United Nations
Environment
Programme

Distr.
GENERAL

UNEP/OzL.Conv.2/Inf.2
22 April 1991

ENGLISH ONLY

SECOND MEETING OF THE CONFERENCE OF
THE PARTIES TO THE VIENNA CONVENTION
FOR THE PROTECTION OF THE OZONE LAYER

Nairobi, 17-18 June 1991

OZONE DEPLETION

Draft Issues Paper

prepared by

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Draft:April 18, 1991

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This paper will summarize: (i) the key conclusions from the latest international scientific, environmental effects, technology, and economics assessments that were completed in July 1989, and were mandated under Article 6 of the "Montreal Protocol on Substances that Deplete the Ozone Layer"; (ii) key scientific and technology findings discovered within the last year; (iii) reporting and systematic observations requirements for CFCs and their proposed substitutes; (iv) research needs; (v) assessment schedules; (vi) current status of international regulations concerning CFCs, Halons and other halogenated chemicals; and (vii) conclusions.

1.0 INTERNATIONAL ASSESSMENT SUMMARIES

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

1.1 Scientific Assessment of Stratospheric Ozone

Recent Findings

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

- Antarctic Ozone Hole: The weight of scientific evidence strongly indicates that chlorinated (largely man-made) and brominated chemicals are primarily responsible for the recently discovered substantial decreases of stratospheric ozone over Antarctica in springtime.
- Perturbed Arctic Chemistry: While at present there is no measurable ozone loss over the Arctic comparable to that over the Antarctic, the same potentially ozone-destroying processes have been identified in the Arctic stratosphere. The degree of any future ozone depletion will likely depend on the particular meteorology of each Arctic winter and future atmospheric levels of chlorine and bromine.
- Long-Term Ozone Decreases: The analysis of the total-column ozone data from ground-based Dobson instruments show measurable downward trends from 1969 to 1988 of 3 to 5% (i.e., 1.8 - 2.7% per decade) in the northern hemisphere (30 to 64oN latitudes) in the winter months that cannot be attributed to known natural processes.
- Model Limitations: These findings have led to the recognition of major gaps in theoretical models used for assessment studies. Assessment models do not simulate adequately polar stratospheric cloud (PSC) chemistry or polar meteorology. The impact of these shortcomings for the prediction of ozone layer depletion at lower latitudes is uncertain.

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

Implications

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

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

- Even if the control measures of the 1987 Montreal Protocol were to be implemented by all nations, today's atmospheric abundance of chlorine [about 3 parts per billion by volume (ppbv)] will at least double to triple during the next century. *Assuming that the atmospheric abundance of chlorine reaches about 9 ppbv by about 2050, ozone depletions of 0 - 4% in the tropics and 4 - 12% at high latitudes would be predicted, even without including the effects of heterogeneous chemical processes known to occur in polar regions.*

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

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

1.2 Environmental Effects

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

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

Human Health

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

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

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

Terrestrial Plants

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

Aquatic Ecosystems

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

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

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

Tropospheric Air Quality

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

Materials Damage

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

Key Areas of Uncertainty

The key areas of uncertainty are in the following areas:

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

1.3 Technology Review

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

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

- 25% of the world's CFCs are used in foam production. It is technically feasible to reduce consumption by 60-70% by 1993 with a virtual phase out by 1995. These reductions are dependent to a large degree on the availability of new HCFCs.
- CFC-113 solvent use in electronic, precision, metal, and dry cleaning represents about 16% of the global consumption of the controlled CFCs. There is no single universal substitute for all CFC-113 solvent uses, but rather a myriad of options. The most predominant use is in the electronics subsector. All CFC-113 solvent uses can be phased out by the year 2000. The CFC-113 phase out is only partially dependent on the availability of HCFCs, due to the large variety of non-HCFC alternatives including: product and process substitutes, water cleaning, no-clean technologies, hydrocarbons (e.g., terpenes, alcohol, and white spirits), etc.
- Sufficient technical options exist now to phase out CFC use as aerosol propellants, with the exceptions being some medical products and other minor uses. CFC-12 use in sterilization can be substantially reduced using existing alternatives and can be phased out by 1995 in developed countries and somewhat later in developing countries. In food freezing applications, substitution is technically feasible and cryogenic techniques (liquid nitrogen) are commercially available.
- Based on industry growth projections at the year 2000, HCFCs are estimated to capture up to 30% of the current CFC market. An additional 10% of demand could be captured by HFCs with the remaining 60% of demand satisfied by product and process substitutes. The use of HCFCs will be essential in achieving early reductions and eventual phase-out of CFCs.
- There are currently no substitute chemicals with equivalent characteristics to halons, but halons are not essential in many of their current uses. Confining halons to essential use and maximizing conservation and management of the bank (halons stored or in existing equipment) could reduce consumption by 50-60% by 1997. Unless new substitutes are developed, a phasedown of 60 - 80% may leave the choice of continuing to use halons in only the most essential areas with the resultant adverse impact on the ozone layer or to proceed with a phase-out and accept an increased fire risk.
- Technology is currently available to capture, recycle, and destroy CFCs and halons; however, more cost effective techniques are currently under development.

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

1.4 Economic Implications

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

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

Economic implications have to be considered in the context of developed and developing economies separately.

Economic/Environmental Benefits of Reduced CFC/halon Use.

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

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

The Costs of Technical Substitution

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

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

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

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

Technology Transfer.

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

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

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

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

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

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

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

2.0 RECENT FINDINGS

2.1 Scientific Understanding of Stratospheric Ozone

- In 1990, the spring-time depletion of the ozone layer over Antarctica was as severe as in 1987 and 1989, but persisted even longer than in these two years and did not disappear until late December.

- Provisional results from a new analysis of the last 11 years and 7 months of TOMS satellite data, supported by ground-based Dobson observations in the northern hemisphere, indicates:

  - total ozone between 65 N and 65 S has been decreasing at an average rate of about 0.26±0.14% per year (3.0% over 11 years and 7 months), after correction for known natural influences on the abundance of ozone (e.g., solar cycle);
  - statistically meaningful ozone depletions at all latitudes in winter north of 30 N, with a maximum depletion of about 9±3% centered at 45 N in February and March.
  - a 3-5% ozone depletion north of 35 N in springtime (April and May);
  - a 4% or greater ozone depletion at all latitudes south of about 40 S throughout the year.
  - no statistically significant ozone trends observed between 30 N and 30 S throughout the year, nor between 30 N and 50 N during summer.

- The observed satellite trends are larger, and extend from winter into the spring period, than reported by the International Ozone Trends Panel (IOTP) for the period 1969 to 1986, and the last international assessment for the period 1969 to 1988.

- The observed ozone depletions at mid-high latitudes in the northern and southern hemisphere are substantially greater (e.g., factors of 2 - 5, depending upon season and latitude) than the decreases predicted by standard gas-phase photochemical models that do not include heterogeneous processes.

- While the cause of the observed ozone depletion has not been unequivocally identified, the ozone changes coupled with other atmospheric data are strongly suggestive of a chlorine-induced effect.

- If the observed decrease in mid-latitude ozone is caused by anthropogenic chlorine emissions, and to a lesser extent bromine emissions, then it is clear that the amount of ozone will continue to decrease over the next decade or so as the stratospheric abundances of chlorine and bromine increase in response to the continued emissions of chlorofluorocarbons (CFCs), methylchloroform, carbon tetrachloride, Halons, and other halogenated substances.

- Under the conditions of the "revised" Montreal Protocol, stratospheric chlorine is projected to increase from about 3.3 ppbv today, to between 4 and 4.5 ppbv between the years 2000 and 2005. Unfortunately, as stated above, current gas-phase photochemical models underestimate the observed decrease in ozone over the past one to two decades, and therefore cannot be used to reliably predict how ozone will respond over the next ten to twenty years to the inevitable increase in atmospheric chlorine and bromine.

- Model calculations have shown that to: (i) minimize peak-chlorine loading; and (ii) eliminate the Antarctic ozone hole and return mid-latitude ozone levels to those of the 1970s as soon as possible (achieved by reducing atmospheric chlorine to about 2 ppbv), will require:

  - a global phase-out in the emissions of long-lived chlorofluorocarbons, methylchloroform, carbon tetrachloride, and Halons as soon as possible

(100% compliance is essential);
- not-in-kind substitution of CFCs wherever practical.
- the substitution of long-lived CFCs with HCFCs having the shortest possible lifetimes, hence low values of ozone depleting potentials (remember that all HCFCs are not equal: those with short atmospheric lifetimes (1-5 years) pose a significantly lower threat to the ozone layer than those with moderately long lifetimes (greater than 15 years));
- a phase-out of halocarbon substitutes (HCFCs and HFCs) sometime in the middle of the next century (phase-out date should depend upon the atmospheric lifetime of the substitute), and possible emission rate limitations;
- the recycling of HCFCs to the maximum extent possible;
- stabilize the atmospheric concentration of bromine at current levels or below.

2.2 Technology Advances

o Solvents: Technologies not widely available in 1989 but now fully commercialized include:

- Retrofit kits and management practices for small vapor degreasers which cut solvent use by up to 50%;
  - HCFC solvent blends and equipment;
  - Semi-aqueous solvents;
  - Closed-loop aqueous equipment (no discharge to drain);
  - Controlled atmosphere soldering.

Twenty or more U.S., European, and Asian multi-national corporations will halt their use of CFC-113 between late 1991 and 1995, and progress is being made on finding suitable substitutes for methylchloroform (methylchloroform was not evaluated in the 1989 technology assessment).

o Sterilization: Technologies not widely available in 1989 but now fully commercialized include:

- An HCFC/ethylene oxide blend provides equivalent sterilization; but not yet approved for medical use.

o Refrigeration and Air Conditioning: Technologies not widely available in 1989 but now fully commercialized include:

- Performance-certified automobile air conditioning recycling equipment is now in widespread use in the U.S., Australia, and elsewhere;
- CFC-11 recycling equipment is entering the market;
- New CFC management devices (purge, capture, leak detection, etc.) are available to significantly cut operating costs;
- HCFC-123 equipment is marketed which achieves the same energy efficiency as the CFC-11 systems they replace;
- R-32 and R-32 blend refrigerants (zero ODP, low GWP) are under intensive review in some applications with a potential of up to 11% increase in energy efficiency;
- European automobile manufacturers will introduce automobile air conditioners using HCFC-134a in limited production this year, and Nissan will replace CFC-12 with HCFC-134a after 1993.

- Rigid Foam: Technologies not widely available in 1989 but now fully commercialized include:
  - Low-CFC rigid insulating foam for domestic refrigerators providing equivalent energy efficiency with up to 30% reduction in CFC (potential CFC reduction depends upon the initial CFC concentration);
  - High pressure gases and blends are now being considered as options.
- Flexible Foam: Technologies not widely available in 1989 but now fully commercialized include:
  - New polyol and blowing agent development;
  - Additives and surfacants to achieve softness.
- Halons: Technologies not widely available in 1989 but now fully commercialized include:
  - At least four candidate agents announced (ODP of zero to 1.1)
  - Existing options reducing Halon use 25 - 30% world-wide prior to the Montreal Protocol restrictions;
  - Existing inventory ("bank") of halon now estimated to provide adequate halon for likely "essential" uses well into the next century.

3.0 REPORTING AND SYSTEMATIC OBSERVATION REQUIREMENTS FOR CFCs and PROPOSED HCFC and HFC SUBSTITUTES

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

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

4.0 RESEARCH NEEDS

The overall goal of the research activities should be to understand the physics, chemistry and transport processes of atmospheric ozone, how natural phenomena and human activities affect it, and the consequences for human health and natural and managed ecological systems. This will require a comprehensive program of systematic observations, process studies, emission scenario development, and predictive modeling. The high priority areas include:

- Characterization of the chemical and meteorological conditions leading to stratospheric ozone loss, in polar regions and at mid-latitudes in both hemispheres. A key question is whether there is a threshold for the onset of rapid ozone depletion in the northern hemisphere, similar to that observed in the development of the Antarctic ozone hole.
- Improved theoretical models of the chemical. radiative and dynamical processes that control the abundance and distribution of ozone.
- Development of a ground-based monitoring network, to complement satellite observations, for atmospheric composition and ground-level UV-B.
- Improved understanding of the effects of UV-B on human health and terrestrial and aquatic ecosystems.

5.0 ASSESSMENTS

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."

Scientific, effects, and technology/economic assessments are currently being prepared for the Fourth meeting of the Contracting Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer. These assessments, their executive summaries, and a synthesis report will be available to governments by January 1, 1992.

6.0 PROVISIONS OF THE "REVISED" MONTREAL PROTOCOL

The second meeting of the parties adjusted existing control requirements or ammended the protocol such that:

- CFCs (11, 12, 113, 114, 115) to be reduced by 50% in 1995, 85% in 1997 and phased out in 2000. A study to be completed in 1992 will assess the feasibility of accelerating the reduction schedule.
- Halons (1211, 1301, 2402) are to be reduced by 50% by 1995 with a phase-out (except for essential uses) to occur by 2000. By decision, the parties voted to establish an ad-hoc technical group to report back to them by 1992 concerning the identification of essential uses.
- Carbon tetrachloride emissions are to be reduced by 85% by 1995 and phased out by 2000.
- Methyl chloroform emissions to be frozen in 1993, reduced by 30% in 1995, 70% in 2000, and phased out in 2005.

- Other fully halogenated CFCs: To be reduced by 20% in 1993, 85% in 1997, and phased out in 2000.

The meeting also adopted non-binding resolutions in the following areas:

- Parties to refrain from producing other halons not now regulated by the Protocol if they pose a threat to the ozone layer
- Parties to use HCFCs only where other alternatives are not available and to phase out these chemicals by no later than 2040 and if possible, not later than 2020.

7.0 CONCLUSIONS

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

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

Current (1990) Montreal Protocol. The total chlorine and bromine loadings of the atmosphere are predicted to peak between 4 and 5 ppbv, and near 20 pptv, respectively, during the 2000 - 2010 time period, and decrease slowly there-after During the next 10 to 20 years, the Antarctic ozone depletion would be expected to be comparable or worse than at present and significant Arctic ozone losses would become more likely. The key issue is quantifying ozone depletion at mid-latitudes in both hemispheres.

Antarctic Ozone "Hole". The Antarctic ozone hole will not disappear until the atmospheric abundance of chlorine is reduced to the levels of the early 1970's: 1.5 - 2 ppbv. In addition, the atmospheric abundance of bromine should be reduced below today's level. This will be achieved, assuming 100% global compliance, through the revised Montreal Protocol by a complete phase-out of the fully halogenated CFCs, halons, carbon tetrachloride, and methyl chloroform, careful consideration of what emission rates of the HCFCs are acceptable, and a phase-out of all HCFC substitutes sometime near the middle of the next century. Even if all anthropogenic sources of atmospheric chlorine were to be eliminated today, the time taken for the abundance of atmospheric chlorine to be reduced below 2 ppbv would be many decades, hence the Antarctic ozone hole will recur seasonally for a long time to come.

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

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

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