Distr.
GENERAL

UNEP/OzL.Pro/WG.1/11/3
29 December 1994

ORIGINAL: ENGLISH

OPEN-ENDED WORKING GROUP OF THE
PARTIES TO THE MONTREAL PROTOCOL
Eleventh meeting
Nairobi, 8-12 May 1995

THE 1994 SCIENCE, ENVIRONMENTAL EFFECTS, AND TECHNOLOGY AND ECONOMIC ASSESSMENTS

Synthesis Report*

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* Prepared at the request of the United Nations Environment Programme, on behalf of the Parties to the Montreal Protocol.

Synthesis Report Panel

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1994 SYNTHESIS REPORT

EXECUTIVE SUMMARY

ES.I. The rates of build-up in the atmosphere of human-made compounds that deplete the ozone layer (e.g. chlorofluorocarbons (CFCs) and halons) have slowed in recent years as a direct result of reductions in global emissions of these compounds, thus demonstrating the intended impact of the Montreal Protocol and its Amendments and Adjustments.

ES.2. The peak global ozone depletion is expected to occur during the next several years, and the stratospheric ozone layer is expected to recover (if other factors remain unchanged) in about 50 years in response to international actions under the Montreal Protocol and its Amendments and Adjustments.

ES.3. Unusually low global ozone has been observed over the past two years, with the most severe Antarctic ozone "hole" and lowest seasonally averaged ozone in the northern hemisphere. These anomalies are likely due, in part, to chemical processes linked to the 1991 eruption of Mt. Pinatubo in the Philippines. The 1994 global ozone levels are returning to values closer to those expected from the longer-term downward trend.

ES.4. Methyl bromide continues to be viewed as a significant ozone-depleting chemical (with an ozone-depleting potential (ODP) of 0.6). Three major anthropogenic sources of methyl bromide are identified: agricultural usage (soil and commodity fumigation), biomass burning, and potentially the exhaust of automobiles using leaded gasoline; in addition to the natural ocean source.

ES.5. The link between a decrease in stratospheric ozone and an increase in surface ultraviolet (UV) radiation has been further strengthened. Measurements of UV radiation at the surface under clear-sky conditions show that low overhead ozone yields high UV radiation and in the amount predicted by radiative-transfer theory. Large increases of surface UV are observed in Antarctica and the southern part of South America during the period of the seasonal ozone "hole."

ES.6. Increases in UV-B radiation (290-315mm) have substantial adverse effects on human health (skin cancer, eye disease, immune systems), and animals, terrestrial plants, aquatic organisms, biogeochemical cycles, tropospheric air quality, and materials. It is estimated that a sustained 1% decrease in stratospheric ozone will result in an increase in non-melanoma skin cancer incidence of approximately 2%. One study has indicated a 6-12% reduction in phytoplankton production in the marginal ice zone during the period of peak spring-time Antarctic ozone depletion.

ES.7. Developed countries, except for a number of countries with economies in transition (CEITs), are generally on schedule to phase out CFCs, carbon tetrachloride, and 1,1,1-trichloroethane (methyl chloroform) by 1996. Halon production was phased out by 1 January 1994.

ES.8. It seems inevitable that compliance of several countries with economies in transition (CEITs) will not occur in 1996 and that significant efforts will be necessary for eventual compliance.

ES.9. In developed countries, the most difficult remaining challenges to the phase-out are for refrigeration and air conditioning servicing, 1,1,1-

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trichloroethane solvent use among small and medium-sized industry, metered dose inhalers, precision cleaning of sophisticated aerospace equipment (rocket motors, oxygen systems, and deep-space guidance systems), and for laboratory and analytical applications.

ES.10. Implementation of alternatives and substitutes to methyl bromide is proceeding in several non-Article 5 countries and is virtually complete in the Netherlands, with the exception of some quarantine uses. Because alternatives to methyl bromide are technically the same in all countries, phase-out schedules for Article 5 countries could be similar to non-Article 5 countries, provided that adequate financing and training are available.

ES.11. The essential use nomination process was successful and collaborative. In many cases, experts identified suitable alternatives or substitutes or helped guide applicants through rapid identification and development.

ES.12. A new, and apparently increasing, challenge is the smuggling of newly produced CFCs and halon. Measures that could reduce this illegal activity could be designed in a way to ensure that quantities and procedures are legitimate, rather than to prohibit trade.

ES.13. Many developing countries are making progress in the phase-out of ozone-depleting substances (ODSs) in a variety of application areas, but are concerned about the availability of ozone-depleting substances, the need for a sustained commitment to assist developing countries, the adequacy of support for the Multilateral Fund for the Implementation of the Montreal Protocol, the capacity of developing countries to adopt new technologies, and the barriers to information exchange.

ES.14. Hydrochloroflurocarbons (HCFCs) remain critical for meeting the near-term CFC phase-out goals. However, they are less important for new equipment produced in the mid- and long-term period. HCFCs are currently necessary for certain new refrigeration and air-conditioning applications, for servicing already installed HCFC equipment, for some rigid thermal insulating and automotive safety foam products, and for several important small uses such as sterilization and precision cleaning. It is not yet determined whether HCFCs will be required to replace halon in critical uses.

ES.15. There are only a limited number of approaches to lowering stratospheric chlorine and bromine abundances beyond those already adopted by the Parties to the Protocol. Four approaches identified by the Science Assessment Panel were evaluated by the Technology and Economics Assessment Panel:

Possible additional controls	Conclusion

1. Methyl bromide reductions	Reductions in some methyl bromide uses for fumigation are technically and economically feasible, with further analysis to be provided in the March 1995 Assessment Report to Parties
2. HCFC phase-out schedule	Further controls of HCFCs are technically and economically feasible, with further analysis to be provided in the March 1995 Assessment Report to the Parties
3. Halon destruction	Although it is technically feasible to destroy halon, existing halon stocks are required for critical uses that have no identified substitutes or alternatives at present
4. CFC destruction	Although it is technically feasible to destroy CFCs, it is not economically feasible because CFC is required for servicing existing refrigeration and air-conditioning equipment at present

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1994 SYNTHESIS REPORT

PREFACE

1. This document is a synthesis by the Assessment Panel Co-Chairs of the latest Science, Environmental Effects, and Technology and Economic Assessment Panel reports[1] that will be part of the information upon which the Parties to the Montreal Protocol will base future decisions regarding protection of the stratospheric ozone layer. Full assessment reports are available from the Ozone Secretariat.

2. Specifically, the Montreal Protocol on Substances that Deplete the Ozone Layer states in its Article 6 that "the Parties shall assess the control measures ... on the basis of available scientific, environmental, technical, and economic information". To provide the mechanisms whereby these assessments are conducted, the Protocol further states that "the Parties shall convene appropriate panels of experts ..." and "... the panels will report their conclusions ... to the Parties".

3. The 1994 assessment reports were prepared by a total of more than 700 of the world's leading experts from 46 countries: Argentina, Australia, Austria, Bahamas, Bangladesh, Belgium, Benin, Brazil, Canada, Czech Republic, Chile, China, Cuba, Denmark, Egypt, France, Germany, Greece, Hungary, India, Iran (Islamic Republic of), Ireland, Israel, Italy, Japan, Jordan, Kenya, Malaysia, Mexico, Netherlands, New Zealand, Norway, Poland, Russian Federation, Singapore, Republic of South Africa, Spain, Saudi Arabia, Sweden, Switzerland, Syrian Arab Republic, Thailand, United Kingdom, United States of America, Venezuela, and Zimbabwe. The chronology of those assessments and the relation to the international policy process are summarized on table 1.

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[1] The December 1994 Technology and Economic Assessment Panel (TEAP) report is based on reports of the seven Technical Options Committees: Aerosol Products, Sterilants, Miscellaneous Uses and Carbon Tetrachloride; Economic Options; Flexible and Rigid Foams; Halons; Methyl Bromide; Refrigeration, Air-Conditioning and Heat Pumps; and Solvents, Coatings and Adhesives.

Table 1

CHRONOLOGY OF ASSESSMENTS AND INTERNATIONAL POLICY

Year	Policy Process	Assessments
1981		*The Stratosphere 1981 Theory and Measurements*
1985	Vienna Convention	*Atmospheric Ozone 1985*
1987	Montreal Protocol	
1988		*Report of the International Ozone Trends Panel*
1989		Scientific, environmental effects, technology, and economics[2] assessments of stratospheric ozone: 1989
1990	London Amendment	
1991		Scientific, environmental effects, and technology and economics assessments of ozone depletion: 1991
1992		*Methyl Bromide: Its Atmospheric Science, Technology, and Economics* (Assessment Supplement)
1992	Copenhagen Amendment	
1994		*Technology and Economic Assessment Report, Including Recommendations on Nominations for Essential Use Production/Consumption Exemptions for Ozone-Depleting Substances, March 1994;* 1994 scientific, environmental effects, and technology and economics assessment reports on ozone depletion
1995		Assessment report, including further elaboration of methyl bromide and HCFC control options,[3] March 1995

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[2] There were separate panels for the technology and economic assessments in 1989 but they were combined in 1991 and subsequent years.

[3] In Decision VI/13 the Parties requested the Assessment Panels to report by March 1995 on the feasibility and implications of the available alternatives and substitutes to HCFC and methyl bromide.

I. MAJOR RECENT FINDINGS

A. Ozone science findings

4. The laboratory investigations, atmospheric observations, and theoretical and modelling studies of the past few years have provided a deeper understanding of the human-influenced and natural chemical changes in the atmosphere and their relation to the Earth's stratospheric ozone layer and radiative balance of the climate system. Since the last international scientific assessment of the state of understanding, there have been several key ozone-related findings, observations, and conclusions:

(a) **The atmospheric growth rates of several major ozone-depleting substances have slowed, demonstrating the intended impact of the Montreal Protocol and its Amendments and Adjustments.** The abundances of the chlorofluorocarbons (CFCs), carbon tetrachloride, methyl chloroform, and halons in the atmosphere have been monitored at global ground-based sites since about 1978. Over much of that period, the annual growth rates of these gases have been positive. However, the data of recent years clearly show that the growth rates of CFC-11, CFC-12, halon-1301, and halon-1211 are slowing down. The abundance of carbon tetrachloride is actually decreasing. The observed trends in total tropospheric organic chlorine are consistent with reported production data, suggesting less emission than the maximum allowed under the Montreal Protocol and its Amendments and Adjustments. Peak total chlorine/bromine loading in the troposphere is expected to occur in 1994, but the stratospheric peak will lag by about 3-5 years. Since the stratospheric abundances of chlorine and bromine are expected to continue to grow for a few more years, increasing global ozone losses are predicted (other things being equal) for the remainder of the decade, with gradual recovery in the twenty-first century;

(b) **The atmospheric abundances of several of the CFC substitutes are increasing, as anticipated.** With phase-out dates for the CFCs and other ozone-depleting substances now fixed by international agreements, several hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs) are being manufactured and used as substitutes. The atmospheric growth of some of these compounds (e.g., HCFC-22) has been observed for several years, and the growth rates of others (e.g., HCFC-142b and HCFC-141b) are now being monitored;

(c) **Record low global ozone levels were measured over the past two years.** Anomalous ozone decreases were observed in the mid-latitudes of both hemispheres in 1992 and 1993. The northern hemispheric decreases were larger than those in the southern hemisphere. Globally, ozone values were 1-2% lower than would be expected from an extrapolation of the trend prior to 1991, allowing for solar-cycle and quasi-biennial-oscillation (QBO) effects. The 1994 global ozone levels are returning to values closer to those expected from the longer-term downward trend;

(d) **The stratosphere was perturbed by a major volcanic eruption.** The eruption of Mt. Pinatubo in 1991 led to a large increase in sulphate aerosol in the lower stratosphere throughout the globe. Reactions on sulphate aerosols resulted in significant, but temporary, changes in the chemical partitioning that accelerated the photochemical ozone loss associated with reactive hydrogen (HO_x), chlorine, and bromine compounds in the lower stratosphere in the mid-latitudes and polar regions. The observed 1994 recovery of global ozone is qualitatively consistent with observed gradual reductions of the abundances of these volcanic particles in the stratosphere;

(e) **Downward trends in total-column ozone continue to be observed over much of the globe, but their magnitudes are underestimated by numerical**

models. Over the period 1979-1994, decreases in ozone abundances of about 4-5% per decade at mid-latitudes in the northern and southern hemispheres were observed by both ground-based and satellite-borne monitoring instruments. At mid-latitudes, the losses continue to be much larger during winter/spring than during summer/autumn in both hemispheres, and the depletion increases with latitude, particularly in the southern hemisphere. Little or no downward trends are observed in the tropics (20°N - 20°S). While the current two-dimensional stratospheric models simulate the observed trends quite well during some seasons and at some latitudes, they underestimate the trends by factors of up to three in winter/spring at mid- and high-latitudes. Several known atmospheric processes that involve chlorine and bromine and that affect ozone in the lower stratosphere are difficult to model and have not been adequately incorporated into these models;

(f) **Observations have demonstrated that halogen chemistry plays a larger role in the chemical destruction of ozone in the mid-latitude lower stratosphere than expected from gas phase chemistry.** Direct in situ measurements of radical species in the lower stratosphere, coupled with model calculations, have quantitatively shown that the in situ photochemical loss of ozone due to (largely natural) reactive nitrogen (NO_x) compounds is smaller than that predicted from gas-phase chemistry, while that due to (largely natural) HO_x compounds and (largely anthropogenic) chlorine and bromine compounds is larger than that predicted from gas-phase chemistry. This confirms the key role of chemical reactions on sulphate aerosols in controlling the chemical balance of the lower stratosphere. These and other recent scientific findings strengthen the conclusion of the previous assessment that the weight of scientific evidence suggests that the observed middle- and high-latitude ozone losses are largely due to anthropogenic chlorine and bromine compounds;

(g) **The conclusion that anthropogenic chlorine and bromine compounds, coupled with surface chemistry on natural polar stratospheric particles, are the cause of polar ozone depletion has been further strengthened.** Laboratory studies have provided a greatly improved understanding of how the chemistry on the surfaces of ice, nitrate, and sulphate particles can increase the abundance of ozone-depleting forms of chlorine in the polar stratosphere. Furthermore, satellite and in situ observations of the abundances of reactive nitrogen and chlorine compounds have improved the explanation of the different ozone-altering properties of the Antarctic and Arctic;

(h) **The Antarctic ozone "holes" of 1992 and 1993 were the most severe on record.**[4] The Antarctic ozone "hole" has continued to occur seasonally every year since it was first observed in the late 1970s, with the occurrences over the last several years being particularly pronounced. Satellite, balloon-borne, and ground-based monitoring instruments revealed that the Antarctic ozone "holes" of 1992 and 1993 were the biggest (areal extent) and deepest (minimum amounts of ozone overhead), with ozone being locally depleted by more than 99% at altitudes between about 14-19 km in October 1992 and 1993. It is likely that these larger-than-usual ozone depletions could be attributed, at least in part, to sulphate aerosols from Mt. Pinatubo increasing the effectiveness of chlorine- and bromine-catalysed ozone destruction. A substantial Antarctic ozone "hole" is expected to occur each austral spring for many more decades because stratospheric chlorine and bromine abundances will approach the pre-Antarctic-ozone-"hole" levels (late-1970s) very slowly during the next century;

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[4] It appears from initial observations that the Antarctic ozone "hole" in 1994 was comparable to that of 1992-1993.

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(i) **Ozone losses have been detected in the Arctic winter stratosphere, and their links to halogen chemistry have been established.** Studies in the Arctic lower stratosphere have been expanded to include more widespread observations of ozone and key reactive species. In the late-winter/early-spring period, additional chemical losses of ozone up to 15-20% at some altitudes are deduced from these observations, particularly in the winters of 1991/92 and 1992/93. Model calculations constrained by the observations are also consistent with these losses, increasing the confidence in the role of chlorine and bromine in ozone destruction. The interannual variability in the photochemical and dynamical conditions of the Arctic polar vortex continues to limit the ability to predict ozone changes in future years;

(j) **Methyl bromide continues to be viewed as a significant ozone-depleting compound.** Increased attention has been focused upon the ozone-depleting role of methyl bromide. Three major anthropogenic sources of atmospheric methyl bromide have been identified: agricultural usage (soil and commodity fumigation), biomass burning, and potentially the exhaust of automobiles using leaded gasoline, in addition to the natural oceanic source. Recent laboratory studies have confirmed the fast rate for the $BrO + HO_2$ reaction and established a negligible reaction pathway producing HBr, both of which imply greater ozone losses due to emissions of compounds containing bromine. While the magnitude of the atmospheric photochemical removal is well understood, there are significant uncertainties in quantifying the oceanic sink for atmospheric methyl bromide. The best estimate for the overall lifetime of atmospheric methyl bromide is 1.3 years, with a range of 0.8-1.7 years. The ozone depleting potential (ODP) for methyl bromide is calculated to be about 0.6 (relative to an ODP of 1 for CFC-11);

(k) **The atmospheric residence times of the important ozone-depleting gases, CFC-11 and methyl chloroform, are now better known.** A reconciliation of observed concentrations with known emissions using an atmospheric model has led to a best-estimate lifetime of 50 years for CFC-11 and 5.4 years for methyl chloroform, with uncertainties of about 10%. These lifetimes provide an accurate standard for gases destroyed only in the stratosphere (such as CFCs and nitrous oxide) and for those also reacting with tropospheric hydroxyl radical OH (such as HCFCs and HFCs), respectively;

(l) **The ODP values for new substances have been determined.** The ODPs for several new compounds, such as HCFC-225ca, HCFC-225cb, and iodotrifluoromethane (CF_3I), have been evaluated and found to be 0.03 or less;

(m) **Many of the substitutes for the CFCs and halons are also notable greenhouse gases.** Several CFCs and halon substitutes are not addressed under the Montreal Protocol (because they do not deplete ozone), but, because they are greenhouse gases, fall under the purview of the United Nations Framework Convention on Climate Change. There is a wide range of values for the global warming potentials (GWPs) of the hydroflurocarbons (HFCs), with many of them having values within an order of magnitude of the ozone-depleting compounds they replace. The perfluorinated compounds, some of which are being considered as substitutes, have very large GWPs. These are examples of compounds whose current atmospheric abundances are relatively small, but are increasing or could increase in the future;

(n) **The Montreal Protocol and its Amendments and Adjustments are reducing the impact of anthropogenic halocarbons on the ozone layer and should eventually eliminate this ozone depletion.** Based on assumed compliance by all Parties with the Montreal Protocol as amended at Copenhagen in 1992, the stratospheric chlorine abundances will continue to grow from their current levels (3.6 parts per billion (ppb) to a peak of about 3.8 (ppb) around the turn of the century. The future total bromine loading will depend upon choices made regarding future human production and emissions of methyl bromide. After around the turn of the century, the levels of stratospheric chlorine and bromine will decrease during the twenty-first and twenty-second centuries. The rate of decline is dictated by the long residence times of the CFCs, carbon tetrachloride, and halons. Global ozone losses and the Antarctic ozone "hole" were first discernible in the late 1970s and recovery is predicted by about 2045, other things being equal. The recovery of the ozone layer would have been impossible without the Amendments and Adjustments to the original Protocol;

(o) **Peak global ozone losses are expected to occur during the next several years.** The ozone layer will be most affected by human-influenced perturbations and susceptible to natural variations in the period around 1998, since the peak stratospheric chlorine and bromine abundances are expected to occur then. Based on extrapolation of current trends, observations suggest that the maximum ozone loss, relative to the late 1960s, will likely be:

(i) About 12-13% at northern mid-latitudes in winter/spring (i.e., about 2.5% above current levels);

(ii) About 6-7% at northern mid-latitudes in summer/autumn (i.e., about 1.5% above current levels); and

(iii) About 11% (with less certainty) at southern mid-latitudes on a year-round basis (i.e., about 2.5% above current levels);

(p) **The link between a decrease in stratospheric ozone and an increase in surface ultraviolet (UV) radiation has been further strengthened.** Measurements of UV radiation at the surface under clear-sky conditions show that low overhead ozone yields high UV radiation and in the amount predicted by radiative-transfer theory. Large increases of surface UV are observed in Antarctica and the southern part of South America during the period of the seasonal ozone "hole." Measurements at Palmer-Station (64 degrees South) in spring time show that the biological effective UV-B radiation when related to DNA-damage can exceed summer values at San Diego, California, United States of America (32 degrees North). Furthermore, elevated surface UV levels at mid-to-high latitudes were observed in the northern hemisphere in 1992 and 1993, corresponding to the low ozone levels of those years. However, the lack of a decadal (or longer) record of accurate monitoring of surface UV levels and the variation introduced by clouds and other factors have precluded the unequivocal identification of a long-term trend in surface UV radiation;

(q) **Peak UV radiation increases are expected to occur during the next several years.** The peak global ozone losses would be accompanied by 15% (northern mid-latitudes in winter/spring), 8% (northern mid-latitudes in summer/fall), and 13% (southern mid-latitudes on a year-round basis) increases in surface erythemal radiation, if other influences such as clouds remain constant. Moreover, if there were to be a major volcanic eruption like that of Mt. Pinatubo, or if an extremely cold and persistent Arctic winter were to occur, then the ozone losses and UV increases could be larger in individual years.

B. Environmental effects findings

5. The increased penetration of solar UV-B radiation (290-315 nm) to the Earth's surface has adverse effects on human health, animals, plants, microorganisms, materials and on air quality.

6. **Increases in UV-B radiation are likely to have substantial adverse**

effects on human health, including increases in the incidence of and morbidity from skin cancer, eye diseases, and infectious diseases. In susceptible (light-skinned) populations, UV-B radiation is the key risk factor for the development of non-melanoma skin cancer. Using information derived from animal experiments and human epidemiology, it is estimated that a sustained 1% decrease in stratospheric ozone will result in an increase of approximately 2% in the incidence of non-melanoma skin cancer. Epidemiological data indicate that the risk of melanoma increases with sunlight exposure, especially during childhood. Chronic exposure to UV-B (resulting in a high, cumulative, lifetime dose) is one of several factors clearly associated with the risk of cataracts. Studies of humans indicate that UV-B radiation can induce suppression of immune systems. The importance of these immune effects for infectious diseases in humans is unknown. However, in areas of the world where infectious diseases already pose a significant challenge to human health and in persons with impaired immune function, the added impact of UV-B-induced immune suppression could be significant.

7. **Physiological and developmental processes of plants are adversely affected by UV-B radiation.** Plant growth can be directly reduced by UV-B radiation. However, plants also have several mechanisms to ameliorate or repair these effects and may acclimatize to a certain extent to increased levels of UV-B. Secondary effects caused by UV-B (such as changes in plant form, biomass allocation to parts of the plant, timing of developmental phases and secondary metabolism) may be equally, or sometimes more, important than the direct damaging effects of UV-B. These changes can have important implications for plant competitive balance, herbivory, plant pathogens, and biogeochemical cycles. These ecosystem-level effects can be anticipated, but not easily predicted or evaluated. Research at the ecosystem level of solar UV-B impacts is barely beginning. Other stress factors such as increasing $C0_2$ and temperature need to be taken into account for future ecological assessments.

8. **UV-B radiation adversely effects phytoplankton productivity and the early development stages of fish and other aquatic organisms.** Phytoplankton productivity is limited to the euphotic zone, the upper layer of the water column in which phytoplankton organisms can move for sufficient sunlight to support net productivity. Exposure to solar UV-B radiation has been shown to affect both orientation mechanisms and motility in phytoplankton, resulting in reduced survival rates for these organisms. Natural phytoplankton communities in the marginal Antarctic ice zone show a direct reduction in phytoplankton production due to ozone-related increases in UV-B. One study has indicated a 6-12% reduction in phytoplankton production in the marginal ice zone during the period of peak springtime Antarctic ozone depletion.

9. The most severe effects of solar UV-B radiation are on early developmental stages of fish, shrimp, crab, amphibians and other animals, decreased reproductive capacity, and impaired larval development. This in turn leads to a significant reduction in the size of the population of consumer organisms. This is of particular importance because more than 30% of the world's animal protein for human consumption comes from the sea and in many countries, particularly the developing countries, this percentage is significantly higher. As a result, it is important to know how increased levels of exposure to solar UV-B radiation might affect the productivity of aquatic systems.

10. **Increases in solar UV radiation could decrease the productivity of marine and terrestrial ecosystems**, hence reducing the uptake of atmospheric carbon dioxide, and in addition can alter both sources and sinks of greenhouse and chemically-important trace gases, such as carbon monoxide (CO), carbonyl sulphide (COS), and possibly other gases. Marine phytoplankton are a major

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sink for atmospheric carbon dioxide, and they have a decisive role in the development of future trends of carbon dioxide concentrations in the atmosphere. These potential changes would contribute to biosphere-atmosphere feedbacks that attenuate or reinforce the atmospheric build-up of these gases.

11. New research on the environmental fate and impact of the HFC and HCFC substitutes for CFCs has focused on trifluoroacetate (TFA), a tropospheric oxidation product of certain HFCs and HCFCs. Although TFA is mildly toxic to some species of marine and freshwater phytoplankton, it will never reach toxic concentrations in oceans or soils because it is biologically degraded.

12. **Synthetic polymers, naturally occurring biopolymers, as well as some other materials of commercial interest are further adversely affected by increases in solar UV radiation.** The nature and the extent of such damage due to increased UV-B radiation in sunlight is quantified in action spectra showing that the shorter UV-B wavelengths processes are mainly responsible for photo-damage ranging from discoloration to loss of mechanical integrity.

13. **An increase in UV-B radiation (e.g. from stratospheric ozone loss) is expected to decrease tropospheric ozone in the background atmosphere, but, in some cases, it will increase production of ozone in the more-polluted regions.** Increases of UV-B radiation result in higher photodissociation rates of key trace gases that control the chemical reactivity of the troposphere, increasing both production and destruction of ozone and related oxidants such as hydrogen peroxide (H_2O_2), which are known to have adverse effects on human health, terrestrial plants, and outdoor materials. Changes in the atmospheric concentrations of the hydroxyl radical (OH) may change the atmospheric lifetimes of greenhouse gases such as methane, HFCs, and HCFCs.

C. Technology and economics findings

14. **Developed countries, except for a number of countries with economies in transition (CEITs), are generally on schedule to phase out chlorofluorocarbons (CFCs), 1,1,1-trichloroethane, and carbon tetrachloride by 1 January 1996.** The phase-out is virtually complete in most developed countries for manufacture of automobile air conditioners, refrigeration, foams (except limited use for rigid polyurethane foams for home appliance insulation), electronics and aerospace products, and non-medical aerosol products. For CFCs, individual countries with aggressive early phase-out goals are best prepared for their approaching deadlines. The European Union (EU) countries are approaching their internal 1 January 1995 CFC phase-out without alarm. Since the 1995 EU phase-out relies heavily on stockpiling by users, experts wonder whether the transition will be smooth after ozone-depleting substance stockpiles are depleted late in 1995/1996. The most difficult remaining challenges are for refrigeration and air-conditioning servicing, 1,1,1-trichloroethane solvent use among small and medium-sized industry, metered dose inhalers, precision cleaning of sophisticated aerospace equipment (rocket motors, oxygen systems, and deep-space guidance systems), and for laboratory and analytical applications. Many laboratory tests are required by government agencies which currently rely on ODSs. Altering those test requirements will therefore require regulatory change.

15. **HCFCs remain critical for meeting the near-term CFC phase-out goals. However, they are less important for new equipment produced in the mid- and long-term period.** Available data indicate that it is technically and economically feasible to reduce the HCFC cap due to the rapid development of alternatives and substitutes to HCFCs. HCFCs are currently necessary for certain new refrigeration and air-conditioning applications, for servicing already installed HCFC equipment, for some rigid thermal insulating and

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automotive safety foam products, and for several important small uses such as sterilization and precision cleaning, where some existing equipment cannot be converted to non-ODS alternatives. It is not yet determined whether HCFCs will be required to replace halon in critical uses. If Article 5 countries are adequately funded and technically assisted, HCFC use could be limited and would eventually decline in these countries as well.

16. **The halon phase-out took effect on 1 January 1994 with little disruption because the fire protection industry had established global information networks and coordinated halon banks.** Halons are in surplus in some countries while in short supply in others. Halon-1301 banking is fully functional in many countries and being organized in others. There is increasing interest in the conservation and banking of halon-1211. Halon banks are important because environmentally acceptable alternatives have not been commercialized for some important fire-protection applications.

17. **Uses of methyl bromide are decreasing in some countries.** Implementation of methyl bromide alternatives and substitutes is virtually complete in the Netherlands with the exception of some quarantine uses, and efforts are at an advanced stage in countries such as Denmark and Italy that have stringent and immediate domestic controls. Because alternatives to methyl bromide are technically the same in all countries, phase-out schedules for Article 5 countries could be similar to non-Article 5 countries, provided that adequate financing and training is available. Implementation efforts are intensifying in countries like the United States, Canada, and the members of the European Union that have controls proposed or scheduled for future years. However, despite the clear findings of the science assessment, persistent criticism of the science of ozone depletion by advocates of continued methyl bromide use discourages investment in alternatives.

18. **A new, and apparently increasing, challenge is the smuggling of newly produced CFCs and halon.** Often smugglers attempt to evade prohibition by describing the substances as recycled or as non-CFC chemicals. These shipments could be primarily from Eastern Europe and developing countries where production facilities are still operating. Measures that could reduce this illegal activity could be designed in a way to ensure that quantities and procedures are legitimate, rather than to prohibit trade. This approach would not impede continued recycling which often depends on the ability to ship substances to recycling facilities or to markets where recycling is economic.

19. **Many developing countries are making progress in the phase-out of ODSs in a variety of application areas, but many challenges remain.** ODS solvent use is rapidly decreasing in cases where cooperation exists with multi-national companies and organizations and with strong market incentives. Where private or Multilateral Fund financing has been available progress appears to be under way in refrigeration and in reducing ODS uses in the manufacture of flexible foam, electronics, and aerosol products. The banking of recycled halons in both the developed and developing countries is growing sufficiently to provide maintenance quantities for existing equipment. Developing countries have also made substantial progress in preparing the way for accelerating ODS phase-out by institutional strengthening such as establishing national ozone units, information exchange, preparation of country programmes, and cooperation with the implementing agencies of the Multilateral Fund over investment project proposals. However, some developing countries have actually increased their use of ODSs due to increased economic growth and constraints in adopting alternatives.

20. The points of concern to developing countries include: availability of ozone-depleting substances (ODSs) to supply developing country basic domestic needs at affordable prices; apprehension that the phase-out in developed

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countries may require special efforts to sustain commitment to assist developing countries; the adequacy of the political and financial support for the Multilateral Fund; the importance of coordination among the implementing agencies of the Multilateral Fund; the capacity of developing countries to adopt new technologies; the barriers to information exchange and; the reluctance of Governments to promote phase-out activities in view of the 10-year grace period to implement the control measures.

21. **It seems inevitable that compliance of several countries with economies in transition (CEITs) will not occur in 1996 and that significant efforts will be necessary for eventual compliance.** Since the signing of the Montreal Protocol and its London Amendment substantial changes have occurred in the countries of the Central and Eastern European region and the territory of the former Soviet Union. Some of the States have ratified the Protocol but 10 of the new States are yet to do so. All States of the Central and Eastern European region as well as Commonwealth of Independent States (CIS) are struggling with the difficulties of the transition from a planned to a market economy, the worldwide recession, market discrimination and exclusion, high inflation rates, and a chronic lack of capital even for investments with short payback time. The reduction of the consumption of ODSs in the Central and Eastern European States has been a consequence of decrease in industrial output due to the factors referred to earlier, and only partly as a result of actual phase-out activities and investments. In a number of the successor States of the Soviet Union, there is no legislative basis for either ratifying or implementing the Montreal Protocol and there are no institutions and authorities to manage the phase-out of ODSs or even to report consumption data and to establish the baseline consumption level. In a number of CEITs, accession to the Protocol as amended in London is difficult because these countries are classified as non-Article 5, a status which includes the obligation to contribute to the Multilateral Fund.

II. FEASIBILITY OF OPTIONS FOR LOWERING STRATOSPHERIC CHLORINE AND BROMINE ABUNDANCES

22. **There are only a limited number of approaches to lowering stratospheric chlorine and bromine abundances beyond those already adopted by the Parties.** Further controls on ozone-depleting substances would not be expected to significantly change the timing or the magnitude of the peak stratospheric halocarbon abundances and hence peak ozone loss. However, there are four approaches identified by the Ozone Science Assessment Panel that, if technically and economically feasible, would steepen the initial fall from the peak halocarbon levels in the early decades of the next century: elimination of methyl bromide from agricultural, structural, and industrial activities; reduce the HCFC cap and accelerate the phaseout schedule; recover and destroy halons; and recover and destroy CFCs.

23. **Prior to discussing these options, it should be noted that failure to adhere to the international agreements will delay recovery of the ozone layer.** If there were to be additional production of CFCs at 20% of 1992 levels for each year through 2002 and ramped to zero by 2005 (beyond that allowed for countries operating under Article 5 of the Montreal Protocol), then the integrated effective future chlorine loading above the 1980 level is predicted to be 9% more over the next 50 years relative to full compliance to the Amendments and Adjustments to the Protocol.

A. Approaches to lowering stratospheric chlorine and bromine abundance that are technically and economically feasible

1. Further control of methyl bromide

24. The Ozone Science Assessment Panel calculated that if emissions of methyl bromide from agricultural, structural, and industrial activities were to be eliminated in the year 2001, then the integrated effective future chlorine loading above the 1980 level (which is related to the cumulative future loss of ozone) is predicted to be 13% less over the next 50 years relative to full compliance to the Amendments and Adjustments to the Protocol.

25. The controls under the current Protocol freeze methyl bromide consumption by January 1995 at 1991 levels in non-Article 5 countries. It is the consensus of the Technology and Economic Assessment Panel (TEAP) and its Methyl Bromide Technical Options Committee that further controls beyond the currently established control levels are technically feasible. The TEAP believes that additional controls on methyl bromide would be more cost-effective per ODP-weighted tonne than additional controls on other controlled substances. Progress beyond a consumption freeze appears possible since several developed nations have already achieved or imposed stricter controls on methyl bromide use. For example, between 1981 and 1991 the Netherlands eliminated its use of methyl bromide in soil fumigation through the use of chemicals and non-chemical alternatives such as improved steam sterilization techniques, artificial and natural growth substrates, resistant plant species, crop rotation, and chemical substitutes. Reductions could be accomplished through increased training; prompt registration of chemical substitutes and not-in-kind alternatives; and substantial investment in containment, recovery equipment, food storage facilities, and other equipment. Comparable investments have already been made in other application areas in order to protect the ozone layer. Using known technology it is technically possible to reduce usage of methyl bromide. It is not technically or economically feasible to phase-out all uses. Estimates of the magnitude of the reduction and its time-scale varied widely among Methyl Bromide Technical Options Committee members. Opinions ranged from a reduction of 50% feasible by 1998, to decreases of only a few percent by 2001. While alternatives are available for the majority of current uses, technically feasible alternatives are not available for less than 10% of 1991 methyl bromide uses. Many of these applications without currently identified alternatives and substitutes are for treatment of exports to meet quarantine standards, where extensive trials and protracted bilateral negotiations may be required. Of course, these uses are currently exempted under the Protocol.

2. Reductions in the HCFC cap and acceleration of the phase-out schedule

26. The Ozone Science Assessment Panel calculated that if emissions of HCFCs were to be totally eliminated by the year 2004, then the integrated effective future chlorine loading above the 1980 level is predicted to be 5% less over the next 50 years relative to full compliance with the Amendments and Adjustments to the Protocol.

27. As noted earlier, HCFCs remain critical for meeting the near-term CFC phase-out goals. They are less important for new equipment available in the mid and long-term period. Few large scale current uses of HCFCs have been reported for solvents, coatings, or adhesives. Available data indicate that it is technically feasible to further limit HCFC consumption by encouraging selection of non-HCFC substitutes to replace CFC, halon, and 1,1,1-trichloroethane; by better containing HCFCs; and by increased recycling. However, a complete phase-out by 2004 is not technically feasible with currently available technology.

28. In considering further HCFC controls, the Parties may wish to take into account that:

(a) Many non-HCFC alternatives to CFCs, halons, 1,1,1-trichloroethane and carbon tetrachloride present their own environmental and worker risks. If HCFCs are not available, users may select more toxic chemicals, potent

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greenhouse gases such as perfluorinated compounds (PFCs), or refrigerants that are not energy efficient or do not have demonstrated long-term reliability. Forcing the early switch from HCFCs to these options could discourage later selection of more environmentally acceptable alternatives because of the prohibitive cost of investment;

(b) HCFCs are sometimes "stepping stones" to next-generation technologies that would either not be possible or would be far more difficult to implement without the technical lessons of HCFC use; and

(c) Some companies demonstrating environmental leadership--at the encouragement of the Protocol, national Governments, and non-government organizations--selected HCFC technologies long before they were proven or practical in an effort to shift away from CFCs at the earliest possible time. This leadership helped create global markets for technologies that protect the zone layer. Parties may wish to consider the advantages of not "turning leaders into losers" by halting HCFC production too soon to allow reasonable recovery of the investment costs. This is particularly true where equipment has a long useful economic life.

B. Approaches to lowering stratospheric chlorine and bromine abundances that are not technically and/or economically feasible

1. Recover and destroy halon

29. The Ozone Science Assessment Panel calculated that if halons presently contained in existing equipment were never released to the atmosphere, the integrated effective future chlorine loading above the 1980 level is predicted to be 10% less over the next 50 years relative to full compliance with the Amendments and Adjustments to the Protocol.

30. Although it is technically feasible to destroy halon, existing halon stocks are required at the present time for critical uses, representing 15-20% of current uses, which now have no identified substitutes or alternatives. Thus, a substantial portion of already produced halon may be necessary to supply essential uses where human life and irreplaceable property is protected.

31. The decision at the Fourth Meeting of the Parties to bring forward the phase-out of halons to 1994 was predicated on the prudent use of banked halons. The halon phase-out took effect 1 January 1994 with little disruption because the fire protection industry had established global information networks and coordinated halon banks. Halons are in surplus in some countries while in short supply in others. Halon 1301 banking is fully functional in many countries and being organized in others. There is increasing conservation and banking of halon 1211.

32. Recovery of halon from non-critical existing uses is proceeding in most countries as a result of the proactive efforts of the fire-protection community. Parties could further promote the recovery of halon in non-critical uses for essential uses in non-Article 5 and Article 5 countries. Moreover, the promotion of mandatory destruction by owners is likely to be counter-productive since it would discourage halon banking and lead to the discharging of halon into the atmosphere.

2. Recover and destroy CFCs

33. The Ozone Science Assessment Panel calculated that if CFCs presently contained in existing equipment were never released to the atmosphere, the integrated effective future chlorine loading above the 1980 level is predicted

to be 3% less over the next 50 years relative to full compliance with the Amendments and Adjustments to the Protocol.

34. It is presently technically but not economically feasible to destroy CFCs because recycled CFCs are necessary to service existing equipment. Most non-Article 5 Parties, and particularly the European Union (EU) with a CFC phase-out in January 1995, may require substantial quantities of CFCs from recovery in order to service existing equipment during the transition to substitute refrigerants. Recovery and destruction of needed CFCs from refrigeration and air-conditioning equipment would increase the dependence on HCFCs and HCFC blends and would be very costly if equipment were prematurely abandoned. Expensive recycling equipment and infrastructure have been developed to protect the ozone layer. It is also likely that CFC shortages would intensify smuggling of CFCs and dumping of CFC-dependent equipment in developing countries.

III. FUTURE ASSESSMENT WORK: HCFC AND METHYL BROMIDE ELABORATION (DECISION VI/13), CHALLENGES FACING ARTICLE 5 COUNTRIES AND COUNTRIES WITH ECONOMIES IN TRANSITION AND ESSENTIAL USES

35. The Sixth Meeting of the Parties requested that the Assessment Panels further elaborate by March 1995 the feasibility and implications of alternatives and substitutes to HCFCs and methyl bromide. The March 1995 report will include an evaluation of the feasibility of reducing the HCFC cap, accelerating the initial reductions, and/or speeding the phase-out. This assessment will also describe the history of technical development in applications where HCFCs were the first feasible alternatives to CFCs but may no longer be required. A full range of methyl bromide control options will be considered.

36. The March 1995 report will also include updated information on the challenges faced by Article 5 countries and countries with economies in transition.

37. In 1994, the essential use nominations process was successful and collaborative. In many cases, the TOC experts identified suitable alternatives or substitutes or helped guide applicants through rapid identification and development. The 1995 report will include evaluations of new nominations for exemption to the phase-out of production for essential uses and will update progress on uses that were granted exemptions in 1994.

Appendix

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Technology and Economic Assessment Panel and Options Committees

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Gary Taylor	Taylor/Wagner	Canada
Helen Tope	Environment Protection Authority, Victoria	Australia
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TEAP Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee

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