhomogeneously mixed gases, such as the nitrogen oxides. Hence, many of the indirect GWPs reported in 1990 by the Intergovernmental Panel on Climate Change (IPCC) are likely to be incorrect.

## 2. *Supporting evidence and related issues*

### *Global Ozone*

82. Independent observations from the ground-based Dobson and M-83/124 instruments and the TOMS satellite instrument all show, for the first time, that there are significant decreases in total column ozone, after accounting for known natural variability, in winter and now in spring and summer in both the northern and southern hemispheres at middle and high latitudes, but not in the tropics. Table 3 illustrates some of these points.

Table 3

*Total Ozone Trends (per cent per decade with 95 per cent confidence limits)*

| | *TOMS: 1979-1991* | | | *Ground-based: 26°N-64°N* | |
|---|---|---|---|---|---|
| Season | 45° S | Equator | 45° N | 1979-1991 | 1970-1991 |
| December-March | -5.2±1.5 | +0.3±4.5 | -5.6±3.5 | -4.7±0.9 | -2.7±0.7 |
| May-August | -6.2±3.0 | +0.1±5.2 | -2.9±2.1 | -3.3±1.2 | -1.3±0.4 |
| September-November | -4.4±3.2 | +0.3±5.0 | -1.7±1.9 | -1.2±1.6 | -1.2±0.6 |

83. There is strong combined observational evidence from balloonsondes, ground-based Umkehr, and the SAGE satellite instruments that, over the past decade, annual-average ozone has decreased in the middle- and high-latitude stratosphere below 25 km (about 10 per cent near 20 km).

84. Ozone losses in the upper stratosphere have been observed by ground-based Umkehr and SAGE satellite instruments. Changes in the shape of the vertical distribution of ozone near 40 km are qualitatively consistent with theoretical predictions, but are smaller in magnitude.

85. Measurements indicate that ozone levels in the troposphere up to 10 km above the few existing balloonsonde stations at northern middle latitudes have increased by about 10 per cent per decade over the past two decades. However, the data base for ozone trends in the upper troposphere, where it is an effective greenhouse gas, are sparse and inadequate for quantifying its contribution to the global radiative balance. It should be noted that the response of ozone in the upper troposphere is particularly sensitive to oxides of nitrogen omitted by aircraft.

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86. The temperature record indicates that a small cooling (about 0.3°C per decade, globally averaged) has occurred in the lower stratosphere over the last two decades, which is consistent with that expected from the observed ozone change.

87. Increases continue in the atmospheric abundances of source gases that affect ozone and the radiative balance. Although methane has continued to increase in the atmosphere, the rate of increase has slowed, for reasons that are not understood. Methyl bromide is the major contributor to stratospheric bromine (15 pptv). The sources of methyl bromide are not well identified; however, significant anthropogenic emissions have been suggested.

88. Recent laboratory studies have identified key heterogeneous reactions and have allowed a more quantitative assessment of the role of global stratospheric sulfate aerosols in leading to enhanced abundances of reactive chlorine substances.

89. Limited observations suggest that the abundance of chlorine monoxide (ClO) in the lower stratosphere at northern middle latitudes is greater than that predicted by models containing only currently known gas-phase chemistry, and the observed seasonal and latitudinal dependences are inconsistent with those predicted. Some new studies that incorporate currently known heterogeneous processes provide an improved simulation for some observed gases, such as ClO and nitric acid.

90. Present models containing only gas-phase processes cannot simulate the observed seasonal ozone depletions at middle and high latitudes. However, models incorporating currently known heterogeneous processes on sulfate aerosols predict substantially greater ozone depletion (e.g., a factor of 2-3 at middle latitudes) from chlorine and bromine compounds compared to models containing only gas-phase processes. Indeed, the heterogeneous models simulate most of the observed trend of column ozone in middle latitudes in summer, but only about half of that in winter.

91. Observed downward trends in global ozone have not yet been fully accounted for. Plausible mechanisms include (i) local heterogeneous chemistry on stratospheric sulfate aerosols (as evidenced by, for example, elevated levels of ClO and the presence of sulfate aerosols at the altitudes of the observed ozone depletion) and (ii) the transport of both ozone-depleted and chemically perturbed polar air to middle latitudes (as evidenced by high levels of reactive chlorine and low levels of reactive nitrogen, which is a characteristic of chemically perturbed polar air). Although other possible mechanisms cannot be ruled out, those involving chlorine and bromine appear to be largely responsible for the ozone loss and are the only ones for which direct evidence exists.

92. Since the middle latitude ozone losses are apparently due in large part to chlorine and bromine, greater ozone losses are expected as long as the atmospheric levels of these compounds continue to increase. With the increases in the levels of chlorine and bromine that are estimated for the year 2000, the additional ozone losses during the 1990s are expected to be comparable to those already observed for the 1980s.

93. There are numerous ways in which further increases in stratospheric halogen abundances can be reduced. Table 4 illustrates the effects of reducing the emissions of several types of halocarbons. Four aspects are shown: (i) the change in peak chlorine loading, (ii) the times at which chlorine abundances have decreased to 2 ppbv (the abundance in the late 1970s, which is when the Antarctic ozone hole started and when the accelerated trends

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in total-column ozone losses in the northern hemisphere began); (iii) the times at which chlorine abundances have decreased to 3 ppbv (the abundance in the mid-late 1980s); and (iv) a measure of the cumulative ozone loss for the time period during which the chlorine levels rise above 3 ppbv. All of the values in Table 4 are relative to the reference scenario (AA).

Table 4

*Scenarios for Reducing Chlorine Emissions*

| *Scenario* | *Peak Cl (ppbv)* | *Year at 3 ppbv* | *Year at 2 ppbv* | *Integral (Cl>3ppbv)* |
|---|---|---|---|---|
| AA | 4.1 (ppbv) | 2027 | 2060 | 22.7 ppbv-yr |
| AA3 | -0.18 | -10 yrs | -7 yrs | -7.6 |
| D | -0.03 | 0 | 0 | -1.3 |
| D3 | -0.10 | 0 | 0 | -2.9 |
| E | 0.00 | -7 | -3 | -2.0* |
| E3 | -0.03* | -10 | -3 | -4.4* |
| F20 | +0.01 | 0 | 0 | +0.8 |
| F40 | +0.02 | +1 | 0 | +1.5 |
| G20 | +0.01 | +5 | +2 | +4.2 |
| AA3 + D3 | -0.21 | -11 | -7 | -10.4 |

* These values should be reduced by a factor of about 2-3 when evaluating ozone loss rather than chlorine loading.

Definitions of scenarios:

AA: Montreal Protocol (10 year lag of 10 per cent of CFCs plus $CCl_4$; no lag for $CH_3CCl_3$ and halons). HCFC-22 increases at 3 per cent per year from 1991 to 2020, ramps to 0 by 2040. No substitution of CFCs with HCFCs.

o Non-substitution scenarios:

AA3: 3 year acceleration of CFCs and $CCl_4$ schedules.
D: 3 year acceleration of $CH_3CCl_3$ schedule.
D3: $CH_3CCl_3$ on the accelerated CFC phase out schedule.
E: HCFC-22 ramp to zero between 2000 and 2020.
E3: HCFC-22 on the accelerated CFC phase-out schedule.

o Substitution scenarios:

HCFC substitutions begin in 1995, no growth to 2000, 3 per cent per year to 2020, ramp to zero by 2030. HCFC-A has a 2-year lifetime, one chlorine, and an ODP of 0.013. CFC-B has a 20-year lifetime, one chlorine, and ODP of 0.13.

F20: 20 per ce nitial substitution, HCFC-A.
F40: 40 per ce nitial substitution, HCFC-A.
G20: 20 per ce nitial substitution, HCFC-B.

94. Stratospheric bromine is 30-120 times more efficient than stratospheric chlorine in destroying ozone on a per atom basis. Therefore, 1 pptv of stratospheric bromine is equivalent to 0.03-0.12 ppbv of stratospheric chlorine.

*Polar ozone*

95. The Antarctic ozone hole in 1991 was as deep and as extensive in area as those of 1987, 1989, and 1990. The low value of total column ozone measured by TOMS in early October in 1991 was 110 Dobson units, which is a decrease of about 60 per cent compared to the ozone levels prior to the late 1970s. The quasi-biennial modulation of the severity of the ozone hole, previously noted, has not occurred during the past three years. This apparent lack of variability in recent years may imply that halogen chemistry is becoming dominant over dynamically induced fluctuations on Antarctic ozone depletion.

96. Recent laboratory studies of heterogeneous processes, re-evaluated field measurements, and modeling studies have strengthened the belief that the cause of the Antarctic ozone hole is primarily chlorine and bromine emissions.

97. High concentrations of ClO have been observed in winter in the Arctic stratosphere between 16-20 km. These observations have been incorporated into diagnostic models that have calculated localized ozone depletions of about 10 per cent at these altitudes over a period of about a month; these are consistent with concurrent ozone measurements.

*Ozone/climate relations*

98. The ozone losses observed in the lower stratosphere over the last decade are predicted to have increased the visible and ultraviolet incoming solar radiation reaching the surface/troposphere system and decreased the downward infrared radiation reaching the surface/troposphere system. For models that allow for the temperature of the stratosphere to adjust to the loss of ozone, the net effect is a decrease in radiative forcing. For middle and high latitudes throughout the year, the magnitude of this decrease may be larger than the predicted increases in the radiative forcing due to the increased abundances of CFCs over the last decade. Indeed, this ozone-induced decrease in radiative forcing could be offsetting a significant proportion of the increased forcing attributed to the increases in the abundances of all greenhouse gases over the same period. Changes in the global annual average radiative forcing due to the observed ozone depletion are predicted to be comparable in magnitude, but opposite in sign, to those attributed to the CFCs over the last decade.

99. Current tropospheric models exhibit large differences in their predictions of changes in ozone, the hydroxyl radical, and other chemically active gases due to emissions of methane, non-methane hydrocarbons, carbon monoxide, and nitrogen oxides. This arises from uncertainties in the knowledge of background chemical composition and an inadequate understanding of chemical reactions and dynamical processes. Hence, these deficiencies limit the accuracy of predicted changes in the abundance and distribution of tropospheric ozone, which is a greenhouse gas, and in the lifetimes of a number of other greenhouse gases, including the HCFCs and HFCs, which depend upon the abundance of the hydroxyl radical.

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### *Ozone Depletion and Global Warming Potentials (ODPs and GWPs)*

100. Steady-state and time-dependent ODPs have been recalculated with improved models that have incorporated more accurate reaction rate coefficients and absorption cross sections and known heterogeneous pr on sulfate aerosols. The numerical values are generally similar to t previous assessments.

101. A new semi-empirical, observation-based method of calculating OI been developed. The resulting values are generally larger (up to a f two as compared to some model-based estimates) for substances with lc stratospheric lifetimes (e.g., HCFC-22 and HCFC-142b) and slightly sm substances with short stratospheric lifetimes (e.g., carbon tetrachlc methyl chloroform). Since this approach utilizes more atmospheric observations and fewer model calculations in characterizing polar ozc losses, it is considered better than standard model ODPs, at least ir polar regions.

102. The direct GWPs (with five different time horizons: 20, 50, 100 and 500 years) for tropospheric, well-mixed, radiatively active subst have been recalculated using updated lifetimes for methane, nitrous c the halocarbons and following the same methodology of IPCC (1990). W exception of methane, new GWP results indicate only modest changes fr IPCC values, but uncertainties still exist in these calculations due limitations in knowledge of the carbon cycle.

103. Because of incomplete understanding of tropospheric chemical pr the indirect GWP of methane had not been quantified reliably at the t this report, although improvements and quantifications of uncertaint: near future are highly likely. The signs of the net changes in radiá forcing from known indirect effects have been established for some o: trace gases: methane, carbon monoxide, and non-methane hydrocarbons, are all positive. The sign of the changes in radiative forcing due t nitrogen oxides cannot currently be established. Furthermore, the bá concept of a GWP may indeed prove to be inapplicable for the very shc inhomogeneously mixed gases, such as the nitrogen oxides and the non- hydrocarbons. Hence, the IPCC (1990) conclusions concerning indirect not only uncertain, but many are also likely to be incorrect, e.g. fc nitrogen oxides.

### *Related issues*

104. *Ultraviolet radiation*. Significant increases in ultraviolet radi have been observed over Antarctica in conjunction with periods of inte ozone depletion. Under clear-sky conditions, these increases are cor with theoretical predictions. Furthermore, a Erythemal Radiative Amplification Factor of 1.25 ± 0.20 has been deduced from simultaneo measurements of column ozone and surface ultraviolet radiation at a site, which is in agreement with a model-calculated value of 1.1. T for the first time, the response of ground-level ultraviolet radiati changes in column ozone has been observed and quantified.

105. *Supersonic aircraft*. A previous, independent assessment of the of a projected fleet of supersonic aircraft on stratospheric ozone h predicted that ozone loss increases with the amount of nitrogen oxid emitted. These models used gas-phase chemistry and assessed ozone lo case of 500 aircraft flying at Mach 2.4 between 17-20 km with an ann use of 7 x $10^{10}$ kg/yr. The annual-average loss of column ozone at mid latitudes in the northern hemisphere is predicted to be 2-6 per cent

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comparable fleet operated at Mach 3.2 between 21-24 km, the comparable column ozone losses are 7-12 per cent. However, recent evidence has shown that reactions on sulfate aerosols can change the partitioning of nitrogen oxides. Two model studies incorporating this heterogeneous chemistry have recently re-examined the Mach 2.4 case and found substantially less ozone change (-0.5 to +0.5 per cent). These implications are being examined as part of a separate assessment.

106. *Shuttles and rockets.* The increase in the abundance of stratospheric chlorine from one projection of U.S. annual launches of nine space shuttles and six Titan rockets is calculated to be less than 0.25 per cent of the annual stratospheric chlorine source from halocarbons in the present day atmosphere (with maximum increases of 0.01 ppbv in the middle and upper stratosphere in the northern middle and high latitudes). The TOMS ozone record shows no detectable changes in column ozone immediately following each of several launches of the space shuttle.

107. *Volcanoes, ozone loss, and climate perturbations.* Major volcanic eruptions, such as Mt. Pinatubo, substantially increase the stratospheric abundance of sulfate aerosols for a few years. Since laboratory and field data show that heterogeneous processes can lead to increased levels of reactive chlorine in the stratosphere, such emissions have the potential to increase ozone losses temporarily. Furthermore, the increased levels of stratospheric sulfate aerosols are predicted to warm the lower stratosphere by about 4°C (which has been observed) and cool the Earth's surface by a much smaller amount.

108. *Tropospheric sulfate aerosols and climate.* Fossil fuel emissions over the past century have increased the tropospheric sulfate aerosol concentrations. Their contribution to the direct radiative forcing of the clear-sky northern hemisphere is contrary to that due to the greenhouse gases and is estimated to be a substantial proportion of the trace gas forcing.

*Implications for Policy Formulations*

109. The findings and conclusions of the research of the past few years have several major implications as input to policy decisions regarding human-influenced substances that lead to stratospheric ozone depletions and to changes in the radiative forcing of the climate system:

*Continued global ozone losses*

110. Even if the control measures of the amended Montreal Protocol (London, 1990) were to be implemented by all nations, the current abundance of stratospheric chlorine (3.3-3.5 ppbv) is estimated to increase during the next several years, reaching a peak of about 4.1 ppbv around the turn of the century. With these increases, the additional middle-latitude ozone losses during the 1990s are expected to be comparable to those observed during the 1980s, and there is the possibility of incurring widespread losses in the Arctic. *Reducing these expected and possible ozone losses requires further limitations on the emissions of compounds containing chlorine and bromine.*

*Approaches to lowering global risks*

111. Lowering the peak and hastening the subsequent decline of chlorine and bromine levels can be accomplished in a variety of ways, including an accelerated phase-out of controlled substances and limitations on currently uncontrolled halocarbons.

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- *Chlorine*. A significant reduction in peak chlorine loading (a few tenths of a ppbv) can be achieved with accelerated phase-out schedules of CFCs, carbon tetrachloride, and methyl*p1741Xchlorof[illegible] stringent controls on HCFC-22 would not significantly reduce peak chlorine loading (at most 0.03 ppbv, especially when ODP weighted), but do hasten the decline of chlorine.

- *Bromine*. A three-year acceleration of the phase-out schedule for the halons would reduce peak bromine loading by about 1 pptv. If the anthropogenic sources of methyl bromide are significant and their emissions can be reduced, then each 10 per cent reduction in methyl bromide would rapidly result in a decrease in stratospheric bromine of 1.5 pptv, which is equivalent to a reduction in stratospheric chlorine of 0.045 to 0.18 ppbv. This gain is comparable to that of a three-year acceleration of the scheduled phase-out of the CFCs.

*Elimination of the Antarctic ozone hole*

112. The phase-out schedule of the amended Montreal Protocol, *if fully implemented by all nations and* if there are no *continued* uses of HCFCs, affords the opportunity to return to stratospheric chlorine abundances of 2 ppbv sometime between the middle and the end of the next century. This is the level at which the Antarctic ozone hole appeared in the late 1970s and hence is about the level that is thought to be necessary (other conditions assumed constant, including bromine loading) to eliminate the ozone hole. *Such levels could never have been reached under the provisions of the original Protocol (Montreal, 1987).*

*Uncertain greenhouse role of CFCs*

113. The weight of evidence suggests that a large part of the observed lower stratospheric decrease in ozone is the result of CFC emissions. Furthermore, the radiative impact of this ozone decrease may have largely offset the predicted direct radiative perturbations at middle to high latitudes due to the CFCs' increases over the last decade. *Hence, even the sign of the overall radiative effect of CFC increases on the climate system over the last decade is uncertain.*

*Utility of GWPs*

114. The direct GWPs are a useful indicator of the relative radiative effects of long-lived, well-mixed, radiatively active trace substances. However, GWPs may be inapplicable for comparing the direct radiative effects of a long-lived, well-mixed gas to the indirect effects of a short-lived gas (for example, carbon dioxide to the nitrogen oxides). *For the latter need, the application of new tools, such as three-dimensional, fully coupled chemistry-climate models may be required.*

## B. *Executive summary of the environmental effects assessment of ozone depletion*

Solar Interactions

115. Significant global scale decreases in total ozone have occurred over the past ten years.

116. All other factors being constant, there is no scientific doubt that decreases in total ozone will increase UV-B radiation at ground level.

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117. Tropospheric ozone and aerosols may have masked the consequences of stratospheric ozone depletion for UV-B in some industrialized regions.

118. It is likely that in areas remote from anthropogenic emissions, the UV-B changes due to stratospheric ozone depletion would be only partially compensated by tropospheric ozone and aerosol increases.

119. There are no reliable estimates of the direction or magnitude of effects of any cloud cover trends on UV-B.

120. Efforts to improve local and regional air quality may bring to light the increases in UV-B associated with the depletion of stratospheric ozone.

*Health*

121. The induction of immunosuppression by UV-B has now been demonstrated in humans, not only those of light pigmentation, but also deeply pigmented individuals. This places all of the world's populations at risk of the potential adverse impacts of UV-B on the immune system, including possible increases in the incidence or severity of infectious disease.

122. An increased number of adverse ocular effects have been associated with exposure to UV. These include age-related nearsightedness, deformation of the lens capsule, and nuclear cataract (a form of cataract that previous information excluded from consideration). These effects appear to be independent of pigmentation. Including nuclear cataract among the forms of cataract likely to increase with ozone depletion enlarges slightly the risk estimates. It is now predicted that, all other things being equal, a sustained 10 per cent decrease in ozone will be associated with between 1.6 and 1.75 million additional cases of cataract per year world-wide.

123. Recent information on the relationship of non-melanoma skin cancer to UV exposures confirms previous findings and has allowed refinement of the carcinogenic action spectrum. Incorporation of this new information into the risk estimation process has led to slightly lower predictions. It is now predicted that a sustained 10 per cent decrease in ozone will be associated with a 26 per cent increase in non-melanoma skin cancer. All other things remaining constant, this would mean an increase in excess of 300,000 cases per year world-wide.

*Terrestrial Plants*

124. Continued research on plant responses to UV-B radiation underscores the concern for agriculture, forestry, and natural ecosystems as the ozone layer is depleted.

125. Growth and photosynthesis of certain plants (e.g., seedlings of rye, maize, and sunflower) can be inhibited even under ambient levels of UV-B radiation.

126. Certain environmental factors, both biotic (e.g. plant diseases and competition with other plants) and abiotic (e.g. carbon dioxide, temperature, heavy metals, and water availability), can interact with the effect of UV-B radiation in plants. This makes it difficult to make quantitative predictions.

127. Although most research to date has been with plants from temperate regions, data also show that certain tropical species may be adversely affected by enhanced UV-B radiation.

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*Aquatic Ecosystems*

128. Marine phytoplankton produce at least as much biomass as all terrestrial ecosystems combined.

129. Recent results show that the aquatic ecosystem is already under UV-B stress and there is concern that an increase in UV-B radiation will cause detrimental effects.

130. One consequence of losses in phytoplankton is reduced biomass production, which is propagated throughout the whole food web. This may result in losses of biomass for human consumption.

131. The marine phytoplankton are a major sink for atmospheric carbon dioxide. Any reduction of the populations would decrease the uptake of carbon dioxide and so augment the greenhouse effect. Also, phytoplankton production of dimethylsulphate (DMS), which acts as a precursor of cloud nucleation, would be reduced, hence potentially affecting global climate.

132. A UV-B induced decrease in microorganisms fixing atmospheric nitrogen would require significant substitution by artificial fertilizers, e.g., in rice production.

*Tropospheric Air Quality*

133. Chemical reactivity in the troposphere is expected to increase in response to increases in UV-B.

134. Tropospheric ozone concentrations could rise in moderate to heavily polluted areas, but should decrease in unpolluted regions (with low oxides of nitrogen levels), as recently confirmed by measurements in the Antarctic.

135. Other potentially harmful substances (hydrogen peroxide, acids, and aerosols) are expected to increase in all regions of the troposphere due to the enhanced chemical reactivity.

136. These changes could exacerbate problems of human health and welfare, increase damage to the biosphere, and might make current air quality goals more difficult and expensive to attain.

*Materials Damage*

137. UV-B radiation is particularly effective in light-induced degradation of wood and plastic products, leading to discoloration, and loss of strength. Increased UV-B content in sunlight will cause more rapid degradation, resulting in increased costs of using higher levels of conventional light stabilizers, possible design of new stabilizers, and faster replacement of the affected products.

138. Available research data are inadequate to estimate reliably the damage from higher UV-B levels to materials. Very limited relevant data are available for important classes of materials such as wood, plastic coatings, plastics used outdoors, and rubber. Data pertaining to performance of plastics in near-Equator regions of the world, with the harshest exposure environments, are particularly needed.

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additional experts served as advisors to the six committees and as peer reviewers. The Assessment describes current uses and quantities of controlled substances, estimates the technically feasible phase-out dates, estimates the quantity and time period for use of transitional substitutes, and specifically describes the implications of 1997 or earlier phase-outs.

*Progress in protecting the ozone layer*

142. The 1989 Technical Options Reports are recognized world-wide as authoritative catalogues of both commercial and emerging technologies to protect the ozone layer. Experts on the 1989 Assessment identified virtually all of the technologies that existed then and described important emerging technologies.

143. The 1989 Assessment, however, underestimated the technical feasibility of early reductions largely because industry and consumers have acted more quickly to reduce their dependence on ozone-depleting substances than had been anticipated. The 1989 Assessment also underestimated the ability of developing countries to phase out ozone-depleting substances when technology became available.

144. Since 1986 there has been a dramatic world-wide reduction in the production of CFCs and halons - a drop that reflects world-wide concern for the ozone layer. CFC production is 40 per cent below 1986 levels. At this rate of progress, consumption[°] will be reduced by 50 per cent in 1992 - a three-year advance on the requirements of the Amended Protocol, as shown in Table 5 below.

Table 5

*Estimated phase-out progress*

| *Product* | *Per cent cut in Production between 1986 and 1991* |
|---|---|
| CFC 11 | 37 |
| CFC 12 | 41 |
| CFC-113 | 41 |
| CFC-114 | 70 |
| CFC-115 | 15 |
| Total CFC | 40 |

145. The CFC global 1991 market has changed in comparison with the 1986 market as follows:

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Yugoslavia.

[°] The Montreal Protocol defines consumption as production plus imports minus exports and therefore does not limit the use of recycled material. This definition of consumptions is used throughout this report.

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Table 6

*Applications of CFCs*

| *Use* | *Per cent decline* |
|---|---|
| Propellants | 58 |
| Cleaning agents | 41 |
| Blowing agents | 35 |
| Polyurethane | 30 |
| Phenolic | 65 |
| Extruded polystyrene | |
| sheets | 90 |
| Boards | 32 |
| Polyolefin | 35 |
| Refrigerants | 7 |
| Total market | 40 |

N.B. Categories do not total as not all applications are covered.

146. Production of halon 1211 and halon 1301 peaked in 1988 and is now declining. Production of halon 2402 within OECD nations has virtually ceased. Many countries[7] have national legislation that is more stringent than the Protocol. Several large CFC/Halon production facilities have been closed and more closures are planned. The world's largest manufacturer of CFCs has announced that it will close its facilities by 1997.

147. Several multinational companies are eliminating the use of ozone-depleting substances far faster than even the stipulations of even the most stringent regulation. By January 1992, the first companies will have eliminated the use of CFC-113 solvents in all their world-wide operations; halon and CFC recycling will be accepted world-wide; the first HFC-134a automobile air conditioners will be commercialized, and many other ozone-safe technologies will be available. The first HFC-134a domestic refrigerators will be commercialized in 1992. The international fire protection community has virtually eliminated halon emissions caused by discharge testing and halon emissions during training and in servicing equipment have been drastically reduced. Educational programmes by fire protection associations are proving successful as users move to alternative fire protection measures, where feasible, and voluntarily limit halon use to essential applications.

*Technical feasibility of early phase-out*

148. In developed countries, it is technically feasible to phase out virtually all consumption[8] of CFCs and halons by 1995-1997, 1,1,1-trichloroethane as early as 1995, and no later than 2000 and carbon

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[7] These headstart countries include Austria, Australia, Canada, Denmark, Finland, Germany, Luxembourg, Netherlands, Norway, Singapore, Sweden, Switzerland, the United States, and the European Economic Community.

[8] As defined by the Montreal Protocol.

tetrachloride in the vast majority of applications by 1995 with final phase-out by 1997. These technically feasible phase-outs are shown graphically at the end of this report.

149. These rapid phase-out schedules require that the results of toxicity tests, environmental assessments, and risk analyses conclude that the alternative substances - HCFC-123, HCFC-124, HCFC-141b, and HFC-134a - can be safely used for refrigeration, air conditioning, insulating foam, and for some aerosol, sterilization, and minor solvent uses; that these HCFCs and HFC are environmentally acceptable; and that they are commercially available in adequate quantities. A rapid phase-out will also require increased short-term use of HCFCs-22 and -142b that are currently available.

150. The 1995 phase-out of 1,1,1-trichloroethane in developed countries depends on world-wide technical cooperation of industry leading to very rapid dissemination and adoption of technologies among many thousands of small users. Without cooperation the phase-out could take until 2000.

151. A 1997 phase-out is technically feasible for refrigeration and air conditioning, but it will involve increased costs. Costs of early retirement of capital could cost several billion dollars, a sum that would rise disproportionately more with the rapidity of the phase-out. Whether or not early retirement is necessary will depend on the success of recycling and recovery at disposal and on the development of technology for simple retrofitting of equipment. Technology for retrofitting air conditioning systems in vehicles is particularly important in some countries.

*Halons*

152. The halon phase-out is contingent on the use of recycled halons as the primary supply of those agents. An orderly transition to alternative fire protection measures, the establishment of procedures to manage the bank of halons adequately, and increased efforts to develop transitional and eventual replacement fire extinguishing agents may minimize the loss of fire protection capability represented by the halon phase-out.

153. The Halon Technical Options Committee did not explicitly consider a halon phase-out before 1997. However, their report provides estimates of the size of the halon bank based on production phase-out in 1995, 1997, and 2000. The existing bank of halon 1211 may be sufficient to maintain equipment that remains in service and to provide into the next century small quantities for most essential applications. The bank of halon 1301 may be adequate not only to maintain systems that remain in service for up to 45 years after production ceases, but also to supply most essential new applications (no more than 10 per cent of the 1986 level of installations for up to 30 years after production ceases). Although halon bank management has not been demonstrated, military and civilian users are moving in that direction. Future production of halons for essential uses under the terms of the Protocol may be necessary if halon banks are depleted and if no environmentally acceptable alternatives and substitutes are available. The cooperation of the fire protection community will continue to be essential. Criteria for identifying essential halons uses have been developed by the Halons Technical Options Committee. However, successful management of the bank of halons would satisfy essential uses for the foreseeable future.

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154. The potential risk to human life posed by the phase-out of halons is of concern. Parties to the Protocol must make decisions based on an integrated overview that balances the threats of stratospheric ozone depletion against the threats from fire or explosion.

*Phase-out in developing countries*

155. It is technically and economically feasible to phase out some applications of ozone-depleting substances in developing countries on the same schedule as developed countries. With adequate financing and technical assistance, these substances can be phased out in non-medical aerosol products, electronics manufacturing, and flexible and non-insulating foam by 1992-1995.

156. Developing countries may need additional time for some applications. In some instances, the information, training, and infrastructure required to phase out a use are not available; in others, developing countries may need to preserve the useful life of capital that depends on CFCs.

157. Financial assistance and training through the Fund are critical. With proper support, it is technically and economically feasible for most developing countries to phase out consumption of controlled substances within five to eight years after developed countries.

158. Most developing countries have both low levels of halon consumption and banked halon. It may therefore be desirable to transfer excess halon recovered from the developed countries to the developing countries for use in essential applications. In addition, national and international regulatory barriers to such transfers should be minimized.

*Some important implications of a 1997 phase-out*

159. The costs of a 1997 phase-out are higher than a 2000 phaseout, particularly in refrigeration and air conditioning. Upto half of the additional cost can be attributed to retrofitting vehicle air conditioners in the United States and Japan. The cost of an early phase-out will depend on the number of systems that may need to be retrofitted and on the cost of each retrofit. Costs may decrease with further development of retrofit technology.

160. The commercial availability of substitutes and alternatives for several small, but important uses of ozone-depleting substances is uncertain. These important uses include oral inhalant drug products, precision cleaning, and drying of high-technology products. In the next assessment, Parties may wish to consider technical developments related to early retirement of capital.

*Transitional substances*

161. The HCFCs required for existing applications and to phase out CFCs for specific applications. The overall ODP impact of transitional substances will be minimized if HCFCs with the lowest ODP are selected and used only where no substitutes are available. The Science Assessment Panel is providing estimates of ODPs.

162. The selection of technologies to replace the use of controlled substances should be made to minimize energy consumption as well as ozone depletion. The energy efficiency of foams and refrigeration equipment has a greater influence on climate change than the emissions of particular substances used in those applications. A report by Alternative Fluorocarbons Environmental Acceptability Study and the United States Department of Energy

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developed a methodology for calculating the Total Equivalent Warming Impact (TEWI) of various substitutes for insulating foam, refrigeration and air conditioning, and solvents.

Table 7

*Estimates of HCFCs for existing and replacement CFC uses*

| *Sector* | *1997 HCFC use (Kilotonnes)* | *Per cent Replaced*[9] | *Most likely HCFCs* |
|---|---|---|---|
| Foams | 150 | 56 | 22, 123, 141b, 142b |
| Refrig./AC[10] | | | |
| Existing[11] | 149 | n.a. | 22, 142b |
| Replace CFC | 86 | 45[12] | 22, 123, 124, 142b |
| Auto retrofit | 0-40[13] | 0-30 | 22, 124 |
| Aerosol products | 20-33[14] | 5-8 | 22, 142b |
| Sterilants | 0-15 | 50-75[15] | 124 |
| Fire fighting | 0-7 | 0-28 | 123 |
| Solvents | 18-50 | 3-8 | 141b, 225 |
| Total | 423-517[16] | | |

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[9] Per cent of CFC used in this application in 1986 and replaced by HCFCs in 1997.

[10] In 1997, 75 per cent of HCFC used in refrigeration and air conditioning is expected to be HCFC-22. The rest will be HCFC-123, HCFC-142b, and HCFC-124.

[11] These are refrigeration and air conditioning applications, as well as refrigerant blends that currently use HCFC-22, including HCFC-22 used in refrigerant mixtures.

[12] It is estimated that 45 per cent of current CFC use will be replaced by HCFCs, 45 per cent by HFCs, and 10 per cent by ammonia.

[13] The amount of HCFC used for vehicle air conditioners depends on the timing of the introduction of HFC-134a in new vehicles, the success of recycling, and the possible use of HCFC in retrofitting. If used, HCFC for vehicle air conditioning will decline to small levels by 2005 when most cars that use CFC air conditioners will be retired or not valuable enough to service (in 2005, cars with CFC-12 will be 10 years or older).

[14] In 1989, 20 kilotonnes of HCFCs were used in industrial and consumer aerosol products. It is expected that total use in 1997 will be between 20 and 30 kilotonnes with an increasing portion used in industrial applications. HFC-134a and HFC-227 could ultimately replace all industrial uses and medical applications.

[15] It is estimated that approximately 25 to 50 per cent of 1986 CFC/Ethylene Oxide (EO) sterilization will be replaced by $Co_2$/EO, pure EO, or alternatives not using EO.

[16] Includes the 149 kilotonnes used in existing HCFC-22 applications.

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163. HCFCs will have to be available for a reasonable time to take into account test: (1) chemicals will be produced only if plant investment can be recovered, (2) users incur costs for transition into and out of HCFC use, and (3) the HCFCs are needed for service during the useful life of the equipment. Refrigeration equipment has a long service life and therefore requires HCFC for service. Foam production and solvent operations require less time and lower costs to change to new chemicals.

164. HCFC transitional substances can be eliminated in some applications faster than in others. Early decisions would avoid the sale of equipment dependent on transitional substances within 15 or 20 years of the final phase-out and thus avoid costs of retrofit or early retirement. Based on the impressive record of technical progress to date and on the intensity of industry's efforts to find final alternatives to ozone-depleting substances, it may be possible for users to phase out these chemicals faster. Future technical assessments should evaluate the rate of technical progress and the prospects for eliminating transitional substances.

*Technical and Environmental Uncertainty*

165. The rate of technological progress has been rapid, but not all questions about acceptability of substitutes have been resolved (e.g., more toxicity testing under way; further applications testing; regulatory approval of inhalant drug products, the best technology to retrofit equipment etc.). The Assessment Panel cannot rule out the possibility that in the future, exemptions may be needed if controlled substances are phased out in 1997, although it cannot state now that any exemptions will be required.

166. There is no perfect substitute. Each substitute has difficult trade-offs in terms of the ODPs of transitional substances, GWPs, energy efficiency, and toxicity. Trade-offs can be minimized and mitigated by recycling and bank management, by limiting the use of transitional or high GWP options only where necessary, and by limiting occupational exposures.

*Developing country concerns*

167. Developing countries must address special problems if they are to meet earlier phase-out dates.

- It is critical to successful phase-out that technologies are available to developing countries, that supporting technical cooperation and training is provided, and adequate financial assistance is forthcoming. It is expected that technologies will be made available through existing channels and mechanisms and supported by the Multilateral Interim Fund. Suitable technologies are clearly available for many aerosol, foam, and solvents applications;

- Many users in developing countries may not know about available substitutes and alternatives. The development of adequate channels for the collection and distribution of information is crucial to the successful transfer of technology and phase-out of controlled substances in developing countries;

- Some developing countries may experience difficulties in limiting occupational exposures or release of toxic chemicals and may therefore want to choose alternatives that have high exposure limits and minimum wastestreams;

- There is concern that producers in developed countries with fast shrinking domestic markets may sell excess controlled substances in developing countries, or that as obsolete equipment that depends on controlled substances, will be sold in the developing countries markets;

- Chemical alternatives, including HCFCs, HFCs, and hydrocarbons, are becoming available through commercial channels both as imports and for production;

- Recovering and recycling at disposal and managing banks of ozone-depleting substances will be difficult in developing countries because of infrastructure training and the handling of small quantities of controlled substances that are cumulatively significant. It will be important for developing countries to optimize the use of these substances and implement their containment and recycling in order to serve their own needs and to eliminate unnecessary emissions;

168. Several developing countries are entering into innovative technology cooperation projects that may be useful models for others to follow. Mexico and China for example, have announced a goal of phasing out controlled substances on the same schedule as developed countries. The Mexican Government and industry are forming partnerships with the U.S. Environmental Protection Agency, the Industry Cooperative for Ozone Layer Protection, and Northern Telecom to phase out solvents. Similar partnerships may speed elimination in other developing countries.

169. The Government of Thailand has announced a new partnership with the United States Environmental Protection Agency, the Japanese Ministry of International Trade and Industry, as well as Japanese and American industry associations to encourage and coordinate the phase-out of solvents in Thailand. This project addresses the fact that solvents contribute 40 per cent of Thailand's CFC use, that up to 97 per cent of solvent use is attributable to Japanese and United States companies, while an additional 22 per cent of solvent use can be ascribed to joint ventures.

170. Refrigeration research and development through joint research programmes with industry and other Governments is taking place in several developing countries, including Brazil and China. The goal is to identify suitable alternatives for each country's specific situation and needs.

*Decisions required in 1995 for a 1997 phase-out*

171. A 1997 phase-out will require a 1994 Assessment at the latest that will address the following:

- Some important applications do not yet have identified alternatives: up to 5 per cent of the population could use oral inhalant drug products which now contain CFCs, but alternative propellants may not be approved by 1997; no suitable alternatives have yet been commercialized for some precision cleaning, adhesive, and electronic manufacturing and fire protection uses;

- A 1997 or earlier phase-out of halons will require adequate arrangements for management of the bank. Progress in such bank management will need to be reviewed;

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- Refrigeration and air conditioning systems are expensive capital investments with long product lives. Based on 1991 calculations, recycling alone is not expected to provide sufficient CFC for service in all countries. Retrofit technology should be reassessed.

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FIGURE 1

Synthesis: Trop. Chlorine Loading (ppb)

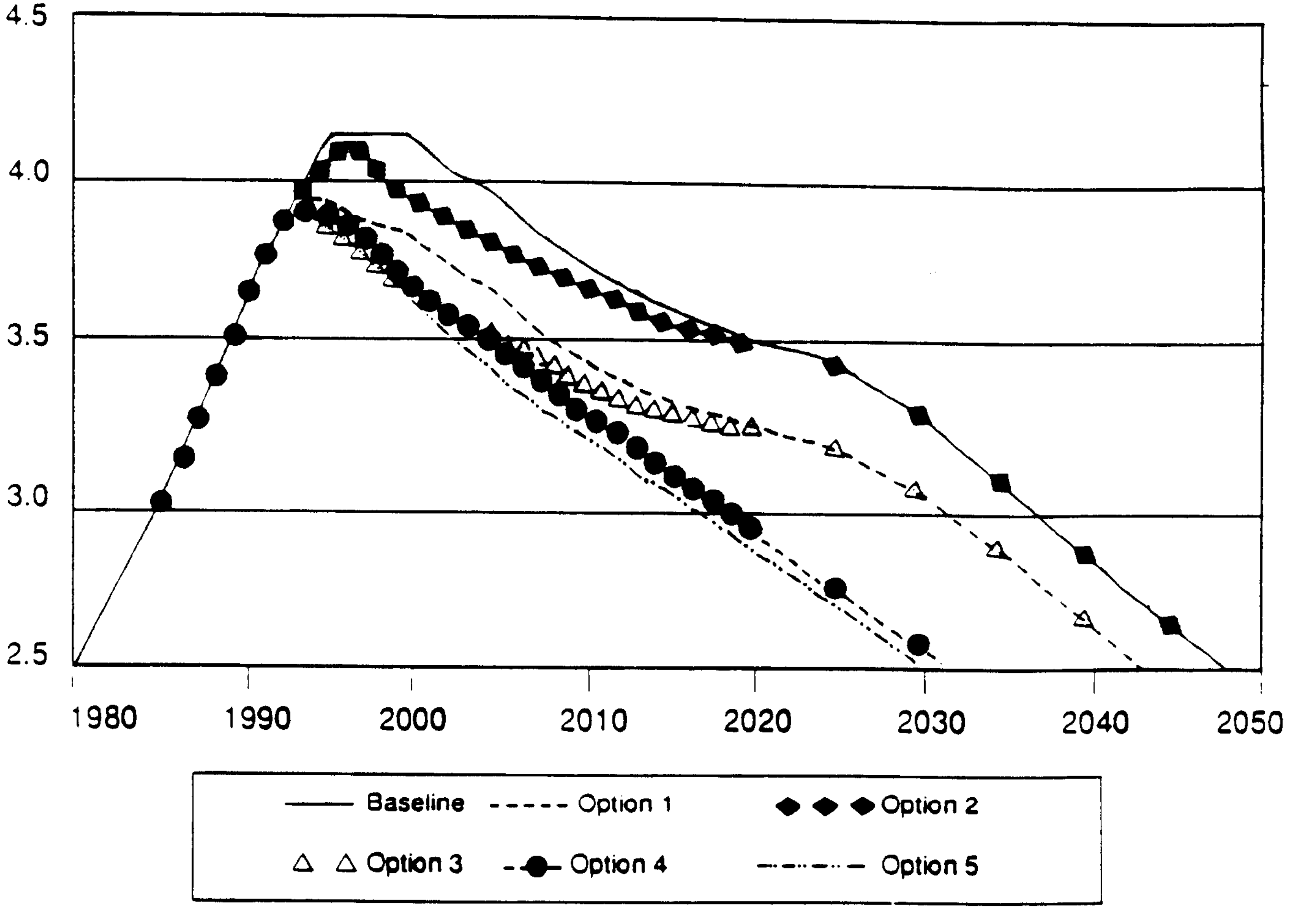
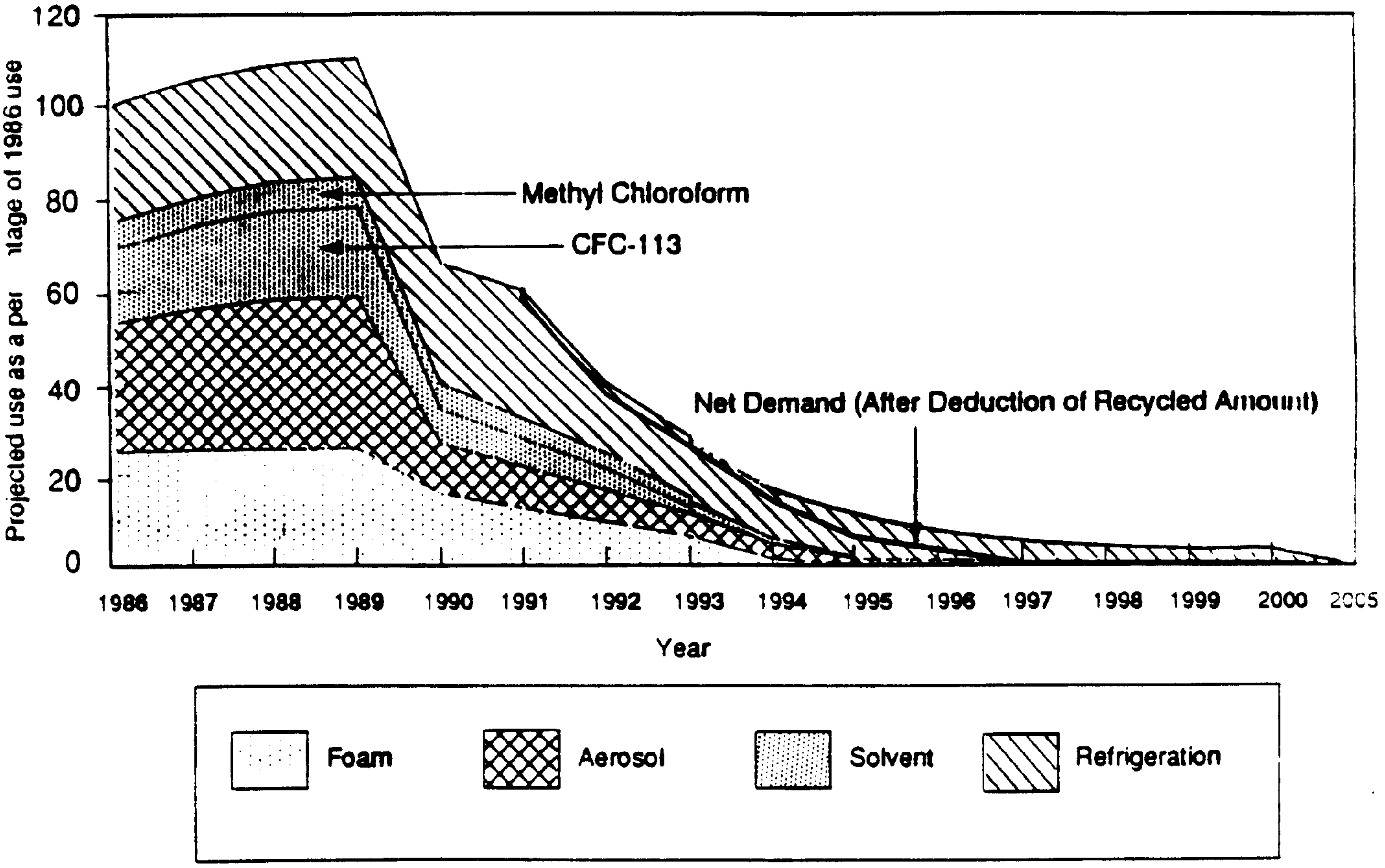


FIGURE 2

## Technically Feasible Production Phase-out for CFC and 1,1,1-Trichloroethane

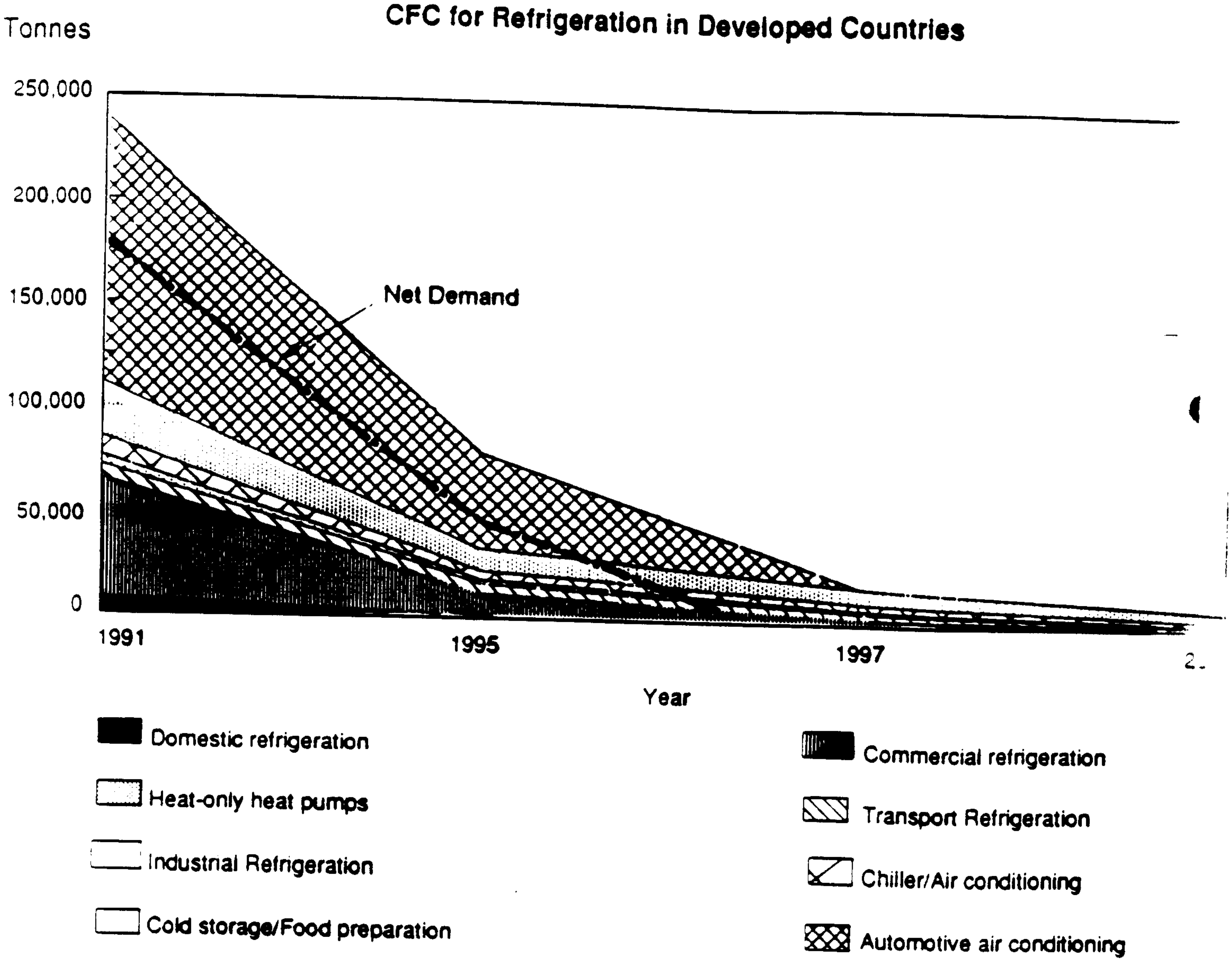


Note 1: The amounts of CFC used in sterilants and miscellaneous uses is small and cannot be depicted in the scale used. Some of the Technical Options Committees agreed upon a range of phase-out dates. This chart presents the technically optimistic case.

Note 2: The use of controlled substances is presented on an ODP weighted basis.

FIGURE 3

CFC for Refrigeration in Developed Countries



Note: Net demand is equal to the total demand minus the recycled CFC available. Therefore, the net demand is the amount new CFC which must be produced. Accelerated retrofit begins in mid-1996 reflecting the inadequate supply of recycled CFC production of virgin CFC is halted in 1997. After 1997, the equipment that cannot be serviced with recycled CFC is retrofitt retired.

## FIGURE 4

## Production Phase-out Projection for Halons (ODP weighted)