REGULATORY IMPACT ANALYSIS:

PROTECTION OF STRATOSPHERIC OZONE

VOLUME II: APPENDICES TO REGULATORY IMPACT ANALYSIS DOCUMENT

PART 1: APPENDICES A-I

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ASSESSING THE RISKS OF TRACE GASES THAT CAN MODIFY THE STRATOSPHERE

VOLUME I: EXECUTIVE SUMMARY

BY

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VOLUME I: EXECUTIVE SUMMARY

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ORGANIZATION

This document summarizes a multi-volume assessment of the risks of stratospheric modification. Since the early 1970s, scientists have been concerned that human activities could alter the composition of the stratosphere, leading to reductions in the quantity of ozone protecting earth from the sun's ultraviolet-B (UVB) radiation. If such reductions in ozone levels occurred, public health and welfare would be harmed.

Substantial scientific progress has been made since concern about ozone depletion was first raised. This document represents a synopsis of current understanding of how atmospheric composition may change, the effects this change is likely to have on ozone abundance and its vertical distribution, and the impacts of these changes in ozone on skin cancer, cataracts, suppression of the immune system, polymers, plants, and aquatic systems. It also examines related changes in climate and the potential impacts of climate change on sea level rise, agriculture, human health, water resources, and forests.

Despite significant improvement in our understanding of these issues, substantial uncertainties remain. This risk assessment identifies and discusses these uncertainties and, where possible, estimates quantitatively their potential significance.

Following a brief introduction, this summary volume is organized into five sections:

- Summary findings (page ES-5);
- Changes in atmospheric composition covers chapters 2, 3, and 4 (page ES-15);
- Potential changes in ozone and climate covers chapters 5 and 6 (page ES-23);
- Human health, welfare, and environmental effects covers chapters 7 through 16 (page ES-32); and
- Quantitative assessment of risks with integrated model covers chapters 17 and 18 (page ES-54).

Readers desiring greater detail are encouraged to refer to the five-volume risk assessment and the three volumes of the technical support reports.

This summary concludes with a brief listing of major prior assessments of this issue.

A

INTRODUCTION

Current scientific theory and evidence indicate that continued increases in the concentrations of a variety of trace gases in the atmosphere are likely to modify the vertical distribution and column abundance of stratospheric and tropospheric ozone. Changes in the total abundance of column ozone would alter the flux of ultraviolet radiation reaching the surface of the earth, and consequently affect public health and welfare. Scientific evidence indicates that increases in ultraviolet-B radiation (UV-B) would alter skin cancer morbidity and mortality, increase cataracts, and probably suppress the human immune system. Evidence also supports the conclusion that such increases could reduce crop yields and alter terrestrial and aquatic ecosystems. Scientific theory and studies also support the conclusion that polymers would be degraded more quickly and that urban tropospheric oxidants would increase as a result of UV-B increases, although additional scientific study is needed to validate the possible effects on tropospheric air quality. The dimensions of many of these risks are at this time unquantifiable. Exhibit ES-1 summarizes these relationships.

Changes in trace gases that can modify the stratosphere can be expected to contribute to climate change in three ways: they are all greenhouse gases that would increase global warming; by modifying vertical distribution of ozone, they could change the Earth's radiative balance and climate dynamics; by adding water vapor to the stratosphere, one of these gases (methane) directly adds to the stratosphere's greenhouse or warming capacity. The effects of global warming include changes in weather and climate patterns; rises in sea level; changes in forests, hydrologic processes, and agriculture; and a variety of associated impacts.

Current science projects that changes in ozone and climate will occur slowly enough in the next decade that it is unclear that monitoring systems will be capable of clearly detecting change, or of attributing changes to particular trace gas increases. Because of the large lags expected between the emission of gases and their ultimate effect on ozone and climate, the stabilization of atmospheric concentrations and the prevention of further change would require large decreases in trace gas emissions. Consequently, while monitoring can provide a valuable system to test model projections, as well as to better understand atmospheric systems, except in the case of a larger than expected atmospheric change, monitoring cannot be expected to provide definitive information about the nature of future risks. With the exception of Antarctic ozone depletion, an unexpected and, at this time, unexplained phenomenon, past monitoring supports current models, which project that ozone depletion and climate change are likely to occur in the face of growth in the concentrations of trace gases.[1] It is important to recognize

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[1] This Risk Assessment was written before the results of the two Antarctic campaigns were available and has not been revised to consider them. It now appears that the Antarctic ozone hole is at least partly caused by man-made chemicals. The implications for ozone in the rest of the world are unclear, depending on whether the loss mechanisms operating in Antarctica are likely to operate elsewhere and on whether Antarctic losses themselves might have global implications. Consequently, until those issues are resolved, we cannot conclude that the 'hole' is a portent of things to come elsewhere on the Earth. In the rest of this summary the original Risk Assessment findings on Antarctica and trends are kept intact.

EXHIBIT ES-1

The Basis for Concern About CFCs and Ozone Depletion

(1) Production of CFCs

(2) Emissions then occur

(3) Concentrations build up

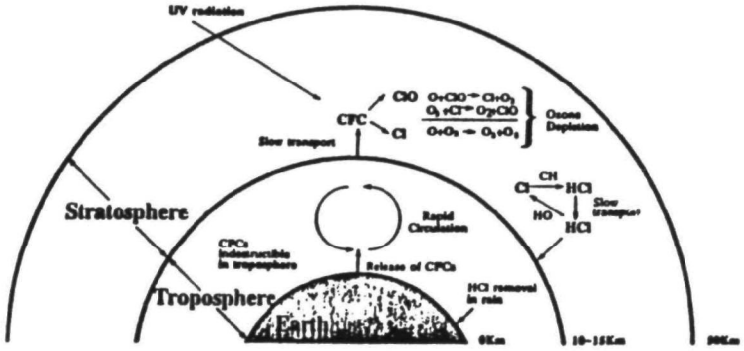
(4) Slow transport to stratosphere

(5) Photodissociation of CFCs releases chlorine

(6) Chlorine catalytically reduces ozone

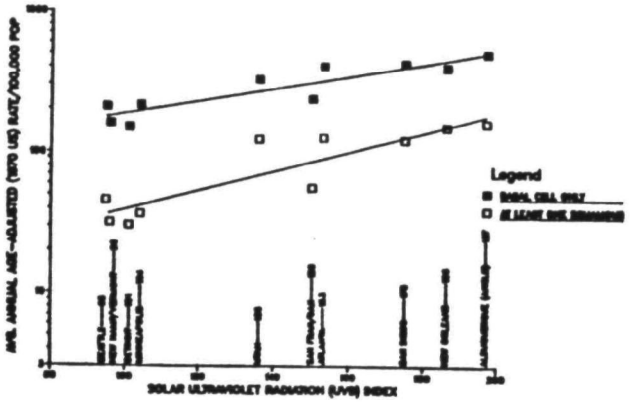
(7) Ozone depletion causes changes in UV-B

(8) CFCs and column reorganization change the climate

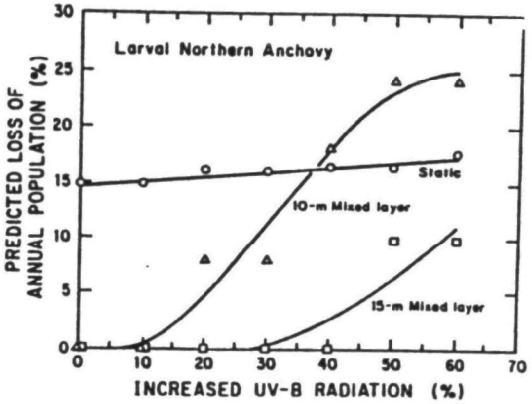


(9) Increases in UV-B produce effects
For example:

On skin cancer



On Larval Northern Anchovy



Causal Chain:

Production → Emissions → Concentrations → Atmospheric Response → UV-B and climate → Effects

Source: NAS (1976), Scotto (1986), and Hunter, Kaupp and Taylor (1982).

that "by the time it is possible to detect decreases in ozone concentrations with a high degree of confidence, it may be too late to institute corrective measures that would reverse this trend" (EPA Science Advisory Board, March 1987).

SUMMARY FINDINGS

Past and Possible Future Changes in Trace Gases

1. Considerable research has taken place since 1974 when the theory linking chlorine from chlorofluorocarbons (CFCs) and depletion of ozone was first developed. While uncertainties remain, the evidence to date continues to support the original theory that CFCs have the potential to decrease stratospheric ozone.

2. Atmospheric measurements show that the chemical composition of the atmosphere -- including gases that affect ozone -- has been changing. Recently measured annual rates of growth in global atmospheric concentrations of trace gases that influence ozone include: CFC-11: 5 percent; CFC-12: 5 percent; CFC-113: 10 percent; carbon tetrachloride: 1 percent; methyl chloroform: 7 percent; nitrous oxide: 0.2 percent; carbon monoxide: 1 to 2 percent; carbon dioxide: 0.5 percent; and methane: 1 percent. More limited measurements of Halon 1211 show recent annual increases of 23 percent in atmospheric concentrations.

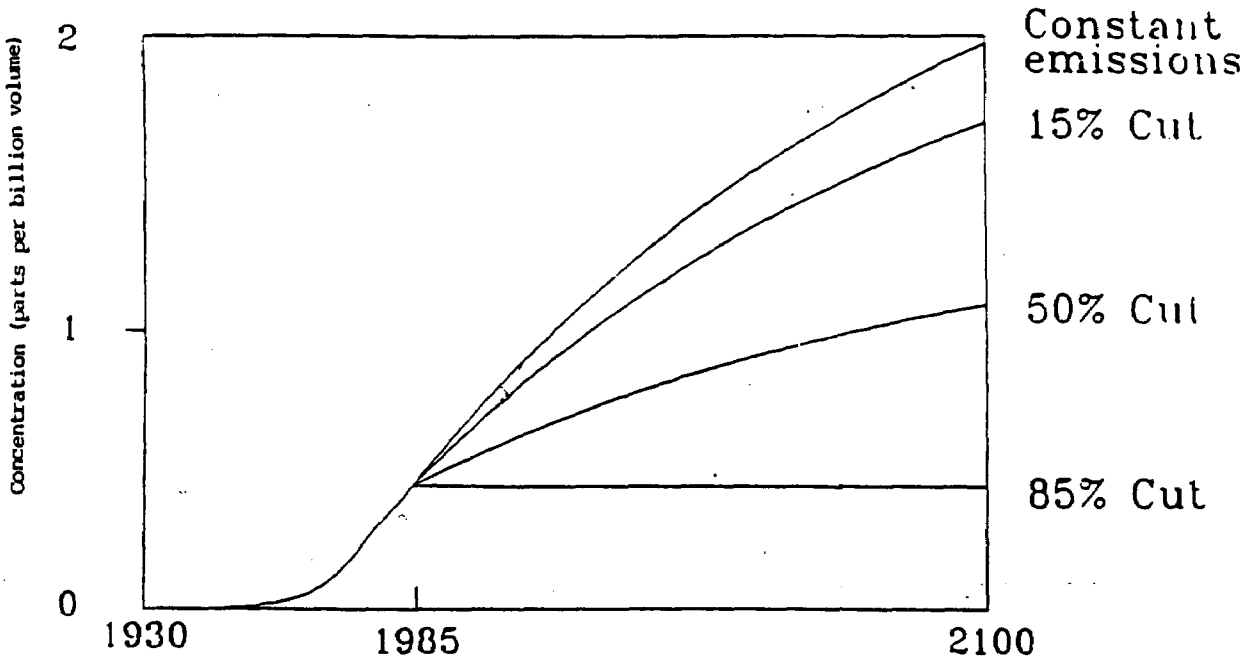
3. CFCs, Halons, methyl chloroform, and carbon tetrachloride release chlorine or bromine into the stratosphere where they act as catalysts to reduce the net amount of ozone. In contrast, carbon dioxide and methane either add to the total column of ozone or slow the rate of depletion. The effect of increases in nitrous oxide varies depending on the relative level of chlorine.

4. CFCs, methyl chloroform, carbon tetrachloride, and Halons are industrially produced. Emissions of methane, carbon dioxide, and nitrous oxide occur from both human activity and the natural biosphere. Because all these gases (with the exception of methane and methyl chloroform) remain in the atmosphere for many decades to over a century, emissions today will influence ozone levels for more than a century. Also, as a result of these long lifetimes, concentrations of these gases will rise for more than a century, even if emissions remain at constant levels. For example, to stabilize concentrations of CFC-11 or -12 would require a reduction in current global emissions of about 80 percent. (Exhibit ES-2 demonstrates effects of various reduction levels on CFC-12 concentrations).

5. In order to assess risks, scenarios of atmospheric change were evaluated using models. For CFCs, methyl chloroform, carbon tetrachloride, and Halons, demand for goods that contain or are manufactured with these chemicals (e.g., refrigerators, computers, automobile air conditioners) and the historic relationship between economic activity and the use of these chemicals were analyzed. These analyses indicate that in the absence of regulation, the use and emissions of these compounds are expected to increase in the future. However, for purposes of analyzing risks, six "what-if" scenarios were adopted that cover a greater range of future production of ozone-depleting substance than is likely to occur.

EXHIBIT ES-2

CFC-12: Atmospheric Concentrations from Different Emission Trajectories



Atmospheric concentrations of CFC-12 will continue to rise unless emissions are cut. Holding emissions constant at today's level or even 15 percent or 50 percent lower would still allow atmospheric concentrations to grow. Only a cut of 85 percent or more could stabilize atmospheric concentrations.

Source: Hoffman, 1986.

Model Projections for Ozone Changes

6. Atmospheric chemistry models were used to assess the potential effects of possible future changes in atmospheric concentrations of trace gases. These models attempt to simulate processes that influence the creation and destruction of ozone. While the models replicate many of the characteristics of the atmosphere accurately, they are inconsistent with measured values of other constituents, thus lowering our confidence in their ability to predict future ozone changes accurately.

7. Based on the results from these models, the cause of future changes in ozone will be highly dependent on future emissions of trace gases. One-dimensional models project that if the use of chlorine and bromine containing substances remains constant globally, and other trace gas concentrations continue to grow, total column ozone levels would at first decrease slightly, and then would subsequently increase. If the use of CFCs continues to grow at past rates and other gases also increase at recent rates, substantial total column ozone depletion would occur by the middle of the next century. If the use of CFCs stays at current levels and the growth in the concentrations of other trace gases slows over time, model results indicate total column ozone depletion will also occur. (Exhibit ES-3 shows various model projections for "what-if" scenarios.)

8. In all scenarios examined, substantial changes are expected in the vertical distribution of ozone. Ozone decreases are generally expected at higher altitudes in all scenarios in which CFC concentrations increase. Ozone increases are expected at lower altitudes in some scenarios examined due to increases in methane concentrations. Such changes may have important climatic effects.

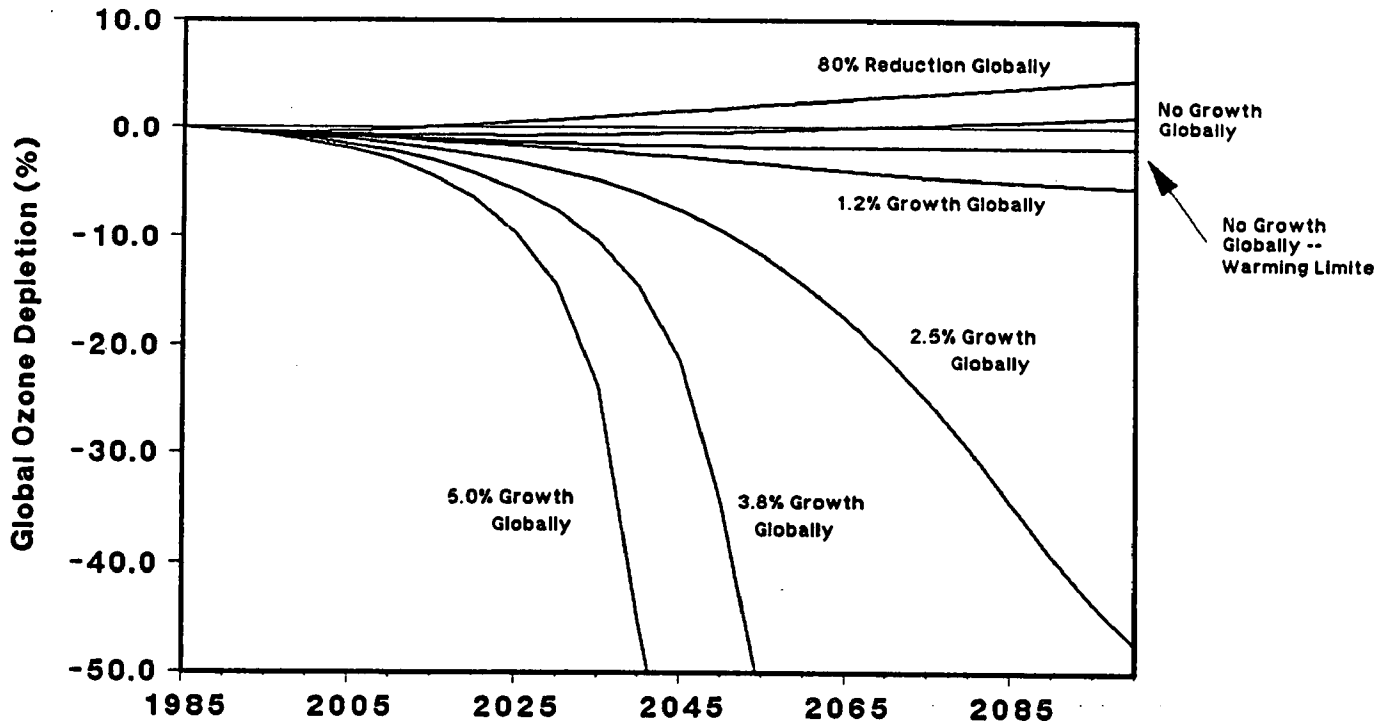
9. Two-dimensional (2-D) models provide information on possible changes in ozone by season and by latitude. Results from 2-D models suggest that global average depletion could be higher than estimates from a one-dimensional (1-D) model for the same scenario. Moreover, the 2-D model results suggest that average annual ozone depletion above the global average would occur at higher latitudes (above 40 degrees), while depletion over tropics is predicted to be lower than the global average; and depletion would be greater in the spring than the annual average. Uncertainties in the representation of the transport of chemical species used in 2-D models introduces uncertainty in the magnitude of the latitudinal gradient of ozone depletion, but all 2-D models project a gradient.

Measurements of Ozone

10. Measurements of ozone concentrations are another valuable tool for assessing the risks of ozone modification. Based on analysis of data for over a decade from a global network of ground-based monitoring stations, ozone concentrations have decreased at mid-latitudes in the upper and lower stratosphere and increased in the troposphere. According to studies using ground-based instruments, there appears to have been no statistically significant change in column ozone between 1970 and 1983. High altitude, lower stratospheric, and total column trends are roughly consistent with current two-dimensional model predictions.

EXHIBIT ES-3

Global Average Ozone Depletion: Emission Scenarios



*This scenario assumes no growth in global production of ozone depleters, and concentrations of other trace gases are prevented from rising to an amount greater than that compatible with an increase in equilibrium global temperature of 3.0°C ± 1.5°C by 2075.

<u>Assumptions</u>:

-- Current 1-D models accurately reflect global depletion; Antarctic ozone hole has no impact on global ozone levels.

-- Greenhouse gases that counter depletion grow at historically-extrapolated rates.

-- Growth rates for ozone depleters are for global emissions; it is assumed that emissions do not increase after 2050.

-- Ozone depletion limited to 50 percent.

11. Recent evidence indicates that since the late 1970s substantial decreases in ozone (up to 50 percent) have occurred over and near Antarctica during its springtime. These losses have been verified by different measurement techniques, and different theories have been suggested to explain the cause of the seasonal loss in ozone. Insufficient data exist to state whether chlorine and bromine are responsible for the observed depletion, or whether some other factor is the cause (e.g., dynamics or changes in solar flux that alters NOx). Furthermore, even if man-made chemicals are the cause of the phenomenon, stratospheric conditions surrounding Antarctica are different from the stratospheric conditions for the rest of the world, so that it cannot be assumed that similar depletion would occur elsewhere. Models did not predict the Antarctic ozone depletion, however. Consequently, the change in Antarctica suggests that ozone abundance is sensitive to yet unknown natural or anthropogenic factors not yet incorporated in current models.

12. Preliminary data from Nimbus-7 suggest a decrease in global ozone concentrations (4-6 percent) may have occurred during the past several years. These data have not yet been published and require additional review and verification. If verified, further analysis would be required to determine if chlorine is responsible for the reported decrease in ozone levels, or whether the decrease is due to other factors or reflects short-term natural variations.

Potential Health Effects from Ozone Depletion

13. Decreases in total column ozone would increase the penetration of ultraviolet-B (UV-B) radiation (i.e., 290-320 nanometers) reaching the earth's surface. (Exhibit ES-4 shows relative increases in UV-B at 295, 305, and 315 nanometers.)

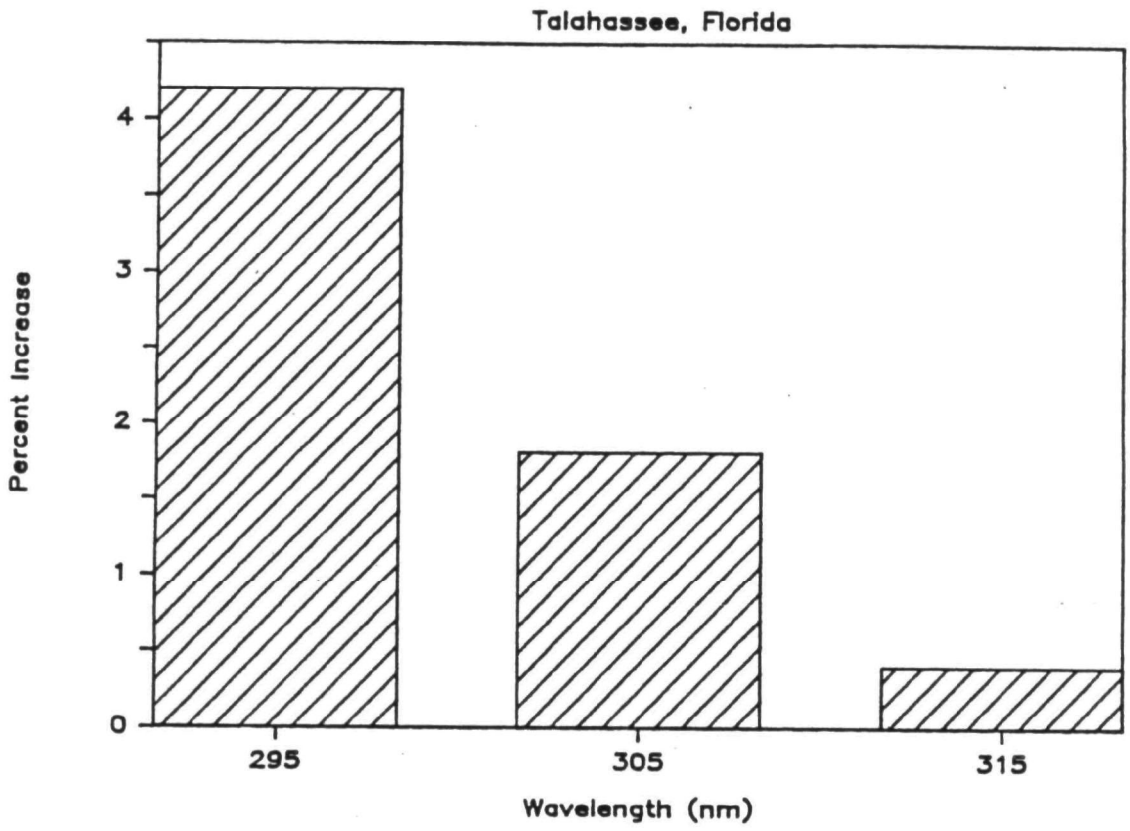
14. Exposure to UV-B radiation has been implicated by laboratory and epidemiologic studies as a cause of two common types of skin cancers (squamous cell and basal cell). It is estimated that there are more than 400,000 new cases of these skin cancers each year. While uncertainty exists concerning the appropriate action spectrum (i.e., the relative biological effectiveness of different wavelengths of ultraviolet radiation), a range of relationships was developed that allows increased incidence of these skins cancers to be estimated for future ozone depletion (these cancers are also referred to as nonmelanoma skin cancers).

15. Studies predict that for every 1 percent increase in UV-B radiation (which corresponds to less than a 1 percent decrease in ozone because the amount of increase in UV-B radiation, depending on the action spectrum, is greater than rather than proportional to ozone depletion), nonmelanoma skin cancer cases would increase by about 1 to 3 percent. The mortality for these forms of cancer has been estimated at approximately 1 percent of total cases based on limited available information.

16. Malignant melanoma is a less common form of skin cancer. There are currently approximately 25,000 cases per year and 5,000 deaths. The relationship between cutaneous malignant melanoma and UV-B radiation is a complex one. Laboratory experiments have not succeeded in transforming

EXHIBIT ES-4

Increases in Ultraviolet Radiation
Due to a 1 percent Ozone Depletion



Ozone depletion would lead to increases in the amount of ultraviolet radiation, particularly at the harmful lower wavelengths, that reaches the earth's surface.

Source: Estimates based on the ozone-UV model developed by Serafino and Frederick (1986).

melanocytes with UV-B radiation. However, recent epidemiological studies, including large case control studies, suggest that UV-B radiation plays an important role in causing melanoma. Uncertainties in action spectrum, dose measurement, and other factors necessitates the use of a range of dose-response estimates. Taking into account such uncertainties, recent studies predict that for each 1 percent change in UV-B intensity, the incidence of melanoma could increase from 0.5 to 1 percent.

17. Studies have demonstrated that UV-B radiation can suppress the immune response system in animals and possibly humans. While UV-B-induced immune suppression has been linked to chronic reinfection with herpes simplex virus and leishmaniasis in animals, its possible impact on other diseases and its impact on humans has not been studied.

18. Increases in exposure to UV-B radiation are likely to increase the incidence of cataracts and could adversely affect the retina.

Potential Effects on Plants and Aquatic Organisms

19. While studies generally show adverse impacts on plants from increased UV-B exposure, difficulties in experimental design, the limited number of species and cultivars tested, and the complex interactions between plants and their environments prevent firm conclusions from being made for the purpose of quantifying risks. Field studies on soybeans suggest that yield reductions could occur in some cultivars of soybeans, while evidence from laboratory studies suggest that two out of three cultivars are sensitive to UV-B.

20. Laboratory studies with numerous other crop species also show many to be adversely affected by UV-B. Increased UV-B has been shown to alter the balance of competition between plants. While the magnitude of this change cannot be presently estimated, the implications of UV-altered, competitive balance for crops and weeds and for nonagricultural areas such as forests, grasslands, and desert may be far reaching.

21. Aquatic organisms, particularly phytoplankton, zooplankton, and the larvae of many fishes, appear to be susceptible to harm from increased exposure to UV-B radiation because they spend at least part of their time at or near surface waters. However, additional research is needed to better understand the ability of these organisms to mitigate adverse effects and any possible implications of changes in community composition as more susceptible organisms decrease in numbers. The implications of possible effects on the aquatic food chain requires additional study.

Effects of Depletion on Tropospheric Ozone and Polymers

22. Research has only recently been initiated into the effects of UV-B on the formation of tropospheric ozone (an air pollutant with negative health and plant effects). An initial chamber and model study shows that tropospheric ozone levels could increase, resulting in additional urban areas being in non-compliance with National Ambient Air Quality Standards. The increase in UV-B would also produce ozone peaks closer to urban centers, exposing larger populations to unhealthy concentrations of tropospheric ozone. The same study also predicts substantial increase in hydrogen peroxide, an acid rain precursor. However, because only one study has been done, the results must

be treated with caution. Additional theoretical and empirical work will be needed to verify these projections.

23. Research indicates that increased exposure to UV-B would likely cause accelerated weathering of polymers, necessitating polymer reformulation or the use of stabilizers in some products, and possibly curtailing use of certain polymers in some areas.

Climate Impacts from Trace Gas Growth

24. The National Academy of Sciences (NAS) has recommended that 1.5°C to 4.5°C represents a reasonable range of uncertainty about the temperature sensitivity of the Earth to a doubling of CO2 or an increase in other trace gases of the equivalent radiative forcing. While some of the trace gases discussed above deplete ozone and others result in higher ozone levels, all, on net, would increase the radiative forcing of the Earth and would contribute to global warming.

25. Using the middle of the NAS range for the Earth's temperature sensitivity and a wide range of future trace gas growth (e.g., from a phase-down of CFCs by 80 percent from current levels by 2010 to a 5 percent annual increase through 2050; CO2 doubling by 2060; N2O increasing at 0.2 percent; CH4 increasing by 0.017 ppm/year through 2100), equilibrium temperatures can be expected to rise from 4°C to 11.6°C by 2075. Of this amount, depending on the scenario, CFCs and changes in ozone would be responsible for approximately 15-25% of the projected climate change. (See Exhibit ES-5)

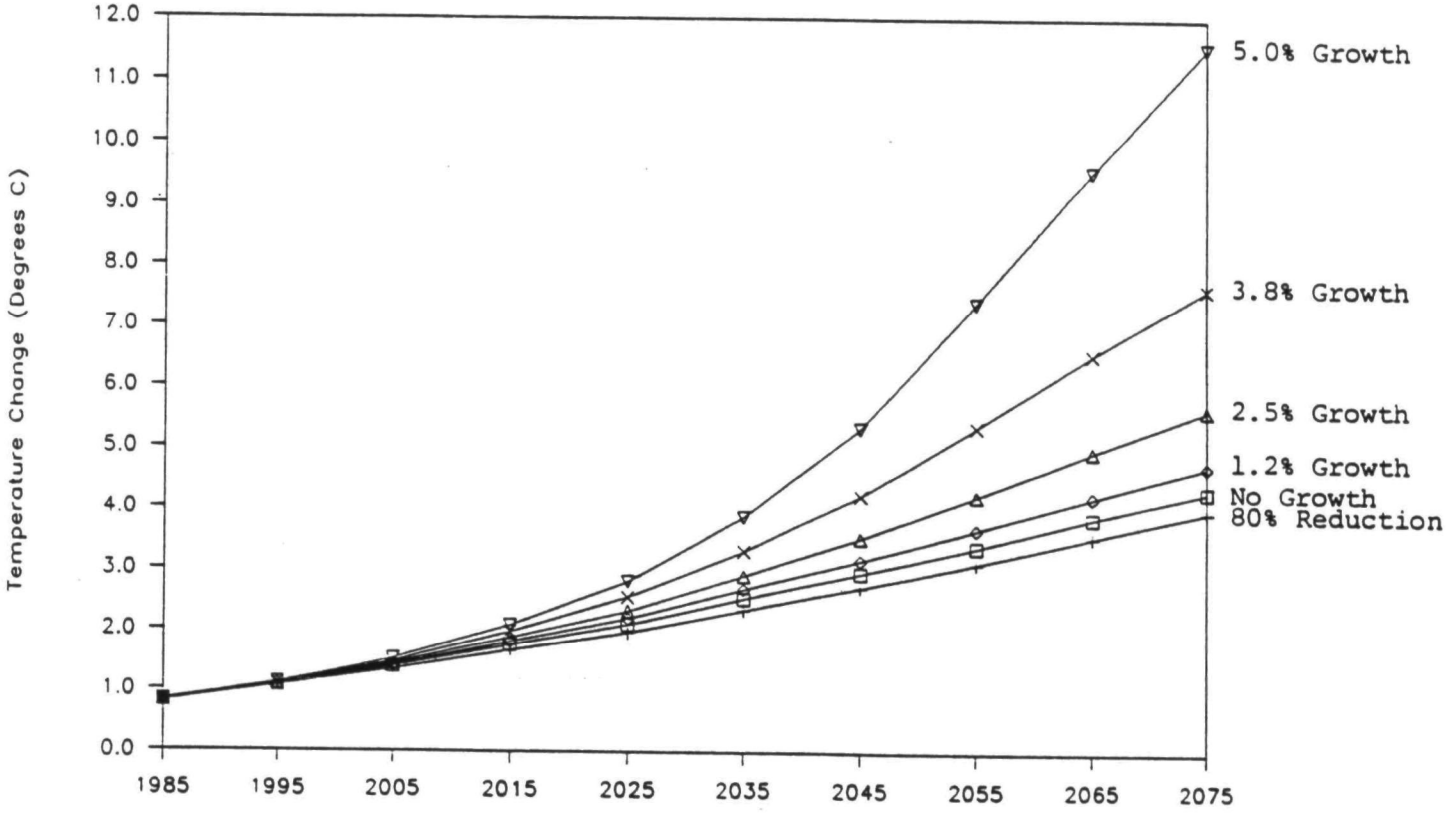
26. In most situations, inadequate information exists to quantify the risks related to climate change. Studies predict that sea level could rise by 10-20 centimeters by 2025, and by 55-190 centimeters by 2075. Such increases could damage wetlands, erode coastlines, and increase damage from storms. Changes in hydrology, along with warmer temperatures, could affect forests and agriculture. However, lack of information about the regional nature of climatic change makes quantification of risks difficult. A study suggests that rising temperatures could adversely affect human health if acclimatization lags.

Summary of Potential Risk

27. To perform the computations necessary to evaluate the risks associated with stratospheric modification, an integrating model was developed to evaluate the joint implications of scenarios or estimates for: (1) potential future use of CFCs and change in other trace gases; (2) ozone change as a consequence of trace gas emissions; (3) changes in UV-B radiation associated with ozone change; and (4) changes in skin cancer cases and cataracts associated with changes in UV-B radiation. Potential impacts of stratospheric modification that could not be quantified were not addressed by the integrating model. On a global basis, the risks of ozone depletion may be greatest for plants, aquatic systems and the immune system, even though knowledge to assess these efforts is much less certain than for skin cancers.

EXHIBIT ES-5

Equilibrium Temperature Change for the Six Emission Scenarios Assuming 3.0°C Warming for Doubled CO2*



* Computed assuming that the climate sensitivity to a doubling of carbon dioxide is 3°C. This assumption is in the middle of the NAS range of 1.5°C to 4.5°C (see Chapter 6). Note that the actual warming that may be realized will lag by several decades or more. To compute the equilibrium warming associated with high or low NAS estimates multiply the y axis 'temperature change' by 1.5 or 0.5.

Growth levels refer to global estimates of production of all ozone depleters.

28. Uncertainty about future risks is partly driven by the rate at which CFC and Halon use and other trace gases grow or decline. For this reason, a wide range of "what-if" scenarios of potential CFC and Halon use and growth in trace gas concentration was evaluated. To reflect the large uncertainties, the scenarios range from an 80 percent global phase-down in the use of CFCs by 2010 to an average annual growth in use of 5 percent per year from 1985 to 2050. For ozone-modifying gases other than CFCs, scenarios were based on recently measured trends, with uncertainties being evaluated by considering a range of future emissions and concentrations.

29. Across the wide range of "what-if" scenarios considered, ozone change by 2075 could vary from as high as over 50 percent ozone depletion to increased abundance of ozone of approximately 3 percent. This range of ozone change implies a change in the number of skin cancer cases among people alive today and born through 2075 ranging from an increase of over 200 million to a decrease on the order of 6.5 million. The overwhelming majority (over 95 percent) of the increases and decreases in skin cancer cases estimated for this wide range of scenarios is associated with basal and squamous cell cancers (i.e., nonmelanoma skin cancer). Mortality impacts are estimated to be on the order of 1.5 to 2.0 percent of the changes in total cases, and a large percentage of the estimated impacts are associated with people born in the future. The statistical uncertainty of these estimates is on the order of plus and minus 50 percent. Additional uncertainties exist, some of which cannot be quantified. The greatest single uncertainty about future risks is driven by the rate at which CFC and Halon use grows or declines. This uncertainty is reflected in the assessment by examining a wide range of "what if" scenarios of future use.

CHANGES IN ATMOSPHERIC COMPOSITION

The abundance of stratospheric ozone depends upon chemical and physical processes that create and destroy ozone. For over a decade scientists have hypothesized that changes in the concentrations of trace gases in the atmosphere could possibly perturb the processes that control ozone abundance and its distribution at different altitudes. The findings of this section summarize the currently available evidence on how emissions and concentrations of various gases may change over time. The findings in this section can be found in chapters 2 through 4 of the body of the risk assessment.

FINDINGS

1. HUMAN ACTIVITIES ARE THE ONLY SOURCE OF EMISSIONS FOR THREE CLASSES OF POTENTIAL OZONE-DEPLETING CHEMICALS: CHLOROFLUOROCARBONS (CFCs); CHLOROCARBONS (CARBON TETRACHLORIDE AND METHYL CHLOROFORM); AND HALONS (chapter 3)[2].

   1a. Since their development in the 1930s, CFCs have become useful chemicals in a wide range of consumer and industrial goods, including: aerosol spray cans; air conditioning; refrigeration; foam products (e.g., in cushions and insulating foams); solvents (e.g., electronics); and a variety of miscellaneous uses.

   1b. CFC-11 (CCl3F) and CFC-12 (CCl2F2) have dominated the use and emissions of CFCs, accounting for over 80 percent of current CFC production worldwide. Because of increased demand for its use as a solvent, CFC-113 (CCl2FCClF2) has become increasingly important as a potential ozone-depleting chemical.

2. MEASUREMENTS OF TROPOSPHERIC CONCENTRATIONS OF INDUSTRIALLY PRODUCED POTENTIAL OZONE-DEPLETING GASES SHOW SUBSTANTIAL INCREASES (chapter 2).

   2a. Measurements of current global average concentrations of CFC-11 are 200 parts per trillion volume (pptv), CFC-12 are 320 pptv, CFC-113 are 32 pptv, carbon tetrachloride (CCl4) are 140 pptv, and methyl chloroform (CH3CCL3) are 120 pptv.

   2b. Based on measurements from a global monitoring network, worldwide concentrations of chlorine-bearing perturbants (i.e., potential ozone depleters) have been growing annually in recent years at the following rates: CFC-11 and CFC-12 at 5 percent; CFC-22 (CHClF2) at 11 percent; CFC-113 at 10 percent; carbon tetrachloride (CCl4) at 1 percent; and methyl chloroform at 7 percent.

   2c. Limited measurements show that global tropospheric concentrations of Halon 1211, a bromochlorofluorocarbon containing both chlorine and bromine (which is potentially more effective at depleting ozone), have been growing recently at 23 percent annually. Concentrations have been measured as one pptv.

   2d. Measurements of tropospheric concentrations of Halon 1301, another brominated compound that is a potential ozone depleter, estimate that concentrations are approximately one pptv. No trend estimates have been published.

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[2] The chapter references refer to the main body of the risk assessment.

3. ALMOST ALL EMISSIONS OF CFC-11, -12, -113, HALON 1211, AND HALON 1301 PERSIST IN THE TROPOSPHERE WITHOUT CHEMICAL TRANSFORMATION OR PHYSICAL DEPOSITION. AS A RESULT, MOST OF THESE EMISSIONS WILL EVENTUALLY BE TRANSPORTED TO THE STRATOSPHERE (chapter 2).

3a. Gases which are photochemically inert accumulate in the lower atmosphere. Their emissions migrate to the stratosphere slowly. Estimates of their atmospheric lifetimes (generally calculated based on the time when 37 percent of the compound still remains in the atmosphere) are the following: CFC-11 is 75 years (107/58 years); CFC-12 is 111 years (400/55 years); CFC-113 is 90 years; CCl_4 is 50 years; Halon 1211 is 25 years; N_2O is 150 years; and Halon 1301 is 110 years. (Where provided, the range in parentheses shows one standard deviation).

3b. Because of their long atmospheric lifetimes, the concentrations of these gases are currently far from steady state and will increase over time unless there is a large reduction in future emissions.

3c. Because of their long atmospheric lifetimes, these gases would continue to contribute to possible future ozone depletion and climate change (CFCs and other gases affecting ozone are also greenhouse gases) long after they are emitted. Full recovery from any depletion or climate change would take decades to centuries.

4. WHILE CFCs USED IN AEROSOLS DECLINED FROM 1974 UNTIL 1984, NONAEROSOL USES OF CFCs HAVE GROWN CONTINUOUSLY AND APPEAR CLOSELY COUPLED TO ECONOMIC GROWTH (chapter 3).

4a. From 1960 to 1974, the combined production of CFC-11 and CFC-12 from both aerosol and nonaerosol applications grew at an average annual rate of approximately 8.7 percent. Total global CFC-11 and -12 production peaked in 1974 at over 700 million kilograms.

4b. From 1976 to 1984, sales of CFC-11 and CFC-12 for aerosol applications declined from 432 million kilograms to 219 million kilograms, an average annual rate of decline of over 8 percent. During the same period, sales for nonaerosol applications grew from 318 million kilograms to 476 million kilograms, an average annual compounded growth rate of 5 percent. By 1986, total CFC-11 and -12 global production was nearly that in 1974.

5. STUDIES OF FUTURE PRODUCTION OF CFCs-11 AND -12 PROJECT AN AVERAGE ANNUAL GROWTH RATE OF APPROXIMATELY 1.0 TO 4.0 PERCENT OVER THE NEXT 15 TO 65 YEARS (chapter 3).

5a. A large number of studies of future global demand for CFCs were conducted by experts from six countries under the auspices of the United Nations Environment Programme. These studies used a variety of methods for estimating both near- and long-term periods. In general, these studies assumed that: (1) demand for CFCs was driven by economic factors; (2) no additional regulations on CFC use were imposed; and (3) consumers or producers do not voluntarily shift away from CFCs because of concern about ozone depletion. These studies

provide a range of growth rates for developing alternative baseline scenarios of future CFC use and emissions.

5b. In general, these studies projected that CFC aerosol propellant applications would remain constant or decrease further in many regions of the world.

5c. In the U.S. over the past four decades new uses of CFCs have developed first in refrigeration, then in aerosols, then in foam blowing, and then in solvents.

5d. Studies have projected that growth in developed countries for nonaerosol applications is expected to be driven by increased use in foam blowing (primarily for insulation) and as solvents, and by the continued introduction of new uses. The wide range of estimates of future growth reflects the large uncertainties related to population and economic growth, and technological change.

5e. Studies suggest that future CFC use in developing countries will grow faster (i.e., at a higher rate) than future CFC use in the developed world. Nevertheless, the projected rates for the developing countries are lower than the historical rates that have been experienced in wealthier countries. While these studies were done using aggregate relationships of GNP and CFC use, they made different assumptions about how closely the pattern of CFC use in developing nations would replicate the pattern in developed nations, generally assuming lower use rates. However, evidence from one recently completed study (not completed at the time of the UNEP workshop) indicates that in developing countries the penetration of CFC-using goods may be occurring faster than expected on the basis of the historical relationship in developed nations. If that study is correct, growth in developing nations would be larger than projected in the above-mentioned studies, which generally assumed less penetration in developing nations than had occurred in developed nations.

5f. Three long-term studies of CFC demand report annual average rates of growth for CFC-11 and CFC-12 over the next 65 years ranging from 0.2 percent to 4.7 percent, with a median estimate of about 2.5 percent. The "what-if" scenarios used for quantitative risk assessment in Chapter 18 span a wider range of growth, including one scenario with substantial decline.

5g. Limited studies on CFC-113 and CFC-22 project that in the absence of regulation or voluntary shifts away from these chemicals, their growth will increase at a faster rate than CFC-11 and -12 as new markets develop and existing ones expand (e.g., use of CFC-113 as a solvent in metal cleaning).

6. THE CHLOROCARBONS (METHYL CHLOROFORM AND CARBON TETRACHLORIDE) ARE USED PRIMARILY AS SOLVENTS AND CHEMICAL INTERMEDIATES. ANALYSIS SUGGESTS LIMITED FUTURE GROWTH FOR THESE CHEMICALS (chapter 3).

6a. Methyl chloroform is primarily used as a general purpose solvent. Global use in 1980 was estimated at nearly 460 million kilograms. Limited analysis of future demand indicates that it is expected to grow at the rate of growth of economic activity (as measured by GNP). Factors affecting future demand include possible control on it or other solvents due to their health effects. Thus, use of methyl chloroform could increase if other solvents are found more dangerous. Similarly, its use could be increased if CFC-113 use is restricted. Because methyl chloroform has a substantially shorter atmospheric lifetime than CFC-113, it has relatively less potential for depleting ozone.

6b. Carbon tetrachloride is primarily used to make CFCs in the U.S. In developing countries it is also sometimes used as a general purpose solvent. In general, future production and emission of carbon tetrachloride is expected to follow the pattern of production of CFCs.

7. HALONS, ON A PER POUND BASIS, POSE A GREATER THREAT (2-1/2 TO 12-1/2 TIMES) TO OZONE DEPLETION THAN DO CFCs (chapter 3).

7a. Halons have been used in hand-held and total-flooding fire extinguishers since the 1970s. Annual production has been limited (approximately 20,000 kilograms) and emissions have been assumed to be only a small fraction of production based on the assumption that the halons remain inside the fire extinguishers. Recent research suggests the proportion of Halons released may be substantially higher. In the U.S., industrial response to concern about depletion from halons is likely to lead to some voluntary steps to curtail emissions.

7b. A single study has projected future demand for Halons.[3] It indicates that near-term demand is growing rapidly and that production may double by the year 2000. In that study, longer-term demand is judged uncertain and may range from an average annual decline of 1 percent from 2000 to 2050 to an annual increase exceeding 5 percent.

7c. The expected rate of Halon emissions is very uncertain. The one study assumed most production would remain within fire extinguisher systems as part of a growing Halon "bank." That study has been the basis for scenarios used in this analysis.

7d. The historic growth in Halon 1211 concentrations (recently measured at over 20% per year) is significantly higher than the rate assumed for future years in the one existing study.

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[3] Since the Risk Assessment was drafted, another study has been developed; see Chapter 3 Appendix. That study was not included in this Risk Assessment.

7e. Discussions with Halon users indicate that Halon 1301 emissions may be underestimated in the study used for this risk assessment. A recent survey showed that existing systems are undergoing widespread testing and accidental discharge occurs more frequently than assumed in prior studies.[4]

7f. Additional analysis of Halon emission estimates are necessary to assess more adequately the risks associated with this trace gas.

8. FUTURE CONCENTRATIONS OF STRATOSPHERIC PERTURBANTS THAT HAVE AT LEAST SOME BIOGENIC SOURCES, CARBON DIOXIDE, METHANE, AND NITROUS OXIDE, ARE DIFFICULT TO PROJECT (chapter 4).

8a. The size of existing source terms (wetland areas, for example) is not known with certainty today for all these trace species. Greatest uncertainty exists for methane, least for CO2. To estimate future emissions reliably requires estimating the growth of source terms (e.g., acreage of rice paddies, wetlands area), which will be determined by many technical, political, environmental, and social factors.

8b. Current emission factors for each source term must be estimated; some are not known today or have not been reliably estimated (emissions from soils, for example).

8c. Possible changes in emission factors due to changes in the environment must be projected. Projection of changes is difficult because the underlying physical or biological processes that determine emissions are not well understood and because changes in the environment that could alter emissions are not easy to project.

8d. Biogeochemical cycles that control the fate of emissions once released into the atmosphere must be understood to determine future concentrations of these trace species; severe limitations to our current understanding of these cycles limits our capacity to determine the consequences of changing emissions in the future.

8e. Possible changes in these biogeochemical cycles due to changes in the environment must be projected; again deficiencies in existing knowledge makes this task difficult.

9. DESPITE THE UNCERTAINTIES ASSOCIATED WITH EACH OF THESE FACTORS, RESEARCHERS HAVE DEVELOPED SCENARIOS FOR THREE GASES WHICH ARE COMMONLY USED. IN THIS RISK ASSESSMENT A SCENARIO CONSISTENT WITH ONES USED IN THE ATMOSPHERIC COMMUNITY'S WILL BE ADOPTED, AS WELL AS SEVERAL SENSITIVITY SCENARIOS TO EXAMINE THE SENSITIVITY OF ATMOSPHERIC EVOLUTION TO THE SCENARIOS (chapter 4).

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[4] Since this risk assessment was originally completed, Halon users in the U.S. have taken a variety of steps to reduce emissions. This step is not considered in this Risk Assessment.

9a. The scenarios used in this risk assessment are consistent with that commonly used by the atmospheric community and assume the following changes in trace gas concentrations:

- o for CO_2, a scenario developed by the National Academy of Sciences (its 50th percentile, i.e., pre-industrial CO_2 concentrations doubling by about 2065);
- o for CH_4, a linear increase in concentrations of 0.017 ppm per year;
- o for N_2O, concentration increases of 0.2 percent per year.

9b. Additional scenarios used to analyze risks will include:

- for CO_2

- o NAS 25th percentile (pre-industrial concentrations doubling by 2100)
- o NAS 75th percentile (pre-industrial concentrations doubling by 2050)

- for CH_4

- o 0.01275 ppm per year growth in concentrations (75 percent of the historically observed 0.017 ppm per year increase)
- o 0.02125 ppm per year growth in concentrations (125 percent of the historically observed 0.017 ppm per year increase)
- o 1 percent compound growth per year in concentrations
- o 1 percent compound growth per year in concentrations from 1985 to 2010, followed by constant concentrations at 2.23 ppm
- o 1 percent compound growth per year in concentrations from 1985 to 2020, growing to 1.5 percent compound annual growth by 2050 and thereafter

- for N_2O

- o 0.15 percent per year compound growth in concentrations
- o 0.25 percent per year compound growth in concentrations

10. <u>DECISION MAKERS SHOULD BE MADE AWARE THAT THE MOST COMMONLY USED SCENARIOS IN STRATOSPHERIC MODELING IMPLICITLY ASSUME THAT FUTURE DECISION MAKERS NEVER TAKE ACTION TO LIMIT THE RISE IN CONCENTRATIONS OF CARBON DIOXIDE, METHANE, AND NITROUS OXIDE, THREE GASES CONTRIBUTING TO THE GREENHOUSE WARMING</u> (chapter 4).

10a. The standard assumption in most atmospheric modeling has been, by default, that greenhouse gases will be allowed to increase without limit regardless of the level of global warming that occurs or is projected.

10b. In order to provide decision makers with adequate information to assess the risks of ozone modification due to rising CFCs and Halons, alternative assumptions about the future of greenhouse gases need to be examined. Two scenarios are examined:

-- limiting global warming to 2°C.
-- limiting global warming to 3°C.

POTENTIAL CHANGES IN OZONE AND CLIMATE

MODELS OF THE ATMOSPHERE THAT INCORPORATE CURRENT SCIENTIFIC UNDERSTANDING OF CHEMISTRY AND PHYSICS PROJECT CHANGES IN GLOBAL OZONE (TOTAL COLUMN AND/OR VERTICAL DISTRIBUTION) AND INCREASES IN GLOBAL SURFACE TEMPERATURE IF TRACE GAS CONCENTRATIONS GROW SIGNIFICANTLY. UNCERTAINTIES ABOUT MAGNITUDES REMAIN LARGE.

Models that incorporate current scientific understanding are used as the primary tool to project the potential consequences of future changes in abundances of trace gases. These models can be partly tested by comparing their results with measurements of the atmospheric, historically observed changes in ozone, and in the case of climate, with paleoclimatic and extraterrestrial environments. While current models accurately represent some aspects of the atmosphere, they fail to replicate other characteristics. This section summarizes the currently available evidence on how changing atmospheric abundance could modify total column ozone, alter column distribution, and change global climate.

FINDINGS

11 STRATOSPHERIC MODELING PROJECTS THAT THE COMBINED EFFECTS OF A VARIETY OF TRACE GASES (CHLOROFLUOROCARBONS, NITROUS OXIDE, CARBON DIOXIDE, HALONS, AND METHANE) ARE LIKELY TO REDUCE THE COLUMN DENSITY OF OZONE UNLESS EMISSIONS OF OZONE DEPLETERS ARE PREVENTED FROM GROWING (chapter 5).

11a. Photochemical theory continues to support the conclusion that chlorine, nitrogen, and hydrogen can catalytically destroy ozone in the stratosphere, thus depleting column levels.

11b. One-dimensional (1-D) models currently predict a 5-9 percent depletion for the equilibrium concentrations of chlorine that would result from constant emission of CFCs at 1977 levels. While useful for intercomparing models, these values cannot be used to assess the risks of depletion in an atmosphere in which other gases are also changing.

11c. One-dimensional (1-D) models predict average column ozone will decrease if global emissions of CFCs and other ozone depleters continue to rise from current levels, even if concentrations of methane, carbon dioxide, and nitrous oxide continue to grow at past rates. For a 3 percent growth of CFCs, models predict over a 25 percent depletion by 2075 if the other gases continue to grow.

11d. Two-dimensional models (2-D) used in steady state multi-perturbant studies that include chlorine, methane, and nitrous oxide project depletion higher than global averages at latitudes greater than 40°N, especially in the spring.

11e. Time-dependent simulations of stratospheric change in which 2-D models are used predict that depletion over 4 percent will occur at some latitudes for all cases of positive growth in CFC emissions. Such models even predict ozone depletion of up to 3 percent at inhabited latitudes for a scenario in which emissions of chlorine-bearing substances are reduced from current to 1980 levels and in which halon emissions are eliminated, but in which the greenhouse gases that counter depletion are allowed to grow at historical rates.

11f. Time-dependent simulation with one 2-D model, with CFCs growing at 3 percent, methane rising at 1 percent, nitrous oxide at 0.25 percent and carbon dioxide growing at 0.6 percent, projects annual average depletion at 40°N of approximately 1.1 percent by 2000 and 5.2 percent by 2030. At 50°N, depletion is projected to be 1.5 percent by 2000 and 6.5 percent by 2030. At 60°N, depletion is projected to be 2.1 percent by 2000 and 8.1 percent by 2030. Springtime depletion would be higher.

11g. Time-dependent simulation with one 2-D model, with CFC-11 and -12 emissions rolled back to 1980 levels, CFC-113 capped, other chlorinated emissions and bromine emissions eliminated, methane rising at 1 percent, nitrous oxide at 0.25 percent, and carbon dioxide at 0.6 percent, projects depletion by 2030 of about 0.5 percent at 40°N, 0.7 percent at 50°N, and 1.1 percent at 60°N (these

depletion values are from 1985 levels). If carbon dioxide concentrations are prevented from growing from current levels, depletion would be anticipated to be higher.

11h. Time-dependent simulations with two other two-dimensional models show roughly comparable results to those reported here, with a slightly less latitudinal gradient. However, these models also project latitudinal gradients from equatorial to polar and regions.

11i. Because of possible increases in the emissions of bromine molecules (see Chapter 4), Halons present a more important risk for stratospheric depletion than has generally been appreciated.

12. CURRENT THEORY AND MODELS FAIL TO REPRESENT ALL OBSERVATIONAL MEASUREMENTS OF THE ATMOSPHERE AND PROCESSES THAT WILL INFLUENCE STRATOSPHERIC CHANGE IN A COMPLETE AND ACCURATE MANNER (chapter 5).

12a. While accurately reproducing many measurements in the current atmosphere, current models fail to reproduce some measurements; the amount of ozone at 40 kilometers is underestimated, for example.

12b. While including representations of most atmospheric processes, current models fail to include all the processes that influence stratospheric composition and structure in a realistic manner. Transport processes, for example, are represented in a simplified manner that does not encompass all the complications of movement in the real atmosphere.

12c. The inability of models to wholly reproduce measurements of the current atmosphere lowers our confidence in them to predict the future; it is possible that models are over- or under-predicting future depletion.

13. UNCERTAINTY ANALYSES THAT CONSIDER A RANGE OF POSSIBLE VALUES FOR CHEMICAL AND PHYSICAL INPUTS CRITICAL FOR MODEL ESTIMATION OF DEPLETION INDICATE THAT DEPLETION IS LIKELY IF CFCS CONTINUE TO GROW (chapter 5).

13a. Uncertainty analyses conducted with one-dimensional models predict depletion for a variety of CFC levels.

13b. Uncertainty analyses using different sets of kinetics and cross sections have not been tested in two-dimensional models. However, different 2-D models have used different approaches for transporting species. This provides a useful test of the sensitivity of model predictions to the uncertainty of how transport actually works. While differing somewhat in the latitudinal gradients of depletion, the models with different transport both predict depletion that increases with distance from the equator.

13c. Not all uncertainties can be tested in the modeling process. The possibility that missing factors may lead to a greater or lesser depletion than indicated in formal uncertainty analyses cannot be excluded.

14: <u>OZONE MONITORING SHOWS CHANGES IN OZONE ROUGHLY CONSISTENT WITH MODEL PREDICTIONS, WITH TWO EXCEPTIONS</u> (chapter 5).

14a. Measurements by balloons and Umkehr show 3 percent depletion at mid-latitudes in the upper atmosphere, 1.3 percent depletion in the lower stratosphere, and 12 percent increases in the lower troposphere. Uncertainty exists about the accuracy of all these observations. These results, however, are roughly consistent with the expectations generated by one-dimensional and two-dimensional models. The ground based measurement system covers only a small part of the Earth and is limited at high latitudes.

14b. Nimbus 7 measurements appear to show a decrease in global ozone, especially at both poles. However, the decrease in Arctic ozone from 1978 to 1984 may have occurred only in the last several years. Concern exists about calibration problems, which make an exact determination of the absolute magnitude of depletion difficult. However, the latitudinal variations in depletion seem to indicate that a real phenomenon is being observed, not just instrumental drift.

14c. The cause of these apparent ozone decreases measured by Nimbus 7 has not been sufficiently analyzed to determine whether the changes (if they are real) can be attributed to manmade chemicals. Other possible explanations include natural variations caused by solar cycles or other processes. The latitudinal gradients of the changes, are, however, roughly consistent with those projected by 2-D model results, although the magnitude is substantially larger than models predict. Until further analysis is performed to determine whether depletion is actually occurring and whether it can be attributed to man-made chemicals, models to assess risks to the stratosphere should not be revised.

14d. Measurements in the Antarctic spring show that the gradual depletion that occurred in the mid-1970s over and near Antarctica has given way to a steep non-linear depletion from 1979 to 1985. The ozone maximum outside Antarctica (between 50°S and 70°S) appears to be showing a decline. The depletion of all areas south of 80°S appears to be 16 percent.

14e. Models with conventional chemistry do not predict "the Antarctic ozone hole." Care should be exercised in interpreting the meaning of the phenomenon. Several hypotheses have been put forward, including a chemical explanation that attributes the loss of ozone to manmade sources (bromine and chlorine), a chemical explanation that attributes the loss to natural sources (NOx, solar cycle), or an explanation that claims the phenomenon is entirely due to the change in climate dynamics. Until more is understood about the true causes of the hole, it is impossible to determine whether the hole is a precursor of atmospheric behavior that will occur in other regions of the world. Until a better understanding of the mechanisms creating the depletion is obtained, the existence of the Antarctic ozone hole should not be used as a basis for making regulatory decisions.

14f. This risk assessment will assume that Antarctic ozone and global trends have no implications for global projections. Future reviews should update this conclusion as necessary.

15. INCREASES IN THE ABUNDANCE OF CFCs AND OTHER TRACE GASES CAN INCREASE GLOBAL TROPOSPHERIC SURFACE TEMPERATURES. THESE GASES CAN ALTER THE VERTICAL DISTRIBUTION OF OZONE AND INCREASE STRATOSPHERIC WATER VAPOR, THEREBY INFLUENCING GLOBAL WARMING (chapter 6).

15a. Trace gases that act as stratospheric perturbants also are greenhouse gases--as their concentrations increase in the troposphere they will retard the escape of infrared radiation from earth, causing global warming.

15b. Increases in methane (CH_4) will also add water vapor to the stratosphere, thereby enhancing global warming. Methane increases will also add ozone to the troposphere, where it acts as a strong greenhouse gas that will further increase global warming.

15c. In all model-generated scenarios of ozone depletion, ozone decreases in the stratosphere above 28 km. This allows more ultraviolet radiation to penetrate to lower altitudes where the "self-healing effect" increases ozone to partially compensate for the ozone loss above. In some scenarios sufficient depletion occurs so that ozone eventually decreases at all altitudes.

15d. Decreases in ozone at approximately 28 km or above will have a warming effect on the Earth. There is a small net gain in energy because the increase in ultraviolet radiation (UV-B) allowed to reach the earth's surface more than compensates for the infrared radiation that is allowed to escape due to depletion of ozone above that altitude.

15e. Below approximately 28 km, increases in ozone are more effective as absorbers of infrared radiation. Consequently, increases in ozone below 28 km also will produce a net warming. In this case, the additional UV blocked by more ozone is less than the additional infrared that is blocked from escaping the earth. Conversely, a decrease in ozone below 28 km will tend to cool the Earth's surface.

15f. The direct effect of column depletion of ozone on global temperatures will depend on the magnitude of the depletion. Until the depletion is of sufficient magnitude that it occurs at the lower part of the column, ozone depletion will be a net contributor to global warming. If the stratosphere continues to deplete so that ozone is depleted below 28 km, this depletion will cause a cooling. One-dimensional models differ from two-dimensional models in the vertical distribution of ozone change, with depletion occurring at all altitudes in the higher latitudes in two-dimensional models, rather than just at high altitudes. Thus, according to 2-D models, the changes in radiative balance will be latitude dependent. At the current time, no studies have been undertaken to determine the net radiative forcing of changes projected by 2-D models.

15g. Radiative forcing may vary strongly with changes in ozone at different altitudes and latitudes. Consequently, until comparisons are made between the models in terms of their global impact, estimates of the effects of changes in the vertical column of ozone on global warming made with 1-D models must be viewed cautiously. In addition, changed vertical distribution of ozone could influence stratospheric dynamics.

16. INCREASES IN TRACE GAS CONCENTRATIONS ASSOCIATED WITH STRATOSPHERIC MODIFICATION ARE LIKELY TO WARM THE EARTH SIGNIFICANTLY (chapter 6).

16a. Two National Academy of Sciences panels have concluded that the equilibrium warming for doubling atmospheric concentrations of CO_2, or for an equivalent increase in the radiative forcing of other trace gases, will most likely be between 1.5° and 4.5°C.

16b. The magnitude of warming that would be directly associated with radiative forcing from increases in trace gases without feedback enhancement would increase temperature by approximately 1.2°C for a doubling of CO_2, and approximately an additional 0.45°C for a simultaneous doubling of N_2O and CH_4. Direct radiative forcing from a uniform 1 ppb increase in both CFC-11 and CFC-12 would increase temperature by about 0.15°C.

16c. The initial warming from direct radiative forcing would change some of the geophysical factors that determine the earth's radiative balance (i.e., feedbacks will occur) and these changes would amplify the initial warming. Increased water vapor and altered albedo effects (snow and ice melting, reducing the reflection of radiation back to space) have been projected by several modeling groups to increase the warming by as much as 2.5°C for doubled CO_2 or its radiative equivalent. Large uncertainties exist about the feedbacks between global warming and clouds, which could further amplify, or possibly reduce, the magnitude of warming.

16d. The three major general circulation modeling groups in the U.S. estimate an average global warming of around 4°C for doubled CO_2 or its radiative equivalent. However, because of uncertainties in the representation of the cloud contributions, greater or lesser amplifications, including a negative feedback that would reduce the warming to 2°C or an even lower value, cannot be ruled out.

16e. Global average temperature has been estimated as having risen about 0.6°C over the last century. This increase is consistent with general predictions of climate models. Attempts to use these data to derive empirically the temperature sensitivity of the earth to a greenhouse forcing are not likely to succeed. Uncertainty about the past concentrations of trace gases in the atmosphere, other exogenous factors that affect the climate (such as aerosols or solar input), and oscillation and instabilities in the internal dynamics of the climate system (such as ocean circulation), currently prevent the derivation of the earth's temperature sensitivity from examination of the historic rise of temperature. This limitation is likely to remain for more than another decade.

16f. The global warming associated with increases in ozone-modifying gases varies with scenarios of future growth in these gases. If the use of CFCs grows at 2.5 percent per year through 2050, CO_2 concentrations grow at the 50th percentile rate defined by the NAS (approximately 0.6 percent per year from 1985 to 2050), N_2O concentrations grow at 0.20 percent per year, and CH_4 concentrations grow at 0.017 ppm per year (approximately 1.0 percent of current concentrations), then equilibrium temperatures would rise by about 5.6°C by 2075 (relative to observed temperature in 1985), based on a temperature sensitivity of 3°C for doubled CO_2. Values would be about 50 percent higher for a 4.5°C-based temperature sensitivity and about 50 percent lower for 1.5°C. If CFC use remains constant through 2050, the projected warming would be about 4.3°C by 2075 (± 50%), and if use were phased out by 2010, projected warming would be about 4.0°C (± 50%).

16g. Efforts to gather worldwide time series data for clouds have begun. If adequate, these data may narrow estimates of the cloud contribution to temperature sensitivity within the next decade. However, because of the complexity of this issue, this effort may fail to resolve the large uncertainties affecting this aspect of climate.

17. <u>THE TIMING OF GLOBAL WARMING DEPENDS ON THE RATES AT WHICH GREENHOUSE GASES INCREASE, THE RATES AT WHICH OTHER FORCINGS SUCH AS VOLCANOES AND SOLAR RADIATION CHANGE, AND THE RATE AT WHICH OCEANS TAKE UP HEAT AND PARTIALLY DELAY TEMPERATURE EFFECTS. A GLOBAL WARMING GREATER THAN VARIATIONS THAT OCCURRED THIS PAST CENTURY IS EXPECTED IN THE NEXT TEN YEARS IF VOLCANIC AND SOLAR FACTORS DO NOT SUBSTANTIALLY CHANGE</u> (chapter 6).

17a. The delay in temperature rise introduced by absorption of heat by the oceans can only be roughly estimated. The simple one-dimensional models of oceans that have been used for this purpose do not realistically portray the mechanisms for heat transport into the oceans. Instead, these models use eddy diffusion to treat heat in a parameterized manner so that heat absorption is consistent with data from the paths of transient tracers. These models indicate that the earth will experience substantial delays (on the order of several decades) in experiencing the full warming from greenhouse gases.

17b. The earth's current average temperature is not in equilibrium with the radiative forcing from current concentrations of greenhouse gases. Consequently, global average temperature would increase in the future even if concentrations of gases did not rise any further. For example, if 2°C is the actual sensitivity of the earth's climate system to a CO_2 doubling, simple models estimate the current "unrealized warming" to be approximately 0.34°C; for a 4°C temperature sensitivity, the current unrealized warming would be approximately 1.0°C.

17c. Only one three-dimensional general circulation model has been used to simulate changes in temperature as concentrations of greenhouse gases increase over time. This simulation shows a faster warming than predicted by simpler one-dimensional models that use ocean box models to simulate time-dependent warming.

17d. Future uptake of heat by the oceans may change as global warming alters ocean circulation, possibly altering the delaying effect of the oceans as well as reducing their uptake of CO_2.

17e. Inadequate information exists to predict how volcanic or solar forcings may change over time. Analyses done of transient warming assume that past levels of volcanic aerosols will continue into the future and that solar forcing changes will average out over relatively short periods of time.

18. WITH A FEW GENERALIZED EXCEPTIONS, THE CLIMATIC CHANGE ASSOCIATED WITH GLOBAL WARMING CANNOT BE RELIABLY PREDICTED ON A REGIONAL BASIS (chapter 6).

18a. In general, as the earth warms, temperature increases will be greater with increasing distance from the equator.

18b. Global warming also can be expected to increase precipitation and evaporation, intensifying the hydrological cycle. While models lack sufficient reliability to make projections for any single region, all perturbation studies with three-dimensional models (general circulation models) show significant regional shifts in dryness and wetness, which suggests that shifts in hydrologic conditions will occur throughout the world.

18c. Current general circulation models represent oceanic, biospheric, and cloud processes with insufficient realism to determine how extreme weather events and climatic norms are likely to change on a regional basis. For example, one analysis of general circulation model outputs suggests that the frequency of extreme climatic conditions will change in many regions of the world. Another model projects increased summer drying in mid-latitudes for perturbation studies, utilizing either of two different representations of clouds. Still another analysis suggests changes in latitudinal gradients of sea surface temperature will play a critical role in determining regional climatic effects.

19. LIMITING GLOBAL WARMING BY REDUCING EMISSIONS OF STRATOSPHERIC PERTURBANTS THAT TEND TO INCREASE OZONE WOULD INCREASE THE STRATOSPHERE'S VULNERABILITY TO OZONE DEPLETION. UNDER SCENARIOS IN WHICH CONTINUED BUFFERING OF OZONE DEPLETION BY OTHER TRACE GASES IS ASSUMED, SUBSTANTIAL GLOBAL WARMING RESULTS (chapter 6).

19a. Decreases in substances with the potential to deplete stratospheric ozone--that is, chlorofluorocarbons and nitrous oxides--would decrease the rate and magnitude of global warming.

19b. Decreases in methane emissions, which have the potential to increase stratospheric and tropospheric ozone and thereby buffer ozone depletion, would decrease warming in three ways: by reducing direct radiative effects from its presence in the troposphere; by lowering water vapor in the stratosphere; and by reducing ozone build-up below 28 km.

19c. Decreases in CO_2 emissions would decrease global warming, but would also have the effect of increasing the stratosphere's vulnerability to ozone depletion.

19d. Decreases in carbon monoxide concentrations, which may occur as energy production practices change, could result in decreases in methane concentrations by increasing OH-radical abundance which, in turn, would shorten the lifetime of methane and could shorten the lifetime of methyl chloroform and CFC-22.

20. ADDITIONAL RESEARCH IS NEEDED ON CLIMATE TO REDUCE UNCERTAINTIES ABOUT GLOBAL WARMING ASSOCIATED WITH TRACE GAS GROWTH (chapter 6).

20a. The key to improving the accuracy of estimates of global temperature sensitivity is to acquire a better understanding of the effect of clouds. This recommendation has been made by numerous groups over the last decade; yet research devoted to this issue remains relatively small.

20b. An increased understanding of ocean circulation is critical to improving estimates of timing and regional projections.

20c. The effect of climate on biological systems and soils and their impact on climate must be modeled if regional estimates of climate change are to be developed.

20d. A better understanding of the radiative properties of CFC-113 and other compounds is needed for estimating the effects of this compound on climate.

20e. Experiments with three-dimensional models that have altered scenarios of vertical ozone need to be undertaken to assess the possible impacts on the magnitude of global warming and on general circulation.

HUMAN HEALTH, WELFARE, AND ENVIRONMENTAL EFFECTS

CHANGES IN COLUMN OZONE ABUNDANCE AND DISTRIBUTION AND A RISE IN GLOBAL TEMPERATURE WOULD BE EXPECTED TO HARM HUMAN HEALTH, WELFARE, AND THE ENVIRONMENT. SOME RISKS CAN BE QUANTIFIED USING RANGES. OTHER RISKS CANNOT BE QUANTIFIED OR DATA NECESSARY FOR QUANTIFICATION ARE AVAILABLE ONLY FOR LIMITED CASE STUDIES.

Ozone shields the earth from UV-B radiation. A decrease in total column ozone will increase this radiation, especially at its most harmful wavelengths. For the DNA action spectrum, a 1 percent depletion would increase the weighted UV flux by about 2 percent. Changes in column ozone and increases in global temperatures could alter many environmental conditions. The findings of this section cover the effects of these changes on human health, ecosystems, crops, materials, air pollution, sea level and other areas that influence human welfare.

FINDINGS

21. BASED ON SURVEYS (PARTICULARLY IN THE UNITED STATES AND IN AUSTRALIA), PROLONGED SUN EXPOSURE IS CONSIDERED TO BE THE DOMINANT RISK FACTOR FOR NONMELANOMA SKIN TUMORS (chapter 7).

    21a. Nonmelanoma skin tumors tend to develop in sun-exposed sites (e.g., the head, face, and neck).

    21b. Higher incidence rates occur among groups subject to greater exposure to the sun's rays because of occupations that necessitate their working outdoors.

    21c. A latitudinal gradient exists for UV-B radiation, and higher incidence rates of nonmelanoma skin tumors generally occur in geographic areas of relatively high UV radiation exposure.

    21d. Skin pigmentation provides a protective barrier that reduces the risk of developing nonmelanoma skin tumors.

    21e. The risk of nonmelanoma skin tumors is highest among genetically predisposed individuals (e.g., those with xeroderma pigmentosum).

    21f. A predisposition to develop nonmelanoma skin tumors exists among light-skinned individuals (skin phenotypes I and II) who are susceptible to sunburn and who have red/blond hair, blue/green eyes, and a Celtic heritage.

22. AVAILABLE EPIDEMIOLOGICAL EVIDENCE INDICATES THAT THE TWO MAJOR TYPES OF NONMELANOMA SKIN TUMORS, SQUAMOUS CELL CARCINOMA (SCC) AND BASAL CELL CARCINOMA (BCC), RESPOND DIFFERENTLY TO SOLAR EXPOSURE. IT HAS BEEN SUGGESTED THAT CUMULATIVE UV RADIATION HAS A GREATER EFFECT ON THE DEVELOPMENT OF SCC THAN ON BCC (chapter 7).

    22a. The BCC/SCC incidence ratio decreases with decreasing latitude and therefore, increasing UV levels.

    22b. BCC is more likely to develop on normally unexposed sites (e.g., the trunk) compared to SCC.

    22c. SCC is more likely than BCC to develop on sites receiving the highest cumulative UV radiation doses (e.g., the nose).

    22d. For a given cumulative level of sunlight exposure, the risk of developing SCC may be greater than the risk of developing BCC.

23. THE RESULTS FROM SEVERAL EXPERIMENTAL STUDIES SUGGEST THAT UV-B MAY BE THE MOST IMPORTANT COMPONENT OF SOLAR RADIATION THAT CAUSES VARIATIONS IN THE INCIDENCE OF NONMELANOMA SKIN TUMORS (chapter 7).

    23a. UV radiation produces nonmelanoma skin tumors in animals. UV-B wavelengths have been shown to be most effective in producing these tumors.

23b. UV-B has been shown to cause a variety of DNA lesions, to induce neoplastic transformation in cells, and to be a mutagen in both animal and bacterial cells.

24. SEVERAL RESEARCHERS HAVE INVESTIGATED THE CHANGES IN THE INCIDENCE OF NONMELANOMA SKIN TUMORS THAT MAY RESULT FROM INCREASES IN EXPOSURE TO SOLAR UV RADIATION. GIVEN UNCERTAINTIES, RANGES OF ESTIMATES OF INCREASED INCIDENCE THAT COULD OCCUR WITH DEPLETION ARE ESTIMATED (chapter 7).

24a. The action spectra for initiation and promotion of basal cell and squamous cell skin cancer have not been precisely determined. Photocarcinogenic studies indicate that the erythema and DNA action spectra span a range likely to encompass that of squamous cell and basal cell skin cancer. The Robertson-Berger (R-B) meter, while providing useful data for describing ambient UV radiation, does not relate as closely to those wavelengths thought to promote sunburn and skin cancer.

24b. Several studies have provided estimates of a biological amplification factor (BAF), which is defined as the percent change in tumor incidence that results from a 1 percent change in UV-B radiation. The results from six studies produced an overall BAF range that is 1.8-2.85 for all nonmelanoma skin tumors.

24c. BAF estimates are generally higher for males than for females and generally increase with decreasing latitude. In addition, the BAF estimates for SCC are higher than the BAF estimates for BCC. This finding is consistent with observations that the BCC/SCC ratio decreases with decreasing latitude and that BCC is more likely to develop on unexposed sites.

24d. Optical amplification (the change in UV-B radiation related to ozone depletion) increases the response of these cancers to ozone depletion, because the relevant action spectra increase more than 1 percent for a 1 percent depletion. For example, a 1 percent depletion has an optical amplification of over 2 for the DNA action spectrum.

24e. Uncertainty exists in the actual doses of solar UV radiation received by populations and in the statistical estimates of the dose-response coefficients. Therefore, a range of estimates must be developed for changes in incidence associated with changes in dose.

24f. Currently available nonmelanoma mortality data are of uncertain accuracy because of the discrepancy of reporting between death certificates and hospital diagnoses and the low proportion of deaths reported on both hospital diagnoses and death certificates. Based on published studies, the rates of metastasis among SCCs and BCCs have been estimated to be 2-20% and 0.0028-0.55%, respectively. The overall case fatality rate for nonmelanoma skin tumors is approximately 1-2% with three-fourths to four-fifths of the deaths attributable to SCC.

24g. Changes in behavior have tended to increase skin cancer incidence and mortality. While some evidence exists that this is reaching a limit, skin cancer rates, even in the absence of ozone depletion, would be likely to rise. Future rates of skin cancer could be reduced if people changed their behavior. Care should be taken, however, in interpreting such a change as a 'cost-free' response.

25. CUTANEOUS MALIGNANT MELANOMA (CMM) IS A SERIOUS LIFE-THREATENING DISEASE THAT AFFECTS A LARGE NUMBER OF PEOPLE IN THE UNITED STATES. THERE ARE SEVERAL HISTOLOGICAL FORMS OF MELANOMA THAT ARE LIKELY TO HAVE SOMEWHAT DIFFERENT ETIOLOGIES AND RELATIONSHIPS TO SOLAR AND UV-B RADIATION (chapter 8).

25a. CMM incidence and mortality is increasing among fair-skinned populations. These increases appear not to be merely the result of improved diagnosis and reporting.

25b. In 1987, it is estimated that there will be an estimated 25,800 cases of CMM and 5,800 fatalities related to melanoma in the United States. In the absence of ozone depletion, the lifetime risk of CMM in the United States is expected to be about 1 in 150.

26. LIMITATIONS IN THE DATABASE PREVENT ABSOLUTE CERTAINTY ABOUT THE RELATIONSHIP OF SOLAR RADIATION, UV-B, AND CUTANEOUS MALIGNANT MELANOMA (CMM) (chapter 8).

26a. There currently is no animal model in which exposure to UV-B radiation experimentally induces melanomas.

26b. There is also no experimental *in vitro* model for malignant transformation of melanocytes.

26c. No epidemiologic studies of CMM have been conducted in which individual human UV-B exposures (and biologically effective doses of solar radiation) have been adequately assessed.

27. EVALUATION OF THE EPIDEMIOLOGICAL AND EXPERIMENTAL DATABASES FOR MELANOMA REQUIRES CLOSE ATTENTION TO THE RELATIONSHIP OF WAVELENGTH AND DOSE AND TO THE VARIATIONS OF SOLAR RADIATION IN THE AMBIENT ENVIRONMENT (chapter 8).

27a. Ozone differentially removes wavelengths of UV-B between 295 and 320 nm; UV-A (320-400 nm) in wavelengths above 350 nm is not removed, nor is visible light (400-900 nm). Ozone removes all UV-C (i.e., wavelengths less than 295 nm).

27b. Wavelengths between 295 nm and 300 nm are generally more biologically effective (i.e., damage target molecules in the skin, including DNA) than other wavelengths in UV-B and even more so than UV-A radiation.

27c. Latitudinal variations exist in solar radiation; model predictions indicate that the greatest variability is seen in cumulative UV-B (e.g., monthly doses) followed by peak UV-B (highest one-day doses) and then cumulative UV-A. Peak UV-A does not vary significantly

across latitudes up to 60°N. Greater ambient variation also exists in UV-B than in UV-A by time of day.

27d. The biologically effective dose of radiation that actually reaches target molecules depends on the duration of exposure at particular locations, time of day, time of year, behavior (i.e., in terms of clothes and sunscreens), pigmentation, and other characteristics of the skin including temporal variations (e.g., changes in pigmentation due to tanning).

27e. Cloudiness and albedo, although causing large variations in the amount of exposure to UV-B and UV-A, do not greatly change the ratio of UV-B to UV-A.

27f. Ozone depletion is predicted to cause the largest increases in radiation in the 295-299 nm UV-B range, less in the 300-320 nm UV-B range; UV-A is virtually unaffected by ozone depletion.

27g. Cutaneous malignant melanoma has a number of different histologic types that vary in their relationship to sunlight, site, racial preference, and possibly in their precursor lesions. Assessment of incidence by types is not consistent among registries, thus complicating attempts to evaluate the relationship between CMM and solar radiation.

27h. Melanin is the principal pigment in skin that gives it color; melanin effectively absorbs UV radiation; the darker the skin, the more the basal layer is protected from UV radiation.

28. <u>A LARGE ARRAY OF EVIDENCE SUPPORTS THE CONCLUSION THAT SOLAR RADIATION IS ONE OF THE CAUSES OF CUTANEOUS MALIGNANT MELANOMA</u> (chapter 8).

28a. Whites, whose skin contains less protective melanin, have higher incidence and mortality rates from CMM than do blacks.

28b. Light-skinned whites, including those who are unable to tan or who tan poorly, have a higher incidence of CMM than do darker-skinned whites.

28c. Sun exposure leading to sunburn apparently induces melanocytic nevi.

28d. Individuals who have more melanocytic nevi have a higher incidence of CMM; the greatest risk is associated with a particular type of nevus -- the dysplastic nevus.

28e. Sunlight induces freckling, and freckling is an important risk factor for CMM.

28f. Incidence has been increasing in cohorts in a manner consistent with changes in patterns of sun exposure, particularly with respect to increasing intermittent exposure of certain anatomical sites.

28g. Immigrants who move to sunnier climates have higher rates of CMM than populations who remain in their country of origin. Immigrants

develop rates approaching those of prior (but native born) immigrants to the adopted country; this is particularly accentuated in individuals arriving before the age of puberty (10-14 years).

28h. It has been suggested that CMM risk may be associated with childhood sunburn; other evidence suggests that childhood sunburn may reflect an individual's pigmentary characteristics or may be related to nevus development, rather than being a separate risk factor.

28i. Most studies that have used latitude as a surrogate for sunlight or UV-B exposure have found an increase in the incidence or mortality of CMM correlated to proximity to the equator. A recent study of incidence using measured UV-B and CMM survey data found a strong relationship between UV-B and incidence of CMM. Another study that used modeled UV-B data and an expanded database on mortality found a strong UV-B/mortality relationship.

28j. One form of CMM, Hutchinson's melanotic freckle, appears almost invariably on the chronically sun-damaged skin of older people.

29. <u>SOME EVIDENCE CREATES UNCERTAINTY ABOUT THE RELATIONSHIP BETWEEN SOLAR RADIATION AND CUTANEOUS MALIGNANT MELANOMA</u> (chapter 8).

29a. Some ecologic epidemiology studies, primarily in Europe or close to the equator, have failed to find a latitudinal gradient for CMM.

29b. Outdoor workers generally have lower incidence and mortality rates for CMM than indoor workers, which appears incompatible with a hypothesis that cumulative dose from solar exposure causes CMM.

29c. Unlike basal cell and squamous cell carcinomas, most CMM occurs on sites that are not habitually exposed to sunlight; this contrast suggests that cumulative exposure to solar radiation or UV-B is not solely responsible for variations in CMM.

30. <u>UV-B RADIATION IS A LIKELY COMPONENT OF SOLAR RADIATION THAT CAUSES CUTANEOUS MALIGNANT MELANOMA (CMM), EITHER THROUGH INITIATION OF TUMORS OR THROUGH SUPPRESSION OF THE IMMUNE SYSTEM</u> (chapter 8).

30a. Xeroderma pigmentosum patients who fail to repair UV-B-induced pyrimidine dimers in their DNA have a 2,000-fold excess rate of CMM by the time they are 20.

30b. UV-B is the most active part of the solar spectrum in the induction of mutagenesis and transformation <u>in vitro</u>.

30c. UV-B is the most active part of the solar spectrum in the induction of carcinogenesis in experimental animals and is considered by most to be a causative agent of nonmelanoma skin cancer in humans.

30d. UV-B is the most active portion of the solar spectrum in inducing immunosuppression, which may have a role in melanoma development.

30e. The limitations in the epidemiologic and experimental database leave some doubt as to the effectiveness of UV-B wavelengths in causing CMM.

31. WHILE UNCERTAINTY EXISTS, INCREASES IN THE INCIDENCE AND MORTALITY OF CUTANEOUS MALIGNANT MELANOMA ARE LIKELY AS A RESULT OF OZONE DEPLETION. WHILE MANY UNCERTAINTIES EXIST (E.G., REGARDING ACTION SPECTRA, PEAK VERSUS CUMULATIVE DOSE, ETC.) ABOUT THE NATURE OF THE RELATIONSHIP BETWEEN UV-B AND MELANOMA, THE FACT THAT UV-B RADIATION VARIES ACROSS THE ENVIRONMENT IN THE RANGE OF VARIATION EXPECTED FROM DEPLETION PROVIDES INFORMATION USUALLY UNAVAILABLE TO RESEARCHERS MAKING QUANTITATIVE RISK ESTIMATES. THUS ALTHOUGH IMPERFECT, EPIDEMIOLOGIC INFORMATION EXISTS TO ESTIMATE A RANGE OF CHANGES IN INCIDENCE AND MORTALITY IF THE OZONE LAYER IS DEPLETED (chapter 8).

31a. Uncertainty exists about the appropriate action spectrum to be used in estimating dose, the best functional form for dose-response, and the best way to characterize dose (peak value, cumulative summer exposure, etc.). Histologically different CMMs (or possibly CMM located at different anatomical sites) are likely to have different dose-response relationships. Most estimates of CMM dose-response relationships fail to consider these histological or site differences. Nonetheless, by encompassing a range of possibilities, it is possible to estimate dose-response because of the systematic variations in UV-B.

31b. A recent study by the NIH presents a well-designed ecological study of melanoma and UV-B using survey data and measured UV-B at ground level. While uncertainties exist, this dose-response relationship, when used with different action spectra and assumptions about the importance of peak versus cumulative exposure, can be utilized to estimate a range of values for cases. The relationship estimates that a 1 percent change in ozone is likely to increase incidence by between slightly less than 1 to 2 percent, depending on the choice of action spectrum. The appropriate action spectrum is likely to be encompassed in the range of erythema and DNA.

31c. Melanoma mortality is estimated at about 25 percent of all cases. This result is consistent with the projections of a dose-response model of mortality developed by EPA/NCI. It is estimated that a 1 percent change in ozone would result in between a 0.3 and a 2.0 percent change in CMM mortality depending on the assumptions about the appropriate dose and UV weighting functions used in the model.

31d. Additional uncertainties for projecting future incidence and mortality of CMM in the U.S. include the lack of an adequate database describing variations in skin pigmentation and human sun-exposure behavior among different populations and estimates of how these relationships may change in the future.

32. UV-B SUPPRESSES THE IMMUNE SYSTEM IN ANIMAL EXPERIMENTS (chapter 9).

32a. UV radiation administered at relatively low doses causes a depression in local contact hypersensitivity (a form of cell-mediated immunity)

resulting from an inability to respond to an antigen presented through UV-irradiated skin.

32b. High doses of UV radiation cause a depression in systemic contact and delayed type hypersensitivity reactions, that result in an inability of the animal to respond to an antigen which is presented to the animal through unirradiated skin.

32c. Both the local and systemic effects on contact hypersensitivity are mediated by a T suppressor cell which prevents the development of active immunity to the antigen.

32d. The immunosuppressive effects of ultraviolet radiation (UVR) have been found to reside almost entirely in the UV-B portion of the ground level solar radiation.

33. SUPPRESSION OF THE IMMUNE SYSTEM MAY PLAY AN IMPORTANT ROLE IN CARCINOGENESIS (chapter 9).

33a. Animals which are UV-irradiated develop T suppressor cells which interfere with the immune response to UV-induced tumors in such a way that the animals are more susceptible to the growth of autochthonous UV-induced tumors. The contribution of the suppression of the immune system to cancer incidence that would result from ozone depletion is reflected in the dose-response estimates of photocarcinogenesis assuming that the action spectra for the two phenomena are the same. If these two impacts have different action spectra, the estimates could be either high or low.

34. LIMITED EXPERIMENTAL DATA INDICATE UV-B SUPPRESSES THE HUMAN IMMUNE SYSTEM (chapter 9).

34a. Although there is limited information about the effects of UV radiation on humans, several studies indicate that the immune response of humans is depressed by UV radiation and is depressed in UV-irradiated skin.

35. UV-B-INDUCED SUPPRESSION OF THE HUMAN IMMUNE SYSTEM COULD HAVE A DELETERIOUS EFFECT WITH REGARD TO MANY HUMAN DISEASES (chapter 9).

35a. Preliminary studies indicate that UV radiation may prevent an effective immune response to micro-organisms that infect via the skin, thus predisposing to reexpression or chronic infection.

35b. Two human diseases that may be influenced by UV-B-induced immune suppression are herpes virus infections and leishmaniasis.

35c. Almost no research has been conducted on the influence of UV-B on other infectious diseases; additional investigation is clearly warranted.

35d. For at least one theory of the mechanisms of UV-B-induced suppression of the immune system (that involving urocanic acid), a possibility exists that non-whites, as well as whites, would be vulnerable to increased immune suppression caused by ozone depletion.

35e. Because UV-B can produce systemic immunologic change, the possibility exists that changes in UV-B could have resulted in effects on diseases whose control requires systemic rather than local immunity.

35f. Immunologic studies to date have not assessed the effects of long-term, low-dose UV-B irradiation. Consequently, the magnitude of this risk cannot be assessed.

36. EVIDENCE EXISTS SUGGESTING THAT CATARACT INCIDENCE WILL CHANGE WITH ALTERATIONS IN THE FLUX OF UV-B CAUSED BY OZONE DEPLETION (chapter 10).

36a. Many possible mechanisms exist for formation of cataracts. UV-B may play an important role in some mechanisms.

36b. Although the cornea and aqueous humor of the human eye screen out significant amounts of UV-A and UV-B radiation, nearly 50 percent of radiation at 320 nm is transmitted to the lens. Transmittance declines substantially below 320 nm, so that less than 1 percent is transmitted below approximately 290 to 300 nm. However, the results of laboratory experiments on animals indicate that short wavelength UV-B (i.e., below 290 nm) is perhaps 250 times more effective than long wavelength UV-B (i.e., 320 nm) in inducing cataracts.

36c. Human cataract prevalence varies with latitude and UV radiation; brunescent nuclear cataracts show the strongest relationship.

37. INCREASES IN THE AMOUNT OF UV-B THAT CAN REACH THE RETINA APPEAR CAPABLE OF CAUSING STABLE RETINAL DISORDERS AND RETINAL DEGENERATION, TWO CAUSES OF BLINDNESS (chapter 10).

38. LIMITED STUDIES ANALYZING THE EFFECT OF INCREASED UV-B RADIATION ON CROPS GENERALLY SHOW ADVERSE IMPACTS. HOWEVER, CONCLUSIONS ABOUT THE AMOUNT OF YIELD LOSSES ATTRIBUTABLE TO UV-B CANNOT BE DRAWN (chapter 11).

38a. Difficulties in experimental design, the large number of species and cultivars, and complex interactions between plants and their environment have prevented quantification of total crop loss from increases in UV-B.

38b. Action spectra for UV damage to higher plants are limited, but indicate a strong weighting toward shorter UV-B wavelengths which are those most affected by ozone reduction.

39. OF PLANT CULTIVARS TESTED IN THE LABORATORY, APPROXIMATELY 70 PERCENT WERE DETERMINED TO BE SENSITIVE TO UV-B; CARE MUST BE TAKEN IN INTERPRETING THIS FINDING (chapter 11).

39a. Different cultivars within a species have exhibited different degrees of UV-B sensitivity. While this suggests selective breeding could limit damage, neither the basis for selectivity nor the potential effect on other aspects of growth has been studied.

39b. Laboratory experiments have been shown to inadequately replicate effects in the field, thus the implications of cultivar sensitivity are not certain.

39c. In some species, mitigation responses more readily apparent in the field (e.g., increased production of UV absorbing flavonoids) have reduced adverse impacts.

40. THE EFFECTS OF UV-B RADIATION HAVE BEEN EXAMINED FOR ONLY FOUR OF THE TEN MAJOR TERRESTRIAL ECOSYSTEMS AND FOR ONLY A THIRD OF THE PLANT GROWTH FORMS (chapter 11).

40a. Little or no data exist on enhanced UV-B effects on trees, woody shrubs, vines, or lower vascular plants.

41. LARGE UNCERTAINTIES EXIST AS A RESULT OF AN IMPERFECT EXPERIMENTAL DESIGN OR DOSIMETRY. EXISTING EXPERIMENTAL FIELD DATA SUGGEST A POTENTIAL REDUCTION IN CROP YIELD FOR SOME CROPS DUE TO ENHANCED UV-B RADIATION (chapter 11).

41a. Field experiments in which UV-B radiation has been supplemented are limited. Several of the earlier field experiments are of limited value since UV-B doses or other factors such as soil temperature were not sufficiently controlled or representative of field conditions. Dose-response studies in the field are particularly different.

41b. The only long-term field studies of a crop involved soybeans. These studies have found that enhanced levels of UV-B, simulating between 16 and 25 percent ozone depletion, caused crop yield reductions of up to 25 percent in a particular cultivar. Smaller reductions in yield were experienced in years where drought conditions existed.

41c. Soybean (CV Essex) yield could be accurately predicted when total UV-B dose, daily maximum temperature, and number of days of precipitation were included in a regression model.

41d. The lipid and protein content of soybean was reduced up to 10 percent; however, higher UV-B doses alone did not consistently result in the largest reductions.

41e. While only several cultivars have been tested in the field, two out of three soybean cultivars tested under laboratory conditions were sensitive to UV-B. If this relationship holds true in the field, it suggests (when considered in light of yield reduction experiments) that UV-B increases could harm the potential of the world agricultural system to produce soybeans.

42. THE EFFECTS OF UV-B ON FUNGAL OR VIRAL PATHOGENS VARY WITH PATHOGEN, PLANT SPECIES, AND CULTIVAR (chapter 11).

42a. Current evidence on possible interactions with pathogens is very limited.

42b. Reduced vigor in UV-sensitive plants could render the plants more or less susceptible to pest or disease damage and thus result in changes in crop yield.

43. CHANGES IN UV-B LEVELS MAY INDUCE SHIFTS IN INTERSPECIFIC COMPETITION (chapter 11).

43a. If enhanced UV-B favors weeds over crops, agricultural costs (e.g., for increased tilling and herbicide application) could increase. However, insufficient evidence exists to form a basis for evaluating this effect.

43b. Increases in UV-B could alter the results of the competition in natural ecosystems and thus shift community composition. Since UV-B changes would be both global and long term, possible UV-induced alterations of plant species balances could result in large-scale changes in the character and equilibrium of vegetation in nonagricultural areas such as forests and grasslands.

44. UV-B RADIATION INHIBITS AND STIMULATES FLOWERING, DEPENDING ON THE SPECIES AND GROWTH CONDITIONS (chapter 11).

44a. The timing of flowering may also be influenced by UV-B radiation, and there is limited evidence that pollen may be susceptible to UV damage upon germination.

44b. Reproductive structures enclosed within the ovary appear to be well-protected from UV-B radiation.

45. INTERACTIONS BETWEEN UV-B RADIATION AND OTHER ENVIRONMENTAL FACTORS ARE IMPORTANT IN DETERMINING POTENTIAL UV-B EFFECTS ON PLANTS (chapter 11).

45a. UV-B effects may be worsened under low light regimes or less apparent under conditions of limited nutrients or water.

45b. Interactions with other environmental effects make extrapolation of data from growth chambers or greenhouses to field conditions difficult and often unreliable.

45c. The combined effect of higher UV-B and other environmental changes cannot be adequately assessed by current data. Extensive, long-term studies would be required.

46. INITIAL EXPERIMENTS SHOW THAT REDUCTIONS IN STRATOSPHERIC OZONE, WHICH INCREASES SOLAR ULTRAVIOLET RADIATION, HAVE THE POTENTIAL TO HARM AQUATIC LIFE. DIFFICULTIES IN EXPERIMENTAL DESIGNS AND THE LIMITED SCOPE OF THE STUDIES PREVENT THE QUANTIFICATION OF RISKS (chapter 12).

46a. Increases in energy in the 290-320 nm wavelengths that would occur if the ozone layer were depleted could harm aquatic life.

46b. Various experiments have shown that UV-B radiation damages fish larvae and juveniles, shrimp larvae, crab larvae, copepods, and plants essential to the marine food web.

46c. Up to some threshold level of exposure, most zooplankton show no effect due to increased exposure to UV-B radiation. However, exposure above the dose threshold elicits significant and irreversible physiological and behavioral effects.

46d. While the exact limits of tolerance and current exposure have not been precisely determined, estimates of these two properties for a variety of aquatic organisms show them to be essentially equal.

46e. The equality of tolerance and exposure suggests that solar UV-B radiation is currently an important limiting ecological factor, and the sunlight-exposed organisms sacrifice potential resources to avoid increased UV-B exposure. Thus, even small increases of UV-B exposure would be likely to further injure species currently under UV-B stress.

46f. A decrease in column ozone is reasonably likely to diminish the time that zooplankton can survive or breed at or near the surface of waters they inhabit. For some zooplankton, the time they spend at or near the surface is critical for breeding. Whether the population could endure a significant shortening of surface time is unknown.

46g. Sublethal exposure of copepods produces a reduction in fecundity.

46h. Of the animals tested, no zooplankton possess a sensory mechanism for directly detecting UV-B radiation; therefore, it would be unlikely that they would actively avoid enhanced levels of exposure resulting from a reduction in column ozone.

46i. Exposure of a community to UV-B stress in controlled experiments has resulted in a decrease in species diversity, and therefore a possible reduction in ecosystem resilience and flexibility.

46j. One experiment predicted an 8 percent annual loss of the larval anchovy population from a 9 percent reduction in column ozone in a marine system with a 10-meter mixed layer.

47. <u>IN COMMON WITH ALL OTHER LIVING ORGANISMS, THE AQUATIC BIOTA COPE WITH SOLAR UV-B RADIATION BY AVOIDANCE, SHIELDING, AND REPAIR MECHANISMS. UNCERTAINTY EXISTS AS TO THE EXTENT TO WHICH SUCH MITIGATION MECHANISMS WOULD OCCUR</u> (chapter 12).

48. <u>DETERMINATION OF UV-B EXPOSURE IN AQUATIC SYSTEMS IS COMPLEX BECAUSE OF THE VARIABLE ATTENUATION OF UV-B RADIATION IN THE WATER COLUMN</u> (chapter 12).

48a. Because aquatic organisms are small and do not usually have fixed locations, it is very difficult to obtain accurate data needed to model the systems and verify results. Current understanding of the life cycle of organisms is very limited.

49. <u>ABOUT ONE HALF OF THE WORLD'S PROTEIN IS DERIVED FROM MARINE SPECIES. IN MANY THIRD WORLD COUNTRIES, THIS PERCENTAGE IS LARGER. RESEARCH IS NEEDED TO IMPROVE OUR UNDERSTANDING OF HOW OZONE DEPLETION COULD INFLUENCE THESE SYSTEMS</u> (chapter 12).

49a. A comprehensive analysis of sublethal and lethal effects of solar UV on littoral, benthos, and planktonic ecosystems is needed.

49b. A model of energy flow analysis leading to protein production where solar input is augmented by increased ultraviolet radiation would be required to better evaluate potential effects. Marine organisms responses to projected increases in UV must be considered in the context of the oceans as a dynamic moving fluid.

49c. Better documentation of the effects of present levels of ultraviolet light on marine organisms is needed.

49d. Intensive research is needed to identify biochemical indices that reflect UV stress in marine organisms.

50. INCREASED UV-B RADIATION WILL ACCELERATE THE DEGRADATION OF POLYMERS (chapter 13).

50a. Several commercial polymers (e.g., polyethylene, polypropylene, poly(vinylchloride)), although theoretically UV transparent, contain chromophore impurities that absorb light in the UV-B region of the spectrum. Other polymers (e.g., polycarbonate) have structural features in their molecules that result in strong UV-B light absorption.

50b. Several polymers have important outdoor applications (e.g., used in siding and window glazing in the building industry, in film and containers in packaging, in housewares and toys, and in paints and protective coatings). Such polymers are likely to be exposed to significant amounts of UV-B radiation. Other polymers are stored outside before use and could deteriorate during these periods.

50c. Absorption of UV-B radiation in polymers causes photo-induced reactions and alters important mechanical, physical, or optical properties of the polymers (e.g., yellowing, brittleness) and thus degrades (i.e., reduces the useful life of) the polymers.

51. INCREASED USE OF UV-STABILIZERS FOR PROTECTION OF POLYMERS AGAINST UV RADIATION WOULD HAVE NEGATIVE EFFECTS (chapter 13).

51a. Increased amounts of stabilizers might adversely affect the processing and use properties of some polymers (e.g., hardness, thermal conductivity, flow characteristics). For example, increased amounts of titanium dioxide in poly(vinylchloride) might affect its processing properties, increasing its costs of production.

51b. Changes in the amount of stabilizer (and other additives) would increase costs of products. Alternatively, manufacturers could develop new formulations to avoid or minimize impurities in production.

51c. The addition of stabilizers to polymers may be limited by practical problems of material characteristics or manufacture. However, other responses may be possible to limit damage.

52. INCREASED UV-B RADIATION DUE TO OZONE DEPLETION COULD HAVE ADVERSE ECONOMIC EFFECTS (chapter 13).

52a. Changes in polymer processing properties can result in more equipment shutdowns, higher maintenance costs, and increased utility costs.

52b. Increased operating costs and material costs (e.g., for stabilizers, lubricants, and other additives) would have an adverse economic impact on the polymer/plastic and related industries.

52c. In a case study using preliminary data and methods, and a given scenario of ozone depletion (26% depletion by 2075), undiscounted cumulative (1984-2075) economic damage for poly(vinylchloride) is estimated at $4.7 billion (USA only). Due to the lack of data, possible damage to other polymers has not been assessed.

53. POTENTIAL DAMAGES TO POLYMERS RELATED TO OZONE DEPLETION AND CLIMATE CHANGE ARE DIFFICULT TO ESTIMATE (chapter 13).

53a. Due to lack of relevant experimental data, only approximate estimation methods are available to determine the potential extent of light-induced damage to polymers and other materials.

53b. Depending upon the chemical nature of a polymer, the components of the compound, and the weathering factors, both temperature and humidity tend to increase the rate of degradation.

53c. Research on dose-response relationships for polymers could increase our ability to project the effects of ozone depletion.

53d. Actual action spectra need to be developed for different polymers.

53e. The feasibility of different mitigation measures needs to be experimentally determined.

53f. The synergistic effects of increased humidity and temperature need to be considered.

54. RESULTS FROM ONE MODELING STUDY AND ONE CHAMBER STUDY SUGGEST THAT INCREASED ULTRAVIOLET RADIATION FROM OZONE DEPLETION MAY INCREASE THE RATE OF TROPOSPHERIC OZONE FORMATION (chapter 14).

54a. According to these studies, increases in UV-B associated with ozone depletion would increase the quantity of ground-based ozone associated with various hydrocarbon and nitrogen oxides emission levels. Results for individual cities vary, depending on the city's location and on the exact nature of the pollution.

54b. According to these studies, global warming would enhance the effects of increased UV-B radiation on the formation of ground-based ozone.

54c. According to these studies, ground-based ozone would form closer to urban centers. This would cause larger populations in some cities to be exposed to peak values.

54d. More research is needed to verify and expand the results of these initial studies.

55. PRELIMINARY RESULTS FROM ONE STUDY ALSO SUGGEST THAT LARGE INCREASES IN HYDROGEN PEROXIDE WOULD RESULT FROM INCREASED UV-B RADIATION (chapter 14).

55a. If hydrogen peroxide increases as predicted in this study, the oxidizing capability potential of the atmosphere, including the formation of acid rain, would be influenced.

55b. More research, especially a chamber study, is needed to verify this effect.

56. INCREASES IN GROUND-BASED OZONE WOULD ADVERSELY AFFECT PUBLIC HEALTH AND WELFARE (chapter 14).

56a. If UV-B increases enhanced ozone production, more U.S. cities would be unable to meet health-based ground-level ozone standards, and background ozone would increase.

56b. Crops, ecosystems, and materials would be adversely affected by increased ground-level ozone.

57. THE PROJECTED GLOBAL WARMING WOULD ACCELERATE THE CURRENT RATE OF SEA LEVEL RISE BY EXPANDING THE DENSITY OF OCEAN WATER, MELTING ALPINE GLACIERS, AND EVENTUALLY INCREASING THE RATE AT WHICH POLAR ICE SHEETS MELT OR DISCHARGE ICE INTO THE OCEANS (chapter 15).

58. GLOBAL AVERAGE SEA LEVEL APPEARS TO HAVE RISEN 10 TO 15 CM OVER THE LAST CENTURY (chapter 15).

58a. Studies of the possible contribution of thermal expansion and alpine meltwater to sea level rise, based on the 0.6°C warming of the past century, indicate that these two sources are insufficient to explain the estimated sea level rise that has occurred during this period. Consequently, some other source, such as melting of the polar ice caps, must be considered a possibility.

59. ESTIMATES OF THE RISE IN SEA LEVEL THAT COULD TAKE PLACE IF MEASURES TO LIMIT THE GLOBAL WARMING ARE NOT UNDERTAKEN RANGE FROM 10 TO 20 CM BY THE YEAR 2025, AND 50 TO 200 CM BY 2100 (chapter 15)

59a. According to published studies, thermal expansion of the oceans alone would increase sea level rise between about 30 cm and 100 cm by 2100, depending on the realized temperature change. This is the most certain contribution.

59b. Melting of alpine glaciers and possibly of ice on Greenland could each contribute 10 to 30 cm through 2100, depending on the scenario. This contribution also has a high degree of likelihood.

59c. The contribution of Antarctic deglaciation is more difficult to project. It has been estimated at between 0 and 100 cm; however, the possibilities cannot be ruled out that (1) increased snowfall could

increase the size of the Antarctic ice sheet and thereby partially offset part of the sea level rise from other sources; or (2) meltwater and enhanced calving of the ice sheet could increase the contribution of Antarctic deglaciation to as much as 2 m. The Antarctic contribution to sea level rise may be more sensitive to time delays after certain threshold conditions are reached than to the magnitude of total warming.

60. OVER THE MUCH LONGER TERM (THE NEXT FEW CENTURIES) DISINTEGRATION OF THE WEST ANTARCTIC ICE SHEET MIGHT RAISE SEA LEVEL BY 6 METERS (chapter 15).

60a. If a disintegration takes place, glaciologists generally believe that such a complete disintegration of the west Antarctic ice sheet would take at least 300 years, and probably at least 500 years.

60b. A global warming might result in sufficient thinning of the Ross and Filcher-Ronne Ice Shelves in the next century to make the process of disintegration irreversible.

61. LOCAL TRENDS IN SUBSIDENCE AND EMERGENCE MUST BE ADDED OR SUBTRACTED TO GLOBAL RISK ESTIMATES IN ORDER TO ESTIMATE RELATIVE SEA LEVEL RISE AT PARTICULAR LOCATIONS (chapter 15).

61a. Most of the Atlantic and Gulf Coasts of the United States--as well as the Southern Pacific coast--are subsiding 10-20 cm per century.

61b. Louisiana is subsiding 1 m per century, while parts of Alaska are emerging 10-150 cm per century.

61c. Due to subsidence already occurring in areas such as Bangladesh, Bangkok, and the Nile delta, these areas are extremely vulnerable to sea level rise.

62. A SUBSTANTIAL RISE IN SEA LEVEL WOULD PERMANENTLY INUNDATE WETLANDS AND LOWLANDS, ACCELERATE COASTAL EROSION, EXACERBATE COASTAL FLOODING, AND INCREASE THE SALINITY OF ESTUARIES AND AQUIFERS (chapter 15).

62a. Louisiana is the state most vulnerable to a rise in sea level. Important impacts would also occur in Florida, Maryland, Delaware, New Jersey, and in the coastal regions of other states.

62b. A rise in sea level of 1 to 2 m by the year 2100 could destroy 50 percent to 80 percent of U.S. coastal wetlands.

62c. Limited studies predict that increased salinity from sea level rise would convert cypress swamps to open water and threaten drinking water supplies in areas such as Louisiana, Philadelphia, and New Jersey. Other areas, such as Southern Florida, may also be vulnerable but have not been investigated.

62d. Studies of Bangladesh and the Nile River Delta indicate that these river deltas, which are already subsiding, would be greatly affected by rising sea level, experiencing significant economic and environmental losses.

63. EROSION PROJECTED IN VARIOUS STUDIES TO RESULT FROM ACCELERATED SEA LEVEL RISE COULD THREATEN U.S. RECREATIONAL BEACHES (chapter 15).

63a. Case studies of beaches in New Jersey, Maryland, California, South Carolina, and Florida have concluded that a 30-cm rise in sea level would result in beaches eroding 20-60 m or more. Major beach preservation efforts would be required if recreational beaches are to be maintained.

64. ACCELERATED SEA LEVEL RISE WOULD INCREASE THE DAMAGES FROM FLOODING IN COASTAL AREAS (chapter 15).

64a. Flood damages would increase because higher water levels would provide a higher base for storm surges.

64b. Erosion would increase the vulnerability to storm waves, and decreased natural and artificial drainage would increase flooding during rainstorms.

65. ESTIMATES OF DAMAGE FROM SEA LEVEL RISE MUST CONSIDER POSSIBLE MITIGATION BY HUMAN RESPONSES (chapter 15).

65a. The adverse impacts of sea level rise could be ameliorated through anticipatory land use planning and structural design changes.

65b. In a case study of two cities, Charleston, South Carolina, and Galveston, Texas, accelerated anticipatory planning was estimated to reduce net damages by 20 to 60 percent.

66. RELATED IMPACTS OF A GLOBAL WARMING WOULD ALSO AFFECT IMPACTS OF SEA LEVEL RISE (chapter 15).

66a. Increased droughts might amplify the salinity impacts of sea level rise.

66b. Increased hurricanes and increased rainfall in coastal areas could amplify flooding from sea level rise.

66c. Warmer temperatures might impair peat formation of salt marshes and would enable mangrove swamps to take over areas that are presently salt marsh.

66d. Decreased northeasters might reduce damage.

67. RESEARCH OPPORTUNITIES EXIST TO IMPROVE SEA LEVEL RISE ESTIMATES AND IMPACTS (chapter 15).

67a. The most critical areas of research for reducing the variation in estimates of future sea level rise are ice melting and runoff in Antarctica and Greenland and ice discharge.

67b. Research in glacial discharge in Antarctica should focus not just on West Antarctica, but on Pine Island and East Antarctica.

67c. An improved program of tidal gauge stations, especially in the southern hemisphere, and satellite altimetry should be used to measure sea level rise and the mass balance of ice sheets.

68. CLIMATE CHANGE HAS HAD A SIGNIFICANT IMPACT ON FORESTS IN THE PAST. IF CURRENT PREDICTIONS PROVE ACCURATE, THERE IS A POTENTIAL FOR DRAMATIC SHIFTS IN FORESTS AND VEGETATION OVER THE NEXT 100 YEARS (chapter 16).[4]

68a. Climate models predict that a global warming of approximately 1.5°C to 4.5°C will be induced by a doubling of atmospheric CO2 and other trace gases during the next 50 to 100 years. The period 18,000 to 0 years B.P. is the only general analog for a global climate change of this magnitude. The geological record from this glacial to inter-glacial interval provides a basis for qualitatively understanding how vegetation may change in response to large climatic change.

68b. The paleovegetational record shows that climatic change as large as that expected to occur in response to CO2 doubling is likely to induce significant changes in the composition and patterns of the world's biomes. Changes of 2°C to 4°C have been significant enough to alter the composition of biomes, and to cause new biomes to appear and others to disappear. At 18,000 B.P., the vegetation in eastern North America was quite distinct from that of the present day. The cold, dry climate of that time seems to have precluded the widespread growth of birch, hemlock, beech, alder, hornbeam, ash, elm, and chestnut, all of which are fairly abundant in present-day deciduous forest. Southern pines were limited to grow with oak and hickory in Florida.

68c. Available paleoecological and paleoclimatological records do not provide an analog for the high rate of climate change and unprecedented global warming predicted to occur over the next century. Previous changes in vegetation have been associated with climates that were nearly 5°C to 7°C cooler and took thousands of years to evolve rather than decades, the time during which such changes are now predicted to occur. Insufficient temporal resolution (e.g., via radiocarbon dates) limits our ability to analyze the decadal-scale rates of change that occurred prior to the present millennium.

68d. Limited experiments conducted with dynamic vegetation models for North America suggest that decreases in net biomass may occur and that significant changes in species composition are likely. Experiments with one model suggest that eastern North American biomass may be reduced by 11 megagrams per hectare (10% of live biomass) given the equivalent of a doubled CO2 environment. Plant taxa will respond individualistically rather than as whole communities to regional changes in climate variables. At this time such analyses must be treated as only suggestive of the kinds of

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[4] Findings 68 to 71 are summarized from Appendix B, which provides a comprehensive review of potential impacts of global climate change.

change that could occur. Many critical processes are simplified or omitted and the actual situation could be worse or better.

68e. Future forest management decisions in major timber-growing regions are likely to be affected by changes in natural growing conditions. For example, one study suggests that loblolly pine populations are likely to move north and northeast into Pennsylvania and New Jersey, while its range shrinks in the west. The total geographic range of the species may increase, but a net loss in productivity may result because of shifts to less accessible and less productive sites. While the extent of such changes is unclear, adjustments will be needed in forest technology, resource allocation, planning, tree breeding programs, and decision-making to maintain and increase productivity.

68f. Dynamic vegetation models based on theoretical descriptions of all factors that could influence plant growth must be improved and/or developed for all major kinds of vegetation. In order to make more accurate future predictions, these models must be validated using the geological record and empirical ecological response surfaces. In particular, the geological record can be used to test the ability of vegetation models to simulate vegetation that grew under climate conditions unlike any of the modern day conditions.

68g. Dynamic vegetation models should incorporate direct effects of atmospheric CO2 increases on plant growth and other air pollution effects. Improved estimates of future regional climates are also required in order to make accurate predictions of future vegetation changes.

69. <u>LIMITED ASSESSMENTS SUGGEST THAT IMPORTANT CHANGES IN AGRICULTURE AND FARM PRODUCTIVITY ARE LIKELY THROUGHOUT THE WORLD IF CLIMATE CHANGE OCCURS AS PREDICTED. ESTIMATES OF IMPACTS ON SPECIFIC REGIONS ARE DIFFICULT TO MAKE BECAUSE REGIONAL PROJECTIONS OF CHANGE CANNOT BE RELIABLY MADE. CURRENT CLIMATIC KNOWLEDGE IS ONLY SUFFICIENT TO SUPPORT VULNERABILITY STUDIES FOR ALTERNATIVE SCENARIOS</u> (chapter 16).

69a. Climate has had a significant impact on farm productivity and geographical distribution of crops. Examples include the 1983 drought, which contributed to a nearly 30 percent reduction in corn yields in the U.S.; the persistent Great Plains drought between 1932-1937, which contributed to nearly 200,000 farm bankruptcies; and the climate shift of the Little Ice Age (1500-1800), which led to the abandonment of agricultural settlements in Scotland and Norway.

69b. World agriculture is likely to undergo significant shifts if trace-gas-induced climate warming in the range of 1.5°C to 4.5°C occurs over the next 50 to 100 years. Climatic effects on agriculture will extend from local to regional and international levels. However, modern agriculture is very dynamic and is constantly responding to changes in production, marketing, and government programs.

69c. The main effects likely to occur at the field level will be physical

impacts of changes in thermal regimes, water conditions, and pest infestations. High temperatures have caused direct damage to crops such as wheat and corn; moisture stress, often associated with elevated temperatures, is harmful to corn, soybean, and wheat during flowering and grain fill; and increased pests are associated with higher, more favorable temperatures.

69d. Even relatively small increases in the mean temperature can increase the probability of harmful effects in some regions. Analysis of historical data has shown that an increase of 1.7°C (3°F) in mean temperature changes by about a factor of three the likelihood of a five-consecutive-day maximum temperature event of at least 35°C (95°F) occurring in a city like Des Moines. In regions where crops are grown close to their maximum tolerance limits, extreme temperature events may have significant harmful effects on crop growth and yield.

69e. Limited experiments using climate scenarios and agricultural productivity models have demonstrated the sensitivity of agricultural systems to climate change. Future farm yields are likely to be affected by climate because of changes in the length of the growing season, heating units, extreme winter temperatures, precipitation, and evaporative demand. In addition, field evaluations show that total productivity is a function of the drought tolerance of the land and the moisture reserve, the availability of land, the ability of farmers to shift to different crops, and other factors.

69f. The transition costs associated with adjusting to global climatic change are not easily calculated, but are likely to be very large. Accommodating to climate change may require shifting to new lands and crops, creating support services and industries, improving and relocating irrigation systems, developing new soil management and pest control programs, and breeding and introducing new heat- or drought-tolerant species. The consequences of these decisions on the total quantity, quality, and cost of food are difficult to predict.

69g. Current projections of the effects of climate change on agriculture are limited because of uncertainties in predicting local temperature and precipitation patterns using global climate models, and because of the need for improved research studies using controlled atmospheres, statistical regression models, dynamic crop models and integrated modeling approaches.

70. <u>WATER RESOURCE SYSTEMS HAVE UNDERGONE IMPORTANT CHANGES AS THE EARTH'S CLIMATE HAS SHIFTED IN THE PAST. CURRENT ANALYSES SUGGEST AN INTENSIFIED HYDROLOGIC CYCLE, IF CLIMATE CHANGE OCCURS AS PREDICTED</u> (chapter 16).

70a. There is evidence that climate change since the last ice age (18,000 years B.P.) has significantly altered the location of lakes -- although the extent of present day lakes is broadly comparable with 18,000 years B.P. For example, there is evidence indicating the existence of many tropical lakes and swamps in the Sahara, Arabian, and Thor Deserts around 9,000 to 8,000 years B.P.

70b. The inextricable linkages between the water cycle and climate ensure that potential future climate change will significantly alter hydrologic processes throughout the world. All natural hydrologic processes--precipitation, infiltration, storage and movement of soil moisture, surface and subsurface runoff, recharge of groundwater, and evapotranspiration--will be affected if climate changes.

70c. As a result of changes in key hydrologic variables such as precipitation, evaporation, soil moisture, and runoff, climate change is expected to have significant effects on water availability. Early hydrologic impact studies provide evidence that relatively small changes in precipitation and evaporation patterns might result in significant, perhaps critical, changes in water availability. For many aspects of water resources, including human consumption, agricultural water supply, flooding and drought management, groundwater use and recharge, and reservoir design and operation, these hydrologic changes will have serious implications.

70d. Despite significant differences among climate change scenarios, a consistent finding among hydrologic impact studies is the prediction of a reduction in summer soil moisture and changes in the timing and magnitude of runoff. Winter runoff is expected to increase and summer runoff to decrease. These results appear to be robust across a range of climate change scenarios.

70e. Future directions for research and analyses suggest that improved estimates of climate variables are needed from large-scale climate models; innovative techniques are needed for regional assessments; increased numbers of assessments are necessary to broaden our knowledge of effects on different users; and increased analyses of the impacts of changes in water resources on the economy and society are necessary.

71. <u>MORBIDITY AND MORTALITY RATES ARE ASSOCIATED WITH WEATHER EXTREMES IN OUR SOCIETY</u> (chapter 16).

71a. Weather has a profound effect on human health and well being. It has been demonstrated that weather is associated with changes in birth rates, outbreaks of pneumonia, influenza, and bronchitis, and related to other morbidity effects, and is linked to pollen concentrations and high pollution levels.

71b. Large increases in mortality have occurred during previous heat and cold waves. It is estimated that 1,327 fatalities occurred in the United States as a result of the 1980 heat wave, and Missouri alone accounted for over 25 percent of that total.

71c. Hot weather extremes appear to have a more substantial impact on mortality than cold wave episodes.

71d. Threshold temperatures, which represent maximum and minimum temperatures associated with increases in total mortality, have been determined for various cities. These threshold temperatures vary regionally; for example, the threshold temperature for winter

mortality in mild southern cities such as Atlanta is 0°C and for more northerly cities such as Philadelphia, threshold temperature is -5°C.

71e. If future global warming induced by increased concentrations of trace gases does occur, it has the potential to affect human mortality significantly. In one study, total summertime mortality in New York City was estimated to increase by over 3,200 deaths per year for a 7°F trace-gas-induced warming without acclimatization. If New Yorkers fully acclimatize, the number of additional deaths is estimated to be no different than today. It is hypothesized that if climate warming occurs, some additional deaths are likely to occur because economic conditions and the basic infrastructure of the city will prohibit full acclimatization even if behavior changes.

QUANTITATIVE ASSESSMENT OF RISKS WITH INTEGRATED MODEL

AN INTEGRATED ASSESSMENT OF RISKS FOR VARIOUS SCENARIOS OF OZONE-DEPLETING SUBSTANCES SHOWS THAT HARM DEPENDS ON THE LEVEL OF THE PRODUCTION OF CHLORINE AND BROMINE BEARING SUBSTANCES.

Risks are evaluated by using the integrated model to simulate the impact of "what-if" scenarios of production of ozone-depleting substances and scenarios of other trace gas concentrations on the atmosphere and on human health and the environment. Sensitivity analyses of alternative assumptions are also conducted.

Analysis of the results of all the scenarios indicates that adverse impacts on health and welfare are lowered with reductions in the production of ozone-depleting substances.

72. MODIFICATION OF THE TRACE GAS COMPOSITION OF THE ATMOSPHERE CAN BE EXPECTED TO ALTER COLUMN OZONE ABUNDANCE (chapter 18).

72a. The range of global average total column ozone change projected for the year 2075 based on a parameterized representation of a one-dimensional model could vary from as high as over 50 percent depletion, for a case where global use of chlorine and bromine bearing substances grows at an average annual rate of 2.8 percent from 1985 to 2100 (5.0 percent per year from 1985 to 2050, followed by no growth through 2100), to increased abundance of ozone of approximately 3 percent, for a case where global use of chlorine and bromine bearing substances declines to 20 percent of its 1985 value by 2010. Exhibit ES-6 displays the global ozone change estimates for these two scenarios, as well as estimates for four scenarios in between; the six "what if" scenarios examined include:

- 80% Reduction: Use of chlorine and bromine bearing substances declines to 20 percent of its 1985 value by 2010, and remains constant thereafter, yielding approximately 3.0 percent increased ozone abundance by 2075;
- No Growth: no growth in use of chlorine and bromine-bearing substances from 1985 to 2100, yielding approximately 0.3 percent increased ozone abundance by 2075;
- 1.2% Growth: 1.2 percent growth from 1985 to 2050, followed by no growth, yielding approximately 4.5 percent depletion by 2075;
- 2.5% Growth: 2.5 percent growth from 1985 to 2050, followed by no growth, yielding approximately 25 percent depletion by 2075;
- 3.8% Growth: 3.8 percent growth from 1985 to 2050, followed by no growth, yielding over 50 percent depletion by 2075;
- 5.0% Growth: 5.0 percent growth from 1985 to 2050, followed by no growth, yielding over 50 percent depletion by 2075.

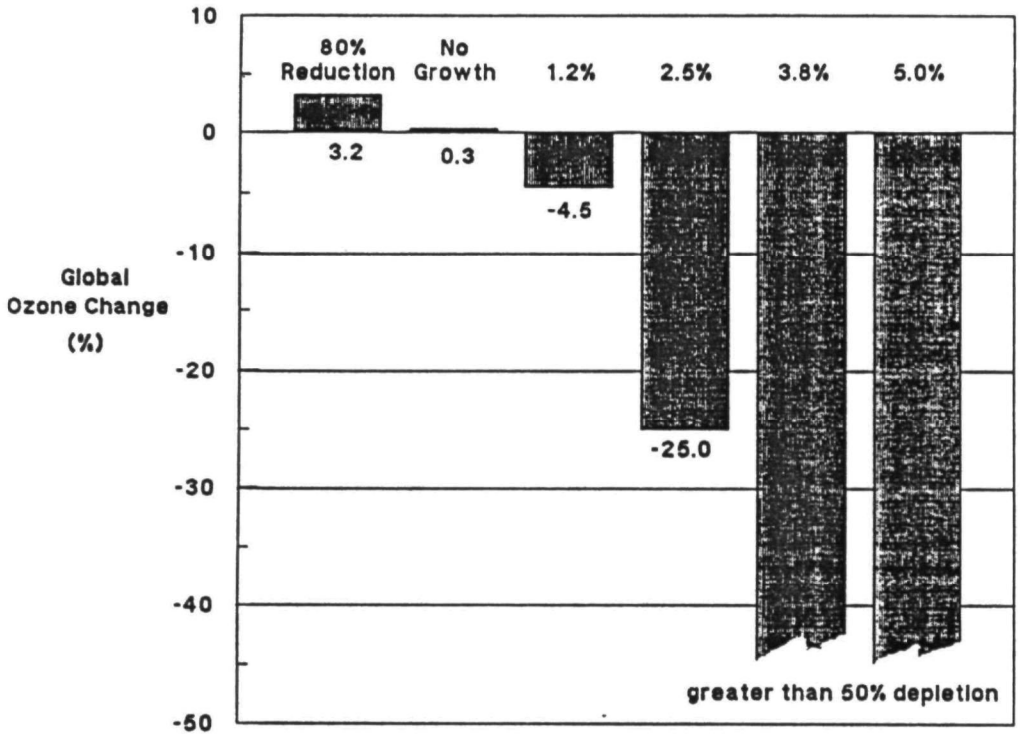
The trace gas concentration assumptions used in these six cases are: CO2 -- NAS 50th percentile; CH4 -- 0.017 ppm per year (approximately 1 percent of current CH4 concentration); and N2O -- 0.20 percent per year.

72b. Current data are not sufficient for distinguishing whether CH4 concentrations are likely to increase in a linear manner (e.g, at 0.017 ppm per year, or approximately 1 percent of current concentrations) or in a compound manner (e.g., at 1 percent per year, compounded annually). The sensitivity of the ozone change estimates in 2075 was evaluated for the following six assumptions regarding future CH4 concentrations:

- Scenario A: compound annual growth of 1 percent from 1985 to 2010, followed by constant concentrations at 2.23 ppm; and

EXHIBIT ES-6

ESTIMATES OF GLOBAL OZONE DEPLETION IN 2075
FOR SIX CASES OF CFC USE



Using a parameterized representation of a one-dimensional model, the potential change in ozone was evaluated for six scenarios: 80% Reduction: global CFC use declines to 20 percent of current levels by 2010, and remains constant thereafter; No Growth: no growth in CFC use from current levels; 1.2% Growth: 1.2 percent growth from 1985 to 2050, followed by no growth; 2.5% Growth: 2.5 percent growth from 1985 to 2050, followed by no growth; 3.8% Growth 3.8 percent growth from 1985 to 2050, followed by no growth; 5.0% Growth: 5.0 percent growth from 1985 to 2050, followed by no growth through 2100). The trace gas concentration assumptions used in these six cases are: CO_2: NAS 50th percentile; CH_4: 0.017 ppm per year (approximately 1 percent of current CH_4 concentration); and N_2O: 0.20 percent per year.

Assumptions:

-- Current 1-D models accurately reflect global depletion; Antarctic ozone hole has no impact on global ozone levels.

-- Greenhouse gases that counter depletion grow at historically-extrapolated rates.

-- Growth rates for ozone depletion are for global emissions; it is assumed that emissions do not increase after 2050.

-- Ozone depletion limited to 50 percent.

- Scenario B: linear growth at 0.01275 ppm per year (75 percent of the 0.017 ppm growth);

- Scenario C: linear growth of 0.017 ppm per year (approximately 1 percent of current concentrations);

- Scenario D: linear growth at 0.02125 ppm per year (125 percent of the 0.017 ppm growth);

- Scenario E: compound annual growth of 1 percent;

- Scenario F: compound annual growth of 1 percent from 1985 to 2020, growing to 1.5 percent compound annual growth by 2050 and thereafter.

For the 2.5% Growth scenario, the estimate of ozone depletion by 2075 ranges from about 14 percent (Scenario F) to 30 percent (Scenario A) across these six CH4 assumptions evaluated. Exhibit ES-7 displays the results for these six CH4 assumptions. As shown in the exhibit, the difference between the 1 percent linear (0.017 ppm per year) and 1 percent compounded assumptions (Scenarios C and E) is approximately 6 percent depletion. This sensitivity of the ozone depletion estimates to the assumption about linear versus compound growth of CH4 concentrations is much larger than the sensitivity to the range of assumptions examined regarding future CO2 concentrations (from the 25th to the 75th percentile NAS estimates) and regarding future N2O concentrations (from 0.15 percent annual compound growth to 0.25 percent annual compound growth).

73. TWO-DIMENSIONAL (2-D) MODELS PREDICT GREATER AVERAGE GLOBAL DEPLETION THAN ONE-DIMENSIONAL (1-D) MODELS. 2-D MODELS ALSO PREDICT THAT OZONE DEPLETION WILL EXCEED THE GLOBAL AVERAGE AT HIGH LATITUDES AND BE LESS THAN THE GLOBAL AVERAGE AT THE EQUATOR (chapter 18).

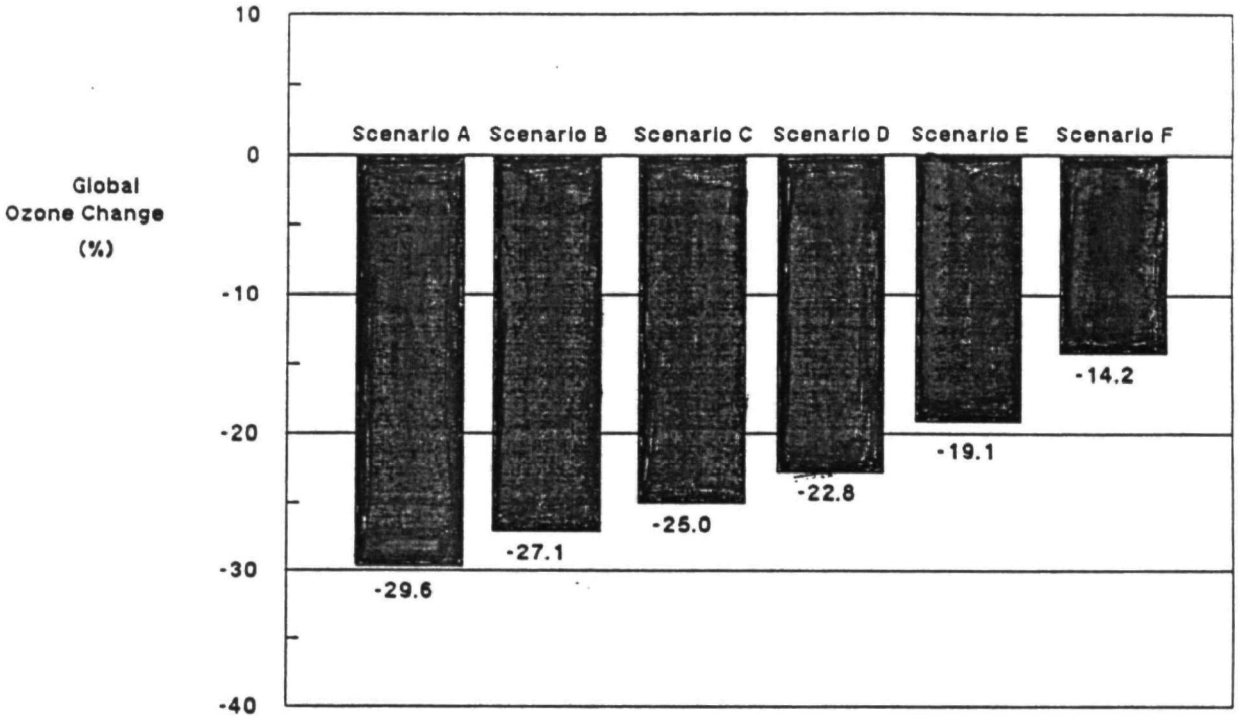
73a. For a case of 3 percent annual growth in emissions of CFCs, no emissions of Halons, and increases in trace gases of: CO2 -- approximately 0.6 percent per year; CH4 -- 1 percent per year; and N2O -- 0.25 percent per year, a 2-D model estimates approximately 5.4 percent global average depletion by 2030. For the same scenario of emissions and trace gas concentrations, the parameterized representation of a 1-D model estimates only 3.0 percent depletion by 2030.

73b. For this same case of emissions and trace gas concentrations, the 2-D model estimates of ozone depletion in 2030 at high latitudes are approximately: 60°N -- 8.7 percent; and 50°N -- 7.0 percent.

74. ESTIMATES OF ATMOSPHERIC MODIFICATION, SKIN CANCER CASES AND DEATHS, CATARACT CASES, MATERIALS DAMAGE, GLOBAL TEMPERATURE, AND SEA LEVEL DEPEND ON THE RATE AT WHICH OZONE-DEPLETING GASES GROW, ATMOSPHERIC RESPONSE, DOSE RESPONSE, AND WHETHER GREENHOUSE GASES THAT COUNTER OZONE DEPLETION GROW INDEFINITELY. THE ASSUMPTIONS BEHIND QUANTITATIVE PROJECTIONS MUST BE NOTED CAREFULLY (chapter 18).

EXHIBIT ES-7

ESTIMATES OF GLOBAL OZONE DEPLETION IN 2075 FOR SIX METHANE CONCENTRATION ASSUMPTIONS



Using a parameterized representation of a one-dimensional model, the potential change in ozone was evaluated for six assumptions about future methane concentration: Scenario A: compound annual growth of 1 percent from 1985 to 2010, followed by constant concentrations at 2.23 ppm; Scenario B: linear growth at 0.01275 ppm per year (75 percent of the 0.017 ppm growth); Scenario C: linear growth of 0.017 ppm per year (approximately 1 percent of current concentrations); Scenario D: linear growth at 0.02125 ppm per year (125 percent of the 0.017 ppm growth); Scenario E: compound annual growth of 1 percent; and Scenario F: compound annual growth of 1 percent from 1985 to 2020, growing to 1.5 percent compound annual growth by 2050 and thereafter.

All estimates based on the 2.5% Growth scenario 1985 to 2100 (2.5 percent growth from 1985 to 2050, followed by no growth thereafter). The other trace gas assumptions used in these cases are: CO_2: NAS 50th percentile; and N_2O: 0.20 percent growth per year.

Assumptions:

-- Current 1-D models accurately reflect global depletion; Antarctic ozone hole has no impact on global ozone levels.

-- Greenhouse gases that counter depletion grow at historically-extrapolated rates.

-- Growth rates for ozone depletion are for global emissions; it is assumed that emissions do not increase after 2050.

-- Ozone depletion limited to 50 percent.

74a. The models used in this risk assessment assume that Antarctic ozone depletion has no global implications and that global trends do not invalidate estimates of current models.

74b. Except as noted, projected effects assume that: greenhouse gases grow at historical rates indefinitely; current one-dimensional models accurately project depletion; production of ozone depleters does not grow after 2050; ozone depletion is limited to 50 percent; the action spectrum causing skin cancers is DNA; and the temperature sensitivity of the earth to doubled CO2 is 3°C.

74c. In 2100, projections of ozone depletion range from over 50 percent for the 5% Growth scenario (ozone depletion is constrained at 50 percent in this analysis) to 47 percent for the 2.5% Growth scenario to an increase in column ozone abundance of nearly 5 percent for the 80% Reduction scenario.

74d. For cohorts born before 2075, the number of additional nonmelanoma skin cancers projected ranges from a 261.5 million increase for the 5% Growth scenario to a 115 million increase for the 2.5% Growth scenario to a reduction of 6.5 million skin cancers for the scenario of 80% Reduction in all ozone depleters.

74e. For cohorts born before 2075, the increase in total melanoma cases ranges from a 1.3 million case increase for the 5% Growth scenario to a 609,000 increase for the 2.5% Growth scenario to 54,000 fewer cases for the scenario of an 80% Reduction in all ozone depleters.

74f. For cohorts born before 2075, total mortality from melanoma and nonmelanoma ranges from a 5.6 million increase for the 5% Growth scenario to a 2.4 million increase for the 2.5% Growth scenario to 115,000 fewer cases for the scenario of 80% Reduction in all ozone depleters.

74g. For cohorts born before 2075, the increase in total cataract cases ranges from 26 million for the 5% Growth scenario to 15.1 million for the 2.5% Growth scenario to 9,500 for the scenario of 80% Reduction in ozone depleters.

74h. The rise in global temperature by 2075 ranges from 11.6°C in the 5% Growth scenario to 5.6°C in the 2.5% Growth scenario to 4°C in the scenario of 80% Reduction in all ozone depleters.

74i. Impacts are also projected for other areas such as sea level rise, ground-based ozone, materials, aquatics, and soybean yield.

75. <u>QUANTITATIVE ESTIMATES OF RISKS VARY WITH ASSUMPTIONS ABOUT FUTURE EMISSIONS OF GREENHOUSE GASES THAT WILL CONTRIBUTE TO GLOBAL WARMING</u> (chapter 18).

75a. Model projections that extrapolate historical growth rates of greenhouse gases, which tend to counter ozone depletion, into the indefinite future assume certain policy decisions from future decisionmakers; alternative assumptions are possible.

75b. If future decisionmakers limit the concentrations of CO_2, N_2O, and CH_4 to prevent global warming from exceeding 2°C (±50%) in 2075, they would by necessity have to limit growth of ozone depleters to the No Growth case; for other cases increases in ozone depleters would be too large to achieve that objective.

75c. Ozone depletion associated with the No Growth or 1.2% Growth scenarios increases nearly 3 to 5 percent if global warming is limited to 3°C (±50%); skin cancer deaths would increase 43 percent for people alive today.

75d. Estimates of methane emissions are inherently uncertain even without consideration of future policy decisions and could affect quantitative risk estimates.

76. <u>QUANTITATIVE ESTIMATES OF RISK VARY WITH UNCERTAINTY ABOUT DOSE-RESPONSE COEFFICIENTS, ACTION SPECTRUM, LIMITS OF OZONE DEPLETION, AND RESPONSIVENESS OF MODELS TO ATMOSPHERIC DEPLETION</u> (chapter 18).

76a. For people alive today and born before 2075, additional skin cancer cases would be reduced 45 percent if one assumes the lower dose-response coefficients that are one standard error below the best estimate and 66 percent higher if one assumes the higher coefficients that are one standard error above the best estimate.

76b. For people alive today and born before 2075, additional skin cancer cases would be reduced 11 percent if the Erythema action spectrum, rather than the DNA action spectrum, were used to measure health effects.

76c. Limiting projected depletion to 50 percent from what the parameterized 1-D model would project reduces projected deaths for later cohorts. For people born from 2030 to 2074, limiting depletion to 50 percent reduces deaths by 13 percent for the 2.5% Growth scenario and 66 percent for the 5% Growth scenario.

76d. For people alive today and born before 2075, skin cancer cases would be reduced 62 percent in the 2.5% Growth scenario if the atmosphere were less sensitive to potential ozone depleters (using the 10th percentile), and increased 54 percent if the atmosphere were more sensitive (using the 90th percentile).

77. <u>WHILE NATIONAL QUANTITATIVE ESTIMATES OF AQUATIC, CROP, GROUND-BASED OZONE, AND SEA LEVEL RISE DAMAGE CANNOT BE MADE AT THIS TIME, CASE STUDY RESULTS INDICATE THAT SIGNIFICANT INCREASES IN GROUND-BASED OZONE, LOSS OF AQUATIC LIFE, SEA LEVEL RISE DAMAGE, AND LOSS OF CROP YIELD ARE POSSIBLE</u> (chapter 18).

MAJOR PRIOR ASSESSMENTS OF THIS ISSUE

A number of prior assessments of stratospheric modification and climate change have been done. A partial list with descriptions is included below:

STRATOSPHERIC OZONE

1. National Academy of Sciences (NAS), 1975, 1976, 1979, 1982, 1983

Several assessments of anthropogenic influences on the stratospheric ozone layer were coordinated by the National Academy of Sciences. The first report, in 1975, focused on the effects of proposed fleets of supersonic transports on the stratosphere. Subsequent reports focused on chlorofluorocarbons.

2. National Aeronautics and Space Administration (NASA), 1977, 1986

NASA has convened several technical panels to review models and chemistry. In addition, it completed a scientific assessment in 1986.

3. World Meteorological Organization,
National Aeronautics and Space Administration,
Federal Aviation Administration,
National Oceanic and Atmospheric Administration,
United Nations Environment Programme,
Commission of the European Communities, and
Bundeministerium fur Forschung und Technologie

International assessments of the stratosphere have been conducted by the European Community, the United Kingdom's Department of the Environment (1979), and by the United Nations Environment Coordinating Committee on the Ozone Layer (1981, 1984, 1986).

The most recent and most ambitious assessment of the scientific issues regarding the stratosphere was coordinated by the World Meteorological Organization with the assistance of several other organizations. Approximately 150 of the world's leading scientists participated in this assessment.

CLIMATE

1. Climatic Impact Assessment Program, 1974

Initial concern over anthropogenic influences on the climate and the stratospheric ozone layer led in 1971 to the establishment of the Climatic Impact Assessment Program (CIAP). Coordinated by the Department of Transportation, CIAP's objective was to assess, by a report in 1974, the impacts of climatic changes due to projected fleets of supersonic transports.

2. National Academy of Sciences: 1979, 1982, 1983

Three panels were convened by the National Academy of Sciences to assess the scientific basis and certainty of the effects of carbon dioxide concentrations on global climate. Reports were released in 1979, 1982, and 1983.

3. World Meterological Organization,
International Council of Scientific Unions, and
United Nations Environment Programme

Efforts to achieve an international scientific consensus on carbon dioxide, trace gases, and climate were coordinated by the World Meterological Organization (WMO), International Council of Scientific Unions (ICSU), and United Nations Environment Programme (UNEP). Assessments were released in 1979, 1981, and 1985.

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APPENDIX B

FEDERAL REGISTER NOTICES

STRATOSPHERIC OZONE PROTECTION PLAN

Federal Register Notice

January 10, 1986

Proposed Rules

Federal Register
Vol. 51, No. 7
Friday, January 10, 1986

This section of the FEDERAL REGISTER contains notices to the public of the proposed issuance of rules and regulations. The purpose of these notices is to give interested persons an opportunity to participate in the rule making prior to the adoption of the final rules.

DEPARTMENT OF HEALTH AND HUMAN SERVICES

Food and Drug Administration

21 CFR Part 163

[Docket No. 85N-0500]

Cocoa Powders; Advance Notice of Proposed Rulemaking on the Possible Amendment of U.S. Standards of Identity

Corrections

In FR Doc. 85-28351 beginning on page 49405 in the issue of Monday, December 2, 1985, make the following corrections:

1. On page 49406, in the third column, in the eleventh line from the bottom, "§ 163.11" should read "§ 163.111";

2. On page 49407, in the second column, in the table, under "4. Food Additives", the second entry should read "4.1.2 Ammonium hydrogen carbonate";

3. On the same page, in the third column, in the table, under "5. Contaminants", the third entry should read "5.3 Lead";

4. On page 49408, in the second column:

a. In the second line of 8.4(b), "1974" should read "1973";

b. After entry 8.7, add the following entry:

8.8 *Determination of sugars* (to be elaborated)[1]

c. The footnote indicators immediately following the headings of entries 8.10 and 8.11 should both be changed to "2";

d. In the second line of the paragraph following entry 8.11, "test" should read "text"; and

5. On page 49409, in the first column, the fourth line of § 163.114 should be deleted.

BILLING CODE 1505-01-M

21 CFR Part 163

[Docket No. 85N-0501]

Chocolate Products; Advance Notice of Proposed Rulemaking on the Possible Amendment of the U.S. Standards of Identity

Correction

In FR Doc. 85-28350 beginning on page 49398 in the issue of Monday, December 2, 1985, make the following correction:

On page 49404, in the third column, in the second and third lines of § 163.145(a), "are prescribed by this identity" should be deleted.

BILLING CODE 1505-01-M

DEPARTMENT OF TRANSPORTATION

Coast Guard

33 CFR Part 166

[CGD 85-097]

Port Access Routes; Approach to Tampa Bay, FL

Correction

In FR Doc. 85-29476, beginning on page 50808 in the issue of Thursday, December 12, 1985, make the following correction: On page 50809, in the second column, in the table of geographic positions, the fourth entry under "Longitude" should read "83°05'06" W."

BILLING CODE 1505-01-M

POSTAL SERVICE

39 CFR Part 111

Correct ZIP Codes for Mailing; Withdrawal of Proposed Rule

AGENCY: Postal Service.

ACTION: Withdrawal of proposed rule.

SUMMARY: On March 19, 1985 the Postal Service published in the Federal Register (50 FR 10991) a proposal to require mailers of certain categories of mail and those who desire to participate in certain presort discount mailings to include a correct five-digit ZIP Code, as defined by certain Postal Service data bases, in the address of each piece. Less than a dozen commenters responded to the proposal. However, the substance of their views was that the proposal contained certain latent ambiguities. In view of these comments, the Postal Service is hereby withdrawing the proposal for further consideration, with the expectation that it may be initiated at a later time

DATE: This withdrawal is effective January 10, 1986.

FOR FURTHER INFORMATION CONTACT: William Price, (202) 268-3521.

List of Subjects in 39 CFR Part 111

Postal Service.

W. Allen Sanders,

Associate General Counsel, Office of General Law and Administration.

[FR Doc. 86-527 Filed 1-9-86; 8:45 am]

BILLING CODE 7710-12-M

ENVIRONMENTAL PROTECTION AGENCY

40 CFR Ch. I

[OAR-FRL-2949-3]

Stratospheric Ozone Protection Plan

AGENCY: Environmental Protection Agency.

ACTION: Announcement of Program Plan.

SUMMARY: This notice describes recent activities related to protection of the stratospheric ozone layer and outlines EPA's program plan for future examination of the issue. By enhancing EPA's research and analysis related to stratospheric ozone protection, this program will provide necessary technical information for use in future Agency decisions on whether or not to regulate chlorofluorocarbons (CFCs) or other chemicals that may affect the ozone layer. In addition, the plan places considerable emphasis on United States participation in on-going international research and discussions of global strategies for protecting the ozone layer.

This notice provides a broad outline and general schedule for the stratospheric ozone protection program. Throughout the implementation of this program, EPA encourages public review and participation. Where appropriate, the Agency will announce in the Federal Register upcoming workshops and

conferences and the availability of papers for review.

FOR FURTHER INFORMATION CONTACT: Stephen Seidel, U.S. Environmental Protection Agency, 401 M St. S.W., Washington, D.C. 20460 (202) 382-2787.

SUPPLEMENTARY INFORMATION:

Background

By preventing most potentially harmful ultraviolet radiation (UV-B radiation) from penetrating to the earth's surface, the ozone layer acts as an important shield protecting human health, welfare and the environment. The possibility that the production, use, and release of chlorofluorocarbons (CFCs) could cause the depletion of stratospheric ozone was first theorized in a 1974 article in *Nature* by Rowland and Molina. If a net depletion of total-column ozone (i.e., the total quantity of ozone encountered by radiation penetrating from the top of the atmosphere to the earth's surface at any given location) occurred, more UV-B radiation would penetrate to the earth's surface.

Possible health and environmental effects of exposure to increased UV-B radiation could include: increases in non-melanoma skin cancer; suppression of the human immune system; decreases in the productivity of commercially important crops and aquatic organisms; and accelerated degradation of polymeric materials. In addition, EPA and the National Institutes of Health have recently initiated studies to determine whether or not exposure to UV-B radiation can contribute to melanoma skin cancer. Finally, production and use of CFCs may contribute to the predicted global warming from the "greenhouse effect" through two pathways. First, changes in the distribution of total-column ozone could possibly increase temperature, and second, CFCs themselves are infrared-absorbing gases that act directly (in the same manner as carbon dioxide) to raise global surface temperature.

Although less was known about the possible causes and effects of ozone depletion in the mid-1970's, EPA and other agencies responded to concerns about this issue by promulgating regulations in 1978 limiting the use of CFCs as a propellant in nonessential aerosol spray cans (43 FR 11301; March 17, 1978). CFC use as an aerosol propellant had grown to 56 percent of total CFC use in this country and 25 percent of total world consumption in 1974. By significantly reducing CFC use and therefore the risks of ozone depletion, this action has provided more time to address the complex scientific questions involved in assessing those risks.

While several other countries also acted to limit CFC use in aerosol propellants, this use continues in most countries. In addition, CFCs are used here and abroad for many important industrial and commercial processes, including refrigeration, air conditioning, and foam blowing, and as a solvent by the electronics industry.

In 1980 EPA issued an advance notice of proposed rulemaking discussing possible further limits on domestic production of CFCs under section 157 of the Clean Air Act, 42 U.S.C. 7457 (45 FR 66726; Oct 7, 1980). However, some of the scientific information summarized in that notice was soon outdated by more recent work in the field, and there have been substantial changes in the research community's understanding of several important aspects of the issue since then. In general, the more recent work has demonstrated that possible changes in the ozone layer are affected by a more complex array of physical and chemical forces than previously thought, and that substantial uncertainties remain to be resolved before such changes can be predicted with confidence. In addition, EPA believes that any decision on further regulation of domestic CFC production or use must be based on further research and analysis, and should be evaluated in the context of possible international regulatory actions. Today's notice outlines the Agency's current plan for further examination and resolution of this issue.

Two current areas of activity set the context in which EPA is acting. Both scientific and diplomatic efforts are underway, and each figures significantly in the Agency's plan. First, the scientific research community has expanded its efforts to improve our understanding of the physical and chemical forces that affect the ozone layer and how these may change over time. For example, researchers now recognize that atmospheric constituents other than CFCs have been increasing, and that future changes in these substances must also be considered in modelling the future evolution of the atmosphere. Researchers have also placed additional emphasis on the potential climatic impacts that might be caused by changes in atmospheric chemical composition.

Several major reports on related scientific issues are planned for the next year. A major review of atmospheric science issues related to ozone modification is scheduled to be published in January 1986. This report is being sponsored by the National Aeronautics and Space Administration (NASA), the World Meteorological Organization (WMO), the United Nations Environment Programme (UNEP), and other national and international organizations. NASA is also preparing a companion report to EPA and Congress on this subject. UNEP's Coordinating Committee on the Ozone Layer will hold meetings in 1986 and will issue a report that covers atmospheric science and other areas of research related to the effects of exposure to UV-B radiation on human health, welfare and the environment. The Fluorocarbon Program Panel of the Chemical Manufacturers Association (CMA) continues to fund research primarily related to ozone monitoring and atmospheric modelling. Finally, in October 1985, the WMO convened a conference in Villach, Austria to examine potential changes in climate that could, in part, result from increases in CFCs and other ozone-modifying substances and from changes in the vertical distribution of ozone.

The second major focus of recent activities has centered on international negotiations concerning protection of the ozone layer. Conducted under the auspices of UNEP, these negotiations resulted in the adoption of the Vienna Convention for the Protection of the Ozone Layer in March 1985. This

convention creates a framework for international cooperation on research, monitoring and information exchange. It also provides procedures for the future adoption of measures to control, limit, prevent or reduce emissions of ozone-modifying substances, should such measures be deemed necessary. This treaty comes into force after formal acceptance by twenty nations.

While successfully adopting the framework convention, the Diplomatic Conference in Vienna failed to agree on any appropriate global control measures. In lieu of such measures, it passed a resolution calling for an economic workshop to analyze relevant aspects of control options and for continued negotiations culminating in a second Diplomatic Conference currently planned for April 1987.

Program Plan

EPA's stratospheric ozone protection program integrates the diverse scientific and economic research being carried on by EPA and by other organizations into a coherent framework for future Agency decisionmaking on both the domestic and international aspects of this issue. (See Figure 1.) Three primary elements of the Agency's program are: (1) conducting analyses and research across a range of economic and scientific subjects aimed at narrowing uncertainties; (2) participating in a series of workshops and conferences both in the United States and abroad aimed at improving understanding of all aspects of this issue; and (3) deciding by November 1987 whether additional domestic regulation of CFCs is warranted, based on the information gained during the period of study.

BILLING CODE 6560-50-M

PROTECTION OF STRATOSPHERIC OZONE

Federal Register Notice

December 14, 1987

federal register

Monday
December 14, 1987

Part II

Environmental Protection Agency

40 CFR Part 82
Protection of Stratospheric Ozone; Final Rule and Proposed Rule

ENVIRONMENTAL PROTECTION AGENCY

40 CFR Part 82

[FRL-3299-9]

Protection of Stratospheric Ozone

AGENCY: Environmental Protection Agency (EPA)

ACTION: Final rule.

SUMMARY: EPA is requiring that individuals or legal entities involved in the production, import or export of specified ozone-depleting chemicals in 1986 provide information regarding these activities to EPA within 30 days.

To implement the Montreal Protocol, EPA must obtain data on United States 1986 production, imports and exports of the chemicals covered by this agreement. This information is critical because the Montreal Protocol uses 1986 activity as the baseline for its restrictions.

In addition to this request for data, EPA is also publishing today in the **Federal Register** its proposed detailed strategy for implementing the *Montreal Protocol on Substances that Deplete the Ozone Layer* (Montreal Protocol). While EPA is asking for public comment on that proposed strategy, this data collection rule is effective immediately.

EFFECTIVE DATE: December 14, 1987.

FOR FURTHER INFORMATION CONTACT: Stephen Seidel; Stratospheric Protection Program; Office of Program Development (ANR-445); Office of Air and Radiation; 401 M Street, SW., Washington, DC 20460. (202) 382-2878.

SUPPLEMENTARY INFORMATION:

I. Background

On September 16, 1987, the United States and 23 other nations signed the *Montreal Protocol on Substances that Deplete the Ozone Layer* (Montreal Protocol). This agreement sets forth a timetable for reducing specified ozone-depleting chemicals. It represents a significant multilateral response to addressing the health and environmental risks of stratospheric ozone depletion.

The requirements contained in the Montreal Protocol and EPA's proposed plan for implementing them within the United States are discussed in detail in a **Federal Register** notice also published today.

To implement the Montreal Protocol, EPA must obtain data on United States 1986 production, imports and exports of the chemicals covered by this agreement. This information is critical because the Montreal Protocol uses 1986 activity as the baseline for its restrictions.

Although the timing of the effective date of the Montreal Protocol is uncertain (it depends on when the conditions for entry into force are satisfied), it could occur as early as January 1, 1989. The effective date (termed entry into force) would be "January 1, 1989 provided that at least eleven instruments of ratification, acceptance, approval of the Protocol or accession thereto have been deposited by States or regional economic integration organizations representing at least two-thirds of 1986 estimated global consumption of the controlled substances * * *." In addition, the *Vienna Convention for the Protection of the Ozone Layer*, under which this Protocol was negotiated, must also have entered into force before the Protocol can take effect. If these conditions have not been satisfied by January 1, 1989, than the Protocol enters into force on the 90th day following the date on which the conditions have been fulfilled.

Recognizing the potentially short time period before entry into force, the participants at the Diplomatic Conference in Montreal passed a "Resolution on Reporting of Data." This resolution "[C]alls upon all Signatories to take, expeditiously, all steps necessary to acquire data and report on the production, import and export of controlled substances in a complete and timely manner * * *."

To implement this conference resolution, the United Nations Environment Program (UNEP) has already requested production and consumption data from signatories and has tentatively scheduled a meeting for early next year at which signatories to discuss and report on data collection efforts.

II. Statutory Authority

EPA is requiring this information under the authority granted it in Section 114 of the Clean Air Act. This section states that "the Administrator may require any person who owns or operates any emission source or who is subject to any requirement of this Act * * * provide such other information, as he may reasonably require * * *."

EPA has elected to require this information by rule to ensure that all producers, importers and exporters receive notice that this information is being collected. If the Agency instead sent letters to firms believed to be involved in these activities, it might not reach the entire universe of involved parties.

EPA intends to send follow-up requests for information under section 114 to producers of the specified ozone-depleting chemicals asking for more detailed information related to past, current, and future production activity. The information requested in those letters will supplement that required by this rule.

The rule is being published as a final action without first seeking public comment for several reasons. First, the rule is limited in scope and simply requires that information on past specified activities be reported. Second, the information requested is straightforward and clearly delineated. Third, the resources involved in reporting this information should be minimal. Only seven firms are believed to produce the specified ozone-depleting chemicals in the United States, while fewer than 20 firms or individuals are likely to have been importers or exporters in 1986. Fourth, this information is not available through existing channels. While some of the information is available through the U.S. International Trade Commission and the Chemical Manufacturers Association, this data is presented in an aggregate manner and does not cover most of the specified ozone-depleting chemicals. Fifth, as discussed EPA will need this information in a timely manner to respond to UNEP's request and to participate in the upcoming meeting on data collection. For these reasons, EPA finds that notice and public comment on this rule are impracticable, unnecessary and contrary to the public interest within the meaning of 5 U.S.C. section 553(b)(B).

III. Requirements of the Rule

A. Affected Parties

The rule applies only to those parties who produced, imported, or exported the specified bulk chemicals (See section III.B below) in 1986. Thus, firms which use chlorofluorocarbons (CFCs) and halons as part of their manufacturing process would not be affected by this rule. In fact, as stated above, EPA believes that only seven firms produced the specified ozone-depleting chemicals in the United States in 1986 and fewer than 20 firms were involved in importing or exporting these chemicals in their bulk form.

It is important to note that imports or exports of products containing or produced with the specified ozone-depleting chemicals would not be covered by this rule. Thus, it would not apply to a firm importing refrigerators containing CFC-12. It would, however, apply to the import or export of any bulk shipments of mixtures or azeotropes

containing the specified chemicals. The definition of controlled substances contained in the Montreal Protocol states that it excludes any of the specified chemicals "whether existing alone or in mixture that is in a manufactured product other than a container used for transportation or storage * * *."

B. Specified Ozone-Depleting Chemicals

The Montreal Protocol and therefore this rule applies to the following chemicals:

(1) CFC-13—Trichlorofluoromethane (CFC-11)
(2) CCl2F2—Dichlorodifluoromethane (CFC-12)
(3) CCl2F-CClF2—Trichlorotrifluoroethane (CFC-113)
(4) CF2Cl-CClF2—Dichlorotetrafluoroethane (CFC-114)
(5) CClF2-CF3—(Mono)chloropentafluoroethane (CFC-115)
(6) CF2BrCl—Bromochlorodifluoromethane (Halon 1211)
(7) CF3Br—Bromotrifluoromethane (Halon 1301)
(8) C2F4Br2—Dibromotetrafluoroethane (Halon 2402)

C. Data Required

EPA is requiring that affected parties provide data on the quantity of each of the specified chemicals that was produced, imported or exported in 1986. The year 1986 is the baseline used in the Montreal Protocol for determining limits on production and consumption (defined as production plus imports minus exports) established by that agreement. As a result, 1986 is the year for which data is sought.

Information on the quantity and location of each of the specified chemicals produced in the United States or its territiories is required along with the amount of those chemicals which may have been used and consumed as chemical intermediaries in the production of other chemicals. The latter information is necessary to avoid double-counting CFC or halon production. Documentation supporting the submission of 1986 production levels could include production records or logs, certified production statements used for other reporting purposes or similar information. Quantities should be reported in kilograms for each of the specified CFCs and halons.

The quantity of each specified chemical imported to the United States and its territories is required to be reported to EPA along with Entry Number, Customs District and Port Code, Employer Identification Number (EIN) or importer number, commodity code, the date and port of entry and the country in which it was produced. The required information on exports includes the quantity exported, the producer of the chemical, the date and port of exit, the EIN, Customs District and Port Code, the commodity code, and the country of final destination. Documentation supporting imports and exports should include copies of official papers (e.g., shippers export declarations, Form 7525 and Entry Summaries, if available) or other evidence confirming such activity.

Affected parties should specify what of the submitted data is covered by 40 CFR, Part 2, Subpart B, which governs the treatment of business information. Congress has given EPA broad authority to secure this information through Section 114 of the Clean Air Act for the purposes of developing regulations and standards.

Under section 114, EPA is empowered to obtain information which may be considered confidential business information. Producers, importers, and exporters may request that EPA consider some or all of the information they supply as confidential at the time it is submitted. Failure to assert a claim of confidentiality at the time of submission may result in disclosure of the information by the Agency without further notice.

D. Submission of Data

The data required under this rule must be submitted to EPA within 30 days following the date of publication of this notice. It should be sent to: Stratospheric Protection Program: Office of Program Development (ANR-445); Office of Air and Radiation; 401 M Street SW., Washington, DC 20460.

E. Failure to Comply

Affected parties failing to submit the required data will be in violation of section 113 of the Clean Air Act and will be subject to fines of up to $25,000 per day. In addition, since the data collected by this rule will likely be used in determining the allocation of rights to produce and import bulk CFCs and halons, the failure to notify EPA of 1986 activities could invalidate future claims to such allocations.

F. Future Steps

EPA intends to use the information required by this rule to develop the U.S. 1986 production and consumption baseline as required under the Montreal Protocol. In addition, this data would also be used as the basis for the proposed "allocated quota" approach to implementing the Protocol (see accompanying proposed rule) which grants past producers and importers rights to produce and consume based on their 1986 activities. EPA intends to publish for comment the allocations based on this data in Spring of 1988. Final allocations providing the basis for issuing rights to import and produce the regulated CFCs and halons would be published as part of the final rule implementing the Montreal Protocol. That final rule is scheduled for promulgation by August 1, 1988.

IV. Additional Information

A. Executive Order 12291

Executive Order (E.O.) 12291 requires the preparation of a regulatory impact analysis for major rules, defined by the order as those likely to result in:

(1) An annual effect on the economy of $100 million or more;

(2) A major increase in costs or prices for consumers, individual industries, Federal, State, or local government agencies, or geographic industries; or

(3) Significant adverse effects on competition, employment, investment, productivity, innovation, or on the ability of United States-based enterprises to compete with foreign-based enterprises in domestic or export markets.

EPA has determined that this regulation does not meet the definition of a major rule under E.O. 12291, and therefore has not prepared a regulatory impact analysis (RIA).

B. Regulatory Flexibility Act

The Regulatory Flexibility Act, 5 U.S.C. sections 601-612, requires that Federal agencies examine the impacts of their regulations on small entities. Under 5 U.S.C. 604(a), whenever an agency is required to publish a general notice of proposed rulemaking, it must prepare and make available for public comment an initial regulatory flexibility analysis (RFA). Such an analysis is not required if the head of an agency certifies that a rule will not have a significant economic impact on a substantial number of small entities, pursuant to 5 U.S.C. 605(b). Because this rule will not have a significant impact on small entities, no RFA has been prepared.

C. Paperwork Reduction Act

The information collection requirements in this rule have been approved by the Office of Management and Budget (OMB) under the Paperwork Reduction Act of 1980, 44 U.S.C. 3501 *et seq.* and has been assigned OMB control number 2060-0158.

Date: December 1, 1987.

Lee M. Thomas,

Administrator.

For the reasons set out in the preamble, Part 82 of Title 40 of the Code of Federal Regulations is added as follows:

PART 82—PROTECTION OF STRATOSPHERIC OZONE

Authority: 42 U.S.C. 7457(b).

§ 82.20 Baseline data collection.

(a) This section applies to any individual or legal entity who engaged in any of the following activities in 1986 involving any of the chemicals specified in § 82.20(b) of this part:

(1) Producers who manufactured the chemicals listed in § 82.20(b) from raw materials or feedstock chemicals;

(2) Importers who transported the chemicals listed in § 82.20(b) from outside the United States or its territories to persons within the United States or its territories; and

(3) Exporters who transported the chemicals listed in § 82.20(b) from within the United States or its territories to outside the United States or its territories.

(b) The chemicals covered by this section are the following:

(1) CFC-13—Trichlorofluoromethane (CFC-11)

(2) CCl2F2—Dichlorodifluoromethane (CFC-12)

(3) CCl2F-CClF2—Trichlorotrifluoroethane (CFC-113)

(4) CF2Cl-CClF2—Dichlorotetrafluoroethane (CFC-114)

(5) CClF2-CF3—(Mono)chloropentafluoroethane (CFC-115)

(6) CF2BrCl—Bromochlorodifluoromethane (Halon 1211)

(7) CF3Br—Bromotrifluoromethane (Halon 1301)

(8) C2F4Br2—Dibromotetrafluoroethane (Halon 2402)

(c) Individuals and legal entities meeting the conditions set forth in § 82.20 (a) and (b) must report the following information along with supporting documentation:

(1) Name, address and telephone number of contact;

(2) The amount (kilograms) of each the substances it produced in 1986 in United States or its territories and the location of its production;

(3) The amount (kilograms) of each of the chemicals listed in § 82.20(b) which was used and entirely consumed as a chemical intermediary in the production of other chemicals;

(4) The amount (kilograms) of each of the chemicals listed in § 82.20(b) which it imported into the United States or its territories in 1986, along with the port and date of entry and the country in which it was produced;

(5) The amount (kilograms) of each of the chemicals listed in § 82.20(b) which in 1986 it exported from the United States or its territories, the producer of the chemical, the date and port of exit, the country of final destination and the date of entry into that country.

(d) Information required by § 82.20(c) must be submitted to EPA within 30 days after the date of publication of this section. Reports should be addressed to: Stratospheric Protection Program; Office of Program Development (ANR-445); Office of Air and Radiation; U.S. Environmental Protection Agency; 401 M Street, SW., Washington DC 20460.

(e) Failure to submit required information by this date shall be a violation of section 114 of the Clean Air Act and may invalidate future claims for allocation of rights to produce or import chemicals listed in § 82.20(b).

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ENVIRONMENTAL PROTECTION AGENCY

40 CFR Part 82

[FRL-3284-9]

Protection of Stratospheric Ozone

AGENCY: Environmental Protection Agency (EPA).

ACTION: Proposed rule.

SUMMARY: EPA is proposing to limit the production and consumption of certain chlorofluorocarbons (CFCs) and brominated compounds (halons) to reduce the risks of stratospheric ozone depletion. Specifically, the proposed rule would require a freeze at 1986 consumption and production levels of CFC-11, -12, -113, -114, and -115 on the basis of their relative ozone depletion weights, followed by reductions to 80 percent and 50 percent of 1986 levels beginning in mid-1993 and mid-1998, respectively. It would also prohibit production and consumption of Halon 1211, 1301 and 2402 from exceeding 1986 levels on a weighted basis beginning in approximately 1992. Under limited circumstances, somewhat higher levels of production (but not consumption) would be permitted. Consumption is defined in the proposed rule as production plus imports minus exports of the bulk chemicals described above.

These requirements are being proposed under section 157(b) of the Clean Air Act and would constitute the United States' implementation of the "Montreal Protocol on Substances That Deplete the Ozone Layer" (Montreal Protocol) which was signed by 24 countries, including the United States, on September 16, 1987 in Montreal, Canada.

However, EPA is proposing that the control requirements described above only take effect if the United States ratifies the Protocol and following entry into force.

EPA's proposed action is in response to growing scientific evidence linking increased atmospheric levels of chlorine and bromine to anticipated depletion of the ozone layer. If ozone depletion occurs, increased levels of harmful ultraviolet radiation would penetrate to the earth's surface resulting in substantial damage to human health and the environment.

To implement the Montreal Protocol, EPA proposes to restrict production and consumption of the specified ozone-depleting chemicals. Quotas reflecting the allowable level of production and consumption will be allocated to each of the firms who engaged in these activities in 1986. Trading of allocated quotas would be permitted. Exports and imports of the restricted chemicals will also be allowed consistent with restrictions contained in the Montreal Protocol. EPA believes that this approach will provide a low-cost means of achieving its regulatory goal, spur technological innovation, minimize administrative requirements and facilitate enforcement. EPA is also considering whether to develop specific regulations limiting CFC and halon use for particular industries to supplement allocated quotas.

As an alternative to the above regulatory approach, EPA is requesting comment on the use of a regulatory fee in addition to allocated quotas. This option is being considered because it addresses concerns that an allocated quota system, by itself, is inequitable—that CFC and halon producers and importers might accrue excessive profits at the expense of CFC and halon user industries and consumers. The fee would be set to obtain for the United States Treasury price increases resulting from the scarcity created by EPA regulations. Alternatively, this same objective could be satisfied by auctioning (instead of allocating) rights to produce and consume CFCs and halons.

In a separate notice accompanying today's proposal EPA is requiring firms involved in producing, importing or exporting any of the regulated chemicals in 1986 to report these activities to EPA.

DATES: A public hearing will be held on January 7, 1988 from 9:00 a.m. to 5:00 p.m. at the location listed below, in order to provide an opportunity for oral presentations of data, views, or arguments concerning the regulations proposed in this notice. Persons who wish to testify at this hearing should notify Stephen R. Seidel at the address listed below prior to December 29, 1987.

Written comments must be submitted to the location listed below by February 8, 1988.

ADDRESSES: The public hearing will be held at the EPA Education Center, 401 M Street, SW., Washington, DC 20460.

Written comments should be sent to Docket No. A-87-20, Central Docket Section, South Conference Room 4, Environmental Protection Agency, 401 M Street, SW., Washington, DC 20460. The docket may be inspected between 8:00 a.m. and 4:00 p.m. on weekdays. As provided in CFR Part 2, a reasonable fee may be charged for photocopying. To expedite review, it is also requested that a duplicate copy of written comments be sent to Stephen R. Seidel at the address listed below.

FOR FURTHER INFORMATION CONTACT: Stephen R. Seidel, Senior Analyst, Office of Program Development, Office of Air and Radiation (ANR-445), EPA, 401 M Street, SW., Washington, DC 20460. Telephone (202) 382-2787.

SUPPLEMENTARY INFORMATION:

I. Overview of the Problem

By preventing much of the potentially harmful ultraviolet radiation (UV-B radiation) from penetrating to the earth's surface, the stratospheric ozone layer acts as a vital shield protecting human health, welfare and the environment.

Concern about possible depletion of the ozone layer from chlorofluorocarbons (CFCs) was first raised in 1974 with publication of research which theorized that chlorine released from CFCs could migrate to the stratosphere and reduce the amount of ozone (Molina and Rowland, 1974). Some of the CFCs have an atmospheric lifetime of over 120 years (i.e., they do not breakdown in the lower atmosphere). As a result, they migrate slowly to the stratosphere where higher energy radiation strikes them, releasing chlorine. Once freed, the chlorine acts as a catalyst repeatedly combining with and breaking apart ozone molecules. If ozone depletion occurs, more UV-B radiation would penetrate to the earth's surface. Moreover, because of the long atmospheric lifetimes of CFCs, it would take many decades to over a century for the ozone layer to return to past concentrations.

In the thirteen years since that theory was first proposed, substantial scientific research has supported the general concern that increased concentrations of chlorine, as well as bromine from halons, in the stratosphere pose substantial risks of depletion resulting in harm to human health and the environment.

Today's proposal is in response to increased concerns raised by the improved understanding of the risks associated with continued use of CFCs and halons. During the past two years, two extensive assessments of these risks have been completed and are relied on by EPA in evaluating the need for additional restrictions on the use of potential ozone-depleting chemicals. The first, *Atmospheric Ozone, 1985* (WMO, 1986), provides an extensive review of the current state of knowledge concerning atmospheric chemistry and modelling, past changes in trace gases that affect ozone levels, and current trends in ozone levels. A second study, *An Assessment of the Risks from Trace Gases that can Modify the Stratosphere* (EPA, 1987), was prepared by EPA and

reviewed by its Science Advisory Board. This study summarizes the state of knowledge related to both atmospheric issues (e.g., possible future changes in ozone levels), and human health and environmental effects if the ozone layer were depleted. These studies and more recent research findings are summarized below in Section IV. They also were relied on extensively in developing the regulatory impact analysis (RIA) prepared in support of this rule which is summarized below in Section VII.

Unlike most issues of concern to EPA, stratospheric ozone protection necessarily involves all nations of the world. Given their long atmospheric lifetimes, CFCs and halons become widely dispersed. As a result, the release of these chemicals in one country could adversely affect the stratosphere above, and therefore the health and welfare of, other countries. Thus, to fully protect the ozone layer from CFCs and halons, an international agreement is essential.

Recognizing the global nature of this issue, the United Nations Environment Program (UNEP) organized negotiations in 1982 aimed at developing an agreement to protect the ozone layer. Following a hiatus in 1986 to develop and assess scientific and economic information, negotiations resumed in December of that year. These negotiations were successfully concluded on September 16, 1987 in Montreal when 24 nations signed a Protocol requiring substantial reductions in the most potent ozone-depleting chemicals. This international agreement represents a concerted effort by the major CFC and halon producing and consuming nations to respond to the risks from continued reliance on ozone-depleting chemicals. It constitutes a landmark agreement among nations to take action in advance to prevent significant environmental damage from occurring. The text of the Protocol is included as an annex to this preamble and is described in greater detail below.

The regulations proposed today would permit the United States to meet the requirements established by the Montreal Protocol. They would also fulfill EPA's responsibility under section 157(b) of the Clean Air Act to protect stratospheric ozone as needed to protect public health and welfare.

Finally, this proposal also meets the requirements of an agreement settling a lawsuit brought by the Natural Resources Defense Council in the District Court of the District of Columbia (NRDC v. Thomas, No. 84-3587 (D.D.C.)) seeking to compel EPA to promulgate regulations under section 157(b). The terms of the settlement (as amended to extend the schedule) require EPA to propose regulations or state its reason for deciding not to regulate by December 1, 1987, and to take final action by August 1, 1988.

II. Background

A. Past Regulatory Actions

Following the initial concerns raised in 1974 about possible ozone depletion from CFCs, EPA and the Food and Drug Administration acted in 1978 to ban the use of CFCs as aerosol propellants in all but "essential applications" (43 FR 11301, March 17, 1978; 43 FR 11318, March 17, 1978). During the early 1970s, CFCs used as aerosol propellants constituted over 50 percent of total CFC consumption in the United States. This particular use of CFCs was reduced in this country by approximately 95 percent. Today's proposal does not affect the existing EPA and FDA regulations restricting the use of CFCs as aerosol propellants.

Since 1978, CFC use has continued to expand in other applications (e.g., as a foam-blowing agent, refrigerant and solvent). Total production now has surpassed pre-1974 levels.

Largely in response to a series of studies by the National Academy of Sciences published in the late 1970s (NAS, 1976, 1979a, and 1979b) which warned of substantial depletion and harm from continued use of CFCs, EPA issued an Advance Notice of Proposed Rulemaking (ANPR) which discussed an immediate freeze on the production of certain CFCs and the possibility of employing a system of marketable permits to allocate CFC consumption among industries which use CFCs (45 FR 66726; October 7, 1980).

Following publication of this ANPR, additional scientific evidence (see for example, *Causes and Effects of Changes in Stratospheric Ozone: Update 1983*, (NAS, 1984)) became available which suggested that the atmospheric factors affecting ozone levels were more complex than previously thought. For example, atmospheric concentrations of gases other than CFCs that also affect ozone were also increasing. Atmospheric models which are used to analyze possible future trends in ozone levels were now capable of simultaneously considering changes in multiple trace gases including CFCs. Because increases in some of these gases (e.g., carbon dioxide and methane) could potentially buffer the depleting effects of CFCs, concern about possible changes in total column ozone levels (i.e., the total amount of ozone encountered by radiation passing from the top of the atmosphere to the earth's surface at any given location) was diminished.

The apparent urgency of the ozone depletion problem was also reduced by the fact that CFC use worldwide in the early 1980s was relatively constant. While some nations did not follow the United States example by reducing their use of CFCs as aerosol propellants, others did, which further reduced global consumption of CFCs. In addition, a downturn in global economic conditions during this period had temporarily reduced the rate of growth of CFCs in nonaerosol applications.

B. EPA's Stratospheric Protection Plan

Since 1983, worldwide production of CFCs has grown at an average annual rate of 5 percent. In light of this rate of growth and further advancements in the scientific understanding of the link between CFCs and ozone depletion, EPA developed its Stratospheric Protection Plan (51 FR 1257, January 10, 1986). This plan described the analytic basis for supporting the on-going international negotiations and for reassessing the need for additional regulations of CFCs and other potential ozone-depleting chemicals.

It also set forth a schedule for both domestic and international activities related to stratospheric ozone protection. It committed EPA to sponsoring or participating in a series of workshops, both here and abroad, aimed at developing information that would be used for international negotiations and for domestic rulemaking. Workshops discussing economic issues related to ozone protection involving interested parties from within the United States were held in March and July of 1986. International workshops covering the same topics were sponsored by UNEP and took place in May and July of 1986 in Rome, Italy and Leesburg, Virginia, respectively.

The plan also committed EPA to preparing the risk assessment document mentioned above and to obtaining review of this document by the Agency's Science Advisory Board (SAB). Meetings of a subcommittee of the SAB organized specifically to review this document were held in November 1986 and January 1987. Comments from the public were also solicited (51 FR 40510, November 7, 1986). The document has been revised in response to comments from the panel and the public and is available in the docket at the address given above. The findings of the risk assessment are described in greater detail below, in Section IV.

Finally, the plan also committed EPA to conducting a rulemaking on possible further regulation of CFCs and to actively participating in the UNEP negotiations on an international agreement to limit ozone-depleting chemicals.

C. International Negotiations

The initial round of international negotiations, conducted under the auspices of UNEP, resulted in the Vienna Convention for the Protection of the Ozone Layer, which was signed in March 1985. This agreement promotes global coordination necessary for the protection of the ozone layer by providing for international cooperation in research, monitoring, and information exchange. While the initial negotiations failed to reach agreement on specific obligations limiting ozone-depleting chemicals, the Vienna Convention provides a framework for the continued negotiation and adoption of international regulatory measures necessary to protect the ozone layer.

On December 1, 1986, negotiations resumed on a possible protocol to limit CFCs and other ozone-depleting chemicals. Despite wide differences in initial positions among participating nations, these negotiations resulted ten months later in the adoption of the Montreal Protocol which was signed on September 16, 1987, by 24 nations. Specific provisions of the Protocol are discussed in detail below, and the full text is printed as an addendum to this notice.

III. Statutory Authority

Section 157(b) of the Clean Air Act (42 U.S.C. 7457(b) authorizes the Administrator to issue "regulations for the control of any substance, practice, process, or activity (or any combination thereof) which in his judgment may reasonably be anticipated to affect the stratosphere, especially ozone in the stratosphere, if such effect in the stratosphere may reasonably be anticipated to endanger public health or welfare. Such regulations shall take into account the feasibility and the costs of achieving such control."

Two aspects of this regulatory authority are notable. First, the Administrator is not required to prove that a "substance, practice, process or activity" does in fact deplete stratospheric ozone before he may regulate it. In 1977 when the ozone protection provisions were added to the Clean Air Act, Congress recognized that scientists were not certain whether stratospheric ozone was being depleted and what was causing any depletion that did occur. *See, e.g.*, H.R. Rep. No. 294, 95th Cong., 1st Sess. 98–99 (1977). However, Congress also recognized the potentially serious health and environmental consequences of ozone depletion if it were occurring, and authorized EPA to act in the face of scientific uncertainty to protect against those adverse consequences. *Id.* Thus, the Administrator may regulate on the basis of "his judgment" that the subject of regulation "may be reasonably anticipated" to affect the stratosphere and that the effect "may be reasonably anticipated to endanger public health and welfare."

Second, the Administrator is given broad latitude to choose what and how to regulate. He is not limited to controlling ozone-depleting substances themselves; he may also regulate "any practice, process, activity" that threatens the ozone layer. Nor is he limited to a particular control strategy. Besides an implicit requirement that regulations be efficacious, the statute requires only that they take into account the cost and technological feasibility of achieving the required level of control. In short, EPA has broad latitude to employ the regulatory options it finds appropriate to control threats to stratospheric ozone that in turn threaten public health and welfare.

IV. Risk Assessment

A. Changes in Atmospheric Composition

Measurements of the concentrations of specific gases over the past decade or longer have produced conclusive evidence that human activities are altering the composition of the earth's atmosphere. Table 1 summarizes the recent rate of increase for several gases, along with the period for which measurements are available. Because each of these gases affects the quantity of ozone, past and future changes in their atmospheric levels are a significant element in understanding the risks of ozone depletion.

Table 1 shows that atmospheric levels of CFC–11 and –12 have grown at the rate of 5 percent annually since 1978. CFC–11 is used primarily as a foam-blowing agent and CFC–12 is used primarily as a refrigerant. Outside the United States, in many countries both are also used extensively as aerosol propellants. Atmospheric levels of CFC–113, which is used primarily as a solvent by the electronics and metal cleaning industries, have been increasing at roughly double this rate during the same period. These growth rates reflect both continued emissions of CFCs during this period and the long atmospheric lifetimes of these chemicals.

TABLE 1.—CHANGES IN ATMOSPHERIC CONCENTRATIONS OF OZONE-MODIFYING GASES

	Measured rates of increase		
	Percent per year	Period	Reference
CFC–11 (CCl3F)	5.0	1978–1985	WMO, 1986.
CFC–12 (CCl2F2)	5.0	1978–1985	WMO, 1986.
CFC–113 (C2Cl3F3)	10.0	1975–1983	Rasmussen and Khalil, 1982.
CFC–114 (C2Cl2F4)	(1)	(1)	(1)
CFC–115 (C2ClF5)	(1)	(1)	(1)
Halon-1211 (CBrClF2)	23.0	1979–1984	Khalil and Rasmussen, 1985.
Halon-1301 (CF3Br)	(1)	(1)	(1)
Halon-2402 (C2F4Br2)	(1)	(1)	(1)
Nitrous oxide (N2O)	0.2	1978–1985	WMO, 1986.
Methane (CH4)	1.0	1977–1985	NASA, 1986.
Carbon Dioxide (CO2)	0.5	1958–1985	WMO, 1986.

[1] No data available.

Much less information is available about growth in Halon 1211, 1301 and 2402. These compounds are becoming more widely used primarily in certain specialized firefighting applications. No data is yet available on atmospheric trends of Halon 1301 or 2402, while very limited measurements suggest that atmospheric levels of Halon 1211 grew at 23 percent annually in recent years. In comparison to the CFCs, total levels of these halons remain very small; because they are believed to be extremely efficient depleters of ozone (Prather et al., 1984; WMO, 1986), they are being proposed for inclusion in this regulation. (See below, Section VI.)

Carbon dioxide and methane are also increasing in the atmosphere, though at annual rates much slower than the CFCs. Unlike CFCs and halons, these have the opposite effect on

concentrations of ozone and could potentially offset depletion caused by increases in these other gases. Carbon dioxide emissions result primarily from the burning of fossil fuels. In contrast, the reason that methane levels have increased is not well understood. Moreover, this gas has a much shorter atmospheric lifetime than CFCs (approximately ten years).

Nitrous oxide levels have also been increasing at approximately 0.2 percent annually. Sources of emissions include fossil fuel combustion and fertilizers. In isolation, nitrous oxides release nitrogen in the stratosphere which would act similarly to chlorine and catalytically destroy ozone. However, depending on the relative levels of chlorine and nitrous oxide, the latter can have the net effect of slowing down the rate of depletion by binding chlorine in a relatively inactive state.

B. Changes in Ozone Levels

The extensive measurements of recent growth in atmospheric levels of ozone-modifying gases provide only indirect evidence that human activities may be altering the earth's ozone layer. To more fully analyze these risks, two approaches have been developed. First, direct measurements of the quantity of ozone have been analyzed to determine if any trends are apparent; and second, atmospheric models have been developed that attempt to project future changes in ozone levels based on assumed changes in atmospheric levels of ozone-modifying gases.

1. Direct Measurements of Ozone Levels

Monitoring of ozone levels has been conducted to various degrees using ground-based instruments for several decades. These measurements examine both total column ozone levels and changes in the quantity of ozone at specific altitudes. Since the late 1970s, satellite-based instruments have expanded the ability to measure ozone levels throughout the world.

Based on the information available at the time, the WMO assessment concluded that total column ozone levels had not substantially been altered—that no statistically significant change had occurred. For example, it cites a study by Reinsel (1985) which shows that for the period 1970 to 1983, total column ozone levels had decreased by only 0.003±1.2 percent per decade which does not represent a statistically significant trend.

The WMO assessment also stated that ozone levels in the upper atmosphere (at approximately 40 kilometers) had, in fact, decreased by approximately 0.2 percent to 0.3 percent per year over the period 1970 to 1980. However, increases in ozone levels in the troposphere (i.e., the lower atmosphere) had offset the decreases above resulting in effectively no change in total column ozone.[1]

Both these findings—essentially little or no change in total column ozone and decreases at 40 km—appear consistent with current atmospheric theories and models and are contained in EPA's risk assessment which was used as the basis for this rulemaking. However, preliminary information that has only recently become available raises the question whether total column ozone levels have, in fact, declined in recent years.

2. Preliminary Evidence of Ozone Depletion

a. Seasonal Ozone Losses in Antarctica. In May 1985, an article was published in *Nature* (Farman, Gardiner and Shanklin, 1985) which provided evidence that ozone levels during the months of September to November over Antarctica had declined by approximately 40 percent from the late 1970s. This discovery of the "Antarctic ozone hole" by the British Antarctic Survey team, based on data from a ground-based instrument, was completely unexpected.

Losses of the magnitude observed in Antarctica were not predicted by current atmospheric theories or models. The Antarctic ozone hole thus raises several important questions. Are the losses in ozone caused by CFCs and halons? Are these loss mechanisms unique to the conditions found above Antarctica or do they have implications for ozone levels elsewhere? Could this seasonal ozone loss itself have implications for global ozone concentrations? How, if at all, do our current theories and models need to be altered to reflect this phenomenon? These questions have been the subject of considerable research within the scientific community since the initial article in *Nature* appeared.

In October 1986, a team of researchers traveled to Antarctica to begin the process of collecting data to aid in answering these questions. Preliminary results from the first National Antarctic Ozone Expedition strongly suggest that anomolous chlorine chemistry plays a role in the development of the ozone hole. Team members reported measurements of chlorine monoxide—a key compound in the catalytic cycle by which chlorine destroys ozone—that were 20–50 times greater than observed elsewhere in the atmosphere (Pyle and Farman, 1987). These measurements have recently been substantiated by preliminary data collected during airplane flights over Antarctica during the formation of the ozone hole in 1987 as part of experiments conducted by the NASA, the National Oceanographic and Atmospheric Administration (NOAA), and others.

Many questions must still be answered before plausible changes in theories and models can be made to account for factors responsible for the ozone hole. Researchers still must determine the exact mechanisms or reactions which produce the high levels of chlorine monoxide and they must also determine the role of dynamic (e.g., meteorological forces including temperature, pressures and winds) factors. Most importantly, they still must determine whether these loss mechanisms are unique to Antarctica or may also affect ozone levels elsewhere and whether losses in Antarctica alone could influence global concentrations of ozone. Until a clearer picture emerges, the scientific issues raised by the Antarctic ozone hole cannot yet serve as a guide for policy decisions.

Because of these remaining uncertainties, EPA believes that no adequate basis yet exists for factoring the causes and global implications of the Antarctic ozone hole into its risk assessment and regulatory scheme. The Agency has de facto assumed that the ozone hole is not related to CFCs and halons. Additional measurements from a second expedition to Antarctica, further review of data obtained from the airplane flights through the ozone hole, and related atmospheric modelling studies should become available in the coming year. The Agency intends to closely follow these scientific developments and will modify its risk assessment if new information warrants such changes. It also intends to actively participate in upcoming international scientific assessments that are required in 1989 and every four years thereafter, which are to be used as the basis for determining the need for changes to the terms of the protocol which could occur beginning in 1990. EPA is particularly interested in comments on its treatment of this issue.

[1] Over the long term, increases in ozone in the lower atmosphere cannot continue to offset decreases in the stratosphere without substantial health and environmental damage resulting. Ozone in the lower atmosphere has been linked to respiratory disease in humans and damage to crops and forests and as a result is regulated by EPA under one of its national ambient air quality standards. Moreover, the same gases producing increased ozone in the lower atmosphere are also greenhouse gases and would contribute to substantial increases in global temperatures.

b. Possible Global Losses in Ozone. Recently published data have also called into question the conclusion that *global* total column ozone levels have not decreased (Kerr, 1987). Ground-based measurements of total column ozone now suggest that a 3 percent to 5 percent decrease has occurred over the past six years. Decreases of a similar magnitude over roughly the same period have been reported based on a preliminary assessment of data from the Nimbus-7 satellite (Kerr, 1987). Because of the complexities in interpreting satellite data (e.g., calibration, instrument drift and other corrections), this data is currently undergoing further scrutiny.

As was the case with the Antarctic ozone hole, global ozone losses of this magnitude appear to fall outside the bounds of what would be expected from current theories and models. If they are confirmed by further review of the evidence, several important questions would be raised. Are these losses in excess of historic variation or are they due to natural causes (e.g. the solar cycle, volcanic activity, etc.)? Are they related to increases in atmospheric levels of CFCs and halons? What, if anything, must be changed in current models to account for such losses?

A thorough review of this data to resolve these important uncertainties has recently been initiated by scientists at NASA and NOAA. Pending the outcome of this assessment, EPA does not believe that this preliminary evidence has yet been adequately reviewed and analyzed by the scientific community to allow for it to be used in its risk assessment or regulatory decisions. Once the on-going review is completed, if new information becomes available and previously unresolved issues are successfully addressed, then EPA will modify its risk assessment to reflect this improved understanding of recent trends in ozone. This information will also be examined in the context of the upcoming international scientific and policy reviews under the terms of the Protocol. EPA specifically requests comments on the appropriate means of factoring new scientific evidence into its risk assessment and future policy decisions.

3. Role of Atmospheric Models in Predicting Future Ozone Levels

While direct measurements provide useful information concerning past changes in ozone levels, atmospheric models are the only available tool for predicting possible future trends in ozone. These models, in more or less detail, attempt to replicate the forces which determine ozone concentrations. For example, current models include approximately 50 chemical species found in the atmosphere and simulate over 140 different reactions among these chemicals which directly or indirectly affect ozone abundance.

From EPA's perspective in evaluating risks, a key question is to what degree these models can accurately predict future ozone changes. As stated above, current models do not predict the Antarctic ozone hole and suggest that global ozone levels should not have yet declined by even one percent based on the historic use of CFCs and halons, and changes in other trace gases. Furthermore, current models fail to accurately project the abundance of all chemical species at all altitudes, thereby lowering our confidence in their predictive powers.

Despite these shortcomings, both the EPA and WMO risk assessments concluded that atmospheric models represent the best available tools for evaluating future trends in ozone levels. These studies show that, when tested against the current make-up of the atmosphere, the existing atmospheric models do a reasonably good job of replicating most key atmospheric constituents. Thus, the models accurately predict many, though certainly not all, of the key chemical constituents which affect the creation and destruction of ozone. While model accuracy will inevitably improve over time, EPA has relied on current versions in assessing the risks of future ozone depletion.

4. Future Trends in Ozone Levels: Assuming No Further Regulation of CFCs or Halons

In utilizing models to predict future ozone trends, the rate of growth of ozone-modifying gases is a key variable. As part of the Regulatory Impact Analysis (RIA) prepared in support of this proposal, EPA examined the risks of ozone depletion from continued use of CFCs, halons and other relevant trace gases. The assumptions underlying this analysis are detailed in Chapter 4 of the RIA and are summarized here.

EPA conducted extensive studies analyzing possible future rates of growth for CFCs and halons in the absence of additional regulations. (See for example: Hammitt et al. (Rand), 1986; Nordhaus and Yohe, 1986; and Gibbs et al. (ICF), 1986.) This issue was also the subject of both EPA and UNEP sponsored workshops in 1986. Based on this review, EPA believes that strong market demand exists for CFC products in many sectors of the economy, both in the United States and abroad, and that in the absence of regulation, use of CFC-11, -12, and -113 would increase. In the RIA, a middle estimate of growth in trace gas emissions was developed. For CFC-11 and CFC-12, the middle estimate implies an average annual growth rate of approximately 2.7 percent, which reflects a 2.5 percent annual growth rate for the developed world, and slightly higher projected growth in the developing world and in the Soviet Union. The middle scenario includes an average annual growth rate of 2.9 percent for CFC-113, 2.6 percent for CFC-114, and 2.6 percent for CFC-115.

Recent studies by Industrial Economics, Inc. (1987), with the cooperation of an ad hoc technical committee representing halon producers and users, provided the basis for estimates of future growth in production of Halon 1211 and 1301, which are assumed to grow at average annual rates of 4.3 and 2.7 percent. Because Halon 2402 is only used in minor applications in the United States, this chemical was omitted from the analysis.

Table 2 shows the range of growth rates assumed for these chemicals. This range of estimates reflect the many factors (e.g., economic and population growth, technological innovation, etc.) which influence projections over this period of time. It also shows the growth rates assumed for carbon dioxide, methane and nitrous oxide which were based on past measurements showing increases for each of these gases. Based on a simplified one-dimensional model of the combined effects of these gases, Table 2 indicates the projected ozone depletion for each of these scenarios. Thus, in the case which represents the mid-range estimate of future trends in emissions of trace gases, projected total column ozone would decline by 3.9 percent by 2025 and by 39.9 percent by 2075. In the case where CFC use only grows by approximately 1.2 percent annually, projected ozone depletion by 2075 would reach 7.0 percent. In the case where CFC use grows at approximately 3.8 percent per year, projected ozone depletion by 2075 would exceed 50 percent.

TABLE 2

(Percent total column depletion)

Year	Low CFC growth	Medium CFC growth	High CFC growth
Projected Future Ozone Depletion in the Absence of Regulation			
1985	0.00	0.00	0.0
1990	0.27	0.27	0.2
2000	0.76	0.88	1.0
2010	1.25	1.71	2.3
2020	1.87	3.00	4.7
2030	2.56	4.86	9.1

TABLE 2—Continued

[Percent total column depletion]

Year	Low CFC growth	Medium CFC growth	High CFC growth
2040	3.33	7.66	18.86
2050	4.32	12.32	>50
2060	5.40	20.27	>50
2070	6.47	32.48	>50
2075	7.06	39.90	>50

Estimates from statistical model developed by Connell (1986) and discussed in EPA Risk Assessment (1987).

CFC and Halon Scenarios

Average implied annual rates of growth (percent)

	1985–2000	2000–2050	Post-2050
Low Scenario			
CFC-11, 12, 114, 115	2.1	1.3	Constant
CFC-113	2.1	1.3	Constant
Halon-1211	5.5	1.5	Constant
Halon-1301	−0.5	1.6	Constant
Medium Scenario			
CFC-11, 12, 114, 115	3.6	2.5	Constant
CFC-113	4.0	2.5	Constant
Halon-1211	8.8	2.9	Constant
Halon-1301	1.1	3.2	Constant
High Scenario			
CFC-11, 12, 114, 115	5.2	3.8	Constant
CFC-113	6.1	3.8	Constant
Halon-1211	12.0	4.4	Constant
Halon-1301	2.0	4.7	Constant

Other Trace Gas Scenarios

Carbon Dioxide

50th percentile scenario from the National Academy of Sciences is used (implied annual growth in atmospheric concentrations of 0.7 percent from 1985 to 2165).

Methane

Annual growth of 0.017 parts per million in atmospheric concentrations.

Nitrous Oxide

Annual growth of 0.2 percent in atmospheric concentrations.

The ozone depletion estimates in Table 2 are based on a parameterization (i.e., a statistical simplification) of a one-dimensional model developed by Lawrence Livermore National Laboratory. A recent comparison of the results of this model with one-dimensional models conducted under the auspices of UNEP showed that this parameterization produced depletion estimates that were somewhat lower than those projected by other models for the same trace gas scenarios. (UNEP, 1987).

While this parameterization provides a reasonable representation of a one-dimensional model (Connell, 1986), by design it provides only a globally averaged estimate of depletion. More sophisticated two-dimensional models have recently been developed which provide estimates of ozone depletion by latitude. Since health and environmental effects will vary by latitude, these more detailed models would be more appropriate for calculating the impacts of depletion. However, because these models are expensive and time-consuming to use, they are of limited utility for examining a wide range of scenarios as required in EPA's risk assessment. In addition, different two-dimensional models differ substantially in the degree to which depletion varies with latitude. As a result of these limitations, EPA's estimates of risks rely only on the previously mentioned one-dimensional parameterization.

A comparison of these different models was conducted by EPA as part of its risk assessment (See Chapter 5). It showed that two-dimensional models predict greater average depletion than one-dimensional models for the same trace gas scenarios. For example, one two-dimensional model (developed by Sze) projects an 18 percent depletion compared to a 15 percent depletion for exactly the same scenario for a one-dimensional model. Two-dimensional models also generally project depletion higher than global averages at latitudes greater than 40 degree North or South, especially in the spring.

5. Effects of Ozone Depletion on Human Health and the Environment

Any decrease in total column ozone would lead to increased penetration of damaging ultraviolet radiation to the earth's surface. Under current atmospheric conditions, the ozone layer blocks most of the UV-B part of the ultraviolet spectrum with the amount screened out increasing with latitude. This current gradient in exposure provides a useful natural experiment demonstrating the effects of different exposure to UV-B radiation.

The health and environmental effects of ozone depletion are briefly described below; for a fuller explanation see Chapter 7 of the RIA and Chapters 7 to 16 of the EPA's risk assessment. EPA has attempted to quantify each effect, but insufficient data has made quantifying some effects impossible. Estimates are also uncertain because of possible changes in future technologies. Additional research to better understand UV-B effects is warranted. However, EPA has taken account of all possible ozone depletion effects in assessing the need for controls.

a. *Increased Incidence of Nonmelanoma Skin Cancers.* Laboratory studies and epidemiological evidence show a strong link between exposure to UV-B radiation and increased incidence of basal and squamous nonmelanoma skin cancers. (See Chapter 7 of EPA's risk assessment.) Several lines of evidence support this relationship: (1) Nonmelanoma skin cancers tend to develop in sun-exposed sites; (2) outdoor workers have higher incidence rates; (3) incidence rates are higher closer to the equator (correcting for differences in skin pigmentation); and individuals genetically susceptible to sunburn have a higher incidence of skin cancers.

Several researchers have correlated UV-B measurements with nonmelanoma skin cancer incidence data. Results from six studies show that a 1 percent depletion of total column ozone would lead to an increase in nonmelanoma skin cancer incidence of 4.8 percent to 7.6 percent.

Based on the expected growth in trace gas emissions for the middle scenario presented in Table 2, the resulting ozone depletion would lead to an increase in incidence of approximately 153 million nonmelanoma skin cancer cases among the United States population alive today and born by the year 2075. Based on current fatality rates from basal and squamous skin cancers, this increase in incidence could be expected to lead to an increase of 3.0 million deaths of people born during this same time period. Given the uncertainties associated with the appropriate dose-response relationship, this projection could fall within the range of 1.5 million to 4.5 million deaths.

b. *Increased Incidence of Melanoma Skin Cancer.* While the current incidence of melanoma skin cancer cases is small compared to nonmelanoma cases, the fatality rate is much higher. While no animal model and in vitro experimental evidence exists explaining the exact relationship between melanoma and UV-B radiation, based on the preponderance of evidence, EPA's risk assessment concluded that increased UV-B exposure would increase the incidence of melanoma. Evidence in support of this conclusion includes: (1) Lighter skinned individuals, whose skin has less protective melanin, have higher melonoma incidence rates than darker skinned individuals; (2) early childhood exposure to sunlight appears to be linked to higher incidence rates; and (3) individuals genetically incapable of repairing sunlight-induced damage to cells have a higher rate of incidence.

Based on a range of estimates for uncertain factors, EPA's risk assessment developed a dose-response relationship which suggests that for every 1 percent increase in ozone depletion, the incidence of melanoma would increase by slightly less than 1 percent to 2 percent and the number of fatalities from melanoma would increase by 0.8 percent to 1.5 percent.

Based on the trace gas scenario which assumed a 2.7 percent average annual

growth in CFCs, and the resulting ozone depletion shown in Table 2, the number of melanoma cases in the United States would increase by 782,100 and the number of fatalities would increase by 187,000 for the population alive today and born by the year 2075. Given the uncertainties associated with the dose-response relationship, the number of deaths could fall within a range of 93,500 to 280,000.

c. *Increased Incidence of Cataracts.* UV-B radiation has been found to play a significant role in the formation of cataracts. Supporting evidence include animal laboratory studies and epidemiological studies. Based on the available research, a dose-response relationship was developed in EPA's risk assessment (See Chapter 10). Assuming trace gas trends and the resulting ozone depletion for the middle scenario described in Table 2, the number of cases of cataracts would increase by 18.2 million for the population in the United States alive today or born through 2075.

d. *Suppression of the Immune System.* Experimental studies show a suppression of the immune response system associated with exposure to UV-B radiation. Current research does not explain the exact mechanism by which the immune system is altered or the potential implications for a wide range of diseases. Limited studies do suggest, however, that UV-B induced suppression may increase the frequency of outbreak of herpes simplex virus and leishmaniasis (i.e., a skin disorder common in the tropics). No quantitative estimates of the potential harm related to immune suppression on these or other possible diseases are at this time possible.

e. *Damages to Plants.* Limited studies have shown that plants exposed to increased levels of UV-B radiation can be harmed. Initial studies showed a substantial vulnerability to UV-B exposure across a wide range of plants. However, these studies were conducted in laboratories or greenhouses and their results have not been replicated under field conditions where photorepair mechanisms may offset damage.

The only long-term controlled field study involves soy beans. This study found that enhanced levels of UV-B radiation simulating a 16 and 25 percent ozone depletion caused reductions in crop yield of up to 25 percent in the tested cultivar. Substantially smaller changes occurred in years when drought conditions also greatly reduced crop yields of the plants grown under naturally occurring conditions (i.e., the control plants). Because a wide range of crops have tested sensitive to increased exposure to UV-B radiation, but have not yet been tested under field conditions, the dose response relationship developed from the field tests of soy beans was used as the basis for estimating impacts on major grain crops in the RIA.

f. *Damage to Aquatic Organisms.* While studies to date have been limited in scope, it appears that increased exposure to UV-B radiation could adversely affect aquatic organisms and potentially disrupt the aquatic food chain. For example, studies suggest that phytoplankton remain close to the water's surface to facilitate photosynthesis. As a result, they would be susceptible to damage from increased UV-B radiation. Similarly, the larvae stage of many fish live at or near the water's surface and would also be susceptible to damage if ozone depletion occurs. A case study showed that a 10 percent ozone depletion would lead to a 6 percent loss in the larval anchovy population. Because a wide range of aquatic organisms have shown a sensitivity to increased exposure to UV-B radiation, but insufficient data exists for developing specific dose-response relationships, the case study examining the effects on anchovy larvae was used as the basis for estimating impacts on a limited group of shellfish and fin fish in the RIA.

g. *Accelerated Weathering of Outdoor Plastics.* Plastics exposed to the outdoor environment under current ultraviolet conditions contain light stabilizers or other additives to reduce damage from chalking, yellowing or brittleness. If UV-B radiation increases, damages would increase or greater expense would be incurred in protecting against the damages from such exposure. A relationship was developed between UV-B exposure and damage to outdoor products made of polyvinyl chloride and incorporated in the analysis presented in the RIA.

h. *Increased Formation of Groundlevel Ozone.* Preliminary studies have assessed the impact of increasedUV-B penetration on the photochemical reactions responsible for the creation of groundlevel ozone. These case studies suggest that groundlevel ozone would form earlier in the day and nearer to population centers, thus exposing more people to its harmful effects. Total amounts of groundlevel ozone would also increase. While substantial harm to human health and welfare could result from increased groundlevel ozone, because of limited data, only the impacts on crop loss were included in the RIA.

i. *Climate Related Impacts Due to Increases in Ozone-Modifying Gases.* CFCs and other gases that modify stratospheric ozone are also greenhouse gases and therefore contribute to concern about future global warming. Based on the rate of growth in trace gases assumed in the middle scenario presented in Table 2, by 2075 a global equilibrium temperature (i.e., the earth's temperature at the time when incoming energy is balanced against outgoing energy) increase of 5.8 degrees centigrade (10.4 degrees Fahrenheit) could be anticipated. Based on earlier reports by the National Academy of Sciences (1983), these estimates could be 50 percent higher or lower to reflect current uncertainties in climate model predictions. This temperature increase could be expected to affect water resources, agricultural productivity, forests, and endangered species. However, because of the difficulty in quantifying these effects, the RIA does not assess the extent of potential harm related directly to climate change.

One possible indirect effect of climate change is increased sea level rise. Based on current models and the trace gas scenario described above, the projected global warming could increase global sea level by 97.8 centimeters by 2075. However, because of the difficulty in quantifying impacts related to sea level rise, the analysis in the RIA is limited to extrapolation of several case studies quantifying damage from sea level rise to major port areas in the United States.

6. Conclusion

Based on the WMO assessment and EPA's recently completed risk assessment, the Agency believes that the current rate of growth in atmospheric levels of ozone-depleting gases is likely to result in substantial depletion of ozone which would lead to significant harm to human health and the environment. While many uncertainties exist and only limited studies are available in several of the areas of potential harm, the current evidence presents a strong case for action to substantially reduce current levels of use of the most potent ozone-depleting chemicals. A comparison of the potential costs of limiting CFCs and halons to the potential health and environmental benefits is presented below in Section VII.

V. The Montreal Protocol

The Montreal Protocol is a comprehensive agreement for dealing with the threat of stratospheric ozone depletion by man-made chemicals. It has three key components. First, it requires parties to significantly reduce their production and consumption of

certain ozone-depleting substances over the next decade. Second, it provides for revision of the reduction requirements based on scheduled, periodic assessments of available scientific, environmental, technical and economic information. Third, it imposes restrictions on trade in ozone-depleting products with nonparties to minimize nonparties' potential to deplete stratospheric ozone and to encourage nations to become parties. Each of these components is described in greater detail below.

The Montreal Protocol will take effect ("enter into force") on January 1, 1989, provided that at least 11 instruments ratifying the Protocol have been deposited by States or regional economic integration organizations representing at least two-thirds of 1986 estimated global consumption of the covered substances, and that the Vienna Convention for the Protection of the Ozone Layer has entered into force. If these conditions have not been fulfilled by January 1, 1989, the Protocol will enter into force on the 90th day following the date on which the conditions have been fulfilled.

The Vienna Convention has so far been ratified by 14 nations, including the United States, as noted above. Twenty instruments of ratifications are required for its entry into force. The Department of State and the White House are currently in the process of requesting from the Senate its advice and consent to ratification of the Protocol, so that the President may ratify it on behalf of the United States.

A. Control Provisions

1. The Chemicals Covered

The Protocol identifies in Annex A two groups of ozone-depleting substances for control "controlled substances"). Group I includes CFC-11, -12, -113, -114, and -115. These chemical compounds are fully halogenated and therefore are strong potential ozone-depleters that are either widely used or potential substitutes for those chemicals which are now widely used.

Group II includes Halon 1211, 1301 and 2402. Because they contain bromine, these chemicals are even stronger potential ozone-depleters than the chemicals in Group I. However, they are currently emitted in small quantities relative to CFCs, substantial uncertainties exist as to their exact ozone depletion weights, and recent evidence suggests that their ozone-depleting potential may substantially depend on atmospheric chlorine concentrations.

The Protocol's coverage extends only to the specified chemicals in bulk form. Its definition of controlled substances excludes chemicals which are in manufactured products other than a container used for the transportation or storage of the chemicals. EPA is seeking comment on the implications of using this definition of controlled substances.

2. "Calculated Levels"

The Montreal Protocol does not place limits on each of the controlled substances. Instead, it places separate limits on the total ozone depletion potential of Group I and Group II controlled substances that a party produces and consumes. A party may consequently produce and consume any mix of the controlled substances within each of the Groups, so long as the total ozone depletion potential of the mix does not exceed the specified limits.

For purposes of calculating total ozone depletion potentials, the Protocol lists in Annex A the "ozone depleting potential" of all but one of the controlled substances. In the case of Halon 2402, it provides that the ozone depleting potential is "to be determined." More generally, it notes that the ozone depleting potentials "are estimates based on existing knowledge and will be reviewed and revised periodically," as provided under Article II, paragraph 9.

The Protocol uses the phrase "calculated levels" to refer to this weighting of controlled substances based on their relative ozone-depleting potentials. It provides under Article 3 that calculated levels be determined for each Group of controlled substances by multiplying the amount of emissions (in kilograms) of each controlled substance within that Group by the ozone depleting potential specified for it in Annex A, and adding together the resulting products.

3. Production and Consumption Limits

Just as the Protocol does not place limits on each controlled substance, it does not place limits on particular uses (e.g. aerosols, refrigeration) of the controlled substances. Instead, the Protocol limits each party's total production and consumption of Group I (CFCs) and Group II (halons) controlled substances for specified 12-month periods. It leaves up to each party how to stay within those limits.

Article 1 of the protocol defines production as "the amount of controlled substances produced minus the amount destroyed by technologies to be approved by the Parties." It defines consumption as "production plus imports minus exports of controlled substances." However, Article 3 provides that after January 1, 1993, any export of controlled substances to non-parties may not be subtracted in calculating the consumption level of the exporting party.

4. Timing and Magnitude of Limits

The limits imposed by the Protocol are generally defined in terms of 12-month periods and keyed to calculated levels of 1986 production and consumption. The year 1986 was chosen as the baseline for controls so that nations did not have an incentive to increase their production and consumption during 1987, when the protocol was being negotiated, in order to establish higher baselines.

a. *Group I controlled substances.* For Group I controlled substances, Article 2 of the Protocol requires each party to reduce in three steps the calculated level of its production and consumption of those substances.

For the first step, paragraph 1 of Article requires that if the Protocol enters into force on January 1, 1989, each party must limit its calculated levels of consumption and production to 1986 levels in the 12-month period commencing July 1, 1989, and in each 12-month period thereafter. If the Protocol enters into force on a later date, each party must meet that limit in the 12 month period commencing on the first day of the seventh month following the date of entry into force of the Protocol, and in each 12-month period thereafter.

However, the Protocol permits each party to increase its production in each of the relevant control periods by up to 10 percent of its calculated level of 1986 production, provided that the increased production is used for one or both of two purposes. One purpose is to satisfy the "basic domestic needs" of developing countries operating under Article 5 of the Protocol. That Article allows developing countries who are parties to the Protocol and whose annual calculated level of consumption of both Group I and Group II controlled substances is less than 0.3 kilograms per capita on the date it becomes a party to the Protocol, to delay its compliance with the Protocol's control provisions by ten years after that specified in those provisions, so long as its per capita consumption does not exceed 0.3 kilograms.

With Article 5, the drafters of Protocol sought to fairly accommodate the "special situation" of developing countries whose 1986 consumption of the controlled substances was low relative to that of developed countries. By allowing developing countries to increase their consumption somewhat

and by allowing parties to increase their production to supply the developing countries, the drafters hoped to encourage developing countries to join the Protocol and make it unnecessary for them to build or expand any capacity for producing controlled substances in order to supply for a limited period of time their growing domestic needs.

The second justification for the parties to increase their production by up to 10 percent of 1986 levels is "for the purposes of industrial rationalization between Parties." Article 1 of the Protocol defines industrial rationalization as "the transfer of all or a portion of the calculated level of production of one Party to another, for the purpose of achieving economic efficiences or responding to anticipated shortfalls in supply as a result of plant closures."

For the second reduction step, paragraph 3 requires each party to limit the calculated level of its production and consumption in the period from July 1, 1993, to June 30, 1994, and in each 12-month period thereafter, to 80 percent of the calculated level of its 1986 production and consumption. Notably, the second reduction step takes effect beginning July 1, 1993, regardless of when the Protocol enters into force, so long as the Protocol has entered into force by that date. As in the case of the first step, each party may exceed its production limit in each control period by up to 10 percent of its 1986 production level, provided the production over the limit is used for one or both of the same two purposes described above.

Finally, for the third reduction step, paragraph 4 requires each party to limit the calculated level of its production and consumption in the period from July 1, 1998, to June 30, 1999, and in each 12-month period thereafter, to 50 percent of its calculated level of 1986 production and consumption. Each party is allowed to exceed its production limit by up to 15 percent of its calculated level of 1986 production, provided the production in excess of the limit is used for one or both of the purposes described above. The third reduction step will automatically take effect beginning July 1, 1998, so long as the Protocol enters into force anytime before July 1, 1998, and unless decided otherwise by a two-thirds majority of the parties present and voting, representing at least two-thirds of parties' total combined calculated level of consumption.

Paragraph 5 of Article 2 provides in limited circumstances for further increases in production of Group I controlled substances during any of the control periods discussed above. That paragraph permits parties to exceed the production limits set out in paragraphs 1 through 4 to the extent they receive, for the purposes of industrial rationalization, transfers of production from parties whose calculated level of 1986 production of Group I controlled substances was less than 25 kilotonnes. However, the total combined calculated levels of production of the parties involved in such a transfer of production may not exceed the production limits set out in Article 2. In addition, the secretariat of the Protocol must be notified of any such transfer.

b. *Group II controlled substances.* For Group II controlled substances, paragraph 2 of Article 2 requires that each party limit the calculated level of its production and consumption of those substances to the calculated level of its 1986 production and consumption of the same. Parties must meet that limit in the 12-month period commencing on the first day of the 37th month following the date on which the Protocol enters into force (January 1, 1992, if the Protocol enters into force on January 1, 1989), and in each 12-month period thereafter. However, each party may increase its production of Group II controlled substances in each control period by up to 10 percent of the calculated level of its 1986 production of those substances, provided that the increased production is used for the same purposes for which increased production of Group I controlled substances is allowed (i.e., supplying developing countries and for the purposes of industrial rationalization).

Article 2 of the Protocol includes several other paragraphs applicable only to particular parties other than the United States (e.g., paragraph 6 and 8). Consequently, those paragraphs will not be summarized here nor implemented by today's proposed rule.

B. Review and Revision Provisions

Built into the Protocol are mechanisms for revising its requirements in response to the latest information on stratospheric ozone depletion and its consequences. Article 6 requires the parties, beginning in 1990, and at least every four years thereafter, to assess the control measures set forth in Article 2 on the basis of available scientific, environmental, technical and economic information. It further provides for panels of experts in the relevant fields to issue reports on such information one year prior to each assessment.

Paragraph 10 of Article 2 permits the parties to change the coverage of the Protocol by revising the list of chemicals included in Group I or Group II of controlled substances, based on the periodic assessments required by Article 6. Should the parties add chemicals to either Group, paragraph 10 also permits the parties to decide on the mechanism, scope and timing of control measures that should apply to those substances. Decisions under paragraph 10 become effective when accepted by a two-thirds majority vote of the parties present and voting.

Paragraph 9 of Article 2 allows parties to adjust the ozone depleting potentials specified in Annex A and the control measures specified in Article 2, based on Article 6 assessments. Paragraph 9 provides that the parties first attempt to attempt to reach consensus on the need for any adjustment; otherwise decisions to make any adjustment must be adopted by a two-thirds majority vote of the parties present and voting representing at least fifty percent of the total consumption of the controlled substances of the parties.

C. Trade Provisions

Article 4 of the Protocol requires parties to impose specified restrictions on trade of ozone-depleting products with nonparties. The purpose of the trade restrictions is to reduce the potential of nonparties to adversely affect the ozone layer and to induce nonparties to join, or at least comply with, the Protocol.

Pursuant to paragraph 1 of Article 4, each party must ban the import of controlled substances from nonparties within one year of the Protocol's entry into force. Under paragraph 2, within three years of the Protocol's entry into force, the parties are to develop a list of products containing controlled substances (e.g., refrigerators, air conditioners); and within one year of the list having become effective, parties not objecting to the list are to ban imports of the listed products from nonparties. Under paragraph 4, within five years of the Protocol's entry into force, the parties shall determine the feasibility of banning or restricting products made with, but not containing, controlled substances (e.g., electronic equipment) and, if feasible, develop a list of such products; and within one year of the list having become effective, parties not objecting to the list are to ban imports of the listed products from nonparties.

Paragraph 5 calls on parties to "discourage" the export to nonparties of technology for producing and utilizing controlled substances. In a similar vein, paragraph 6 requires parties to "refrain" from providing new financial help for the export to nonparties of anything that would facilitate the production of controlled substances.

Article 4 also provides for several exemptions from the trade restrictions. Paragraph 7 provides that paragraphs 5 and 6 will not apply to products, equipment, plants or technology that contribute to the reduction of emission of controlled substances; and paragraph 8 exempts from the restrictions of paragraphs 1, 3 and 4 those nations that do not join, but are found to be in compliance with, the Protocol.

D. Other provisions

As for its implementation, the Protocol establishes requirements for parties to report relevant data (Article 7); an accompanying conference resolution calls for UNEP to convene a meeting of government experts to recommend to the parties measure for harmonizing and coordinating data on production, imports and exports of controlled substances. The Protocol also requires the parties at their first meeting to develop enforcement mechanisms and penalties for non-compliance (Article 8).

To ease compliance, the Protocol calls for the parties to cooperate in the research, development and exchange of information on emissions reduction technologies, substitutes for ozone-depleting products, and control strategies (Article 9). It also urges parties to lend one another, and particularly developing countries, technical assistance to facilitate participation in and implementation of the Protocol (Article 10).

VI. Proposed Action

A. Scope and Stringency

EPA proposes to implement the Montreal Protocol, provided that it enters into force and the United States ratifies it. Based on its assessment of the available evidence, EPA believes that the Protocol's requirements are an appropriate response to the potential ozone depletion problem at this time. Moreover, given that potential ozone depletion is a global problem requiring a global response, EPA believes that the Protocol is the most effective means of addressing the problem. For these reasons, EPA believes that implementation of the Protocol would best protect public health and welfare from the adverse effects of any ozone depletion.

The Protocol may be amended in ways that could significantly affect the stringency of the control regime it prescribes. For example, the Protocol provides explicitly that the fifty percent reductions in consumption and production required by Article 2, Paragraph 4, will not come into effect if the Parties by a two-thirds majority vote otherwise. In the event that any such amendment is adopted by the parties, EPA intends to conduct rulemaking to consider the effect the changes should have on the control regime prescribed by these regulations.

1. Basis for control requirements

EPA's assessment of the risks of ozone depletion indicates that the Protocol's control requirements are an appropriate response, particularly considering that the Protocol permits revisions of the requirements as new information warrants.

The chemicals covered by the Protocol are those which currently pose the greatest threat to stratospheric ozone. Moreover, the Protocol's different treatment of CFCs and halons reasonably reflects differences in what is known about the ozone depletion potential of the two classes of chemicals and the volume of their respective emissions.

The extent to which a chemical will contribute to ozone depletion depends on its chlorine and bromine content and its atmospheric lifetime. Table 3 lists these characteristics for those compounds considered for coverage. It illustrates that the chemicals in Group II (halons) have greater ozone depletion potentials than the chemicals in Group I (CFCs), and that Group I chemicals have greater ozone depletion potentials than CFC-22 and methyl chloroform. It also shows that carbon tetrachloride (CCl_4) is a stronger potential ozone-depleter than several of the chemicals included in Group I.

TABLE 3.—RELATIVE OZONE-DEPLETING POTENTIAL OF CHEMICAL COMPOUNDS

Compound	Lifetime (years)	Ozone-depleting potential [1] (mass basis)
CFC-11	75	1.0
CFC-12	111	1.0
CFC-113	90	0.8
CFC-114	185	1.0
CFC-115	380	0.6
Halon-1211	25	3.0
Halon-1301	110	10.0
Halon-2402	([2])	6.0
HCFC-22	20	0.05
Methyl Chloroform	6.5	0.1
CCl_4	50	1.06

[1] Measured relative to CFC-11 which is set to 1.0. Values reported on a mass basis (i.e. per kilogram).

[2] Not reported.

Sources: Lifetime estimates are based on WMO (1986), and are summarized in EPA Risk Assessment, 1987, and EPA Regulatory Impact Analysis, 1987. Ozone depletion potentials for CFC-11, -12, -113, -114, -115, Halon-1211 and 1301, methyl chloroform, and CCl_4 approximate those estimated by the Lawrence Livermore National Laboratory one-dimensional atmospheric model (Connell, personal communication). Ozone depletion potential for Halon-2402 reported at negotiations for *Montreal Protocol on Substances that Affect the Ozone Layer* (Bakken, personal communication). Values for CFC-11, -12, -113, -114, -115, and Halon 1211 and 1301 are listed in Annex A of the Montreal Protocol. These values are preliminary estimates based on currently available research and are likely to change over time as new information becomes available.

HCFC-22 and methyl chloroform are appropriately excluded from coverage for several reasons. First, as Table 3 shows, they are substantially less harmful to the atmosphere than the other chemicals considered for coverage. Second, they have short atmospheric lifetimes, so their future atmospheric concentrations can be more quickly reduced by emission limits if such reductions are determined to be necessary in the future. Third, both chemicals are potential substitutes for some of the more potent ozone-depleting chemicals covered by the Protocol.

In contrast, carbon tetrachloride is a relatively strong potential ozone-depleter, but its small volume of emissions makes it reasonable to exclude. Most carbon tetrachloride is consumed as a feedstock to producing CFCs and relatively little is emitted into the atmosphere.

CFC-114 and CFC-115 are reasonably included despite currently minor production levels because they are fully halogenated CFCs and therefore have long atmospheric lifetimes and are relatively strong potential ozone-depleters. Furthermore, if they were not covered, they could be substituted in some uses for the covered CFCs. If such substitutions were to occur, the risk of ozone depletion would not be substantially reduced. [2]

[2] It should be noted that CFC-115 can be used in a blend with HCFC-22 in several commercial refrigeration applications. While any such use of CFC-115 would be covered by the Protocol's control requirements, shifting from CFC-12 to this blend would substantially reduce the overall ozone-depleting potential of the chemicals used. Since this reduction in ozone depletion would occur without substantially altering product prices, industry may continue this trend as one means of reducing risks from ozone depletion.

Table 3 also highlights the substantial concern with Halon 1211, 1301 and 2402 as potential ozone-depleters. Because bromine remains in a chemically reactive state in the stratosphere, it is an extremely effective catalyst contributing to ozone depletion. However, while general agreement exists that the halons are, kilogram for kilogram, more potent ozone-depleters than CFCs, substantial uncertainties exist regarding their ozone-depletion potential. As a result, the ozone depletion weights provided in Table 3 and Annex A of the Protocol, particularly in the case of the halons, should be viewed as preliminary, and are likely to change as more information becomes available.

EPA examined the effect on future ozone depletion based on projections from a simplified one-dimensional atmospheric model. For a baseline case where CFCs are reduced by 50 percent over ten years, if the halons were allowed to continue to grow at expected rates, depletion of 3.2 percent would occur by 2075. By freezing halon production at current levels, the level of predicted ozone depletion would be reduced to 1.3 percent by 2075.

EPA's risk assessment also indicates that the Protocol's reduction requirements would substantially reduce potential depletion and thus the adverse health and welfare effects of depletion. As shown earlier in Table 2, based on model projections, continued trends in worldwide use of CFCs in the absence of regulation could result in substantial ozone depletion sometime during the early part of the next century.

The extent to which limits on CFC and halon production and consumption could reduce estimated ozone depletion is dependent, in part, on future trends in other trace gases, the extent to which other nations also reduce their consumption and production of ozone-depleting chemicals, and the ability of current models to predict future changes in ozone levels. The assumptions underlying this analysis are explained in detail in the RIA accompanying this rulemaking.

Several different levels of emission reductions and their effects on ozone depletion are presented in Table 4. These estimates are compared to the base case (no regulation) shown earlier in Table 2. They indicate that international action to freeze CFCs at 1986 levels alone would substantially reduce depletion compared to the base case, but would still result in approximately 6 percent depletion by 2075. In contrast, model projections indicate that the reductions required by the Montreal Protocol and the anticipated participation by most developed and developing nations, would result in less than 2 percent depletion by 2075. If the United States were to take additional steps beyond the 50 percent reduction required by the Protocol and reduce its CFC consumption by 80 percent, depletion would only be reduced by an additional 0.1 percent.

TABLE 4.—OZONE DEPLETION LEVELS FOR ALTERNATIVE REDUCTION OPTIONS

[Percent depletion of total column ozone]

Case	2000	2025	2050	2075
1 No controls	0.9	3.9	12.4	39.9
2 CFC freeze	0.6	2.3	4.3	6.2
3 CFC 20%	0.8	1.9	3.4	5.0
4 CFC 50%	0.6	1.5	2.3	3.2
5 CFC 80%	0.6	1.2	1.6	2.2
6 CFC 50%/Halon freeze	0.8	1.3	1.6	1.3
7 CFC 50%/Halon freeze/U.S. 80%	0.6	1.2	1.4	1.2
8 U.S. only/CFC 50%	0.8	3.1	8.5	20.4

Source: Cases 1–6 assume specified reductions are taken on the timetable specified in the Montreal Protocol and that 94 percent of the non-U.S. developed world and 65 percent of the developing world participate in making these reductions. Case 7 assumes that the U.S. takes unilateral action. A more detailed discussion of assumptions is included in Chapter 5 of the RIA.

Given the many variables and uncertainties involved in predicting ozone depletion far into the future, the Protocol's control requirements achieve a reasonable degree of risk reduction. Moreover, the Protocol includes review and revision mechanisms for obtaining more or less risk reduction as advances in modelling capability, new data, or other relevant developments warrant.

The Protocol's trade provisions are also a reasonable means of reducing the risk of stratospheric ozone depletion. As model projections indicate, broad observance of the Protocol is needed to effectively protect stratospheric ozone, and nations that neither joined nor complied with the Protocol would endanger the ozone layer. Implementation of the Protocol's trade restrictions would reduce the potential for those nations to adversely affect the ozone layer and would induce them to join the Protocol.

2. International Considerations

Taken as a whole, EPA believes that the Protocol effectively addresses the global problem of potential ozone depletion. The Agency thus considers it unwise to risk undermining the agreement by deviating from its requirements.

As explained earlier, EPA believes that the available evidence fully supports the need for the Protocol's control requirements. Moreover, failure by the United States to meet all the requirements would set a damaging precedent. For the Protocol to be effective, nations cannot pick and choose which of its provisions to implement.

Requiring the United States to do more than the Protocol requires could also be counterproductive. Were EPA to implement the reductions required by the Protocol regardless of whether the Protocol enters into force, or require greater reductions than the Protocol requires, other nations might have less incentive to join the Protocol. The failure of many nations to join the United States in banning CFCs in aerosols demonstrates that unilateral United States action does not necessarily lead other nations to reduce their emissions, and raises the concern that other nations might "free-ride" on United States reductions to avoid making costly reductions themselves. In any event, as noted earlier, even if EPA were to require that the United States take an additional step beyond the Protocol and reduce its consumption by 80 percent, potential ozone depletion would only be reduced by an additional 0.1 percent.

B. Control Strategy

As noted earlier, the Montreal Protocol leaves up to each party how to achieve the required reductions in production and consumption. EPA's goal in implementing the Protocol is to provide the market place with as much flexibility as the Protocol permits to achieve the required reductions in the most economically efficient manner possible.

1. Economic Incentives Versus Engineering Controls/Bans

Two general approaches for achieving the Protocol's required reductions of controlled substances were evaluated by the Agency. One approach relies on market incentives to achieve low cost reductions in the use of CFCs and halons. Under this approach EPA could either directly restrict the supply of CFCs and halons or assess a regulatory fee on their use. Either case would increase costs of using CFCs which would give those firms with relatively low-cost reduction options an economic incentive to reduce their use of these chemicals. Those firms where no such reduction opportunities exist would continue to use CFCs, although they would have to pay a higher price.

According to economic theory, providing firms with an incentive to make cost-effective reductions should

minimize the costs to society of meeting the regulatory goal. Three alternative economic incentive approaches were evaluated: marketable rights based on auctions ("auctioned rights"), marketable rights allocated by quota to past producers and importers ("allocated quotas"), and regulatory fees.

The second general approach is the use of traditional engineering controls and product or chemicals bans ("engineering controls or bans"). It involves EPA deciding which specific industries or uses of CFCs and halons should be regulated. EPA would make this decision based on the availability of low cost reductions, the quantity of reductions achieved, the administrative burdens of monitoring compliance, the enforceability of the regulation, and the impacts on small businesses. This approach is EPA's usual method of regulating pollution. It was considered alone, and a supplement to allocated quotas based on the extent to which CFC users may be postponing the adoption of low cost reductions "hybrid option").

EPA evaluated each of these options in light of the following criteria: Certainty of achieving the desired environmental goal; economic costs and efficiency in meeting that goal; equity considerations; administrative costs and enforceability; legal certainty; and impacts on small business.

Each of the options has specific advantages, but also raises possible problems. The regulatory fees option should provide for least cost reductions, while providing clear price incentives for users to reduce their reliance on CFCs and halons and for producers to introduce chemical substitutes. However, regulatory fees alone would not ensure that the freeze or reductions of controlled substances would be achieved during the time period required by the Protocol. For example, more firms than anticipated could decide to pay the fee and continue using CFCs or halons. Engineering controls or bans would pose the same problem, since uses of CFCs or halons that were not regulated could continue to grow, possibly offsetting reductions from the regulated uses.

Engineering controls or bans would also be administratively burdensome, considering the many thousands of small firms that use CFCs or halons. In the case of regulatory fees, another concern is whether EPA has the legal authority to impose a fee which would result in revenues in excess of the costs of operating the program; regulatory fees might be invalidated as beyond the Agency's authority under the Clean Air Act. (The legal issues concerning fees are discussed in a separate analysis prepared by EPA which is contained in the docket.)

The auctioned rights option would entail auctioning rights allowing a specified amount of production or consumption of CFCs or halons. The auctions would be open to any interested party. The total amount of production and consumption rights auctioned would reflect EPA's regulatory goal. Revenues from the auction would go to the United States Treasury. Firms seeking to use CFCs or halons would have to obtain rights at auction or by purchasing them from other firms on a secondary market. Alternatively, to the extent CFC or halon producers or suppliers had not purchased rights at auction, final users of these chemicals could simply buy them directly through their existing channels of supply. EPA would monitor compliance by checking whether producers and importers held rights authorizing their production and consumption.

Like all the economic incentive approaches, auctioned rights should provide for economically efficient reductions. In addition, any revenues from the auction would go to the general treasury.[3] Concerns have been raised, however, that auctions, at least initially, would create large uncertainties for firms about price and availability, and could lead to speculation and short-term hoarding of permits (beyond a firm's actual needs) during the auction process.[4] Also, legal questions have been raised concerning EPA's authority under the Clean Air Act to implement an auction to allocate rights. (These issues are also discussed in the EPA analysis contained in the docket.)

EPA favors simply allocating rights equal to the quantity of allowable production and consumption to producers and importers of controlled substances in 1986. Since producers and importers are small in number (probably no more than 15 to 20), it would be far less burdensome to allocate rights to them instead of users. Similar to auctioned rights, firms allocated rights could buy and sell them to respond to changes in market conditions. Price increases as a result of decreased supplies should provide firms using CFCs or halons with the economic incentive to make the lowest cost reductions of controlled substances. Unlike auctioned rights or regulatory fees, this option avoids raising any legal issues concerning EPA's regulatory authority.

The major concern about the allocated quotas option is one of equity—should current CFC and halon producers and importers reap a possible windfall profit from the scarcity created by EPA's regulation? The extent to which CFC and halon prices increase over time will determine the magnitude of this potential gain.

A second concern (one that applies to all of the economic incentive approaches) is that certain industries where low-cost reductions are possible may decide not to make these reductions, at least for a time, and may elect instead to continue their use of CFCs or halons. For example, CFCs are a very small part of the costs of a computer. As a result, firms in this industry may be better able to pass on price increases to their customers. If available inexpensive reductions are not realized by these or other industry groups, then CFC and halon prices could increase more than they otherwise would, resulting in additional economic burden on all firms using these chemicals. The impact of this burden could be particularly large in the near term, before new chemical substitutes become available.

These two concerns are discussed in greater detail in a later section which describes potential remedies to these problems and presents the alternative regulatory approaches still under consideration by the Agency.

2. Design of Allocated Quota System

EPA proposes to implement the Montreal Protocol using a system of allocated, marketable "rights."[5] The Protocol's limits on production and consumption would be translated into allocated quotas of production rights and consumption rights. The Protocol's separate treatment of Group I and Group II controlled substances would be reflected in separate rights for each group of controlled substances. Similarly, the Protocol's definition of

[3] The argument advanced by economists is that equity would be served were revenues from the auction or regulatory fees to go to the Treasury because the revenues would represent payments from those who damage the environment to those who are damaged, i.e., citizens.

[4] Speculation can be an aid to market functioning. Of course, if speculators enter the market and bid up the price to levels higher than market value, they will lose money in their subsequent efforts to sell in the aftermarket. However, to the extent prices are bid up by speculators and remain higher for some time, small firms using CFCs or halons may be adversely affected.

[5] The word "rights" is used as a matter of convenience. The "rights" that would be created by the regulations are really privileges, since, if future circumstances or shifts in the regulatory approach warrant changes in allocations of controlled substances, EPA may by rulemaking modify the amount of rights allocated.

limits in terms of "calculated levels" of Group I or Group II substances would be carried over into the definition of rights. (As explained earlier, calculated level is determined by multiplying the emissions of each controlled substance by its ozone depletion weight and adding together the resulting products for all the controlled substances within each Group.) Thus, rights would be specified in terms of calculated level of Group I or Group II controlled substances, so that holders of rights could select any mix of controlled substances within each Group, provided that the total calculated level of the mix did not exceed the calculated level of the rights held.

a. *Chemical Coverage and Ozone Depletion Weights.* The regulations would include the same chemicals in Group I and Group II of controlled substances as the Protocol does. They would likewise adopt the Protocol's ozone depletion weights for each of the controlled substances. However, the regulations would also provide an ozone depletion weight for Halon 2402, whereas the Protocol leaves the weight for that halon for later determination. EPA is proposing a 6.0 weight for Halon 2402 based on its assessment of the chemical's ozone depletion potential. The Agency will also propose this weight for adoption by the Protocol parties; but should the parties establish a different weight and scientific evidence support their choice, EPA would revise its regulation to conform to the Protocol. In the meantime, EPA believes it appropriate to propose its assessment of the ozone depletion weight of Halon 2404 to give industry a basis for judging their compliance with the halon limit.

b. *Production Rights and Consumption Rights.* Production rights held by firms would authorize them to produce a calculated level of controlled substances equal to the calculated level of rights they hold.[6] Rights would be apportioned among producers of controlled substances according to the calculated level of controlled substances each produced in 1986, the baseline year established by the Protocol. The total of these "baseline production rights" would thus equal United States production in 1986.

Consumption rights would authorize holders to *produce or import* a calculated level of controlled substances equal to the calculated level of the rights held. As described earlier, the Protocol defines consumption as production plus imports minus exports, and keys its consumption limits to 1986 levels of these three components of the consumption equation. Since exports of controlled substances are subtracted from, and therefore aid compliance with the consumption limit, no rights would be required to export (although exporters would be required to report their exports to EPA). Nor would users of CFCs or halons ever become involved with either production or consumption rights—only producers, importers, and exporters would be directly involved in this proposed regulatory system.

Baseline consumption rights would be apportioned to producers and importers, but in a manner that takes account of 1986 exports. Importers would be allotted baseline consumption rights equal to the calculated level of their 1986 imports of controlled substances. Producers would be apportioned baseline consumption rights equal to the calculated level of their 1986 production, less a proportionate share of the calculated level of the United States' total 1986 exports. The apportionment formula for determining each producer's consumption rights would be the producer's 1986 production multiplied by a correction factor equivalent to:

$$\frac{[(\text{U.S. 1986 production})-(\text{U.S. 1986 exports})]}{(\text{U.S. 1986 production})}$$

EPA believes producers' baseline consumption rights should be reduced to reflect exports because producers generally have been the major exporters of controlled substances.

In a separate rule also appearing in today's Federal Register, EPA is requiring producers, importers and exporters of controlled substances in 1986 to provide the Agency with the information needed to determine the United States' 1986 production and consumption levels, individual producer's baseline production and consumption rights, and individual importer's baseline consumption rights. Based on the information received, the Agency plans to publish proposed baseline apportionments in time for final apportionments to be included in this rule when it is promulgated on August 1, 1988.

As their definitions suggest, production and consumption rights overlap, but not entirely. To produce controlled substances, a firm must have both production and consumption rights; to import controlled substances, it need have only consumption rights. The overlap simply mirrors the overlap of the Protocol's limits on production and consumption (i.e., production plus imports minus exports). Several examples illustrate how the two limits may interact and how the proposed regulatory system would accommodate these interactions.

Assume the United States in 1986 produced 100 units, imported 10 units, and exported 5 units of Group I controlled substances. United States 1986 production would be 100 units and its 1986 consumption 105 units. After the Protocol's freeze on Group I controlled substances took effect, the United States could not produce up to 105 units of controlled substances for domestic consumption even though it would stay within its consumption limit, because it would exceed by 5 units its production limit. Unless the United States gained the right to increase its production in the manner permitted by the Protocol (described below), it could only obtain the remaining 5 units of controlled substances permitted by the consumption limit by importing them. To restate this scenario in terms of rights, United States producers would be granted production rights for 100 units of controlled substances. Producers and importers would be granted consumption rights for 105 units. Thus, producers could produce up to 100 units of controlled substances using all of their 100 production rights and 100 of the 105 available consumption rights; the remaining consumption rights could be used to import controlled substances.

c. *Allowance for Additional Consumption Rights.* A slightly different example illustrates another aspect of the proposed regulatory system. Assume the United States in 1986 produced 100 units, imported 5 units, and exported 10 units of controlled substances, for a 1986 production level of 100 and a 1986 consumption level of 95. In this case, baseline consumption rights would not be plentiful enough to permit producers to produce all 100 units for which they held baseline production rights. The Protocol would permit production of all 100 units, provided that at least 5 are

[6] Production rights would be required for virgin production but not for recycling, of controlled substances. Production used and consumed as a chemical intermediary is also exempt. Further, the Protocol defines production of controlled substances as the amount produced minus the amount destroyed "by technologies to be approved by the parties." Because no such technologies have yet been approved, this proposal does not include any provision for credits for destruction. However, EPA intends to work with industry in the future to review existing and new destruction technologies and, if appropriate, submit these technologies to the Parties for their approval.

exported so that the consumption limit is not exceeded. The proposed regulations would permit the same by granting additional consumption rights upon proof of exports of controlled substances to any nation until January 1, 1993, and to any party of the Protocol beginning January 1, 1993.[7] If a producer held production rights for 12 units and consumption rights for 10 units, he could produce the 10 units for which he held production rights, export 2 of the units, and receive from EPA additional consumption rights for 2 units. With those additional consumption rights, he could produce all 12 units for which he held production rights.

The regulations would require controlled substances to be exported before additional consumption rights would be granted, to ensure that the United States stayed within its consumption limits. If EPA were to grant additional consumption rights based merely on a producer's plan or agreement to export controlled substances, the United States could exceed its consumption limits if the producer did not ultimately export the substances but nonetheless increased his production as allowed by the additional consumption rights he received. The regulations would moreover require that exports reach their destination—not just leave the United States—before additional consumption rights would be granted. This requirement is necessary to track controlled substances for purposes of determining parties' compliance with the consumption limits. Otherwise, on the last day of any control period, parties could export controlled substances as needed to stay within consumption limits, but since the exported controlled substances would likely not arrive at their destinations until the following control period, no party would have to include the controlled substances in the tally of its consumption.

Anyone who exports controlled substances could obtain consumption rights equal to the calculated level of controlled substances exported. If the exporter were not also a producer, he could sell the consumption rights to a producer. As further explained below, all rights created by the regulations would be transferable subject to EPA verification that the transferor in fact possesses the rights being transferred.

To illustrate another possible scenario, assume total United States exports increased over 1986 levels, so that the United States was below its consumption limit. While the United States could not increase its production (except under the circumstances described below), it could increase its imports up to the level permitted by the consumption cap. To restate this in terms of rights, if a producer with production rights for 10 units and consumption rights for 12 units exported 6 units, he could acquire additional consumption rights for 6 units and import a total of 8 units.

As the above examples demonstrate, the Protocol's production and consumption limits can interact in many ways. EPA has tried to create a regulatory system flexible enough to accommodate the possible interactions. Comments are requested on whether the proposed system does provide adequate flexibility and how it might be improved.

d. *Scheduled Reduction of Production and Consumption Rights.* The regulatory system must also provide for the Protocol's scheduled reductions. The proposed regulations would do so by reducing the number of rights granted over time. For Group I controlled substances, it would grant producers and importers 100 percent of their apportioned baseline production and consumption rights for the first reduction step; 80 percent of the same for the second reduction step; and 50 percent of the same for the third. For Group II controlled substances, the regulations would grant 100 percent of the apportioned 1986 baseline production and consumption rights for all the applicable control periods.

The proposed regulations do not yet specify the control periods to which the grants of rights would apply, since the Protocol makes the timing of the freezes of Group I and Group II substances dependent on when the Protocol enters into force. EPA solicits comments on the appropriate time period for which these rights would apply. EPA would promulgate the dates of the control periods in a future rulemaking after the Protocol has entered into force and before the Protocol's requirement have taken effect.

Even after the date of entry into force is known, however, a question will remain as to the proper dates for the freeze of Group I controlled substances at 1986 levels. The issue arises from the potential discontinuity in the timing of the first and second steps of the reduction schedule for Group I controlled substances. The Protocol specifies 12-month control periods for all three steps of the Group I reduction schedule. But while the Protocol provides that the second step will take effect beginning July 1, 1993, it makes the start of the first step dependent on when the Protocol enters into force. If the Protocol enters into force on January 1, 1989, the freeze will take effect beginning July 1, 1989. In that case, the end of last freeze control period will coincide with the start of the first control period for the second step. On the other hand, if the Protocol enters into force on any date other than January 1st, there would be overlapping control periods, unless EPA defined the last control period as lasting less than 12 months.

To avoid this problem, EPA intends to promulgate dates for the last control period of the freeze that do not overlap with the first control period of the 80 percent step. Unless the Protocol enters into force on January 1, the last control period of the freeze would be less than 12 months long, and the rights granted for that period would be reduced accordingly. EPA solicits comments on this approach.

e. *Allowance for Additional Production Rights.* As explained earlier, the Protocol allows parties to exceed their production limits by certain amounts under certain circumstances. For the first and second steps of the reduction schedule for Group I controlled substances and for the freeze of Group II controlled substances, the Protocol permits parties to exceed the applicable production limits by 10 percent of the calculated level of their 1986 production in order to supply the "basic domestic needs" of parties that are developing countries and "for the purposes of industrial rationalization." For the third step of the Group I reduction schedule, the Protocol allows production to exceed the 50 percent production limit by 15 percent of 1986 production levels for the same two purposes. These allowances are termed "potential production rights".

EPA believes that the driving force behind the developing countries and industrial rationalization provisions was to minimize the construction of new manufacturing capacity, particularly during the initial period when states are deciding whether to adhere to the Protocol. So viewed, the provisions for 10 and 15 percent increases in production are intended to allow nations that already have substantial installed manufacturing capacity to make available limited amounts of supplies to satisfy demand from developing nations, and to offset for losses in production that might be sustained by shutting

[7] As noted earlier, the Protocol requires that, beginning January 1, 1993, only exports to parties will be subtracted in determining consumption. EPA will in future rulemakings promulgate a list of parties based on the list kept by the Secretariat of the Protocol.

down inefficient or obsolete facilities. The cushion provided by the allowable "potential production rights" will provide sufficient flexibility in the market to accommodate these needs without undue price increases that might encourage construction of new manufacturing capacity.

Accordingly, EPA proposes to implement the provisions for 10 and 15 percent production increases by allocating "potential production rights" that could be converted to production rights upon proof of exports of controlled substances to parties. Every producer granted baseline production rights would also be granted potential production rights equal to 10 or 15 percent of his baseline production rights, depending on the control period and group of controlled substances involved. A producer could then obtain authorization from EPA to convert his potential production rights to production rights to the extent he exported controlled substances to parties.

Because the industrial rationalization provision refers to transfers between *parties*, and the developing country provision similarly limits production increases to those necessary to supply *parties* that are developing countries, EPA would authorize conversion of potential production rights only to the extent controlled substances have been exported to parties. In future rulemakings, EPA would promulgate, and from time to time revise, as Appendix B to these regulations, a list of nations that are parties to the Protocol. That list would be based on the list of parties kept by the Secretariat of the Protocol.

EPA would otherwise issue notices authorizing conversion of potential production rights on the same basis as the Agency would grant additional consumption rights upon proof of exports. In both cases, EPA would require that the exported controlled substances arrive in the country importing them before EPA would issue the authorizing notice or grant consumption rights. EPA would also limit the authorization or the consumption rights to the control period in which the exports arrived in the importing country.

For a producer to make use of production rights converted from potential production rights, he would also have to obtain consumption rights in the same amount. Since any controlled substances he exported to a party would provide the basis for obtaining additional consumption rights, EPA would treat requests for authorization to convert potential production rights as requests for additional consumption rights, as well. Therefore, upon proof of exports to parties, EPA would (1) issue a notice authorizing the conversion of potential production rights equal to the calculated level of the exports, for the control period in which the exports arrived in the importing nation, and (2) grant consumption rights in the same amount for the same control period.

Anyone (not just producers) exporting controlled substances to parties could obtain *authorization* to convert potential production rights, whether or not he held potential production rights. If he did not hold potential production rights, he could either purchase such rights from, or sell his authorization to, someone who does. If enough controlled substances were exported to parties, it would be possible for EPA to issue authorizations to convert more potential production rights than there were potential production rights to convert. In that case, authorizations beyond those needed to convert all available potential production rights could not be used without violating the terms of the Protocol and would therefore be useless.

f. *Transfers Involving 25 Kilotonne Parties.* The Protocol also allows a party to increase its production beyond the 10 or 15 percent allowances, if it receives a transfer, "for the purposes of industrial rationalization," of a calculated level of production from another party whose 1986 calculated level of production was less than 25 kilotonnes. However, unlike the other provisions related to industrial rationalization, this section of the Protocol provides that "the total combined calculated levels of production of the Parties concerned (may) not exceed the (Protocol's) production limits."

EPA proposes to implement this provision by permitting anyone ("the recipient") to obtain production rights in excess of baseline production rights to the extent a "25-kilotonne party" agrees to transfer to him some amount of the calculated level of production that the party is permitted under the Protocol and to decrease its production by that amount. In a future rulemaking, EPA would promulgate a list of 25-kilotonne parties as Appendix D to these regulations. EPA would adopt a list of 25-kilotonne parties compiled by the Protocol parties, but absent such a list, the Agency would compile its own based on information available from the Secretariat of the Protocol and the parties themselves.

EPA believes that any transfer meeting these requirements would serve the purposes of industrial rationalization, which are to "achiev[e] economic efficiencies" or "respond[ ] to anticipated shortfalls in supply as a result of plant closures." EPA could reasonably assume that any such transfer would "achiev[e] economic efficiencies" since the United States recipient of a 25-kilotonne party's production presumably would not seek that production unless it were economically efficient for him to produce it.

The regulations would require that the recipient of a 25-kilotonne party's production obtain from the principal diplomatic representative in that party's embassy in the United States a document clearly stating that the 25-kilotonne party will decrease its production by the amount it is transferring to the recipient. The 25-kilotonne party's agreement to decrease its production by the amount being transferred would ensure that the total combined calculated levels of production of the United States and the 25-kilotonne party would not exceed the limits applicable to the two parties under the Protocol. Upon obtaining a copy of this document and other requisite information, EPA would notify the Secretariat of the Protocol of the transfer, as required by the Protocol, and issue a notice granting the recipient production rights equivalent to the calculated level of production transferred.

g. *Transfer of Rights.* As pointed out earlier, all of the rights and authorizations obtained pursuant to the regulations would be transferable. However, for a transfer to be effective, the transferor would first be required to submit a transfer request to EPA. The Agency would maintain records of who holds what rights or has been issued authorizations to convert potential production rights. If EPA's records indicated that the transferor possessed sufficient rights or authorization to cover the transfer request, EPA would issue a notice of transfer to the transferor and transferee. The transfer would take effect as of the date EPA issued the notice, and EPA would revise its records to reflect the transfer.

EPA is proposing these transfer requirements because of the need to assure compliance with the Protocol. A fraudulent transfer of rights or authorization would not only result in higher emissions of ozone-depleting substances, but risk the United States exceeding the Protocol's limits. Thus, EPA has provided for the procedural safeguards described above to minimize the possibility of fraudulent or mistaken transfers.

h. *Prohibitions on Production or Import in Excess of Rights.* The

capstone of the proposed system of production and consumption rights would be the prohibitions on production and import of controlled substances. The regulations would prohibit anyone from producing a calculated level of controlled substances in excess of the amount of "unexpended" production rights held by that person. Similarly, they would prohibit anyone from producing or importing a calculated level of controlled substances in excess of the amount of "unexpended" consumption rights held by that person. A person's "unexpended" production or consumption rights would be the total of the calculated level of production or consumption rights he holds, minus the calculated level of controlled substances the person has produced and/or imported, depending on the type of rights involved. In short, the prohibitions prevent anyone at any time from producing or importing controlled substances in amounts greater than the unused production and consumption rights that he holds at the time.

i. *Import Bans.* In addition to implementing the Protocol's production and consumption limits, the regulations would also enact the Protocol's ban on imports of controlled substances from any nonparty, except nonparties found to be in compliance with the Protocol's requirements. The Protocol requires that parties impose, and the regulations would accordingly implement, that ban beginning one year after the Protocol enters into force. In future rulemakings, EPA would promulgate, and from time to time revise, as Appendix C to these regulations, a list of nonparties found to be in compliance with the Protocol.

The Protocol also provides for parties to impose import bans on products containing and products made with, but not containing, controlled substances. However, those provisions are not self-executing, as they require further action of the parties to implement. Thus, EPA is not proposing to impose further import bans, but will promulgate such bans in future rulemakings when the parties have taken the necessary action. EPA is nonetheless seeking comments on products that should be covered by the future bans. The Agency is also seeking comment on whether any additional steps (e.g., labelling of products containing or produced with controlled substances from nonparties) might be warranted either prior to or in conjunction with the trade restrictions contained in the Protocol.

j. *Reporting and Recordkeeping.* EPA is considering a variety of alternative recordkeeping and reporting requirements. One option is to require firms involved in the production of the regulated chemicals to maintain the following information: Weekly records of the quantity of regulated chemicals produced at each facility including controlled substances produced and consumed for feedstock purposes; and weekly records of the quantity and purchaser of controlled substances produced at each plant. These records would be retained for a period of four years.

In addition, EPA would require monthly reports from producers of the controlled substances for each plant and for all plants owned by the same company within 15 days after the end of each month. The reports would include the following: summaries of monthly production of the controlled substances; monthly summaries of the quantity of sales for each of the controlled substances; the quantity and source of material containing recoverable controlled substances and the quantity of controlled substances recovered; summaries of total monthly and control-period-to-date production of the calculated levels of Group 1 and Group 2 controlled substances; and total rights the producer holds at the end of each month.

Another approach and the way EPA is presently leaning is to require the following information: daily records of the quantity of the CFCs and halons produced at each facility including controlled substances produced and consumed for feedstock purposes; daily records of the quantities of HCFC-22 and CFC-116 that may also be produced at the same facilities; continuous records of reactive temperature and pressure within the primary reactor and initial distillation column at each facility during the production operations; daily records of purchases and use of the following materials consumed in producing the regulated chemicals at each plant: carbon tetrachloride, perchloroethylene, chloroform, hydrofluoric acid, hydrochloric acid, bromine, HCFC-22 and CFC-23; and daily records of the quantity and purchaser of controlled substances produced at each plant. These records would be retained for a period of four years.

Under this approach, monthly reports required within 15 days of the end of each month would include the following: summaries of monthly production of the controlled substances, specifying the quantity used and consumed as feedstocks, and production quantities of HCFC-22 and CFC-116, if they are produced at the same facility; monthly summaries of the quantity of sales for each of the controlled substances; description of any material alterations in the annual production plan required for each facility by EPA (as described below); description of any shifts in operating characteristics; the quantity and source of material containing recoverable controlled substances and the quantity of controlled substances recovered; summaries of total monthly and control-period-to-date calculated production levels of Group I and Group II controlled substances; and the producer's total consumption rights, production rights and authorization to convert potential production rights to production rights.

EPA is leaning toward requesting daily instead of weekly records of production since daily records will provide more precise information on production. The more precise information will aid in evaluating trades (determining expended versus unexpended production rights), pinpointing violations, and will ease checks on production records when using process parameters (quantities of raw materials, temperature, pressure) to calculate production. It is not expected that daily records will impose a significant burden on the industry since information currently available to EPA indicates that manufacturers already keep production data on a once per shift basis. Records of raw materials, process parameters, and other CFC compounds (HCFC-22 and CFC-116) produced at the regulated facilities are requested to provide a check on production records. Records of sales of controlled substances would provide not only a check on production records, but would provide EPA information on whether exporters have actually purchased the reported quantity of controlled substances exported. Records of imports and exports are requested on a daily basis since EPA will need to check the date of import/export against records held by U.S. Customs and the U.S. Census to verify compliance.

This information would provide EPA with a double-check on whether producers and importers are staying within their production and consumption rights. EPA solicits comment on both of these approaches to reporting and recordkeeping requirements. EPA is specifically interested in the level of reporting necessary to ensure compliance with permit restrictions.

Whatever approach is chosen, failure to maintain the required records or file these reports in a timely manner may result in EPA assuming production for the unknown period at maximum

capacity for the purposes of evaluating compliance.

Records and reports could be required for each facility at each plant owned by a company or they could be required on an aggregate, company-wide basis. EPA is presently inclined to require that all production and sales records be maintained for individual production facilities, but that monthly reports to EPA be submitted containing information for both individual plants and aggregated for all the plants owned by a firm.

With this approach, EPA would not grant rights for each CFC or halon production facility or plant, but will instead grant rights that are company-wide. However, to facilitate enforcement with respect to these rights, EPA will require that firms inform EPA on an annual basis of their intended production plans for each facility and plant and notify the Agency of any significant shifts in the location or quantity of production described in these plans as part of their monthly reports. While compliance with these annual production plans will not be binding, they provide useful information to EPA for purposes of compliance monitoring. EPA solicits comments on the sufficiency of these requirements.

For firms engaged in the import of controlled substances, EPA is also considering a variety of alternative reporting and recordkeeping requirements. EPA is presently inclined to require the maintenance of daily records of the quantity of controlled substances, either alone or in mixtures, that are imported; the dates and ports of call of imports; the date and port of entry into the United States or its territories; the dates on which and the country in which the imported controlled substances were produced; and a name and address from which additional information can be obtained. Monthly reports by importers to EPA must include summaries of the above information along with totals for control-period-to-date and the importer's total consumption rights at the end of the month. EPA will further verify reported import activities with information obtained by U.S. Customs and with information reported through data presented by other nations to the Secretariat to the Protocol.

Exporters must report all exports not previously reported in the context of obtaining consumption or production rights. Reports would be required on a monthly basis and include: name and address of exporter and recipient of the exports; the exporter's Employer Identification Number (EIN); the type and quantity of controlled substances exported; the date and port from which the exports were shipped; the date and country in which the exports arrived; and the source from which the exported controlled substances were purchased.

To facilitate the collection of the relevant information, EPA is requesting the U.S. Department of Commerce for permission to obtain copies of Shipper's Export Declarations (Form 7525–V) filed by exporters of controlled substances. EPA is also requesting the Customs Service for permission to obtain copies of "Entry Summaries" (Form 7501) filed by importers of controlled substances. EPA solicits comments on these reporting and recordkeeping requirements.

k. *Compliance and Penalties.* Based on its review of reports and records and possible site inspections, EPA would determine whether firms are in compliance with the regulations. The regulations would define a violation as the production or import of every kilogram of controlled substances in excess of unexpended production or consumption rights, or in contravention of the ban on imports from nonparties.

Under section 113(b) of the Clean Air Act, penalties of up to $25,000 per day per violation can be assessed. Thus, a firm that produced two kilograms of controlled substances beyond its rights would be potentially subject to a maximum fine of $50,000. In addition to the various remedies under the Clean Air Act, EPA has the authority to seek injuctive relief to limit further production or sales, and to seek to have any activity in excess of unexpended rights subtracted from future year's rights. Also, the Agency may bring criminal penalties against knowing violators, as set forth under section 113(c) of the Act.

Given that compliance with the terms of the Montreal Protocol is determined on a twelve month basis, the control period would be for one block year (unless otherwise specified), and EPA would track compliance over that same period. However, tracking compliance on an annual basis presents some practical limitations—in extreme circumstances a firm could go out of compliance only at the end of the period. With a shorter averaging time or a rolling average compliance could be judged earlier or more frequently. As an alternative to the block annual control period, EPA could specify a rolling twelve-month control period where compliance could be measured at the end of each month based on the previous twelve months of production. This alternative would provide greater assurance that the United States satisfies its obligations under the Montreal Protocol, but could somewhat limit the flexibility of firms in meeting shifting market conditions during the course of a year. EPA proposes to initially specify compliance on a block one year control period, but will consider shifting to a twelve-month rolling control period if difficulties in ensuring compliance develop. EPA may impose the twelve-month rolling quota on firms that have violated production or consumption rights or in cases where compliance monitoring is hindered.

1. *Effective Date.* The proposed regulations would not take effect until the Montreal Protocol enters into force. After the Protocol has entered into force, EPA would revise the effective date section of regulations to include the date of entry into force.

The United States is now in the process of ratifying the Protocol. That process includes completion of an environmental impact statement concerning the Protocol, and submittal of the Protocol by the President to the Senate for its advice and consent. If the Senate gives its advice and consent, the ratification document then goes to the President for his signature and, once signed, is deposited at the United Nations headquarters. Unless unanticipated delays are encountered, EPA expects this process to be completed well before the January 1, 1989 target date for entry into force.

m. *Payment of Fees.*[8] (a) *Background.* In recognition of the fact that producers and importers of controlled substances would receive production and consumption rights which would allow them to engage in their activities, EPA has examined the feasibility and desirability of making the administration of this regulatory system as self-supporting as possible by having the producers and importers bear some of its costs through payment of administrative fees. EPA is proposing to include Sec. 82.14 in the proposed rule, which would provide for EPA to collect fees in advance for granting production and consumption rights. The authority for this provision is the Independent Offices Appropriation Act ("IOAA"), 31 U.S.C. 9701 (formerly 31 U.S.C. 483(a)), which permits and encourages Federal agencies to recover, to the fullest extent possible, costs attributable to special benefits provided to identifiable recipients.

[8] Payment of *administrative fees* to cover the costs of operating the program is being proposed regardless of the regulatory approach (e.g. allocated quotas, auctions, or regulatory fees) employed. Because the fee simply covers the costs of operating the program, the legal issues concerning a fee used as a regulatory tool are not applicable.

The following describes the broad outlines of the fee program.

(b) *Activities, the Cost of Which are Proposed for Recovery* The Supreme Court has stated that agency activities for which costs are properly chargeable to the recipient are those which "bestow[ ] a benefit on the applicant, not shared by other members of society." In *National Cable Television Ass'n* v. *U.S.*, 415 U.S. 336, 340–41 (1974). The Court of Appeals for the D.C. Circuit has further specified that the full costs of providing a service may be recovered when:

- The Agency has identified specific activities for which the fee is being assessed;
- The service produces a private benefit;
- The value of the benefit is reasonably related to the fee;
- The benefit accrues at least in part to an identifiable private beneficiary and not merely to an entire industry; and
- The service produces no independent public benefit. *Central & Southern Motor Freight Tariff Ass'n* v. *U.S.*, 777 F.2d 722, 730 (D.C. Cir. 1985).

Based on these criteria, EPA proposes to recover the full costs of the following activities, all of which relate to apportioning and administering production and consumption rights:

(1) Determining the amount of baseline production and baseline consumption rights apportioned to specific producers and importers.

(2) Processing applications, under Secs. 82.9 and 82.11 for additional production rights, and taking associated actions (e.g. notifying the Secretariat of the Protocol of 25-kilotonne party transfers).

(3) Processing applications under Sec. 82.10 for additional consumption rights.

(4) Processing applications under Sec. 82.12 for transfers of rights.

(5) Processing and maintaining the reports required to be submitted to EPA under Sec. 82.13.

EPA requests comments on whether to charge for additional activities, such as audit and enforcement activities.

(c) *Determination of Costs of Activities.* EPA proposes to recover the following costs of the activities described above:

(1) Direct labor costs, which will be based on the grade level of staff working directly on the activities;

(2) Indirect labor costs, which will include managerial and supervisory support, and secretarial/clerical support; and;

(3) Overhead costs, including office space costs, utilities, equipment, and materials.

By the first day of any control period, every person owning production or consumption rights applicable to that control period would have to pay EPA the full amount of the fee owed. Failure to pay the fee on a timely basis would result in the person being treated as owning no production or consumption rights during the control period, until payment is made. Late payment would be subject to interest computed at the Federal short-term rate.

Under EPA's proposed system, owners of production or consumption rights would make one fee payment as of the beginning of the control period. No additional fees would arise from applications to EPA under Secs. 82.9–82.12 for additional production or consumption rights or transfers of rights. EPA solicits comments on the merits of charging separately for EPA's costs in processing such applications and reducing the up-front fees accordingly. In addition, EPA solicits comments on procedures for imposing fees with respect to audit or enforcement activities, if EPA determines to impose such fees.

(d) *Fee Waivers or Adjustments.* There may be circumstances under which waivers from, or adjustments of, fees would be appropriate. While the IOAA is silent concerning such matters, it does provide that the President shall set policies concerning the implementation of the IOAA. Office of Management and Budget (OMB) Circular A–25, Sec. 9(b) contains guidelines for Federal user charge systems and provides for exceptions to a general user fee policy under several circumstances. Under these guidelines, waivers may be appropriate under the following circumstances:

(1) *Public Interest.* If the person uses the controlled substances as part of activities designed to promote the public interest, the fee may be waived. EPA solicits comments on the circumstances under which this exemption may be applicable.

(2) *Economic Hardship.* A fee may be waived or adjusted if its imposition would result in an economic hardship on the person. Considerations for an economic hardship waiver include size of the firm and amount of sales or use of controlled substances.

(3) *Small Business.* EPA solicits comment on whether waivers of adjustments would be appropriate for small businesses, based on number of employees and annual gross revenue from sale or use of the controlled substance.

EPA further solicits comments on whether a fee should be charged for processing an application for a waiver or adjustment (which would be refunded if the waiver or adjustment is granted).

3. Other Regulatory Options Considered

As a regulatory scheme, allocated quotas of production and consumption rights appear to offer the advantages of the other options while avoiding many of their potential problems. However, as discussed above, it is not free from concerns.

By restricting the supply of CFCs and halons through regulation, EPA would effectively create a scarcity that would result in higher prices for the controlled substances as demand for CFCs and halons exceeded supply over time. Under the allocated quota approach, any additional revenue that would result from the scarcity created by this regulation accrue to the firms allocated rights.

The magnitude of these transfer revenues would depend on how much the prices for the regulated chemicals increased over time. Based on the analysis presented in the RIA, Table 5 presents EPA's estimates of possible transfer revenues that would accrue primarily to the chemical manufacturers, assuming that they allowed market forces to determine what price and which firms purchase CFCs and halons. (If market forces do not operate, the producers and importers will determine allocation to users based on criteria other than prices.) Table 5 shows that, even for scenarios where price increases are small in the initial years and gradually increase to the price where expected chemical substitutes come into play, the total amount of transfers could range from $2.0 billion to $5.7 billion from 1989 through 2000. For the scenario where CFC price increases in the early years are more substantial (e.g., the "stretchout cases" where implementation of low cost reductions is delayed), the amount of the transfers increases accordingly. Overall, for the decade leading up to the turn of the century, transfer revenues were calculated to be approximately three times greater than the social costs (i.e., the real resource costs to reduce use) involved in meeting the control requirement.

TABLE 5.—PRELIMINARY ESTIMATE OF POTENTIAL SOCIAL COSTS AND TRANSFERS TO PRODUCERS

	Least cost	Stretchouts		
		Moderate	Moderate/major	Major
CFC price increases (1985 $/kg)				
1989	00	00	00	00

TABLE 5.—PRELIMINARY ESTIMATE OF POTENTIAL SOCIAL COSTS AND TRANSFERS TO PRODUCERS—Continued

	Least cost	Stretchouts		
		Moderate	Moderate/major	Major
1994	2.21	3.50	3.70	5.48
1999	3.77	5.48	5.48	5.48
2005	3.77	5.48	5.48	5.48
2075	5.48	5.48	5.48	5.48
Social costs (present value in millions of 1985 dollars)				
1989-2000	689	1,146	1,828	1,850
1989-2075	27,040	29,220	37,910	38,140
Transfer revenues (present value in millions of 1985 dollars)				
1989-2000	1,975	2,516	2,757	5,703
1989-2075	6,163	7,096	6,378	9,400

Assumes CFCs regulated with an initial freeze in 1989 at 1986 levels, 20 percent reduction in 1993 and 50 percent reduction in 1998, and halons frozen at 1986 levels in 1992.

Social costs are discounted at a 2 percent rate, and transfer costs are discounted at a rate of 6 percent, reflecting the opportunity cost of funds in the private sector.

Source: Estimates taken from RIA.

An argument can be made that the above analysis overstates the quantity of transfers. According to this line of reasoning, chemical manufacturers may not behave competitively and would not allow market prices to determine who gets these chemicals, but would instead directly allocate them to their customers based on past sales. CFC and halon prices would increase only gradually reflecting the higher costs of producing less of these chemicals and the need to generate capital for research and production of chemical substitutes. The resulting lower price increases could act as a disincentive to the introduction of more expensive, substitute chemicals.

While no estimate of the price increases under this scenario has been calculated, given the slow rate of price increase in the EPA scenarios, the overall difference in the quantity of transfers is not likely to differ substantially. Thus, even in the scenario where CFC and halon producers allocate their allowable production and limit price increases, transfers on the order of a nearly a billion dollars or more are likely over the next ten years. This raises questions as to whether possible profits from continued production of the restricted chemicals might have the undesired effect of delaying the introduction of less profitable chemical substitutes.

EPA has explored a number of possible approaches to improving the equity of its proposed regulation by reducing or eliminating the potential transfers to the CFC and halon producers and importers. One approach, the use of auctions to allocate marketable rights, was mentioned in an earlier section. Under this option, EPA would auction rights to all interested parties and the resulting transfers would accrue to the U.S. Treasury.

An advantage of the auction approach is that it takes CFC allocation out of the hands of producing firms and allows the market to function. While detailed design of an auction is not presented, as an aid to commenters, the major characteristics of auction forms most likely to be applicable to the case of CFCs can be briefly presented. An advantage in the design of an auction of CFC permits is the availability of existing models provided by the auctions regularly conducted by the Federal Government in the areas of government procurement, leasing of mineral rights (including onshore and outer continental oil and gas development, coal leases, geothermal development, etc.), and Treasury bills.

The government auctions are typically structured as "first-price sealed-bid" auctions,[9] in which potential bidders submit sealed bids and the highest bidder is awarded the item for the price he bid. An alternative is the "second-price sealed-bid" auction, in which the highest bidder wins the item but pays a price equal not to his own bid but to the second-highest bid. Variations on these forms can be used: for example, the government may impose a reserve price, discarding all bids if they are too low; and bidders may be charged an entry fee for the right to participate.

When a fixed quantity of a good is put up for sale (such as with the weekly Treasury bill auction), two kinds of sealed bid auctions are used to sell multiple units, as explained below. In the discriminatory sealed bid auction, each of the bidders pays the amount he bid. In the uniform-price sealed bid auction, each successful bidder pays a price equal to the highest unsuccessful bid. Procedurally, bidders submit bids that consist of both a price and a desired number of units of the commodity. Enough units are available that a number of the highest bidders can be awarded the units for which they bid. The government then ranks all buyers' bids by price from highest to lowest, and cumulates the quantities bid.[10] The result is a market demand curve.

To aid in reducing uncertainty, the introduction of an auction as an allocation mechanism could be phased in according to a preannounced schedule (such as every three months); each auction would offer only a fraction of total rights for sale. The phase-in approach would allow time for procedural and substantive familiarity to be gained by all parties; if necessary, limitations could be placed on the amount of rights any one firm could acquire. With a very short timeframe between auctions, a firm concerned about the bidding up of prices could hold back, bid only its true value for rights in a subsequent auction, and have less concern over rights acquisition. To the extent it is desirable to protect small firms or particularly vulnerable industries, set asides could be designated for these groups.

In EPA's consideration of the use of an auction to allocate rights, several concerns have arisen. EPA is concerned about the potential large uncertainties regarding the price and availability of the controlled substances which an auction might create, particularly in its initial years. Related concerns are that big companies could easily outbid small companies, that speculators would drive up the price of rights, and that companies would hoard supplies.[11] As suggested above, a number of steps in designing an auction could be taken to address these concerns.

The final concern involves the question of EPA's legal authority under the Clean Air Act to operate an auction. Such an auction would constitute regulatory action by an administrative agency, pursuant to an asserted grant of authority from Congress, requiring the payment of money by the private sector to the U.S. Treasury. The principal legal issues EPA is considering concern (1) whether such an asserted grant of congressional authority constitutes a delegation by Congress of its constitutional power to impose taxes or, alternatively, its constitutional power to regulate commerce; and whether Congress in fact granted such authority for an auction under the statutes EPA administers.

One potential alternative—a "zero revenue auction"—might avoid some of the legal and practical problems. This alternative would not yield revenue to the government.

Under this approach, each producer (or user) would receive a provisional

[9] Sealed-bids are preferred due to risk aversion on the part of bidders

[10] The cumulation process may require several steps (not detailed here)

[11] To some extent uncertainty stems from the shortages themselves and sufficient information regarding the auction form would alleviate concerns over the method of allocation.

allocation of rights equal to its 1986 production (or use). Each producer or user would then be required to submit a sealed bid presenting the number of rights it would purchase at a range of alternative prices (i.e. its demand schedule). These bids would be aggregated to construct the market demand for these rights. The resulting market price would then be set at the price that equates market demand with the 1986 ceiling on total production.

Each firm's final allocation will be its reported demand at the market price. Each firm would then pay an amount equal to the price of these rights times its final allocation and receive back an amount equal to the price times its provisional allocation. Net payments to the government would be zero for all firms taken together. Each firm would receive exactly the number of rights it initially stated it would be willing and able to purchase at the equilibrium price.

The zero revenue auction has several features that make it an attractive interim option. First, it virtually eliminates uncertainty by guaranteeing each firm the number of rights it initially reported in its ceiled bids at each alternative price.[12] Second, it automatically produces the first round of trades in the system of marketable permits, thus reducing any one firm's ability to hoard, speculate, or to outbid others. Third, it produces a public price signal providing information for future (non-zero revenue) auctions and other allocation systems that the government may want to implement as well as for potential entrants into the industry. Finally, if the auction is conducted for users (as opposed to producers), it would address the concerns that some users may be forced out of business. Each user could guarantee that it stays in business or be compensated for going out of business at a price to which it agreed.

If it is determined that EPA lacks the authority to conduct an auction, legislative authorization would be necessary. These legal issues are addressed in greater detail in an analysis prepared by EPA which is included in the docket.

EPA is specifically interested in receiving comments on the desirability of using auctions as the method of allocating rights, the possible steps EPA could take to minimize disruption in the early years of an auction, and the legal issues concerning the possible need for additional legislative authority.

If the legal obstacles to auctioning marketable permits cannot be resolved, a potentially attractive alternative would involve EPA allocating CFC or halon rights to firms now using (as opposed to producing, importing, or exporting) these chemicals. This option is very similar to the scenario described above whereby the chemical producers would reallocate their allowable quotas to their customers based on historic sales. The major difference is that in the option where EPA allocates rights directly to users, the possibility of transfers from users to producers is substantially reduced. However, under this option EPA would be required to allocate rights to approximately 10,000 firms who now buy directly from CFC and halon producers. EPA is interested in receiving comments on the desirability of this approach and possible ways to minimize the administrative burden of the intitial allocation.

Another attractive option which provides a strong alternative to the auction option would be to combine allocated quotas with a regulatory fee. While a fee alone would not ensure compliance with the reductions required by the Montreal Protocol, when teamed with allocated quotas, this flaw would be remedied. The quota would provide a relatively straightforward means of ensuring that the reductions required by the Montreal Protocol are achieved. A fee assessed against producers and importers would provide an economic incentive for the introduction of chemical substitutes and for firms to employ other low cost methods of reducing emissions. It would also provide clear signals about future price increases and avoid many of the potential uncertainties associated with auctions. The fee would also capture most of the transfers for the U.S. Treasury, thus serving equity.

The fee would be set to capture all or most of the CFC and halon price increases which result from the scarcity created by EPA's regulations. The marginal cost of the CFC control alternatives (including substitutes) would provide the primary basis for setting the level of such fees. As with tradable rights, fees would be scaled on the basis of ozone-depleting potential, e.g. dollars per kilogram-equivalent of ozone-depleting substance produced.

An important design consideration is the extent to which periodic fee adjustments would occur on an automatic basis or would require regulatory intervention. With the quota system in place, automatic fee changes specifically intended to bring actual CFC production into alignment with production goals would not be necessary. However, any adjustments needed as a result of significant changes in economic activity, new scientific evidence, and/or discovery that the cost of switching to certain substitutes was different than previously thought would likely be difficult to accomplish on an automatic basis. On the other hand, the more automatic the adjustment, the more certainty for investment and production decisions the system is likely to provide.

Another important design consideration is the extent to which the fee should be phased in: should it be set from the start at levels calculated to extract the full amount of transfer payments or should it be set low (merely as a price signal) and subsequently adjusted upward in (either small or large) increments?

Collection of fee payments would be directly from the firms allocated the CFC and halon quotas, on a periodic (e.g. monthly or annual) basis.

EPA seeks comments on the fees-with-quotas option, in comparison with both the auction option and the allocated quota option without fees. EPA is interested in receiving comments on the desirability and implementation issues related to this option, including the legal issues raised earlier.

Under a final approach to reducing the potential inequities of the allocated quota systems, some portion of the transfers could be recaptured through voluntary donations by the producers to an industry-wide research organization. This approach would not be mandated by EPA, but would be pursued by a voluntary organization created by CFC and halon producer and user industries. Essentially, some or all of the producer firms would agree to set aside some portion of the price increase from CFCs and halons to support research activities. Funds set aside for this organization could be used to support projects to aid producers and users in their transition away from the use of these regulated chemicals. Examples of possible projects could include: joint toxicity testing for new chemicals; studies to support fire and building code changes; testing of the compatibility of new chemicals with existing equipment; education and training to encourage increased recycling by professionals involved with servicing equipment using CFCs and halons; support for tests required to obtain regulatory approvals needed for product substitutes, etc. All

[12] In fact, any firm could go so far as to guarantee its provisional allocation as its final one by reporting that it would purchase its provisional allocation regardless of the price. If all firms did this, the provisional allocation would be the final one and change hands.

proposed projects would be submitted on a voluntary basis and reviewed by a committee representing the members of the institute.

Joint research groups have been established by other industries (e.g., the Electric Power Research Institute) and are generally highly regarded by their members. Several CFC user groups have already initiated and funded joint efforts to resolve obstacles to testing and using CFC substitutes. The major halon producers and users have agreed in principal to pursue this option with the chemical producers assessing a few cent per kilogram tariff on all halon sales to fund joint projects to reduce emissions, to develop new fire protection chemicals and practices. EPA is interested in comments on the possible structure and scope of this type of organization, how it might aid in facilitating technology transfer and the extent to which it might add to research and development efforts undertaken anyway by individual firms.

The second major concern with allocated quotas relates to the possibility that some industries—particularly those where CFCs or halons are only a small fraction of total product cost—may be slow to respond to economic incentives to reduce their use of the controlled substances and may elect to simply pay higher prices for CFCs/halons instead. The rate at which firms will move to make cost effective reductions rests on a behavioral assumption about the extent to which firms will minimize production costs. To gain some insights into the effect of alternative assumptions on cost-minimizing behavior, EPA included in the RIA several scenarios where the analysis assumed that firms elected to delay or failed entirely to pursue certain cost-effective, low-cost reduction options.

Table 5 shows the differences in CFC prices for various assumptions about the rate at which firms employ low-cost use reductions. Compared to the "least cost" case where reductions are taken as they become cost competitive and technologically available, the three "stretchout" cases demonstrate that should firms not seek to minimize costs, CFC prices, social costs and transfers could all increase. Given the assumption on the availability of substitutes in the future, these increases occur primarily in the early years when the burden on user industries will be most difficult and before chemical substitutes for many applications will be commercially available.

This analysis shows the close interrelationships among CFC- and halon-using industries under the proposed regulatory approach. To the extent those industries where inexpensive reductions are available postpone making such reductions, prices of CFCs and halons would likely increase to all industries. For those user groups where CFCs are a large percentage of final product price (e.g., the foamblowing applications), such increases could be burdensome particularly in the initial years before chemical substitutes come to market and place a ceiling on such cost increases. Table 6 shows EPA estimates of the total amount of CFCs and halons consumed by the major user industries.

TABLE 6.— 1985 U.S. CONSUMPTION OF CFCS AND HALONS BY MAJOR USER INDUSTRIES

Industry	Total weighted use (mill kg)	Chemicals used
Flexible Foam	18.6	CFC-11
Rigid polyurethane foam.	61.3	CFC-11, 12
Rigid non-urethane foam.	12.8	CFC-12, 114
Refrigeration and air conditioning.	96.0	CFC.11, 12, 114, 115
Aerosol	11.6	CFC-11, 12
Solvent	54.8	CFC-113
Fire extinguisher	43.4 [1]	Halon-1211, 1301, 2402
Miscellaneous	22.0	CFC-12

[1] Estimates do not include Halon 2402.
Source: Estimates prepared for EPA Regulatory Impact Analysis.

Of course, direct limits on specific CFC or halon uses—either bans or engineering controls—also have serious drawbacks. They would reduce or effectively eliminate the markets' ability to allocate CFCs and halons to their highest valued uses and result in a waste of resources. This happens because they reduce individual's and firm's rewards from finding those uses as well as their incentives to find substitutes that do not deplete ozone.

Requirements of this type are also generally inflexible and unresponsive to changes in the relative values of CFCs and halons in other uses. An approach relying on bans and engineering controls places in the hands of the Federal government basic decisions on the use of these chemicals. There is no guarantee that the mandated restrictions will result in better or more valuable uses of these chemicals.

Since the initial limits are at 1986 levels, any shortfall in supply (and associated increases in prices) are not likely to be large in the early years. Further, it could take several years to promulgate regulations restricting specified uses. Thus, such regulations may not be helpful in easing the transition.

However, because of the potential concerns that some users may not minimize their costs, EPA is seeking comment on the desirability of supplementing the allocated quota system with direct limits on specific CFC or halon user industries where inexpensive reductions appear feasible. These limits could be established by EPA on a voluntary (e.g., the publication of technical guidance) or mandatory basis, or they could start as voluntary and become mandatory, through a rulemaking procedure, only if necessary. They could be developed through the traditional agency process or through a different process (e.g., a negotiated process) with greater involvement of industry and other interested groups.

In developing the RIA cost analysis, EPA obtained substantial information from a variety of sources on low-cost measures to reduce CFC and use. Based on its preliminary cost analysis, the following steps to reduce CFC and halon use appear possible during the period covered by this regulation:

a. *Commercial Air Conditioning.* Firms in this industry have taken steps in recent years to shift away from CFC-12 in air conditioning. For example, window and central units are no longer of concern from the perspective of this proposal because they now use HCFC-22. Commercial chillers have already begun to shift, but could make greater use of HCFC-22, CFC-502, CFC-500 and other chemicals and mixes with ozone depletion weights that are significantly lower than CFC-11 and CFC-12. Although CFC-502 is a blend of 48.8 percent HCFC-22 and 51.2 percent CFC-115, it has a combined ozone depletion weight of approximately 0.3, and therefore represents a potentially attractive option for many firms. By altering their market mix and shifting more toward CFC-22, CFC-502, etc., substantial reductions in CFC-11 and CFC-12 use are currently possible.

Nonetheless, there appear to be substantial emissions resulting from current practices of venting CFCs during routine maintenance. Relatively minor design changes (e.g., different valves) by equipment manufacturers could facilitate improved servicing practices and reduced emissions.

Over the longer-term, chemical substitutes may make it possible to eliminate use of CFC-11 and CFC-12 in new equipment. The most promising chemical substitute now appears to be

HFC-134a. This chemical does not contain any chlorine and therefore would not deplete ozone. It has passed preliminary short-term toxicity tests, but has not yet undergone longer-term testing and is not yet available in commercial quantities. Recent industry estimates suggest this chemical could be available in 5 years to 6 years if no major problems are encountered. It has many of the same chemical and physical properties of CFC-12 and initial tests suggest that it might require only minor changes to be used in new equipment. It is likely, however, to cost several times the current price of CFC-12.

Automobile Air Conditioning. Approximately 25 percent of all CFCs are used in automobile air conditioners making it by far the single largest user industry. In the near term, the auto manufacturers could improve component quality and several could redesign their air conditioning units to require a lower initial CFC charge per unit. While substantial progress has been made in reducing emissions in manufacturing over the past years, EPA's analysis suggests that a wide variance exists among automobile manufacturers and that additional steps could be taken in this area. Other CFC reductions which appear possible in the near term at the point of manufacture include completing the switchover to helium gas for testing systems and eliminating unnecessary losses during charging.

Over the longer term, automobile manufacturers appear to have several promising options for eliminating this use of CFC-12, including the use of chemical substitutes (e.g., HCFC-22, CFC-142b/22 blend, and HFC-134a). In addition, alternate air conditioning systems including a modified sterling cycle may be feasible. Because of the difficulty in knowing which of these or other options will prove to be most attractive, research into several of these options simultaneously may be desirable.

Even if automobile manufacturers are capable of shifting away from CFC-12 based air conditioners over the next seven years or longer, substantial quantities of CFC-12 will still be required to service the existing fleet. Although a large number of facilities service car air conditioners (leaving aside for the moment the portion of the market serviced by car owners directly), several promising options deserve attention because of the large quantity of CFCs used by this market segment.

One option involves the sale of small containers used by car owners and some service centers to recharge vehicles. These containers eliminate the possibility of recovery at a service station, resulting in substantial quantities of CFCs lost through venting, and losses due to refrigerant trapped in the container following use.

A second option involves the possibility of blending a non-CFC chemical with CFC-12 to reduce the latter's use in servicing the aftermarket. Initial research has shown promising preliminary results that such a compound could be used in existing equipment without costly modifications and would be more energy efficient and less expensive.

c. *Electronics and metal cleaning.* Perhaps the fastest growing use of CFCs is the use of CFC-113 as a solvent by the electronics industry. Because CFC-113 is nontoxic and compatible with a variety of materials, its use has increased substantially during the past several years, particularly as health concerns have been raised concerning other chlorinated solvents currently being used.

Because of the high cost of CFC-113 and the fact that it is used as a solvent and therefore is not consumed in the manufacturing process, recovery and reclamation of substantial quantities of CFC-113 already occurs. However, based on EPA's preliminary analysis, additional opportunities exist for improved recycling. For example, existing equipment frequently does not have automatic covers or hoists (in the case of open top vapor degreasors), both of which could reduce losses. In addition, operating practices could be improved to further reduce CFC losses.

Increased recovery of CFC-113 may be particularly important because of the drawbacks of switching from CFC-113 to other chlorinated solvents. EPA's Office of Toxic Substances, as part of its Chlorinated Solvents Task Force, is working along with other EPA offices and other agencies such as the Occupational Health and Safety Administration and Consumer Product Safety Commission, to review the use of methylene chloride, perchloroethylene, trichloroethylene, and methyl chloroform in solvent and other applications. Before switching to any of these alternatives, firms should consult with EPA and state agencies to determine current requirements and the potential for future regulations. In the case of metal cleaning applications, alternatives to these chlorinated solvents which might be appropriate for many current applications including aqueous cleaning as well as other non-chlorinated solvents.

The electronics industry consumes CFC-113 to remove solder flux from printed circuit boards, to degrease semiconductors, to manufacture etchant gases, to degrease printed circuit boards in storage media manufacture, and in other ways. Viable alternatives exist for each of these uses. Beginning in the short term and expanding over the longer term, the use of aqueous cleaning and flux that does not require cleaning appears most promising. EPA convened a panel of experts in this field and they reported that it is technically possible to eliminate up to 90 percent of current CFC-113 use in non-surface mount applications by substituting aqueous cleaning. The remaining 10 percent depends on non-aqueous cleaners because of design choices that can be changed over time. An important step in facilitating the use of aqueous and non-clean fluxes may involve working with the U.S. military to review its current solvent and solder specifications to facilitate the use of these alternatives where appropriate.

d. *Flexible Foam.* This industry group includes makers of polyurethane foam slabstock used primarily for bedding and mattresses. CFC-11 is used as an auxiliary blowing agent in that segment of the industry which produces less expensive, low density or supersoft foams. Many producers now use methylene chloride to make similar foam products. However, because of toxicity concerns and the possibility of more stringent regulations both inside and outside the workplace, it is unlikely that many firms will elect to switch to this alternative blowing agent.

No alternative technologies or chemical substitutes currently appear as the likely replacements for use of CFC-11 in blowing flexible foam. Instead, in the near-term it is possible that the very softest, lowest density foams will be replaced by firmer foams blown without an auxiliary agent. Over the longer-term, depending on its price, HCFC-123 may become a viable replacement for CFC-11 blown foam. This chemical appears to be a possible replacement for CFC-11 in many foam applications. It has similar industrial properties and initial tests suggest that it might be an effective substitute blowing agent. HCFC-123 has a substantially shorter lifetime than CFC-11 and therefore has not been included under the chemicals covered by this proposal. However, additional toxicity tests will be required before widespread use is possible and the costs of this substitute are likely to be approximately 2 times to 3 times the current price of CFC-11. Like HFC-134a, this chemical should be commercially available in 5 years to 6 years assuming no major problems are encountered.

In addition to slabstock foam, flexible molded foam blown with CFC-11 is used primarily in seat and back cushions by auto manufacturers and also in some furniture uses. Several companies have stated that they currently do not use CFC-11 as an auxiliary blowing agent; they have shifted to water blown foam. Other companies have noted that within three months they will also shift out of CFC use and into water blown foams.

e. *Commercial and Residential Refrigeration.* As was the case with air conditioning, over the last few years, commercial refrigeration has moved in the direction of shifting some uses from CFC-12 to HCFC-22, CFC-502, CFC-502 and other refrigerants. This trend is likely to continue in the area of commercial refrigeration. Manufacturers can also further reduce emissions from leak testing and rework. Increased recovery at reworking, venting and disposal will also reduce the use of CFCs. Over the longer term, HFC-134a appears promising as a means of eliminating this use of CFC-12.

For home refrigerators, the same substitute may prove feasible. In addition, home appliances might be produced using a modified sterling cycle or other technology that does not use CFC as its refrigerant. CFC-500, which has as ozone-depleting potential of 0.7, can be used in some appliances such as dehumidifiers.

f. *Rigid Insulating Foam.* CFC-11 is widely used as a foam blowing agent to make various forms of insulating foam (e.g., polyurethane, isocyanurate, phenolic, etc.). Its molecular weight and low thermal conductivity make CFC-11 an excellent chemical in the manufacture of highly efficient insulating materials used for roofs, walls, and foundations.

In the near-term, this use of CFCs may not be significantly reduced because of its utility in saving energy (and meeting code requirements) and because no substitute blowing agents are available. However, some product substitutes may make inroads into its current market. Over the longer-term, HCFC-123 may become an attractive means of reducing this use of CFC-11.

g. *Rigid Packaging Foam.* CFC-12 is used as a blowing agent in the manufacture of polystyrene foam which is widely used in the food packaging industry. CFC-12 currently competes with pentane as a blowing agent for producing this foam with each capturing about 50 percent of the market.

Because of pentane's potential problems with flammability and air pollution, many firms now using CFC-12 will not want to incur the substantial costs of shifting to this chemical. Instead, recent process development efforts have demonstrated that HCFC-22 can effectively be used as an alternate blowing agent. Industry estimates suggest that only minimal costs would be incurred in converting a plant from CFC-12 to HCFC-22 (on the order of $50,000 to $100,000) and that operating costs and efficiencies will not be significantly affected. An application was recently approved by the Food and Drug Administration granting non-objection (e.g., a ruling that the proposed product for a particular use does not differ materially from an already approved product) to the use of HCFC-22 blown foam in fast food packaging.

h. *Total Flooding Fire Extinguishant Systems.* Halon 1301 is used almost exclusively as the agent in total flooding systems used to protect computer centers, document rooms, libraries, military installations, etc. Because it is nontoxic (which allows it to be discharged without evacuating the facility) and because it does not leave a residue, its provides an extremely useful function in protecting high value property.

In response to recent concerns about the role of halons as a potential ozone-depleting substance, the industry has initiated a series of steps to better understand and reduce any unnecessary emissions of this gas. For example, the industry decided not to require mandatory discharge testing of new systems as part of a review of its fire protection code. It is exploring the development of alternative test gases and ways to limit discharges from false alarms. It also conducted an industry-wide survey to determine current uses and sources of emissions and is exploring ways to track halons from the time of production to their release as basis for possibly shifting to an emissions (instead of production) based regulatory regime.

In the near term, the voluntary emission reduction steps described above might provide ample room for continued growth in the number of systems assuming substantial reductions from unnecessary testing and false alarms can be realized. Over the longer term, alternate chemicals may be developed, more efficient use of these chemicals may be possible (e.g., shifting from 1301 total flooding systems to more directed, less depleting 1211 systems), or the industry may be capable of demonstrating that an emissions based regulatory system is a viable means of protecting the environment while continuing the use of these chemicals.

i. *Halon Fire Extinguishers.* Halon 1211 is used extensively in wheeled and handheld portable fire extinguishers. These extinguishers are used in situations where human exposure to the agent is possible (e.g., airplanes) or where concerns exist about harm from residues from other agents (e.g., computers). At the same time, these extinguishers have recently penetrated the broader consumer market and some percentage are now being purchased and used for applications where other agents would be adequate.

In addition, the major user of Halon 1211 is the military as part of its training exercises. The U.S. military has already initiated a review of possible steps to reduce unneccesary steps from training and is also working on developing alternative fire-fighting agents.

j. *Sterilization.* CFC-12 in combination with ethylene oxide (EO) (in a 12/88 blend) is widely used by hospitals, medical equipment manufacturers and contractors for sterilizing equipment. While 30 percent of the commercial market and majority of hospitals now use this CFC/EO blend, other options are currently feasible.

Hospitals could shift to a blend of carbon dioxide and ethylene oxide and totally eliminate their use of CFC-12. While this shift requires that a chamber be able to withstand higher pressure and may involve a longer processing time, neither of these concerns are expected to create problems for most hospitals.

Because of their higher volume use, commercial sterilizers could economically increase their recapture and recovery of CFC-12 through the addition of carbon adsorption or refrigerated condensors. In turn, hospitals could elect to increase their reliance on contract sterilizers as an alternative to shifting to carbon dioxide/ethylene oxide mix.

Sterilization using cobalt radiation has recently achieved a growing share of the market and offers another attractive alternative to current use of CFC-12 in this application. Other methods of sterilization such as electron beam and alternative chemicals are also possible over a longer time period.

Finally, EPA is also seeking comment on the desirability of requiring that products produced with the controlled substances be labelled. This requirement would provide useful information for consumers. By making it possible for consumers to distinguish between those spraycans that contained CFCs and those that did not, it was an effective part of the regulatory program limiting this use of CFCs in 1978. Labelling requirements could be used as

an adjunct to any of the other regulatory options described above.

VII. Impact of Proposed Action

A. Reductions in Ozone Depletion

The proposed regulation would substantially reduce the threat of stratospheric ozone depletion and the accompanying risks to human health and the environment. As shown earlier in Table 4, in the absence of any regulation, a continuation of current trends in the use of ozone-depleting chemicals could result in a global average of 12 percent depletion by 2050 and as much as 40 percent depletion by 2075.

By reducing consumption of the most potent ozone-depleting CFCs in approximately a decade by 50 percent from 1986 levels and by freezing consumption of halons 1211, 1301, and 2402, the projected depletion of ozone would be substantially eliminated. Based on current models, these limitations (assuming a significant portion of other nations take similar steps) would result in depletion estimates of 1.6 percent by 2050 and under 1.4 percent by 2075.

Given the large uncertainties concerning current atmospheric models, the rates of growth of other trace gases, and reduction steps by other nations, EPA's proposed action represents a reasonable near-term strategy for safeguarding the ozone layer. However, as we develop a better understanding of these factors, EPA intends to periodically reassess its actions. The Agency also intends to participate in similar reassessments conducted under the auspices of the Montreal Protocol.

B. Economic Impact

In its regulatory impact analysis, EPA has examined the potential costs (in terms of U.S. industry) and health and environmental benefits also limited to the U.S. which are likely to result from the proposed action. The analysis assumes that a large portion of other developed and developing nations join with the United States in reducing their consumption and production of the controlled substances.

Given the nature of this issue, the RIA necessarily covers a broad range of areas. On the costs side, this analysis covers eight major industrial groupings: refrigeration; air conditioning; flexible foam; rigid foam; solvent cleaning; sterilization; miscellaneous; and fire extinguishant. The RIA contains information on over 650 different control options for limiting use of CFCs and halons within these industrial groupings.

The potential benefits from limiting the amount of future depletion also cover a broad range of health and environmental concerns. An increase in the quantity of damaging ultraviolet radiation flux would represent a major change in one of the basic environmental parameters potentially affecting to varying degrees most forms of biological life. While research to date on the effects of increased exposure to UV-B radiation has been limited, the RIA explores several specific potential areas of damage, only some of which can be quantified with currently available information.

1. Economic Costs of Reductions

EPA used a bottom-up approach in analyzing the costs of meeting the proposed regulation. As described above, studies were initiated in eight major CFC and halon use categories. These groupings were then further divided into 82 specific applications. For example, refrigeration was divided into 18 categories including retail food, home refrigerators, refrigerated transport, etc. Finally costs and emission reduction estimates were developed for over 650 distinct control options covering the full range of use applications. These options included engineering controls, chemical substitutes, product substitutes, recovery and recycling, and work practices. Cost estimates included capital and operating expenses (including, where applicable, any energy penalty). Technologies were assessed in terms of the date at which they would be available (0–3 years, 4–7 years, or longer), and the rate and limits for achieving market penetration.

The cost estimates for these reductions were used as the input for the Integrated Assessment Model (IAM) which provided estimates of the total cost of meeting a regulatory goal. The model operates by prioritizing the potential reductions on the basis of least cost and the judgment of EPA's contractors based on discussion with industry representatives concerning the likely response to regulations on the part of specific industry sectors.

The output from the model provides an estimate of the total social costs for meeting a required level of reductions, the CFC or halon price increases which would likely accompany such costs, and the amount of transfers which would be involved. Table 5 contains these estimates for proposed regulation under four different assumptions concerning the rate at which firms respond to changes in market conditions resulting from restrictions on the regulated chemicals.

The "least cost" scenario assumes that all reductions are taken as soon as they are technologically available and as soon as the cost of CFCs or halons exceed the cost of making the reduction. In this scenario, CFC price increases are minimal in the early years, rise to $3.77/kg around the turn of the century and plateau around $5.48/kg well before 2075 when chemical substitutes have penetrated major markets.

The low initial cost increases reflect the large quantity of CFC and halon reductions that are available with current technologies and which either will save firms money (e.g., through additional CFC or halon recovery) or which are competitive. In the latter years of the analysis, the $5.48 price ceiling reflects the anticipated costs of alternative chemicals (e.g., primarily HFC-134a replacing CFC-12 and HCFC-123 replacing CFC-11 in foam applications) which could replace large quantites of current CFC use. In the least cost scenario, total social costs were calculated to be $689 million through 2000 and $27 billion through 2075 (all social costs assume a 2 percent discount rate).

In contrast to the "least cost" case, the other scenarios assume varying degrees of delay in implementation of steps to reduce CFC and halon use. Firms might delay their response for any of several reasons: They lack information about the availability or applicability of a technology; they are less concerned about minimizing costs in the short-run because they can pass on price increases to consumers; they may lack access to capital to make a shift to a lower cost technology; or they may assume a high "hurdle rate" (i.e., the desired return on capital for any new investments) for capital committed to pollution control.

The costs of meeting the proposed regulation under these alternative scenarios is also shown in Table 5. The social costs calculated from the IAM through 2000 ranged from $1.1 billion to $1.8 billion depending on the rate at which firms implemented low cost reductions. The CFC price increase which would accompany these costs in all scenarios reached $5.48/kg just before the turn of the century. However, the range of transfer costs during this time period (1989–2000) was much wider, reflecting different price increase in the initial years. In the "moderate stretchout" case transfers through 2075 totaled $7.15 billion, while in the "major stretchout" case transfers totaled $9.4 billion.

Thus, the rate at which firms implement low cost reductions is an

important determinant, particularly in the near-term, of the costs and transfer payments involved in meeting the proposed regulations.

As part of analyzing the economic costs of reducing CFC and halon use, the RIA also takes into consideration possible impacts of the proposed regulation on energy use. CFCs are used in a wide range of energy-related areas including insulation for buildings and appliances. Its thermal efficiency also affects energy consumption of refrigerators and other appliances.

Based on the analysis in the RIA, no significant increases in energy consumption or costs are likely to occur. In the near-term, CFCs are still likely to be used in major appliances. In the case of insulation, building and energy codes generally require a set level of energy efficiency which will either continue to be satisfied by CFC-blown foam or by other insulating materials (e.g. fiberglass). In the longer-term, substitute blowing agents are likely to be developed and formulations modified to maintain current insulating values.

2. Health and Environmental Benefits

The RIA also contains a description of the potential benefits that would result from actions to limit the risks from ozone depletion. In some of the health and environmental areas, sufficient research has been completed to provide a basis for a dose response relationship which can be used for calculating potential benefits. Examples of these areas include nonmelanoma and melanoma skin cancer, and cataracts. In other areas, research on UV-B radiation effects primarily has taken the form of case studies. For example, research on plant effects has progressed the furthest on soy beans, while research on aquatic effects has examined potential impacts on anchovies. In these and similar areas (e.g., increased groundlevel ozone formation and sea level rise impacts), the RIA quantifies benefits based on an extrapolation from existing case studies. Finally, in several areas, initial studies have clearly shown that increased UV-B radiation will cause damage, but not enough information exists to quantify those impacts. Examples include suppression of the immune system and climate related impacts on water resources, agriculture, forests, etc. A detailed decription of the derivation of the benefits estimates are included in volumes 1 and 2 of the RIA.

Table 7 summarizes estimates of the economic benefits which would result from the proposed actions to prevent future depletion of the ozone layer. These benefits reflect the difference between the base case (no regulation) described in Section IV and the "CFC 50%, Halon Freeze" case which forms the basis for this proposed regulation.

It should be stated that projecting benefits out to the year 2075 is a very speculative exercise at best (but is required because of the long atmospheric lifetime of these chemicals). The estimates are subject to substantial uncertainties both in the calculation of the dose-response effects, and in the economic values placed on such effects. Due to this enormous uncertainty, the benefits have been estimated in ranges.

TABLE 7.—SUMMARY OF BENEFITS FROM PROPOSED REGULATION*

	Reference scenario
Effects.	
Skin cancer cases	154.43 million cases.
Skin cancer deaths	3.14 million cases.
Cataract cases	17.6 million cases
*Valuation.***	
Value of skin cancer cases	$61.3 billion
(low and high sensitivity)	($1.5 bill.–$205 bill.)
Value of skin cancer deaths.	$6.35 trillion.
(low and high sensitivity)	($17.4 bill.–$342 trl.)
Value of cataract cases	$2.57 billion.
(low and high sensitivity)	($72 mill.–$7.8 bill.).
Damage to crops	$23.4 billion.
(low and high sensitivity)	($2.3 bill.–$46 bill.).
Damage to fish	$5.5 billion.
(low and high sensitivity)	($3 bill.–$11.4 bill.).
Damage to crops from ground level ozone.	$12.4 billion.
(low and high sensitivity)	($1.1 bill.–$24.9 bill.).
Damage to polymers	$3.12 billion.
(low and high sensitivity)	($221 mill.–$6.3 bill.).
Sea level rise damage to major ports.	$4.3 billion.
Total monetary benefits:	$6.3 trillion.
(low and high sensitivity)	($29 bill. to $340 tril.).

* Shows value of avoided damage relative to "no regulation" For populations alive today and born before 2075.

** Ranges for damage valuation reflect the following scenarios: the high scenario assumes a 1 percent discount rate and a $4 million value of life which increases by 3.4 percent per year The low scenario assumes a 6 percent discount rate and a $2 million value of life which increases by 0.85 percent per year The medium scenario assumes a 2 percent discount rate and a $3 million value of life which increases by 1.7 percent per year.

Health effects (skin cancer incidence and mortality, and cataract incidence modeled based on dose-response estimates presented in EPA (1987). Crop estimates presented for grain crops based only on dose response developed for soy beans. Damage to fish estimated for commercial harvest of fin and shell fish based on dose response developed for anchovies. Polymer estimates based on dose response models developed for PVC and extended to include acrylics and polyesters. Damage to crops from ground level ozone based on case studies of 3 U.S. cities and a national crop loss model See level rise estimates assume anticipatory action to lessen damages, but only includes storm damage to major ports based on limited case studies.

The total benefits through 2075 were estimated to be between $29 billion and $340 trillion (benefit estimates were discounted over a range of 1 percent to 6 percent annually). The majority of these benefits resulted from decreases in the number of deaths from skin cancer which is an area where effects research has progressed the furthest. The skin cancer benefit estimates, however, assume no improvement in our ability to treat skin cancer. If a cure for cancer were discovered, these benefits would decrease enormously. Because more limited research has been undertaken in the area of potential damage to crops and aquatic organisms, the estimates of potential benefits for these areas are also uncertain. In its report to EPA, the Science Advisory Board stated that it believed that damage related to these areas could prove to be of greater global magnitude than harm from skin cancers.

3. Comparison of Costs and Benefits

Based on the analysis presented above and detailed in the RIA, the estimated benefits from the proposed regulation would far exceed the estimated costs. Table 8 summarizes these benefits and costs. It shows that for those areas where quantification was possible, benefits would total from $29 billion to $340 trillion for the period 1989–2075. In comparison, costs of reducing CFCs and halons called for by the proposed regulation for the same period would total approximately $27 billion. Table 9 illustrates the extreme sensitivity of this analysis to specific individual assumptions about discount rates and the valuation of life. Additional sensitivities are included in the RIA.

TABLE 8.—COMPARISON OF COSTS AND BENEFITS THROUGH 2075 by Scenario

[Billions of 1985 dollars]

	Health and environmental benefits	Costs	Net benefits
No Controls:			
CFC Freeze	5,995	7	5,988
(low)	16	0.7	15
(high)	324,000	12	323,988
CFC 20%	6,132	12	6,120
(low)	17	2	15
(high)	330,000	21	229,979
CFC 50%	6,299	24	6,275
(low)	18	5	13
(high)	339,000	41	338,959
CFC 80%	6,400	31	6,369
(low)	19	7	12
(high)	341,000	51	340,949
CFC 50%/ Halon freeze	6,463	27	6,436
(low)	19	5	14
(high)	345,000	46	344,954
CFC 50%/ Halon freeze/U.S. 80%	6,506	34	6,472
(low)	19	7	12
(high)	346,000	56	345,944
U.S. only CFC 50%	2,852	27	2,825
(low)	8	5	3
(high)	135,000	46	134,954

All dollar values reflect the difference between the No Controls Scenario and

the specified alternative scenario. Valuation of the health and environmental benefits applies only to people born before 2075; costs are estimated through 2075.

Ranges for damage valuation reflect the following scenarios: the high scenario assumes a 1 percent discount rate and a $4 million value of life which increases by 3.4 percent per year. The low scenario assumes a 6 percent discount rate and a $2 million value of life which increases by 0.85 percent per year. The medium scenario assumes a 2 percent discount rate and a $3 million value of life which increases by 1.7 percent per year.

Source: EPA Regulatory Impact Analysis, 1987.

TABLE 9.—SUMMARY OF RESULTS OF SENSITIVITY ANALYSES FOR COSTS AND MAJOR HEALTH BENEFITS FOR PEOPLE BORN BEFORE 2075

Sensitivity	Ozone depletion by 2075 (percent)	Value of lives lost (10^9)	Control costs (10^9)	Net present value of benefits—costs (10^9)
1 Base case (assumes a two percent discount rate)				
No controls	39 9	6,499		
Protocol	1 3	150	27	
Difference	38 6	6,349	27	6,322
2 Discount rates				
A. 1 percent				
No controls	39 9	24 650		
Protocol	1 3	388	46	
Difference	38 6	24,262	46	24 216
B. 6 percent				
No controls	39 9	71		
Protocol	1 3	9	5	
Difference	38 6	62	5	57
3. Value of life				
A. $2 million				
No controls	39.9	4,333		
Protocol	1.3	100	27	
Difference	38 6	4,233	27	4,206
B $4 million				
No controls	39 9	8 667		
Protocol	1 3	225	27	
Difference	38 6	8,442	27	8,415

Source EPA Regulatory Impact Analysis, 1987

VIII. Additional Information

A. Executive Order 12291

Executive Order (E.O.) 12291 requires the preparation of a regulatory impact analysis for major rules, defined by the order as those likely to result in:

(1) An annual effect on the economy of $100 million or more:

(2) A major increase in costs or prices for consumers, individual industries, Federal, State, or local government agencies, or geographic industries; or

(3) Significant adverse effects on competition, employment, investment, productivity, innovation, or on the ability of United States-based enterprises to compete with foreign-based enterprises in domestic or export markets.

EPA has determined that this proposed regulation meets the definition of a major rule under E.O. 12291, and has prepared a regulatory impact analysis (RIA). That document, along with this notice of proposed rulemaking, has been submitted to the Office of Management and Budget (OMB) for review under Executive Order 12291. Any comments from OMB and any EPA responses to such comments are available for public inspection at the Central Docket Section, South Conference Room 4, Docket No. A-87-20, U.S. Environmental Protection Agency, 401 M Street SW., Washington, DC 20460. A copy of the RIA has also been placed in the rulemaking docket.

B. Regulatory Flexibility Act

The Regulatory Flexibility Act, 5 U.S.C. 601-612, requires that Federal agencies examine the impacts of their regulations on small entities. Under 5 U.S.C. 604(a), whenever an agency is required to publish a general notice of proposed rulemaking, it must prepare and make available for public comment an initial regulatory flexibility analysis (RFA). Such an analysis is not required if the head of an agency certifies that a rule will not have a significant economic impact on a substantial number of small entities, pursuant to 5 U.S.C. 605(b). EPA has prepared an initial regulatory flexibility analysis for the regulations proposed in this notice, and this initial RFA has been placed in the rulemaking docket.

The initial RFA concluded that of the many industries potentially affected by the proposed regulation, the foam blowers were the only group that could be substantially affected based on the criteria contained in EPA guidelines on preparation of an RFA. For their industries, because CFCs are such a minor portion of total product costs, price increases of the magnitude anticipated by this regulation would not result in significant economic impacts.

The preliminary RFA suggests that different segments of the foamblowing industry are likely to be affected to different extents depending on the availability of chemical substitutes versus alternative products. For example, the polystyrene foam blowers may be able to shift from CFC-12 to HCFC-22 without incurring large capital costs and therefore would remain competitive with paper and other forms of packaging. In the case of rigid foam, price increases may cause some loss of market share to non-CFC blown foam or to other materials. Due to data limitations and the inability to accurately model behavioral changes, the number of firms that might go out of business versus the number that would shift to providing other insulating material could not be determined.

In designing and evaluating its regulatory options, EPA sought to minimize the burdens placed on small firms. In addition, the proposed hybrid approach (allocated quotas plus targetted regulations) would further reduce potential increases in CFC prices and thereby reduce the impact on the foamblowing industry. Because foam blowing is one of the major uses of CFCs, providing foam blowers with set asides and outright exemptions would have substantial impacts on efforts to protect the ozone layer or substantially increase costs to other industries.

C. Paperwork Reduction Act

The information collection requirements in this proposed rule will be submitted for approval to the Office of Management and Budget (OMB) under the Paperwork Reduction Act of 1980, 44 U.S.C. 3501 *et seq.* Comments on these requirements should be submitted to the Office of Information and Regulatory Affairs, OMB, 726 Jackson Place, Washington, DC 20530 marked "Attention: Desk Officer for EPA." The final rule will respond to any OMB or public comments on the information collection requirements.

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Date: December 1, 1987.

Lee M. Thomas,

Administrator.

United Nations Environment Programme

MONTREAL PROTOCOL ON SUBSTANCES THAT DEPLETE THE OZONE LAYER

Final Act, 1987

Montreal Protocol on Substances That Deplete the Ozone Layer

The Parties to this Protocol,

Being Parties to the Vienna Convention for the Protection of the Ozone Layer,

Mindful of their obligation under that Convention to take appropriate measures to protect human health and the environment against adverse effects resulting or likely to result from human activities which modify or are likely to modify the ozone 1 year,

Recognizing that world-wide emissions of certain substances can significantly deplete and otherwise modify the ozone layer in a manner that is likely to result in adverse effects on human health and the environment,

Conscious of the potential climatic effects of emissions of these substances,

Aware that measures taken to protect the ozone layer from depletion should be based on relevant scientific knowledge, taking into account technical and economic considerations,

Determined to protect the ozone layer by taking precautionary measures to control equitably total global emissions of substances that deplete it, with the ultimate objective of their elimination on the basis of developments in scientific knowledge, taking into account technical and economic considerations,

Acknowledging that special provision is required to meet the needs of developing countries for these substances,

Noting the precautionary measures for controlling emissions of certain chlorofluorocarbons that have already been taken at national and regional levels,

Considering the importance of promoting international co-operation in the research and development of science and technology relating to the control and reduction of emissions of substances that deplete the ozone layer, bearing in mind in particular the needs of developing countries,

Have agreed as follows:

Article I: Definitions

For the purposes of this Protocol:

1. "Convention means the Vienna Convention for the Protection of the Ozone Layer, adopted on 22 March 1985.

2. "Parties" means, unless the text otherwise indicates, Parties to this Protocol.

3. "Secretariat" means the secretariat of the Convention.

4. "Controlled substance" means a substance listed in Annex A to this Protocol, whether existing alone or in a mixture. It excludes, however, any such substance or mixture which is in a manufactured product other than a container used for the transportation or storage of the substance listed.

5. "Production" means the amount of controlled substances produced minus the amount destroyed by technologies to be approved by the Parties.

6. "Consumption" means production plus imports minus exports of controlled substances

7. "Calculated levels" of production, imports, exports and consumption means levels determined in accordance with Article 3

8. "Industrial rationalization" means the transfer of all or a portion of the calculated level of production of one Party to another, for the purpose of achieving economic efficiencies or responding to anticipated shortfalls in supply as a result of plant closures.

Article 2: Control Measures

1. Each Party shall ensure that for the twelve-month period commencing on the first day of the seventh month following the date of the entry into force of this Protocol, and in each twelve-month period thereafter, its calculated level of consumption of the controlled substances in Group I of Annex A does not exceed its calculated level of consumption in 1986. By the end of the same period, each Party producing one or more of these substances shall ensure that its calculated level of production of the substances does not exceed its calculated level of production in 1986, except that such level may have increased by no more than ten per cent based on the 1986 level. Such increase shall be permitted only so as to satisfy the basic domestic needs of the Parties operating under Article 5 and for the purposes of industrial rationalization between Parties.

2. Each Party shall ensure that for the twelve-month period commencing on the first day of the thirty-seventh month following the date of the entry into force of this Protocol, and in each twelve-month period thereafter, its calculated level of consumption of the controlled substances listed in Group II of Annex A does not exceed its calculated level of consumption in 1986. Each Party producing one or more of these substances shall ensure that its calculated level of production of the substances does not exceed its calculated level of production in 1986, except that such level may have increased by no more than ten per cent based on the 1986 level. Such increase shall be permitted only so as to satisfy the basic domestic needs of the Parties operating under Article 5 and for the purposes of industrial rationalization between Parties. The mechanisms for implementing these measures shall be decided by the Parties at their first meeting following the first scientific review.

3. Each Party shall ensure that for the period 1 July 1993 to 30 June 1994 and in each twelve-month period thereafter, its calculated level of consumption of the controlled substances in Group I of Annex A does not exceed, annually, eighty per cent of its calculated level of consumption in 1986. Each Party producing one or more of these substances shall, for the same periods, ensure that its calculated level of production of the substances does not

exceed, annually, eighty per cent of its calculated level of production in 1986. However, in order to satisfy the basic domestic needs of the Parties operating under Article 5 and for the purposes of industrial rationalization between Parties, its calculated level of production may exceed that limit by up to ten per cent of its calculated level of production in 1986.

4. Each Party shall ensure that for the period 1 July 1998 to 30 June 1999, and in each twelve-month period thereafter, its calculated level of consumption of the controlled substances in Group I of Annex A does not exceed, annually, fifty per cent of its calculated level of consumption in 1986. Each Party producing one or more of these substances shall, for the same periods, ensure that its calculated level of production of the substances does not exceed, annually, fifty per cent of its calculated level of production in 1986. However, in order to satisfy the basic domestic needs of the Parties operating under Article 5 and for the purposes of industrial rationalization between Parties, its calculated level of production may exceed that limit by up to fifteen per cent of its calculated level of production in 1986. This paragraph will apply unless the Parties decide otherwise at a meeting by a two-thirds majority of Parties present and voting, representing at least two-thirds of the total calculated level of consumption of these substances of the Parties. This decision shall be considered and made in the light of the assessments referred to in Article 6.

5. Any Party whose calculated level of production in 1986 of the controlled substances in Group I of Annex A was less than twenty-five kilotonnes may, for the purposes of industrial rationalization, transfer to or receive from any other Party, production in excess of the limits set out in paragraphs 1, 3 and 4 provided that the total combined calculated levels of production of the Parties concerned does not exceed the production limits set out in this Article. Any transfer of such production shall be notified to the secretariat, no later than the time of the transfer.

6. Any Party not operating under Article 5, that has facilities for the production of controlled substances under construction, or contracted for, prior to 16 September 1987, and provided for in national legislation prior to 1 January 1987, may add the production from such facilities to its 1986 production of such substances for the purposes of determining its calculated level of production for 1986, provided that such facilities are completed by 31 December 1990 and that such production does not raise that Party's annual calculated level of consumption of the controlled substances above 0.5 kilograms per capita.

7. Any transfer of production pursuant to paragraph 5 or any addition of production pursuant to paragraph 6 shall be notified to the secretariat, no later than the time of the transfer or addition.

8. (a) Any Parties which are Member States of a regional economic integration organization as defined in Article 1(6) of the Convention may agree that they shall jointly fulfill their obligations respecting consumption under this Article provided that their total combined calculated level of consumption does not exceed the levels required by this Article.

(b) The Parties to any such agreement shall inform the secretariat of the terms of the agreement before the date of the reduction in consumption with which the agreement is concerned.

(c) Such agreement will become operative only if all Member States of the regional economic integration organization and the organization concerned are Parties to the Protocol and have notified the secretariat of their manner of implementation.

9. (a) Based on the assessments made pursuant to Article 6, the Parties may decide whether:

(i) adjustments to the ozone depleting potentials specified in Annex A should be made and, if so, what the adjustments should be; and

(ii) further adjustments and reductions of production or consumption of the controlled substances from 1986 levels should be undertaken and, if so, what the scope, amount and timing of any such adjustments and reductions should be.

(b) Proposals for such adjustments shall be communicated to the Parties by the secretariat at least six months before the meeting of the Parties at which they are proposed for adoption.

(c) In taking such decisions, the Parties shall make every effort to reach agreement by consensus. If all efforts at consensus have been exhausted, and no agreement reached, such decisions shall, as a last resort, be adopted by a two-thirds majority vote of the Parties present and voting representing at least fifty per cent of the total consumption of the controlled substances of the Parties.

(d) The decisions, which shall be binding on all Parties, shall forthwith be communicated to the Parties by the Depositary. Unless otherwise provided in the decisions, they shall enter into force on the expiry of six months from the date of the circulation of the communication by the Depositary.

10. (a) Based on the assessments made pursuant to Article 6 of this Protocol and in accordance with the procedure set out in Article 9 of the Convention, the Parties may decide:

(i) Whether any substances, and if so which, should be added to or removed from any annex to this Protocol; and

(ii) The mechanism, scope and timing of the control measures that should apply to those substances;

(b) Any such decision shall become effective, provided that it has been accepted by a two-thirds majority vote of the Parties present and voting.

11. Notwithstanding the provisions contained in this Article, Parties may take more stringent measures than those required by this Article.

Article 3: Calculation of Control Levels

For the purposes of Articles 2 and 5, each Party shall, for each Group of substances in Annex A, determine its calculated levels of:

(a) Production by:

(i) Multiplying its annual production of each controlled substance by the ozone depleting potential specified in respect of it in Annex A; and

(ii) Adding together, for each such Group, the resulting figures;

(b) Imports and exports, respectively, by following, *mutatis mutandis*, the procedure set out in subparagraph (a); and

(c) Consumption by adding together its calculated levels of production and imports and subtracting its calculated level of exports as determined in accordance with subparagraphs (a) and (b). However, beginning on 1 January 1993, any export of controlled substances to non-Parties shall not be subtracted in calculating the consumption level of the exporting Party.

Article 4: Control of Trade With Non-Parties

1. Within one year of the entry into force of this Protocol, each Party shall ban the import of controlled substances from any State not party to this Protocol.

2. Beginning on 1 January 1993, no Party operating under paragraph 1 of Article 5 may export any controlled substance to any State not party to this Protocol.

3. Within three years of the date of the entry into force of this Protocol, the Parties shall, following the procedures in Article 10 of the Convention, elaborate in an annex a list of products containing controlled substances. Parties that have

not objected to the annex in accordance with those procedures shall ban, within one year of the annex having become effective, the import of those products from any State not party to this Protocol.

4. Within five years of the entry into force of this Protocol, the Parties shall determine the feasibility of banning or restricting, from States not party to this Protocol, the import of products produced with, but not containing, controlled substances. If determined feasible, the Parties shall, following the procedures in Article 10 of the Convention, elaborate in an annex a list of such products. Parties that have not objected to it in accordance with those procedures shall ban or restrict, within one year of the annex having become effective, the import of those products from any State not party to this Protocol.

5. Each Party shall discourage the export, to any State not party to this Protocol, of technology for producing and for utilizing controlled substances.

6. Each Party shall refrain from providing new subsidies, aid, credits, guarantees or insurance programmes for the export to States not party to this Protocol of products, equipment, plants or technology that would facilitate the production of controlled substances.

7. Paragraphs 5 and 6 shall not apply to products, equipment, plants or technology that improve the containment, recovery, recycling or destruction of controlled substances, promote the development of alternative substances, or otherwise contribute to the reduction of emissions of controlled substances.

8. Notwithstanding the provisions of this Article, imports referred to in paragraphs 1, 3 and 4 may be permitted from any State not party to this Protocol if that State is determined, by a meeting of the Parties, to be in full compliance with Article 2 and this Article, and has submitted data to that effect as specified in Article 7.

Article 5: Special Situation of Developing Countries

1. Any Party that is a developing country and whose annual calculated level of consumption of the controlled substances is less than 0.3 kilograms per capita on the date of the entry into force of the Protocol for it, or any time thereafter within ten years of the date of entry into force of the Protocol shall, in order to meet its basic domestic needs, be entitled to delay its compliance with the control measures set out in paragraphs 1 to 4 of Article 2 by ten years after that specified in those paragraphs. However, such Party shall not exceed an annual calculated level of consumption of 0.3 kilograms per capita. Any such Party shall be entitled to use either the average of its annual calculated level of consumption for the period 1995 to 1997 inclusive or a calculated level of consumption of 0.3 kilograms per capita, whichever is the lower, as the basis for its compliance with the control measures.

2. The Parties undertake to facilitate access to environmentally safe alternative substances and technology for Parties that are developing countries and assist them to make expeditious use of such alternatives.

3. The Parties undertake to facilitate bilaterally or multilaterally the provision of subsidies, aid, credits, guarantees or insurance programmes to Parties that are developing countries for the use of alternative technology and for substitute products.

Article 6: Assessment and Review of Control Measures

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.

Article 7: Reporting of Data

1. Each Party shall provide to the secretariat, within three months of becoming a Party, statistical data on its production, imports and exports of each of the controlled substances for the year 1986, or the best possible estimates of such data where actual data are not available.

2. Each Party shall provide statistical data to the secretariat on its annual production (with separate data on amounts destroyed by technologies to be approved by the Parties), imports, and exports to Parties and non-Parties, respectively, of such substances for the year during which it becomes a Party and for each year thereafter. It shall forward the data no later than nine months after the end of the year to which the data relate.

Article 8: Non-Compliance

The Parties, at their first meeting, shall consider and approve procedures and institutional mechanisms for determining non-compliance with the provisions of this Protocol and for treatment of Parties found to be in non-compliance.

Article 9: Research, Development, Public Awareness and Exchange of Information

1. The Parties shall co-operate, consistent with their national laws, regulations and practices and taking into account in particular the needs of developing countries, in promoting, directly or through competent international bodies, research, development and exchange of information on:

(a) Best technologies for improving the containment, recovery, recycling or destruction of controlled substances or otherwise reducing their emissions;

(b) Possible alternatives to controlled substances, to products containing such substances, and to products manufactured with them; and

(c) Costs and benefits of relevant control strategies.

2. The Parties, individually, jointly or through competent international bodies, shall co-operate in promoting public awareness of the environmental effects of the emissions of controlled substances and other substances that deplete the ozone layer.

3. Within two years of the entry into force of this Protocol and every two years thereafter, each Party shall submit to the secretariat a summary of the activities it has conducted pursuant to this Article.

Article 10: Technical Assistance

1. The Parties shall, in the context of the provisions of Article 4 of the Convention, and taking into account in particular the needs of developing countries, co-operate in promoting technical assistance to facilitate participation in and implementation of this Protocol.

2. Any Party or Signatory to this Protocol may submit a request to the secretariat for technical assistance for the purposes of implementing or participating in the Protocol.

3. The Parties, at their first meeting, shall begin deliberations on the means of fulfilling the obligations set out in Article 9, and paragraphs 1 and 2 of this Article, including the preparation of workplans. Such workplans shall pay special attention to the needs and circumstances of the developing countries. States and regional economic integration organizations not party to the Protocol should be encouraged to participate in activities specified in such workplans.

Article 11: Meetings of the Parties

1. The Parties shall hold meetings at regular intervals. The secretariat shall convene the first meeting of the Parties

not later than one year after the date of the entry into force of this Protocol and in conjunction with a meeting of the Conference of the Parties to the Convention, if a meeting of the latter is scheduled within that period.

2. Subsequent ordinary meetings of the Parties shall be held, unless the Parties otherwise decide, in conjunction with meetings of the Conference of the Parties to the Convention. Extraordinary meetings of the Parties shall be held at such other times as may be deemed necessary by a meeting of the Parties, or at the written request of any Party, provided that, within six months of such a request being communicated to them by the secretariat, it is supported by at least one third of the Parties.

3. The Parties, at their first meeting, shall:

(a) Adopt by consensus rules of procedure for their meetings;

(b) Adopt by consensus the financial rules referred to in paragraph 2 of Article 13;

(c) Establish the panels and determine the terms of reference referred to in Article 6;

(d) Consider and approve the procedures and institutional mechanisms specified in Article 8; and

(e) Begin preparation of workplans pursuant to paragraph 3 of Article 10.

4. The functions of the meetings of the Parties shall be to:

(a) Review the implementation of this Protocol;

(b) Decide on any adjustments or reductions referred to in paragraph 9 of Article 2;

(c) Decide on any addition to, insertion in or removal from any annex of substances and on related control measures in accordance with paragraph 10 of Article 2;

(d) Establish, where necessary, guidelines or procedures for reporting of information as provided for in Article 7 and paragraph 3 of Article 9;

(e) Review requests for technical assistance submitted pursuant to paragraph 2 of Article 10;

(f) Review reports prepared by the secretariat pursuant to subparagraph (c) of Article 12;

(g) Assess, in accordance with Article 6, the control measures provided for in Article 2;

(h) Consider and adopt, as required, proposals for amendment of this Protocol or any annex and for any new annex;

(i) Consider and adopt the budget for implementing this Protocol; and

(j) Consider and undertake any additional action that may be required for the achievement of the purposes of this Protocol.

5. The United Nations, its specialized agencies and the International Atomic Energy Agency, as well as any State not party to this Protocol, may be represented at meetings of the Parties as observers. Any body or agency, whether national or international, governmental or non-governmental, qualified in fields relating to the protection of the ozone layer which has informed the secretariat of its wish to be represented at a meeting of the Parties as an observer may be admitted unless at least one third of the Parties present object. The admission and participation of observers shall be subject to the rules of procedure adopted by the Parties.

Article 12: Secretariat

For the purposes of this Protocol, the secretariat shall:

(a) Arrange for and service meetings of the Parties as provided for in Article 11;

(b) Receive and make available, upon request by a Party, data provided pursuant to Article 7;

(c) Prepare and distribute regularly to the Parties reports based on information received pursuant to Articles 7 and 9;

(d) Notify the Parties of any request for technical assistance received pursuant to Article 10 so as to facilitate the provision of such assistance;

(e) Encourage non-Parties to attend the meetings of the Parties as observers and to act in accordance with the provisions of this Protocol;

(f) Provide, as appropriate, the information and requests referred to in subparagraphs (c) and (d) to such non-party observers; and

(g) Perform such other functions for the achievement of the purposes of this Protocol as may be assigned to it by the Parties.

Article 13: Financial Provisions

1. The funds required for the operation of this Protocol, including those for the functioning of the secretariat related to this Protocol, shall be charged exclusively against contributions from the Parties.

2. The Parties, at their first meeting, shall adopt by consensus financial rules for the operation of this Protocol.

Article 14: Relationship of This Protocol to the Convention

Except as otherwise provided in this Protocol, the provisions of the Convention relating to its protocols shall apply to this Protocol.

Article 15: Signature

This Protocol shall be open for signature by States and by regional economic integration organizations in Montreal on 16 September 1987, in Ottawa from 17 September 1987 to 16 January 1988, and at United Nations Headquarters in New York from 17 January 1988 to 15 September 1988.

Article 16: Entry Into Force

1. This Protocol shall enter into force on 1 January 1989, provided that at least eleven instruments of ratification, acceptance, approval of the Protocol or accession thereto have been deposited by States or regional economic integration organizations representing at least two-thirds of 1986 estimated global consumption of the controlled substances, and the provisions of paragraph 1 of Article 17 of the Convention have been fulfilled. In the event that these conditions have not been fulfilled by that date, the Protocol shall enter into force on the ninetieth day following the date on which the conditions have been fulfilled.

2. For the purposes of paragraph 1, any such instrument deposited by a regional economic integration organization shall not be counted as additional to those deposited by member States of such organization.

3. After the entry into force of this Protocol, any State or regional economic integration organization shall become a Party to it on the ninetieth day following the date of deposit of its instrument of ratification, acceptance, approval or accession.

Article 17: Parties Joining After Entry Into Force

Subject to Article 5, any State or regional economic integration organization which becomes a Party to this Protocol after the date of its entry into force, shall fulfil forthwith the sum of the obligations under Article 2, as well as under Article 4, that apply at that date to the States and regional economic integration organizations that became Parties on the date the Protocol entered into force.

Article 18: Reservations

No reservations may be made to this Protocol.

Article 19: Withdrawal

For the purposes of this Protocol, the provisions of Article 19 of the Convention relating to withdrawal shall apply, except with respect to Parties referred to in paragraph 1 of Article 5. Any such Party may withdraw from this Protocol by giving written notification to the Depositary at any time after four years of assuming the obligations specified in paragraphs 1 to 4 of Article 2. Any such withdrawal shall take effect

upon expiry of one year after the date of its receipt by the Depositary, or on such later date as may be specified in the notification of the withdrawal.

Article 20: Authentic Texts

The original of this Protocol, of which the Arabic, Chinese, English, French, Russian and Spanish texts are equally authentic, shall be deposited with the Secretary-General of the United Nations.

In witness whereof the undersigned, being duly authorized to that effect, have signed this protocol.

Done at Montreal this sixteenth day of September, One Thousand Nine Hundred and Eighty Seven.

ANNEX A.—CONTROLLED SUBSTANCES

Group	Substance	Ozone depleting potential [1]
Group I:	$CFCl_3$ (CFC-11)	1.0
	CF_2Cl_2 (CFC-12)	1.0
	$C_2F_3Cl_3$ (CFC-113)	0.8
	$C_2F_4Cl_2$ (CFC-114)	1.0
	C_2F_5Cl (CFC-115)	0.6
Group II:	CF_2BrCl (halon-1211)	3.0
	CF_3Br (halon-1301)	10.0
	$C_2F_4Br_2$ (halon-2402)	([2])

[1] These ozone depleting potentials are estimates based on existing knowledge and will be reviewed and revised periodically.
[2] To be determined.

For the reasons set out in the preamble, Part 82 of Title 40 of the Code of Federal Regulations is proposed as follows:

1. The authority citation for Part 82 continues to read as follows:

Authority: 42 U.S.C. 7457(b).

2. Part 82 is amended by adding the following §§ 82.1 through 82.14 and appendices A through D to read as follows:

PART 82—PROTECTION OF STRATOSPHERIC OZONE

Sec.
82.1 Purpose and scope.
82.2 Effective date.
82.3 Definitions.
82.4 Prohibitions.
82.5 Apportionment of baseline production rights.
82.6 Apportionment of baseline consumption rights.
82.7 Grant and phased reduction of baseline production and consumption rights for group I controlled substances.
82.8 Grant and freeze of baseline production and consumption rights for group II controlled substances.
82.9 Allowance for production rights in addition to baseline production rights.
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82.11 Exports to parties.
82.12 Transfers of production and consumption rights.
82.13 Recordkeeping and reporting requirements.
82.14 Payment of fees.
Appendix A to Part 82—Controlled substances and ozone depletion weights.
Appendix B to Part 82—Parties to the Montreal Protocol.
Appendix C to Part 82—Nations complying with, but not party to, the protocol.
Appendix D to Part 82—Twenty-five-kilotonne parties.

Authority: 42 U.S.C. 7457(b).

§ 82.1 Purpose and scope.

(a) The purpose of these regulations is to implement the *Montreal Protocol on Substances that Deplete the Ozone Layer* under authority provided by section 157 of the Clean Air Act. The Montreal Protocol requires each nation that becomes a Party to the Protocol to limit its total production and its consumption (defined as production plus imports minus exports) of certain ozone-depleting substances according to a specified schedule. The Protocol also requires Parties to impose certain restrictions on trade in ozone-depleting substances with nonparties.

(b) This rule applies to any individual, corporate, or governmental entity that produces, imports, or exports controlled substances.

§ 82.2 Effective date.

The regulations under this Part will take effect when the Montreal Protocol enters into force. The Montreal Protocol will enter into force on January 1, 1989, provided that at least 11 instruments of ratification, acceptance, approval of the Protocol or accession thereto have been deposited by States or regional economic integration organizations representing at least two-thirds of 1986 estimated global consumption of the controlled substances, and provided that the Vienna Convention for the Protection of the Ozone Layer has entered into force. If these conditions have not been fulfilled by January 1, 1989, the Protocol will enter into force on the ninetieth day following the date on which the conditions have been fulfilled.

§ 82.3 Definitions.

As used in this Part, the term:

(a) "Administrator" means the Administrator of the Environmental Protection Agency or his authorized representative.

(b) "Baseline consumption rights" means the consumption rights apportioned under Sec. 82.6.

(c) "Baseline production rights" means the production rights apportioned under Sec. 82.5.

(d) "Calculated level" means the level of production, exports or imports of controlled substances determined for each Group of controlled substances by:

(1) Multiplying the amount (in kilograms) of production, exports or imports of each controlled substance by that substance's ozone depletion weight listed in Appendix A to this Part; and

(2) Adding together the resulting products for the controlled substances within each Group.

(e) "Consumption rights" means the privileges granted by this Part to produce and import calculated levels of controlled substances; however, consumption rights may be used to produce controlled substances only in conjunction with production rights. A person's consumption rights are the total of the rights he obtains under Secs. 82.7 (baseline rights for Group I controlled substances), 82.8 (baseline rights for Group II controlled substances), and 82.10 (additional consumption rights upon proof of exports of controlled substances), as may be modified under Sec. 82.12 (transfer of rights).

(f) "Control periods" means those periods during which the prohibitions under Sec. 82.4 apply. Those periods are:

(1) For Group I controlled substances: [reserved]

(2) For Group II controlled substances: [reserved]

(g) "Controlled substance" means any substance listed in Appendix A to this Part, whether existing alone or in a mixture, but excluding any such substance or mixture that is in a manufactured product other than a container used for the transportation or storage of the substance listed.

(h) "Export" means the transport of controlled substances from within the United States or its territories to persons or countries outside the United States or its territories.

(i) "Facility" means any process equipment (e.g., reactor, distillation column) to convert raw materials or feedstock chemicals into controlled substances.

(j) "Import" means the transport of controlled substances from outside the United States or its territories to persons within the United States or its territories.

(k) "Montreal Protocol" means the *Montreal Protocol on Substances that*

Deplete the Ozone Layer which was adopted on September 16, 1987, in Montreal, Canada.

(l) "Nations complying with, but not joining, the Protocol" means any nation listed in Appendix C to this Part.

(m) "Party" means any nation that is a party to the Montreal Protocol and listed in Appendix B to this Part.

(n) "Person" means any individual or legal entity, including an individual, corporation, partnership, association, state, municipality, political subdivision of a state, Indian tribe, and any agency, department, or instrumentality of the United States and any officer, agent, or employee thereof.

(o) "Plant" means one or more facilities at the same location owned by or under common control of the same person.

(p) "Potential production rights" means the production rights obtained under Sec. 82.9 (a) and (b).

(q) "Production" means the manufacture of a controlled substance from any raw material or feedstock chemical; however, production does not include the manufacture of controlled substances that are used and entirely consumed in the production of other chemicals.

(r) "Production rights" means the privileges granted by this Part to produce calculated levels of controlled substances; however, production rights may be used to produce controlled substances only in conjunction with consumption rights. A person's production rights are the total of the rights he obtains under Secs. 82.7 (baseline rights for Group I controlled substances), 82.8 (baseline rights for Group II controlled substances), and 82.9 (c) and (d) (additional production rights), as may be modified under Sec. 82.12 (transfer of rights).

(s) "Twenty-five-kilotonne Party" means any nation listed in Appendix D to this Part.

(t) "Unexpended consumption rights" means consumption rights that have not been used. At any time in any control period, a person's unexpended consumption rights are the total of the calculated level of consumption rights he holds at that time for that control period, minus the calculated level of controlled substances that the person has produced and imported in that control period until that time.

(u) "Unexpended production rights" means production rights that have not been used. At any time in any control period, a person's unexpended production rights are the total of the calculated level of production rights he holds at that time for that control period, minus the calculated level of controlled substances that the person has produced in that control period until that time.

§ 82.4 Prohibitions.

(a) No person may produce at any time in any control period, a calculated level of controlled substances in excess of the amount of unexpended production rights held by that person at that time for that control period. Every kilogram of such excess constitutes a separate violation of this regulation.

(b) No person may produce or import at any time in any control period, a calculated level of controlled substances in excess of the amount of unexpended consumption rights held by that person at that time for that control period. Every kilogram of such excess constitutes a separate violation of this regulation.

(c) A person may not use his production rights to produce a quantity of controlled substances unless he owns at the same time consumption rights sufficient to cover that quantity of controlled substances, nor may he use his consumption rights to produce a quantity of controlled substances unless he owns at the same time production rights sufficient to cover that quantity of controlled substances. However, consumption rights alone are required to import controlled substances.

(d) Beginning one year after the effective date of this Part, no person may import any quantity of controlled substances from any nation not listed in Appendix B to this Part (Parties to the Montreal Protocol), unless that nation is listed in Appendix C to this Part (Nations Complying with, But Not Party to, the Protocol). Every kilogram of controlled substances imported in contravention of this regulation constitutes a separate violation of this regulation.

§ 82.5 Apportionment of baseline production rights.

Persons who produced one or more controlled substances in 1986 are apportioned calculated levels of baseline production rights as set forth in paragraphs (a) and (b) of this section. Each person's apportionment is equivalent to the calculated levels of that person's production of Group I and Group II controlled substances in 1986.

(a) For Group I controlled substances:

Person	Calculated level
[Reserved]	[Reserved]

(b) For Group II controlled substances:

Person	Calculated level
[Reserved]	[Reserved]

§ 82.6 Apportionment of baseline consumption rights.

Persons who produced, imported, or produced and imported one or more controlled substances in 1986 are apportioned calculated levels of baseline consumption rights as set forth in paragraphs (a) and (b) of this section. The apportionment for each person who imported controlled substances is equivalent to the calculated levels of Group I and Group II controlled substances that the person imported in 1986. The apportionment for each person who produced controlled substances is equivalent to the calculated levels of Group I and Group II controlled substances that the person produced in 1986, multiplied by a correction factor. The general equation for the correction factor is (the calculated level of 1986 United States production minus the calculated level of 1986 United States exports) divided by (the calculated level of 1986 United States production); correction factors are separately calculated for Group I and Group II controlled substances.

(a) For Group I controlled substances:

Person	Calculated level
[Reserved]	[Reserved]

(b) For Group II controlled substances:

Person	Calculated level
[Reserved]	[Reserved].

§ 82.7 Grant and phased of baseline production and consumption rights for group I controlled substances.

(a) For each of the control periods that ends before July 1, 1993, every person is granted 100 percent of the baseline production and consumption rights apportioned to him under Secs. 82.5(a) and 82.6(a).

(b) For each of the control periods that occurs between July 1, 1993, and June 30, 1998, inclusive, every person is granted 80 percent of the baseline production and consumption rights apportioned to him under §§ 82.5(a) and 82.6(a).

(c) For each of the control periods that begins after June 30, 1998, every person is granted 50 percent of the base-line production and consumption rights apportioned to him under §§ 82.5(a) and 82.6(a).

§ 82.8 Grant and freeze of baseline production and consumption rights for group II controlled substances.

For each of the control periods specified in § 82.3(f)(2), every person is granted 100 percent of the baseline production and consumption rights apportioned to him under § 82.5(b) and 82.6(b).

§ 82.9 Allowance for production rights in addition to baseline production rights.

(a) Every person apportioned baseline production rights for Group I controlled substances under § 82.5(a) is also granted a calculated level of potential production rights equivalent to:

(1) 10 percent of his apportionment under § 82.5(a), for each control period ending before July 1, 1998; and

(2) 15 percent of his apportionment under § 82.5(a), for each control period beginning after June 30, 1998.

(b) Every person apportioned baseline production rights for Group II controlled substances under § 82.5(b) is also granted a calculated level of potential production rights equivalent to 10 percent of his apportionment under § 82.5(b), for each control year specified in § 82.3(f)(2).

(c) A person may convert potential production rights, either granted to him under paragraphs (a) and (b) of this section or obtained by him under § 82.12 (transfer of rights), to production rights only to the extent authorized by the Administrator under § 82.11 (Exports to Parties). A person may obtainauthorization to convert potential production rights to production rights either by requesting issuance of a notice under § 82.11or by completing a transfer of authorization under § 82.12.

(d) Any person ("the recipient") may obtain productionrights in accordance with the provisions of this paragraph.

(1) A nation listed in Appendix D to this Part (Twenty-five-kilotonne Parties) must agree to transfer to the recipient at a specified time some amount of the calculated level of production that the nation is permitted under the Montreal Protocol. The recipient must obtain from the principal diplomatic representative in that nation's embassy in the United States a document clearly stating that that nation agrees to reduce its allowable calculated level of production by the amount being transferred to the recipient and for the control period(s) to which the transfer applies.

(2) The recipient must submit to the Administrator a transfer request that includes a true copy of the document required by paragraph (d)(1) of this section and that sets forth the following:

(i) The identity and address of the recipient;

(ii) The identity of the Twenty-five-kilotonne Party;

(iii) The names and telephone numbers of contact persons for the recipient and for the Twenty-five-kilotonne Party;

(iv) The amount of allowable calculated level of production being transferred; and

(v) The control period(s) to which the transfer applies.

(3) After receiving a transfer request that meets the requirements of paragraph (d)(2) of this section, the Administrator will:

(i) Notify the Secretariat of the Montreal Protocol of the transfer; and

(ii) Issue the recipient a notice granting the recipient production rights equivalent to the calculated level of production transferred, and specifying the control periods to which the grant of production rights applies. The grant of production rights will be effective on the date that the notice is issued.

§ 82.10 Allowance for consumption rights in addition to baseline consumption rights.

(a) Except as limited by paragraph (b) of this section, any person may obtain, in accordance with the provisions of this paragraph, consumption rights equivalent to the calculated level of controlled substances that the person has exported from the United States or its territories. The consumption rights granted under this section will be valid only during the control period in which the exports arrived in the country to which they were transported.

(1) The person who exported (the "exporter") the controlled substances must submit to the Administrator a request for consumption rights setting forth, with supporting documentation, the following:

(i) The identities and addresses of the exporter and the recipient of the exports (the "importer");

(ii) The exporter's EIN (Employer Identification Number);

(iii) The names and telephone number of contact persons for the exporter and for the importer;

(iv) The quantity and type of controlled substances exported;

(v) The date on which and the port from which the controlled substances were exported from the United States or its territories;

(vi) The country to which the controlled substances were exported and the date on which they arrived in that country;

(vii) The source from which and the date on which the exporter purchased the controlled substances.

(2) The Administrator will review the information and documentation submitted under paragraph (a)(1) of this section, and issue the exporter a notice granting the exporter consumption rights equivalent to the calculated level of controlled substances that the documentation verifies were exported. The grant of the consumption rights will be effective on the date the notice is issued.

(b) No consumption rights will be granted after January 1, 1993, for exports of controlled substances to any nation not listed in Appendix B to this Part (Parties to the Montreal Protocol).

§ 82.11 Exports to parties.

In accordance with the provisions of this section, any person may obtain authorization to convert potential production rights to production rights by exporting controlled substances to nations listed in Appendix B to this Part (Parties to the Protocol). Authorization obtained under this section will be valid only during the control period in which the controlled substances arrived in the party to which they were exported. A request for authorization under this section will be considered a request for consumption rights under § 82.10, as well.

(a) The exporter must submit to the Administrator a request for authority to convert potential production rights to production rights. That request must set forth, with supporting documentation, the following:

(1) The identities and addresses of the exporter and the importer;

(2) The exporter's EIN number;

(3) The names and telephone numbers of contact persons for the exporter and for the importer;

(4) The quantity and type of controlled substances exported;

(5) The date on which and the port from which the controlled substances were exported from the United States or its territories;

(6) The country to which the controlled substances were exported and the date on which they arrived in that country; and

(7) The source from which and the date on which the exporter purchased the controlled substances exported.

(b) The Administrator will review the information and documentation submitted under paragraph (a) of this section, and assess the quantity of controlled substances that the documentation verifies were exported to a party. Based on that assessment, the Administrator will issue the exporter a notice authorizing the conversion of a specified quantity of potential production rights to production rights in a specified control year, and granting

onsumption rights in the same amount or the same control year. The uthorization may be used to convert otential production rights to production ights as soon as the date on which the notice is issued.

82.12 Transfers of Production and Consumption Rights.

Any person ("transferor") may ransfer to any other person "transferee") any amount of the transferor's consumption rights, production rights, potential production rights, or authorization to convert potential production rights to production rights, as follows:

(a) The transferor must submit to the Administrator a transfer request setting forth the following:

(1) The identities and addresses of the transferor and the transferee;

(2) The names and telephone numbers of contact persons for the transferor and for the transferee;

(3) The type of rights (i.e., consumption rights, production rights, or potential production rights) or authorization being transfered;

(4) The Group of controlled substances to which the rights or authorization being transferred pertains;

(5) The amount of rights or authorization being transferred;

(6) The control period(s) for which the rights or authorization are being transferred; and

(7) The amount of unexpended rights of the type and for the control period being transferred that the transferor holds as of the date of the request.

(b) If the records maintained by the Administrator, taking into account any previous trades and any production or imports reported by the transferor, indicate that the transferor possessed, as of the date the transfer request was processed, unexpended rights or authorization sufficient to cover the transfer request, the Administrator will issue a notice of transfer to the transferee and the transferor. The notice will specify the transferor and transferee, and the amount, type and control year of the rights or authorization transferred. The transfer will be effective on the date the notice of transfer is issued.

§ 82.13 Recordkeeping and reporting requirements.

(a) Unless otherwise specified, the recordkeeping and reporting requirements set forth in this section take effect as follows:

(1) For Group I controlled substances, beginning with the first day of the first control period specified in § 82.3(f)(1).

(2) For Group II controlled substances, beginning with the first day of the first control period specified in § 82.3(f)(2).

(b) Unless otherwise specified, reports required by this section must be mailed within 15 days of the end of the applicable reporting period to the Administrator.

(c) Records and copies of reports required by this section must be retained for four years.

(d) In reports required by this section, quantities of controlled substances must be stated in terms of kilograms.

(e) Every person ("producer") who will produce controlled substances during a control period must comply with the following recordkeeping and reporting requirements:

(1) By the first day of each control period, every producer must submit to the Administrator a plan estimating for each of his facilities the type and amount of controlled substances he will produce and the time periods during which the controlled substances will be produced. The plan must also include estimates of the quantities of chlorodifluoromethane (HCFC–22) and hexafluoroethane (CFC–116) each of these facilities will produce in that control period. Any change in the plan during the control period must be communicated to the Administrator no later than the month following the change, as part of the monthly report required under paragraph (e)(3) of this section.

(2) Every producer must maintain the following:

(i) Daily records of the quantity of each of the controlled substances produced at each facility, including controlled substances produced for feedstock purposes;

(ii) Daily records of the quantity of HCFC–22 and CFC–116 produced at each facility also producing controlled substances;

(iii) Continuous records of the reactive temperature and operating pressures within the primary reactor and initial distillation column during the production operations at each facility; and

(iv) Daily records of the quantity of the following raw materials and feedstock chemicals purchased for and used at each plant: carbon tetrachloride, perchloroethylene, chloroform, hydrofluoric acid, hydrochloric acid, bromine, CFC–113, HCFC–22, and CFC–23.

(v) Daily records of the quantity and purchaser of controlled substances produced at each plant.

(3) For each month, every producer must provide the Administrator with a report containing the following information:

(i) The production and sales in that month of each controlled substance, specifying the quantity of any controlled substance used for feedstock purposes for each plant and totaled for all plants owned by the same person;

(ii) The quantities of HCFC–22 and CFC–116 produced that month at the same facilities producing any of the controlled substances for each plant;

(iii) A description of any shifts that have occurred that month in the planned utilization of facilities as described in the plan provided to the Administrator under paragraph (e)(1) of this section;

(iv) The total for that month and for the control-period-to-date of calculated levels of production for Group I and Group II controlled substances for each plant;

(v) The producer's total consumption rights, potential production rights, production rights and authorization to convert potential production rights to production rights, as of the end of that month; and

(vi) The quantity and names and addresses of the source of recyclable or recoverable materials containing the controlled substance which is recovered at each plant. For any person who fails to maintain the records and reports required by this paragraph, the Administrator may assume that the person has produced at full capacity during the period for which records or reports were not kept, for purposes of determining whether the person has violated the prohibitions at Sec. 82.4.

(f) For Group I controlled substances, beginning with the first control period specified under Sec. 82.3(f)(1), and for Group II controlled substances, beginning one year after the Montreal Protocol enters into force, any person ("importer") who imports controlled substances during a control period must comply with the following recordkeeping and reporting requirements:

(1) Any importer must maintain the following daily records:

(i) The quantity of each controlled substance imported, either alone or in mixtures;

(ii) The date on which the controlled substances were imported;

(iii) The port of exit and port of entry through which the controlled substances passed; and

(iv) The dates on which and the country in which the imported controlled substances were produced.

(2) For each month, every importer must submit to the Administrator a

report containing the following information:

(i) The daily records required in paragraph (g)(1) of this section for the previous month;

(ii) The total for that month and for the control-period-to-date of calculated levels of imports for Group I and Group II controlled substances; and

(iii) The importer's total consumption rights at the end of that month.

(g) For any exports of controlled substances not reported under Secs. 82.10 (additional consumption rights) or 82.11 (Exports to Parties), the person ("exporter") who exported the controlled substances must submit to the Administrator the following information within one month of the otherwise unreported exports leaving the United States:

(1) The names and addresses of the exporter and the recipient of the exports;

(2) The exporter's EIN number;

(3) The type and quantity of controlled substances exported;

(4) The date on which and the port from which the controlled substances were exported from the United States or its territories;

(5) The country to which the controlled substances were exported and the date on which they arrived in that country; and

(6) The source from which and that date on which the exporter purchased the controlled substances exported.

§ 82.14 Payment of fees.

[Reserved]

Appendix A to Part 82—Controlled Substances and Ozone Depletion Weights

Controlled substances	Ozone depletion weights
A Group I	
CFCl3—Trichlorofluormethane (CFC-11)	1.0
CCl2F2—Dichlorodifluoromethane (CFC-12)	1.0
CCl2F-CClF2—Trichlorotrifluorethane (CFC-113)	0.8
CF2Cl-CClF2—Dichlorotetrafluoroethane (CFC-114)	1.0
CClF2-CF3—(Mono)chloropentafluoroethane (CFC-115)	0.6
B Group II	
CF2BrCl—Bromochlorodifluoromethane (Halon 1211)	3.0
CF3Br—Bromotrifluoromethane (Halon 1301)	10.0
C2F4Br2—Dibromotetrafluoroethane (Halon 2402)	6.0

Appendix B to Part 82—Parties to the Montreal Protocol

[Reserved]

Appendix C to Part 82—Nations Complying With, But Not Parties to, the Protocol

[Reserved]

Appendix D to Part 82—Twenty-Five-Kilotonne Parties

[Reserved]

[FR Doc. 87-28215 Filed 12-11-87; 8:45 am]

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C

FINAL RULE
PROTECTION OF STRATOSPHERIC OZONE

TO BE SUPPLIED WHEN FEDERAL REGISTER
COPIES ARE AVAILABLE

APPENDIX C

ANALYSIS OF HOW CFC REGULATIONS CAN CHANGE FUTURE CFC CONSUMPTION BY TECHNICAL RECHANNELING

1. INTRODUCTION

The probable association between ozone depletion and chlorofluorocarbon (CFC) emissions motivated negotiations under the auspices of the United Nations Environment Programme to reach an agreement to limit production and consumption. In September 1987 this led to an establishment of an international protocol to control CFC emissions that will reduce emissions by 50 percent in joining nations by 2000. To estimate the effectiveness of this protocol in reducing ozone depletion requires evaluating which nations will participate in the protocol and what will be the impact of the protocol on future CFC demand in both non-complying and complying nations.

A large number of projections of future demand of CFCs have been made. However, almost all of these were made on the assumption of no protocol and assume technological developments that are unlikely to be fully realized under the protocol in place. Consequently, to evaluate the protocol's effectiveness requires consideration of how CFC demand/use could be indirectly altered as a result of changes in technology caused by the protocol. This paper examines this issue. It examines the reasons the "technology frontier" is likely to diminish as well as the magnitude of that likely diminution of demand. It also discusses the difficulty of analyzing even the sign of the costs of this change in demand, and suggests some future analyses needed to address these issues more comprehensively.

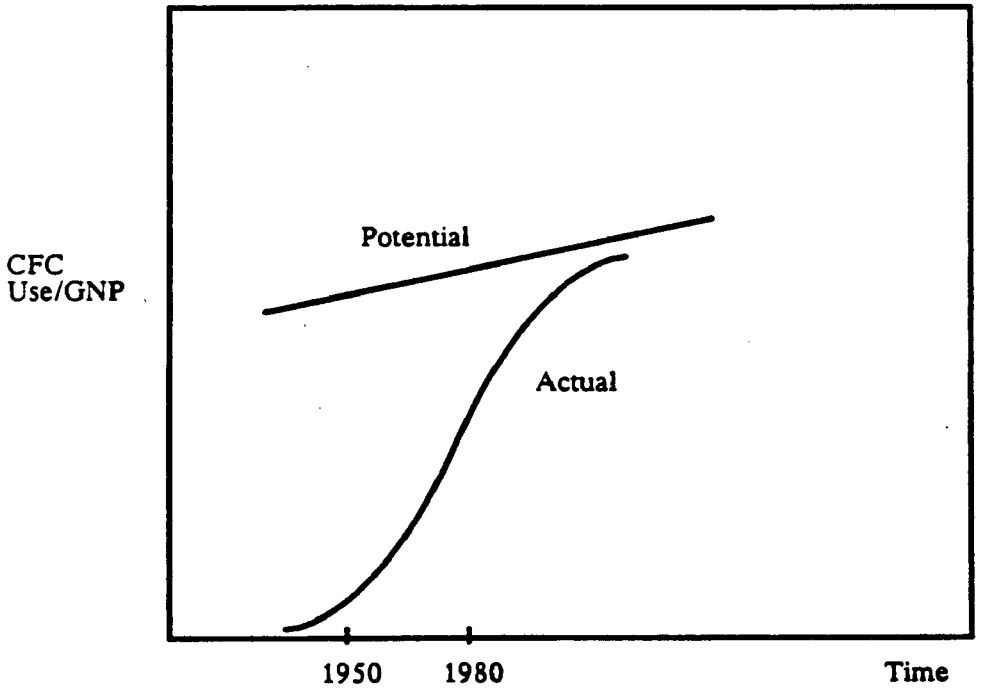
2. THE TECHNOLOGY FRONTIER AND ITS EFFECTS ON CFC DEMAND AND USE

Nordhaus and Yohe used the concept of a technology frontier in their work on projecting CFCs (Nordhaus and Yohe, 1986). Conceptually, a technology frontier defines a potential or saturation use of CFCs that depends on technology, income, tastes, and population. The actual growth of demand/use in a nation depends on two things: the future of the frontier and the rate at which nations approach it. Exhibit 1, taken from Nordhaus and Yohe, schematically illustrates how the path of actual consumption will, over time, tend towards the technology frontier.

2.1 The Historical Growth of the Frontier

Nordhaus and Yohe point out the future of the technology frontier is not certain, but has been positive in the past. Quinn et al. analyze this historical growth pattern in more detail (Quinn et al., 1986). Quinn defines the first period of CFC uses as the mid 1930s through the 1940s -- with the development of refrigerator applications. A major new product emerged in the 1950s -- air conditioning. A second major use developed in the late 1940s and early 1950s, aerosols. New applications developed for twenty years, so that by 1974, the aerosol use area was reaching maturity, just as the ozone controversy started. Quinn discusses foam as a third major use, with the 1960s being a period of initial growth, and with many new applications still being developed

EXHIBIT 1



The top line defines the potential technology frontier for use of CFCs. It slopes upward over time, reflecting technological advances and development of new markets. The bottom line illustrates the path of actual consumption, which over time approaches the technology frontier.

Source: Nordhaus and Yohe, 1987.

today. A fourth major use area (for CFC-113) was solvents, with major use starting the late 1970s and with new applications continuing to be developed today. (Other use areas exist sterilization, food freezing, etc.). The pattern Quinn notes is a major new use each decade followed by at least two decades (for that use) of major new products.

Besides his qualitative analysis, Quinn also estimates elasticities for non-aerosol CFC use for CFC-11 and -12, demonstrating that throughout the 50 year time span there has been a strong relationship between CFC use and income. Exhibit 2 schematically illustrates the strong growth of new uses and products from the 1930s to the early 1980s.

DISAGGREGATING THE COMPONENTS OF DEMAND/USE

In order to understand how demand develops, it is useful to analyze its components and their relationship to the technology frontier. This will provide a better organizing structure for analyzing future demand and the potential effects of the international protocol on it. CFC demand use can be divided into four components: new uses (e.g., aerosols were a new use); new products (for example, the mousse in Europe was a new aerosol product); market expansion of existing products (for example, mousses are still expanding in Europe (Knollys, 1986)); and the replacement and servicing of existing products (for example, deodorants are primarily a replacement product in Europe, without much market expansion). Expansion of the technology frontier affects each, with the greatest influence on new uses and products and with some influence on the improvement of existing products.

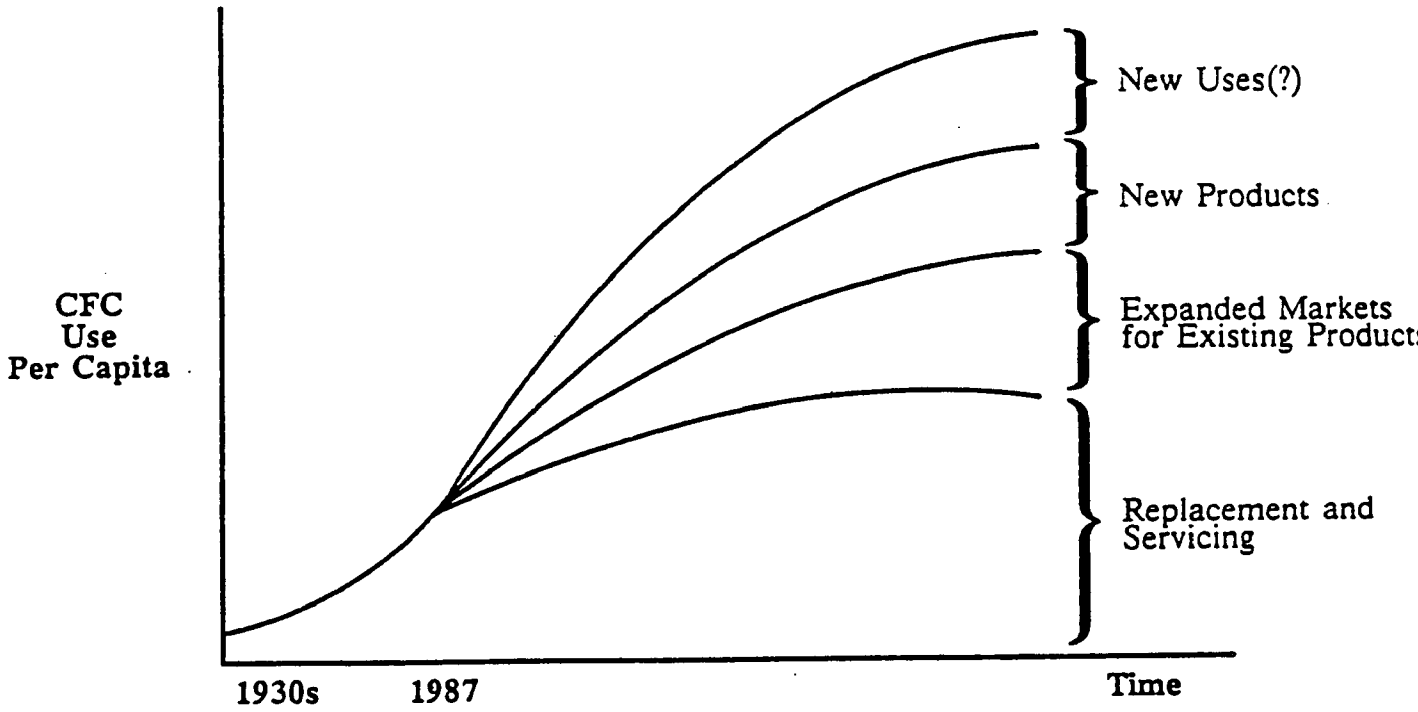
In the past fifty years there have been a variety of forces that have driven each of these components of growth. New uses resulted as a function both of research and the inherent physical possibilities of CFC molecules. New products have depended on both R&D and on information diffusion -- it has taken time for people to develop products. Products in the market expansion stage have required time to penetrate potential markets, with marketing and the development of a service capability driving the rate of expansion and with technological improvements in products occurring as producers/users "move up" the learning curve. Finally, mature products have expanded as a result of income and population growth, with technological improvement tending to decrease the intensity of use needed to produce the product (for example, air conditioning charges have fallen).

FUTURE RATES OF GROWTH

Even in the absence of an international protocol, the future growth rates of new uses and additional applications could vary from past rates, since the possibility exists that uses and applications have been exhausted. Quinn, however, shows that consistency of growth has been maintained for 50 years. Hedenstrom, Samuelsson, and Ostman (1986) have listed an impressive set of new products. Personal communications to EPA from industrial companies on new products indicates that new products have been under development. On the other hand, indefinite extrapolation of past rates of technology growth and demand seems unlikely (Nordhaus and Yohe, 1986, Gibbs, 1986). Consequently, most

EXHIBIT 2

COMPONENTS OF THE CFC BASELINE



analysts who have projected CFC growth have assumed that, over time, the technology frontier will decline (U.S. EPA 1987a). This, however, does not fully define the issue since an international protocol is quite likely to influence R&D at every level of production and use of CFCs and their substitutes. The issue, then, is "how would we expect the international protocol to effect this change?"

In fact, the indirect effect of the international protocol is that it is likely that the CFC frontier will contract more, with a consequent effect on CFCs. As this happens, CFC demand/use will likely diminish (from where it would have been) even in countries that do not join the proposed international protocol, with all countries having lower saturation levels of demand given the smaller range of new CFC-using products.

3. THE IMPACT OF THE INTERNATIONAL PROTOCOL ON THE TECHNOLOGY FRONTIER AND CFC DEMAND

The introduction of the international and national regulations to limit CFC use is likely to profoundly influence the research and development aimed at finding new uses and new products to use CFCs. For example: corporations such as McDonald's have announced that they will be abandoning use of CFC blown food packaging; the foam industry has talked of launching a "Manhattan Project" to find non-CFC technologies to blow foam (diverting research from new products to use CFCs); a major computer corporation has told EPA that a wholly new product has been aborted due to its use of CFCs. These changes represent the beginning of altered R&D patterns. CFCs have received enormous press publicity and congressional attention, and have been identified as molecules that will be under continued regulatory pressure for a long time to come, not just for ozone, but also because of their greenhouse effect (Mintzer, 1987). Bills to regulate them continue to emerge (e.g., Stark, 1987). Thus, even investments intended to improve existing products are themselves likely to decrease.

Simultaneously, this pressure will create an unusual market for substitutes, creating an unusually large demand all at once. This is likely to make substitute development less expensive.

The importance of a sudden "jump" cannot be overestimated. Technology development, once started, tends to gain its own momentum, channeling efforts for innovation and use in certain existing directions. A set of technical experts develop who actively promote a fundamental approach to using a technology and who investigate new uses, ways of improving old uses, finding new products, etc. Simultaneously, subsidiary related industries and technologies are created that tend to support the technology. Over time, a technology becomes the "only" solution sought as industries "satisfice" using acceptable solutions that exist, with improvements at the margin, rather than seeking out new technologies. This process has certainly existed for CFCs, and by itself constituted a powerful obstacle to alternative technologies. The international protocol is likely to start a different channel moving. For example, in electronics, aqueous solutions have had a hard time developing because soldering fluxes were not designed for them (U.S. EPA 1987b). Firms that have decided to shift to aqueous solutions have had to "fight the system," experiencing difficulties because few other firms have simultaneously done so. Another

obstacle has been military specifications, which have specified CFCs. The international protocol will change this situation in which the incremental obstacles of using aqueous solutions are so high, creating a macroinstability. Many firms will favor a change simultaneously, so that venders of solder will have a greater incentive to develop aqueous compatible fluxes. Similarly, with many electronic firms expressing concern, the military is much more likely to respecify its parts based on performance creating a climate favorable to innovation, perhaps leading to greater efficiencies than now exist. Such macroinstability has produced efficient innovation in the past (Klein, 1977).

3.1 Factors Influencing the Strength of Technological Rechanneling

Several factors will influence the relative strength of technological rechanneling on different countries:

(1) Growth in developing nations will be less affected than in developed nations.

Growth in poorer countries is more likely to depend on income growth that increases consumption of maturer products; growth in richer countries who are closer to their technology frontier is more likely to depend on changes in technology (Nordhaus and Yohe, 1986). Thus, a protocol that is less stringent, such as a freeze, would tend to have the same effect as a more stringent protocol in developed countries, but have a differential effect in developing countries.

(2) The impact of technological rechanneling is likely to be delayed several years.

R&D takes time to be successful; much of the effect will occur in the future.

(3) The stringency of the international protocol will have an impact.

The more stringent the protocol, the clearer the signal, the lower the transition costs and the less desirable CFC based technologies are likely to be in the future.

3.2 A Method for Estimating Impact

It would be desirable to use an empirically-derived estimate of the sensitivity of the technology frontier to stringency. Unfortunately this is impossible for several reasons: for one thing, no one knows what new CFC-based uses and new products would have been developed in the absence of the protocol; for another, there is no historical experience on which to base an empirical estimate. While a strong empirical basis for estimating the relative influence of stringency on changed demand is lacking, the important ramifications of the international protocol can be evaluated on the growth of non-participants,

non-compliers, and developing nations by using parametric sensitivity analysis that spans a range of effects.

The magnitude of rechanneling will be tested for four cases (Exhibit 3), a moderate, low, and high case, and no rechanneling (a limit that gives the worst case in terms of ozone depletion, but highest costs). The rechanneling multiplier is the percent of demand in a scenario that will occur if a protocol is implemented. For example, if a CFC 50 Percent/Halon Freeze protocol that enters into force in 1990 is implemented, developing nations will grow at 50 percent of the rate otherwise assumed in Case 1 (moderate rechanneling), 62.50 percent in low rechanneling, and 20 percent in high rechanneling, implying a range of more than 300 percent in the low to high estimate of rechanneling. A ten year lag in this effect is assumed. Clearly, other parameters could be used, but these constitute a reasonable set.

4. ANALYSIS OF THE OPPORTUNITY COST OF THE CHANGING TECHNOLOGY FRONTIER

Technological rechanneling changes the technology frontier so that demand/use is not developed, thereby reducing emissions. The legal instruments nations use to further reduce demand will then further reduce use. Exhibit 4 shows how two kinds of "costs" could be associated with the change in demand; that is, costs of technological rechanneling and costs of regulation. It is for these latter reductions that conventional economic techniques can estimate costs. However, it cannot be assumed that there are no costs to technological rechanneling. In a theoretically optimal world, there clearly would be a loss, although estimation of its value would be more problematical. There exists a large body of literature, however, that disputes the assumptions of neoclassical microeconomics, especially as regards innovation (Klein, 1977; Simon 1982).

History is replete with cases of technological channeling which have led to systems that appear sub-optimal: the keyboard and its type organization, for example, were developed because 19th century typewriter technology required an arrangement of keys that they slowed typing (they got stuck and were difficult to unstick). After the technology of keyboards improved, so that the bars would return fast enough to allow touch typing, the keyboard was never rearranged, too many people were committed to the old technology, so that even today, typewriting is harder to learn and less productive than theoretically optimal.

The English measurement system is another example of technological channeling that plagues U.S. machine tool manufacturers. The lines of U.S. televisions are fewer than Europeans, giving worse pictures, constituting another example of technological channeling. Worse yet, the size of word processing screens have been established based on a standard for computer design that assumed televisions would be used as video display terminals. This standard prevents use of full page screens (which would be more efficient for editing). Thus quite recently a course of technological channelling (software and hardware) has resulted in a sub-optimal economic efficiency.

Simon and others have pointed out that firms satisfice, choosing what they know will work, rather than optimizing. Klein (1977) has argued that macro-instability (such as caused by the protocol) can lead to a search for new

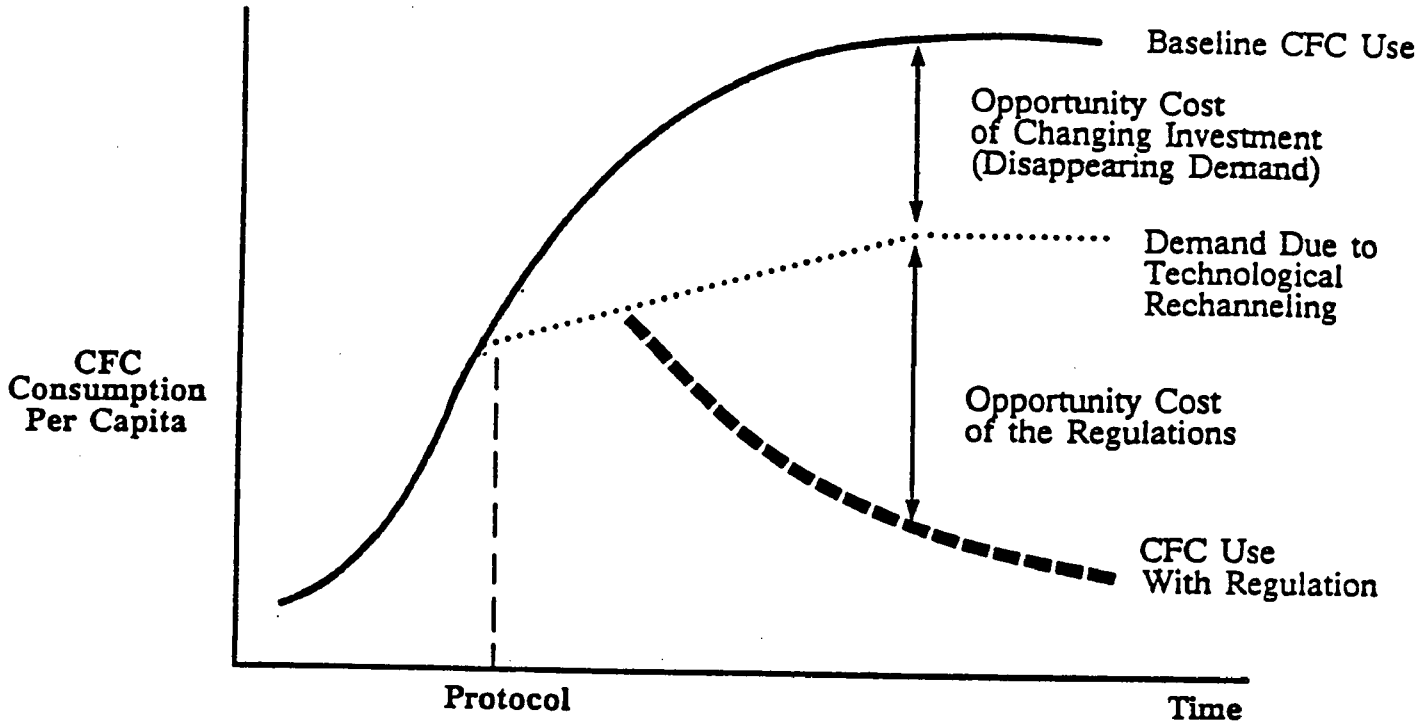
EXHIBIT 3

RECHANNELING MULTIPLIERS

	No Protocol	Freeze	Freeze + 20	Freeze + 50	Freeze + 80		
Developed	1	0.5	0.5	0.375	0.375	Case 1	Moderate technological rechanneling
Developing	1	.75	.625	0.5	0.5		
Developed	1	.75	.750	0.5	0.375	Case 2	Low technological rechanneling
Developing	1	.875	.75	0.625	0.5		
Developed	1	.375	.375	.250	.250	Case 3	High technological rechanneling
Developing	1	.5	.375	.200	.10		
						Case 4	No technological rechanneling

EXHIBIT 4

USE OF CFCs UNDER ALTERNATIVE BASELINE AND REGULATORY SITUATIONS



The protocol will technologically rechannel demand by focusing R&D away from new uses, new products, and improved products towards totally different areas. It is uncertain what will be the opportunity cost (or benefit) of this change.

technologies that improves efficiencies, while Olson (1982) has even claimed that historical improvement in efficiency of nations is driven by disruption. Thus, even the sign of the opportunity cost (benefit) of the technological rechanneling cannot be estimated, since it is not clear that superior technologies were not being ignored due to prior technological channelling.

This argument is not merely academic. In the case of the use of CFCs in aerosols, for example, the claim has been made that moving U.S. industry to hydrocarbons lead to rapid improvement of hydrocarbon propelling technology, pumps sprays, and other delivery systems that were more effective and efficient than CFC propelled aerosols. (Dispute exists on this from some segments of industry and the European aerosol industry which was not regulated.) One group of authors has estimated that over $170 million savings per year due to this macrostability-induced rechanneling (Kavanaugh, Barth, and Jaenicke, 1986).

5. FUTURE RESEARCH NEEDS

Strong evidence indicates that implementation of an international protocol will cause resources to be diverted away from the development of new CFC-uses and products. This diversion will lower the potential (maximum or saturation) level of CFC use (i.e., lower the theoretical CFC frontier) which, in turn, will reduce actual CFC use. The extent of the change is uncertain; a range must be tested. The costs are undeterminable. Additional work in this area is necessary before definite conclusions can be drawn. One possible avenue is to examine the other components of CFC demand, the existing stock of product, the manufacturing of additional CFC-related products for replacement, and the manufacturing of additional products to add to the existing stock. This "bottom-up" approach would provide greater insight into the factors that will influence future demand for CFCs. Development of alternative parameters (to reflect the disaggregate approach) could significantly narrow uncertainty. Given the complexity and importance of the issue, continued efforts to model the future use of CFCs are clearly warranted.

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APPENDIX D

CFC USE IN DEVELOPING COUNTRIES AND THE UNEP PROTOCOL

1. INTRODUCTION

International negotiations to freeze and reduce the emissions of chlorofluorocarbons (CFCs) and halons[1] have been concluded under the auspices of the United Nations Environment Programme. The result of these negotiations is the Montreal Protocol on Substances that Reduce the Ozone Layer. Despite concerns over ozone depletion and actions taken against aerosol propellant applications in several industrial countries, global use of CFCs in non-aerosol applications has continued to grow. The use of CFCs in less developed countries (LDCs)[2] has contributed to the overall growth of global CFC use and continued growth is expected.[3]

This paper examines future CFC use in less developed countries (LDCs) and a range of factors by which it may be affected. The approach of this paper is to combine quantitative estimates of future CFC use in developing countries with an examination of qualitative factors such as development issues and indicators, and international economic, financial, business and trade issues. Together, these factors may provide a base on which to assess potential future use of CFCs in developing countries. These issues are of concern in evaluating the potential future environmental impact of LDC use of CFCs, the potential impact of U.S. domestic regulations, and the potential impact of the Montreal Protocol in helping reduce the use of CFCs in developing countries. The following questions are addressed below:

- What factors may affect the potential future growth of CFC use in developing countries?
- Based on limited available data, how much may CFC use in LDCs be expected to grow?

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[1] Although the Montreal protocol regulates both CFCs and halons, this paper is limited to use of CFCs in developing countries.

[2] The terms less developed countries, LDCs, underdeveloped countries, and developing countries are used interchangeably. "Newly industrialized countries" (NICs) refers to the small group of developing countries that have experienced greater economic growth and industrial development than most other LDCs. This group of NICs includes: Brazil, Mexico, Singapore, Taiwan, South Korea, Hong Kong, and Argentina, among others.

[3] The use of CFCs in developing countries is directly addressed in the Montreal Protocol in several articles, including: Article 5 - Special Situation of Developing Countries; Article 9 - Research, Development, Public Awareness and Exchange of Information; and Article 10 - Technical Assistance, Montreal Protocol on Substances that Deplete the Ozone Layer, United Nations Environment Programme, 1987.

- How and why will CFC use differ among LDCs?
- How might CFC use in LDCs be affected by the implementation of international protocol provisions in the industrial countries?
- How attractive is joining the protocol versus not joining for the LDCs?

Section 2 provides the focus of this report. The issue of CFC use in three groups of developing countries is examined: newly industrialized countries (NICs), least developed countries and large developing countries. Particular consideration is given to: the relationship between economic development and CFC use; the position of LDCs in the international structure of production of CFC end-user industries; and LDC development and industrialization strategies.

Section 3 presents a range of estimates of potential future growth of CFC use in LDCs. Several scenarios of future LDC CFC use are discussed and compared. The implied relationships between CFC use and GNP in the scenarios are examined.

Section 4 examines the potential effect on LDC use of CFCs if industrial countries implement the regulations of the UNEP protocol and LDCs refrain from joining. The impact of protocol-induced changing technology on future LDC CFC use is also discussed.

Section 5 examines the relative attractiveness of joining the UNEP protocol for the three groups noted above. Factors affecting the decisions of LDCs to join or not join the protocol are discussed.

2. CFC USE IN DEVELOPING COUNTRIES

2.1 Differences in CFC Use in LDCs and Industrial Countries

The use of CFCs in LDCs has similarities and differences from that in industrial countries. On the one hand, CFC use has greatly increased in those LDCs that, like the developed countries, have entered the industrialization path and require CFCs to serve manufacturing production in their most dynamic industries, such as automobiles and electronics. On the other hand, the growth of CFC use has been very uneven among LDCs, and there exists a significant difference in the amount of CFCs produced and consumed by industrial countries and LDCs, with consumption in the industrial countries far exceeding that in the developing countries. This difference is graphically displayed in Exhibits D-1, D-2, and D-3, which illustrate estimated current CFC production/use and per capita CFC production/use in various developing and industrial countries.

2.2 Three Groups of LDCs

Differences among developing countries exist which affect their current and potential use of CFCs. Most significant are differences in economic structure

EXHIBIT D-1

CFC-11 AND CFC-12 PRODUCTION/USE FOR VARIOUS COUNTRIES
(kg/millions)

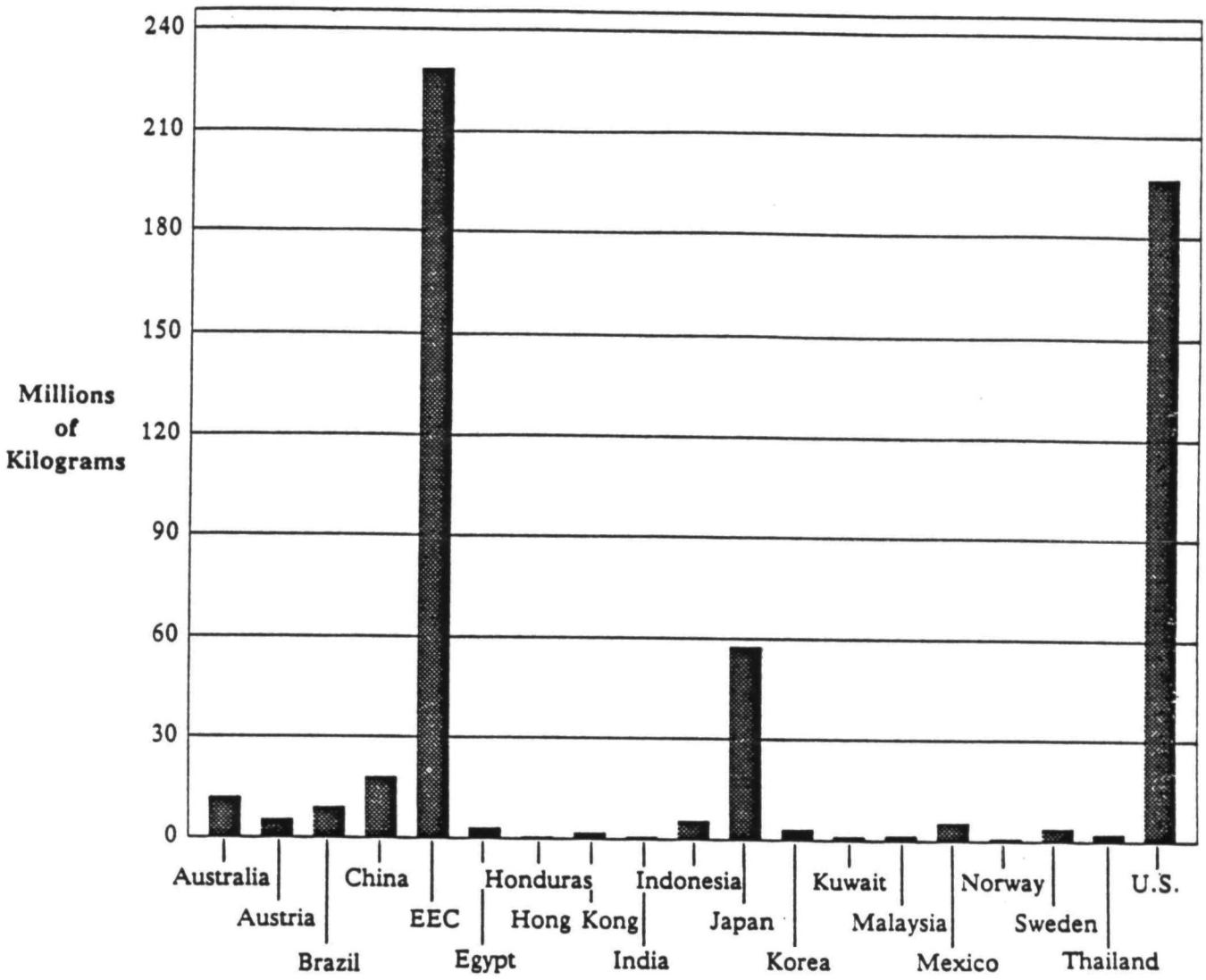

EXHIBIT D-2

CFC-11 AND CFC-12 PRODUCTION/USE PER CAPITA FOR VARIOUS COUNTRIES (kg/capita)

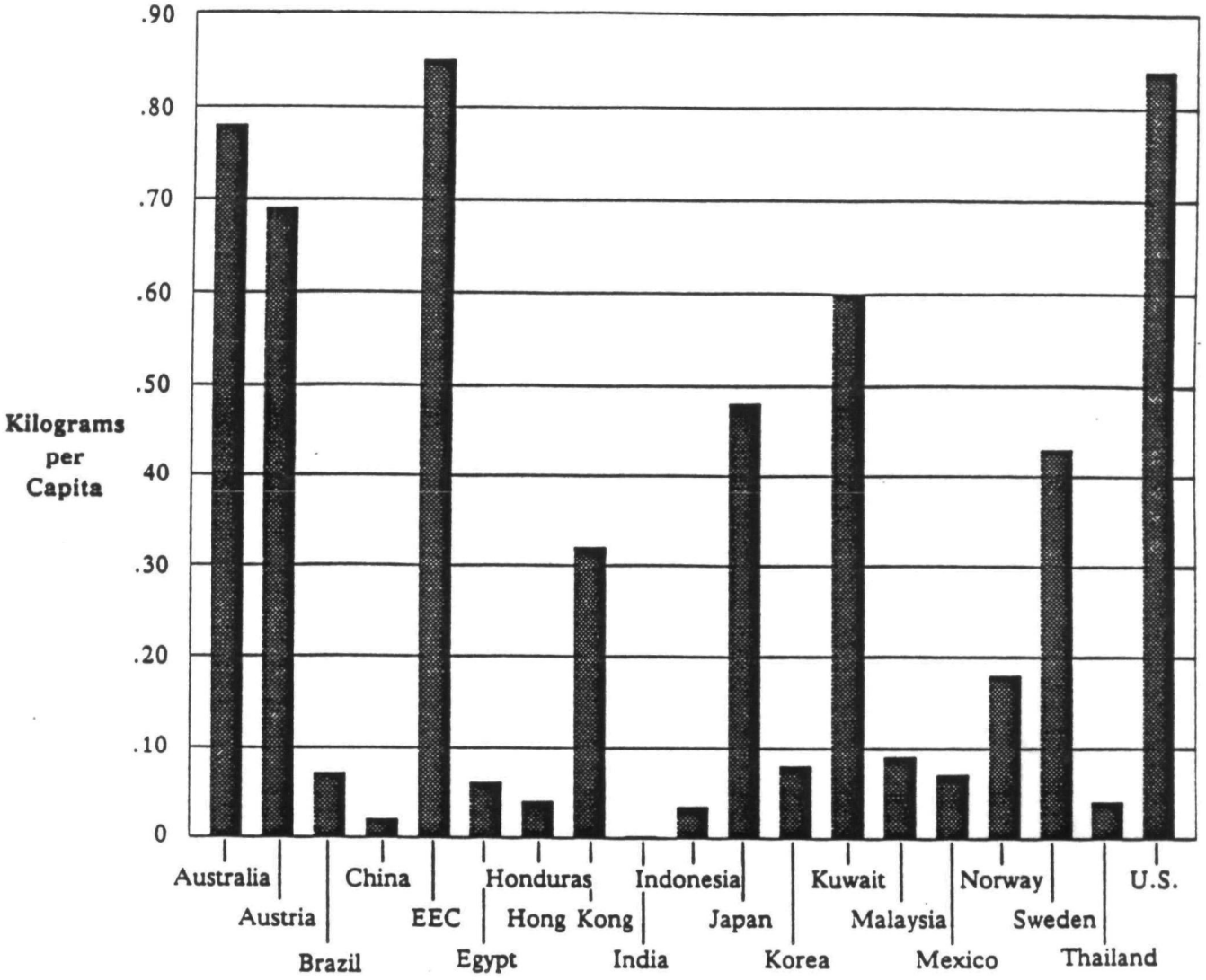

EXHIBIT D-3

ASSUMPTIONS, DATA AND REFERENCES FOR EXHIBITS D-1 AND D-2

	Population a/ (Thousands)	GNP a/ (Millions)	CFC-11 + CFC-12 Use/ Production (Mill kg)	CFC-11 + CFC-12 Use Per Capita (kg)	CFC-11 + CFC-12 Use (kg) Per $ Bill GNP	Year of Use/ Production Data
Australia	15,369	169,557	12.0 c/	0.78	.07	1984
Austria	7,549	67,045	5.2 d/	0.69	.08	1985
Brazil	132,600	228,072	8.9 m/	0.07	.04	1985
China	1,019,102	294,572	18.0 e/	0.02	.06	NA
EEC	269,017	2,396,766	228.5 f/	0.85	.10	1985
Egypt	45,169	30,144	2.9 g/	0.06	.10	1985
Honduras	4,093	2,656	0.2 g/	0.04	.08	1984
Hong Kong	5,400	34,182	1.7 n/	0.32	.05	1985
India	749,200	194,729	0.4 o/	0.001	.002	1982
Indonesia	158,900	85,806	5.4 p/	0.03	.06	1984
Japan	119,259	1,159,124	57.5 h/	0.48	.05	1985
Korea	40,100	84,611	3.1 q/	0.08	.04	1985
Kuwait	1,720	26,064	1.0 i/	0.60	.04	NA
Malaysia	14,863	26,679	1.4 j/	0.09	.05	NA
Mexico	75,011	157,372	5.2 k/	0.07	.03	1983
Norway	4,133	55,650	0.7 l/	0.18	.01	1984
Sweden	8,331	99,750	3.6 l/	0.43	.04	1984
Thailand	49,169	38,864	2.0 g/	0.04	.05	1984
U.S.	234,496	3,176,670	197.4 b/	0.84	.06	1985

a/ The World Bank, (1986), "The World Bank Atlas, 1986," Washington, D.C. Numbers reflect 1983 estimates for GNP and Population. GNP is in real U.S. 1982 dollars.

b/ United States International Trade Commission, (1986), "Preliminary Report on U.S. Production of Selected Synthetic Organic Chemicals (Including Synthetic Plastics and Resin Materials) July through September, October through December, and Cumulative Totals 1986," USITC, Washington, D.C., February 20, 1986. Imports and exports were not considered. 1985 production estimates.

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n/ Census and Statistics Department (1985), Hong Kong Trade Statistics, Hong Kong. Product coverage includes Dichlorofluormethane, Trichlorofluoromethane and Dichlorodifluoromethane mix Trichloro-fluoromethane. Production/use calculated as Imports-Exports + Production.

o/ Directorate General of Commercial Intelligence and Statistics, (1982), Monthly Statistics of the Foreign Trade of India, Calcutta, India. Product coverage includes "other halogenated derivatives of hydrocarbons." Use/Production calculated as Imports - Exports + Production.

p/ Biro Pusat Statistik (1984), Indonesia Foreign Trade Statistics, Jakarta Indonesia. Product coverage includes "other halogenated derivatives of hydrocarbons." Use/Production calculated as Imports - Exports + Production.

q/ Office of Customs Administration (1985), Statistical Yearbook of Foreign Trade, Seoul, Republic of Korea. Product Coverage includes Chlorofluoromethanes. Use/Production calculated as Imports - Exports + Production, production assumed to be zero.

and levels of development and industrialization. There are also significant differences in the size of individual LDCs, which may also affect CFC use.

For purposes of this report, we distinguish among three groups of LDCs: newly industrialized countries (NICs), least developed countries, and large developing countries. We also examine the additional importance of development strategy as a factor influencing CFC use. Individual LDCs for which we have CFC production and/or use data, and projected future CFC use are identified according to the group they most approximate in economic structure or size.[4]

- NICs. These are the newly industrialized countries. They are distinguished from most LDCs due to both the significant and growing role in their economies of the manufacturing sector and their ability to produce internationally competitive products in global industries such as automobiles and electronics. As such, the NICs have higher CFC consumption levels than other LDCs. With higher relative per capita incomes, the NICs also consume greater numbers of CFC end-user products. Brazil, Republic of Korea and Hong Kong are NICs.

- Least Developed Countries. Most developing countries are in the least developed country category. The economies of these countries are largely based on agriculture and primary commodities, such as cocoa, copper, coffee, and bauxite. Industrial development is at a very low level and mainly serves agricultural production and resource extraction activities. Of the 36 countries identified as least developed countries by the IMF, the overwhelming majority are African countries. Use of CFCs in these countries is mainly limited to the importation of products containing or manufactured with CFCs. As such, CFC use is small and should continue to remain so. For this report, we include in the least developed group, Egypt, Honduras and Thailand.

- Large Developing Countries. The large developing countries are distinguished by the size of their populations and domestic markets. Although the overwhelming majority of their populations are extremely poor, the size of these countries has allowed them to develop significant manufacturing sectors for both domestic and export markets. Although their population size ensures continued small levels of per capita CFC

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[4] It should be noted that the diversity of LDCs requires even greater differentiation than just three categories. For example, Thailand and Egypt are included here among the least developed countries. Although they are poorer and less developed than the NICs, Thailand and Egypt have manufacturing industries that would distinguish them from most of the least developed countries categorized as such by the World Bank and IMF.

use, these countries exhibit higher total levels of CFC use than other LDCs, and even some industrial countries. (See Exhibits D-1 and D-2). The Peoples Republic of China, India and Indonesia are included here as large developing countries.

- Development Strategy. Developing countries are also distinguished by their development strategies. These strategies tend to be either inward or outward-looking in orientation, with some countries combining industry-specific import substitution with industry-specific export promotion. Those developing countries that have implemented the most successful outward-looking development strategies have both strengthened their ties to the international economy and industrial countries' markets, and increased their production and export of CFC end-user products such as automobiles (Brazil, South Korea), electronics (Hong Kong, South Korea, India, Thailand), and refrigeration and air conditioning (Brazil, Hong Kong, India, South Korea, Thailand). As such, CFC consumption and demand in these countries has risen, in part, due to development strategy.

It is important to recognize that just as LDC development strategies have tended to encourage greater CFC use, development strategies can also play a role in reducing CFC use in developing countries. LDCs have choices in determining which industries they target for development. They also can influence the types of technologies used in their manufacturing sectors. As substitute chemicals, products and production processes are developed which do not use and/or use less CFCs, LDC governments can play an active role to encourage the introduction of these new technologies.

It is important to distinguish between the current importance of CFCs in the LDC production of certain goods, and the relative importance of CFCs to long-term economic development in the LDCs. The current industrialization plans of many LDCs, particularly the NICs, are based on the development of CFC end-user industries. Given the current use of CFCs in industries such as automobiles, electronics and refrigeration equipment, developing countries that base their economic growth on these industry sectors could be positively or negatively influenced by the availability of CFCs. However, conscious action by LDC governments to incorporate technologies that use less CFCs as they become commercially viable, could reduce overall CFC use in these countries, especially with regard to production for export markets. As such, there is little reason to assume that unlimited access to CFCs is a precondition for long-term economic growth in the developing countries. At the same time, near-term adjustment costs of adopting alternative CFC-free technologies must be acknowledged. The need to reduce such adjustment costs is addressed by the Montreal Protocol in Articles 5 and 10 which encourage both financial and technical assistance for LDCs to adopt non-CFC based technologies.

2.3 Development and CFC Use

Economic growth and GNP per capita are often used as proxies for development. GNP per capita may indeed provide the best single development indicator, which is one reason it was used in recent analyses of CFC use projections.[5] While the use of GNP per capita as an explanatory variable of LDC use of CFCs may be reasonable for making projections, alone it cannot explain the complexity of domestic and international factors that influence economic development and CFC use in these countries.

Economic growth refers to an increase in per capita real income. Economic development, on the other hand, refers to the variety of structural changes in an economy and society that permit the conditions required for economic growth to become self-sustaining. This distinction is particularly relevant here because industrialization is one important aspect of economic development, and CFCs are used in many industrial processes. However, growth of per capita real income need not directly parallel industrialization; it may lag behind or exceed industrialization in different countries and, possibly, even in a single country at different times. As such, CFC use may increase, concurrently, with stagnant or declining per capita income as occurred in several countries in recent years. Reflecting the changing economic base of many LDCs, manufacturing and industry have experienced strong growth in the past two decades in many LDCs, while agriculture has declined as a portion of GDP. In addition, several LDCs have increased domestic import substitution and production capacity. This is especially true for CFC-related industries. (Some major development indicators, including those of most direct relevance to future LDC use of CFCs, are noted in Exhibit D-4.)[6]

The relationship between CFC use and development is heavily influenced by the characteristics of the CFC end-user industries, such as: automobiles, electronics, air conditioning, refrigeration, and foam products. These industries have played an important role in the industrial development of the LDCs examined here, especially automobiles and electronics. These products have been produced for both domestic and export markets and have required increasing amounts of CFCs to keep pace with growing production output.

Because insufficient alternative chemicals, product substitutes, production processes and recovery technologies are commercially available to displace all CFC use, CFCs may be essential in the near-term to the growth of specific industries. Where CFC use is constrained under the UNEP protocol, CFC conservation in other industries may not be sufficient to "free-up" levels of CFCs sufficient to sustain all growth. Therefore, CFCs are currently an important input to the economic development and industrialization path chosen by these countries.

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[5] See section 3 below for a summary of projections.

[6] See Attachment D-1 for historical economic development data for selected developing countries, including: Brazil, China, Egypt, Honduras, Hong Kong, India, Indonesia, South Korea and Thailand.

EXHIBIT D-4

DEVELOPMENT FACTORS AFFECTING THE USE AND PRODUCTION OF CFCs

1. Population Size and Growth Rate
2. Gross National Product Per Capita and Growth Rate
3. Distribution of Gross Domestic Product by Sector
4. Growth Rate of Specific Sectors
5. Distribution of Manufacturing Value Added
6. Energy Consumption Per Capita
7. Growth in Production of Commercial Energy
8. Merchandise Exports
9. Merchandise Imports
10. Origin and Destination of Exports
11. Net Inflow of External Capital
12. Long-Term Debt Service as Percentage of GNP and Exports
13. Income Distribution
14. Urban Population as Percentage of Total Population
15. Growth of Urban Population
16. Climate
17. Commercial and Domestic Levels of Food Refrigeration

The level of CFC use is also influenced by other key development factors. Consumption of CFC end-user products in developing countries is greatly driven by per capita income and related factors. Also important are the physical and human infrastructure -- availability of electricity, roads, and adequate skilled labor -- necessary for the production and/or operation of these products; urbanization; and availability of the requisite financing for developing physical and human infrastructure. Each of these factors is discussed in turn.

GNP Per Capita. As GNP per capita grows in developing countries, the tendency is for consumption of certain consumer items to rise. Because CFCs are used as inputs in the production of durable goods such as automobiles, refrigerators, and air-conditioning units, and demand for these goods is positively related to changes in income, as income increases the use of CFCs may also increase. Although unavailable to large parts of LDC populations, these products provide important benefits and meet basic types of family needs. As such, the CFC end-user products are among the first that families in developing countries may purchase as income increases.

Families without refrigerators need to shop daily for perishables to avoid food spoilage. Automobiles and/or trucks provide great time savings in countries with very poor transportation systems, as well as a potential source of new employment where these vehicles are used for commercial purposes. Basic consumer electronics such as televisions, radios, and stereos are often the first items purchased as incomes rise due to their low relative cost vis-a-vis other "luxuries," especially in urban areas. In rural areas where incomes are generally lower than in cities, a television or radio may be purchased to provide group entertainment for an entire village.

Growth of GNP per capita will vary among developing countries. Whereas growth in the NICs may be expected to continue to be strong over the foreseeable future, recent overall growth trends have been negative for successive years in numerous developing countries. Also, as noted in the social indicators in Exhibit 2 of Attachment D-1, income distribution is weighted towards the highest quantile of households in many LDCs, which will also affect future demand for CFC end-user products.

Infrastructure. The increased use of CFC end-user products is greatly dependent on the development and availability of an adequate physical infrastructure. The products' requirements are very basic. Automobiles need roads. Refrigerators, air conditioners, and consumer electronics require adequate electricity generation in order to operate. In this regard, the growth of per capita energy consumption should reflect increased use of these CFC end-user products. As noted in Exhibit 4 of Appendix D-1, average annual growth rates of energy production and per capita energy consumption have greatly increased since 1970.

Infrastructural development also affects industrial CFC use in developing countries in that it makes possible the production of these items. The production of automobiles, electronics, refrigerators, and air conditioners requires adequate generation of electricity, transportation systems, communications systems, etc. Whether this production is mainly for the domestic market or for export will further influence LDC use of CFCs.

Urbanization. Increased urbanization in developing countries will tend to put upward pressure on the demand for and consumption of CFC end-user products. People in urban areas generally have higher incomes than in rural areas, even among the poorer sections of the urban population. (Clearly, quality of life must be distinguished from income.) Urban areas have more developed infrastructures, higher per capita electricity consumption, and greater concentrations of paved roads and cars. Populations in most LDCs have increasingly shifted from rural to urban areas in the last twenty years and this pattern is expected to continue. This trend is reflected in the fact that the number of cities with over 500,000 people has more than doubled in many LDCs over the last 15-20 years.

Urbanization itself, however, will proceed differently among LDCs, reflecting differing paces and types of economic development. Urbanization will be influenced by the character and pattern of agricultural development and industrialization, and the resultant availability of employment opportunities in rural or urban areas. For example, internal migration to urban areas will be encouraged by development strategies that commercialize agriculture, increase rural inequalities, and provide little or no technical assistance, credit, or fertilizer to small farmers. Conversely, policies that increase cultivable land, permit more equitable distribution of rural incomes and/or land, and reduce rural population fertility may reduce internal migration to urban areas.[7] These patterns will have different implications for future use of CFCs in developing countries.

Development Financing. The availability and directed use of development financing in LDCs will greatly affect the development indicators noted above and, accordingly, their respective influence on the use of CFCs in developing countries. Uncertainties exist about future financing of development in many LDCs. The protocol directly addresses the need of developing countries for external assistance to facilitate their adoption of environmentally safe substances and technology.[8] This may help relieve some of the pressure in the LDCs to direct limited funds to environmental protection by providing bilateral and multilateral subsidies, aid, credits, loan guarantees and technology transfer assistance specifically directed at use of alternative technologies to reduce CFC use and emissions.

Economic growth in developing countries strongly parallels public sector spending and investment, due to the central economic role of the state in most LDCs. In recent years, as a result of many factors, both government capital investment and GNP per capita growth have been negative. Economic recession has reduced tax revenues, increased budget deficits, forced government officials to focus on short-term needs and generally constrained available development

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[7] See, Robert A. Pastor, ed., Migration and Development in the Caribbean: The Unexplored Connection, Westview, 1985.

[8] See, "Article 5: Special Situation of Developing Countries;" Montreal Protocol on Substances That Deplete the Ozone Layer, United Nations Environment Programme, 1987.

financing. This has been further exacerbated by the debt crisis in several countries. Consumer demand for CFC end-user products and infrastructural investments have suffered as a result. Although this trend will reverse itself, the vulnerability of the developing countries to both domestic and international economic shocks ensures continued uncertainty regarding the future availability of development financing and sustainability of related economic growth. In assessing potential future use of CFCs in LDCs, it is important, however, to distinguish between short-term and long-term patterns of growth.

2.4 Global Factors

The future use of CFCs in developing countries will be greatly affected by a variety of global conditions. Some of these factors are beyond the control of the LDCs and others will be influenced by LDC policies and bargaining with a host of international economic, political, and financial players. The interaction of these various international factors will directly affect LDC production, use, import, and export of CFC chemicals and CFC end-user products. This is due to two factors:

- the general position of the developing countries in the international economic and financial system; and
- the particular position of individual LDCs in the international structure of production of the CFC chemical and end-use industries.

The first factor relates to the macroeconomic condition of a developing country. Shifts in the pace of economic growth and inflation in the industrial economies can directly affect a developing country's performance through international economic and financial market linkages. Other factors of equal importance include shifts in interest rates and exchange rates, as well as international trade restrictions.[9]

The second factor -- the particular position of LDCs in the international structure of production -- relates to the industrial use of and demand for CFCs in developing countries. Major CFC end-user industries -- automobiles, electronics, refrigerators, and air conditioners -- are international industries. Industry output in the developing countries for each product group is largely determined by the business decisions of transnational corporations (TNCs) centered in the industrial countries.[10] Generally, the relative autonomy of the subsidiary in a LDC to make investment and production decisions is strengthened when subsidiary output is targeted at the local market and weaker

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[9] Goldsbrough, D. and Iqbal H. Zaidi, "How Performance in Industrial Economies Affects Developing Economies," Finance and Development, Vol.23, No. 4, December, 1986.

[10] There are exceptions to this, such as the Korean automobile industry which is largely an indigenous industry. However, here too, foreign capital through TNC investments from the U.S. and Japan are playing a growing role as the Koreans turn their attention to exports requiring greater technological sophistication and quality.

when targeted at the global market. In recent years, production in developing countries of automobiles, electronics, refrigerators, and air conditioners has been increasingly targeted for export markets, particularly in the industrial countries. For large LDCs, domestic markets may be large enough to support domestically-oriented industries (computers and autos in Brazil, for example). But here too, TNCs often exert significant influence on the development of these industries and markets.

The large degree of control that TNCs have over production, technological and product development decisions, and quality control standards has potentially important implications for the future use of CFCs in developing countries. Most significant is the potential for TNCs to either play a positive role in the transfer of alternative, CFC-free technologies and production processes to the developing countries as they become commercially viable, or to play a negative role by exporting CFC using technologies to potential pollution havens. In this regard, the Montreal Protocol encourages the former and discourages the latter. As noted above, efforts to facilitate financial and technical assistance for developing countries to adopt alternative technologies is an obligation of protocol membership, as stipulated in Article 5. In addition, the Protocol's trade control provisions require that each signatory discourage the export of, and export finance for technology, plants and equipment to non-parties that use or produce CFCs and halons.[11]

3. POTENTIAL FUTURE RATES OF GROWTH OF CFC USE IN LDCs

The future use of CFCs in LDCs will be driven by the various development factors described above, including the rates of growth of the LDC economies. Although LDCs are currently believed to account for a relatively small portion of global CFC use, the use and emissions of CFCs by the LDCs could have an important impact on stratospheric ozone if their use grows. In particular, if developed countries agree to restrict CFC use, and if CFC use grows in the LDCs, then the LDC contribution to global CFC emissions could become significant. This section presents a range of estimates of potential future growth in LDC CFC use.

Section 3.1 presents the results of a study of global CFC use by T.H. Quinn, et al. of The RAND Corporation.[12] Section 3.2 presents results of a study by M.J. Gibbs of ICF Incorporated, which was also about global CFC use.[13] Section 3.3 reviews the results from a preliminary analysis of future use of CFC-related

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[11] See, "Article 4: Control of Trade with Non-Parties," Montreal Protocol on Substances that Deplete the Ozone Layer, United Nations Environment Programme, 1987.

[12] Quinn, T.H., et al. (1986), "Projected Use, Emissions, and Banks of Potential Ozone-Depleting Substances," N-2282-EPA, The RAND Corporation, prepared for the U.S. Environmental Protection Agency, Washington, D.C.

[13] Gibbs, M.J. (1986), "Scenarios of CFC Use: 1985-2075," ICF Incorporated, prepared for the U.S. Environmental Protection Agency, Washington, D.C.

products by Daniel Kohler of The RAND Corporation that was specifically geared toward LDCs.[14]

Section 3.4 identifies the range of potential future CFC growth that is implied by a range of assumptions about two key determinants of future CFC use: economic growth (measured as GNP) and the income elasticity of demand for CFCs.[15] Finally, section 3.5 summarizes the estimates presented in the preceding sections.

3.1 Quinn Scenarios of CFC Use in Developing Countries

Quinn (1986) presents a range of scenarios of potential future global CFC-11 and CFC-12 use for the period 1980 to 2075. The scenarios are based on assumptions regarding how the future use of CFCs in various parts of the world may unfold, using the historical development pattern of CFC markets in developed countries as a guide for bounding the scenario assumptions. Quinn divided the world into the following regions: U.S.; EEC; Pacific developed nations; other developed nations; Eastern Bloc nations; Latin America; Africa; and Asia and other developing nations. This section summarizes Quinn's scenarios for the three regions that can be considered to be representative of developing nations: Latin America, Africa, and Asia/other.

Future use of CFCs was projected for three time periods: 1980 to 2000, 2000-2040, and 2040-2075. The uncertainties of the estimates are assumed to increase into the future. During the first period (1980-2000) CFC markets in developing countries are assumed to be at very early stages of the development process. Consequently, all the scenarios presented by Quinn for these developing nations in this period are based on the assumption that CFC use will grow at a rate equal to the growth rate of GNP per capita. Because the populations of developing nations are expected to continue to increase during this period (implying that the rate of growth of GNP will exceed the rate of growth of GNP per capita), this assumption implies an income elasticity of less than one. Exhibit D-5 summarizes the Quinn estimates for CFC-11 and CFC-12 for the LDC regions for this period.

As shown in the exhibit, Quinn's assumptions result in LDC CFC growth in the range of 2.3 to 2.8 percent per year for the period 1980 to 2000. These rates

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[14] Kohler, D.F., et al. (1987), "Projections of Consumption of Products Using Chlorofluorocarbons in Developing Countries," N-2458-EPA, The RAND Corp., prepared for the U.S. Environmental Protection Agency, Washington, D.C.

[15] The income elasticity of demand for a commodity is a key parameter in the analysis that follows. It is defined as the percentage change in demand (or use) of a commodity associated with a one percent change in income. (Income, for a nation, is often measured by GNP, or GNP per capita). When the demand for a commodity increases (in percentage terms) by an amount greater than the increase in income (also in percentage terms), then the income elasticity exceeds 1.0. If the commodity demand and income change by the same amount, the income elasticity is equal to 1.0. Finally, if the increase in commodity demand is smaller than the increase in income, the income elasticity is less than 1.0.

EXHIBIT D-5

SUMMARY OF QUINN CFC SCENARIOS FOR DEVELOPING NATIONS: 1980 to 2000

	GNP/Capita Growth	Population Growth	GNP Growth a/	CFC Growth b/	Implied Income Elasticity c/
Latin America	2.8%	2.2%	5.1%	2.8%	0.55%
Africa	2.3%	2.3%	4.6%	2.3%	0.50%
Asia, Other	2.7%	1.8%	4.5%	2.7%	0.60%

a/ GNP growth is the GNP per capita growth compounded with the population growth.

b/ CFC use is assumed by Quinn to grow at the same rate as GNP per capita during this period.

c/ Income elasticity is computed as the ratio of the CFC growth rate to the GNP growth rate.

Source: Quinn, T.H., et al. (1986), "Projected Use, Emissions, and Banks of Potential Ozone-Depleting Substances," N-2282-EPA, The RAND Corporation, prepared for the U.S. Environmental Protection Agency, Washington, D.C.

are dependent on the projected rates of GNP per capita growth, which are uncertain. Of note is that given the rates of population growth (and hence GNP growth) also reported by Quinn, the implied income elasticities for the three LDC regions are in the range of 0.5 to 0.6.

Quinn's LDC regional economic growth rate assumptions for the period 2000 to 2040 range from continued growth at the rate of growth of GNP per capita, to growth on the order of about 3.5 times this rate. The large growth rate is based on the assumption that the LDCs would experience CFC market development in the same manner as the U.S. experienced in the post-World War II period. During this period Quinn estimates that the relative rate of CFC use growth to GNP per capita growth was in this range. Quinn's assumptions for the period 2000 to 2040 imply that CFC use growth in the LDC regions may range from about 2.0 percent per year (the assumed GNP per capita growth rate) to roughly 7.0 percent per year (3.5 times this lower rate).

Quinn reports that projections in the final period are very uncertain, and assumes that the growth in CFC use in the LDC regions may be on the order of GNP per capita growth in those regions, and Quinn reports a value of about 1.5 percent per year. Overall, the Quinn scenarios portray potential LDC CFC growth as follows:

- relatively slow growth through the year 2000, with rates equal to the rate of growth in GNP per capita (which implies a rate less than the rate of GNP growth);
- possibly higher rates of growth between 2000 and 2040, ranging from 1.0 to about 3.5 times the rate of growth of GNP per capita; and
- very uncertain growth beyond 2040, possibly driven by the rate of growth of GNP per capita.

3.2 Gibbs Scenarios of CFC Use in Developing Countries

Gibbs (1986) presented five scenarios of CFC-11 and CFC-12 use through the year 2075 for three regions: the U.S.; non-U.S. OECD countries; and non-OECD countries. Although the non-OECD region includes all the East Bloc nations (which are not considered LDCs), this region is the most analogous to LDCs in the Gibbs study.

Gibbs' scenarios for the U.S. and the non-U.S. OECD regions were based on a range of GNP and population scenarios and relationships between population, GNP and CFC use developed from historical U.S. data. Gibbs assumed, however, that the relationships based on historical U.S. data would not likely be applicable to the non-OECD countries. Therefore, Gibbs' scenarios of CFC use in this region were based on a range of "logistic" or S-shaped curves. The shape of this curve implies that the growth of CFC use over time will not be constant; the rate is initially high, with declining rates as market saturation is achieved.

The range of S-shaped curves used by Gibbs to project scenarios of potential CFC use in the non-OECD region is driven by alternative assumptions about the level at which market saturation is achieved. The saturation level was defined as the level of use per capita simulated to be achieved by 2075. The level was chosen as a fraction of the use per capita observed today in the non-U.S. OECD region; with the fraction defined as the ratio of the projected 2075 GNP per capita value in the non-OECD region to the current GNP per capita value for the non-U.S. OECD region.

Exhibit D-6 displays a summary of Gibbs' scenarios for the non-OECD region for the period 1985 to 2000. Five alternative GNP projections were used, producing estimates of CFC growth ranging from 3.7 percent per year to nearly 10 percent per year. Gibbs suggests that the lowest and highest scenarios may be bounding cases. The implied income elasticities are also reported. The elasticity estimates are initially higher than the rates implied by Quinn's scenarios for this same period.

Gibbs' scenarios for the period 2000 to 2075 show declining rates of growth and declining income elasticities over time. The range of his estimates is very large by 2075 (about a factor of 10), reflecting uncertainties in population and GNP per capita projections, as well as uncertainties in the potential level of market saturation in this region. The range of growth rates for the 2000 to 2075 period is about 2.8 percent to 3.7 percent for this non-OECD region.

3.3 Kohler Estimates of Demand for CFC Related Products in Developing Countries

Kohler examined potential future demand in developing countries for individual CFC end-user products, including: automobiles; refrigerators; and air conditioners. Future LDC consumption of these products for the period 1980 to 2000 was estimated using "a series of models employing baseline data on relationships between consumption of CFC-intensive products and average GNP, along with reasonable population forecasts and alternative assumptions about GNP growth."[16] The projections include CFC end-user products both domestically produced and/or imported from industrial or other developing countries. This top-down approach for individual products is combined with a bottom-up examination of CFC end-user product ownership at the household level. It illustrates a key underlying source of industrial demand for CFCs.

The results of the Kohler study indicate that in the developing countries examined, consumption of CFC end-user products may increase at a rate comparable to the rate of GNP growth between the years 1980 and 2000. Growth rate projections for consumption of CFC end-user products in selected LDCs are presented for three GNP scenarios in Exhibits D-7, D-8, and D-9. The three GNP growth rate scenarios are, respectively, Scenario A: extrapolated to the future based on 1960-1980 growth rates; Scenario B: IMF baseline projections for 1987-1990; and Scenario C: GNP per capita growth of one percent per year. (This scenario is presented primarily to test the implications of a global recession over the next thirteen years).

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[16] Kohler et al., op. cit., p. 65.

EXHIBIT D-6

SUMMARY OF GIBBS SCENARIOS OF FUTURE CFC USE IN NON-OECD COUNTRIES: 1985 to 2000

Scenario	GNP Growth	CFC Growth	Implied Income Elasticity a/
Limits to Growth	2.5%	3.7%	1.5
Low Growth	3.3%	5.0%	1.5
Medium Growth	3.5%	6.7%	1.9
High Growth	4.0%	9.6%	2.4
No Limits to Growth	4.6%	9.8%	2.1

a/ The implied elasticity is computed as the ratio of the CFC use growth to the GNP growth.

Source: Gibbs, M.J. (1986), "Scenarios of CFC Use: 1985-2075," ICF Incorporated, prepared for the U.S. Environmental Protection Agency, Washington, D.C.

EXHIBIT D-7

Scenario A: RAND GNP and Product-Consumption Annual Growth Rates in Selected LDCs: 1980-2000[a]

Country	Population[b]	GNP[b]	Cross-Section Model Automobiles[c]	Growth Rate Model Automobiles[d]	Cross-Section Model (Point Estimate) Refrigerators[e]	Cross-Section Model (High Point Estimate) Refrigerators[f]	Air Conditioning[g]
Brazil	2.1%	7.3%	7.9%	4.2%	4.6%	5.2%	9.3%
India	2.0%	3.4%	3.7%	6.8%	4.2%	7.3%	4.0%
Indonesia	1.8%	5.9%	7.0%	6.8%	7.5%	10.4%	7.5%
South Korea	1.5%	8.6%	9.9%	4.7%	5.4%	5.9%	11.3%
Algeria	3.7%	7.0%	7.9%	6.6%	5.7%	6.7%	8.2%
Argentina	1.3%	3.5%	4.0%	3.0%	2.5%	3.4%	4.4%
China	1.0%	4.8%	5.5%	5.7%	6.6%	9.8%	6.7%
Iran	3.0%	8.4%	9.0%	3.5%	4.6%	4.9%	10.5%
Mexico	2.2%	4.9%	5.3%	4.2%	3.9%	4.8%	5.9%
Nigeria	3.5%	7.7%	8.4%	7.2%	7.6%	9.2%	9.4%
Saudi Arabia	3.8%	12.2%	9.8%	-10.4%	4.1%	4.1%	15.5%
South Africa	3.0%	5.3%	5.5%	4.4%	4.3%	5.2%	6.1%
Turkey	1.9%	5.5%	6.0%	4.7%	4.7%	5.8%	6.9%
Venezuela	2.8%	5.5%	5.8%	2.2%	3.7%	4.2%	6.5%

Source: D.F. Kohler, J. Neaga, and F. Camm, "Projections of Products Using Chlorofluorocarbons in Developing Countries," The RAND Corporation, prepared for U.S. Environmental Protection Agency, January 1986.

Notes: a RAND estimates based on projected GNP growth rates estimated from GNP per capita during the period 1960-1980.

b Estimates from Kohler (1986), pg. 20. The rate of population growth was calculated for each country assuming exponential growth ((Pop2000/Pop1980)/(1/20)). GNP values were calculated by projecting GNP per capita to the year 2000, dividing GNP per capita by population, and calculating the implied exponential growth rate.

c Estimates from Kohler (1986), pg. 26. Growth rates were calculated assuming an exponential growth of automobile stock.

d Estimates from Kohler (1986), pg. 32. Growth rates were calculated assuming an exponential growth of automobile stock.

e Estimates from Kohler (1986), pg. 41. Growth rates were calculated assuming an exponential growth of domestic refrigerators stock.

f Estimates from Kohler (1986), pg. 46. Growth rates were calculated assuming an exponential growth of domestic refrigerators stock.

g Estimates from Kohler (1986), pg. 54. Growth rates were calculated assuming an exponential growth of domestic air conditioning stock.

EXHIBIT D-8

Scenario B: RAND GNP and Product-Consumption Annual Growth Rates in Selected LDCs: 1980-2000[a]

Country	Population[b]	GNP[b]	Cross-Section Model Automobiles[c]	Cross-Section Model (Point Estimate) Refrigerators[d]	Air Conditioning[e]
Brazil	2.1%	4.7%	5.0%	3.7%	5.6%
India	2.0%	6.0%	6.9%	8.3%	7.6%
Indonesia	1.8%	4.7%	5.6%	5.9%	5.8%
South Korea	1.5%	6.0%	7.0%	4.6%	7.8%
Algeria	3.7%	4.7%	5.3%	4.5%	5.1%
Argentina	1.3%	4.5%	5.3%	2.9%	5.8%
China	1.0%	6.0%	6.9%	8.3%	7.9%
Iran	3.0%	4.6%	4.9%	3.7%	5.3%
Mexico	2.2%	4.7%	5.0%	3.7%	5.6%
Nigeria	3.5%	4.7%	4.9%	4.9%	5.2%
Saudi Arabia	3.8%	4.8%	4.8%	4.0%	5.2%
South Africa	3.0%	3.7%	3.5%	3.4%	3.9%
Turkey	1.9%	3.9%	4.0%	3.6%	4.7%
Venezuela	2.8%	4.9%	5.2%	3.6%	5.8%

Source: D.F. Kohler, J. Neaga, and F. Camm, "Projections of Products Using Chlorofluorocarbons in Developing Countries," The RAND Corporation, prepared for U.S. Environmental Protection Agency, January 1986.

Notes: a RAND estimates based on projected GNP growth rates estimated from IMF baseline projections for the years 1987-1990 (IMF, 1985)

b Estimates from Kohler (1986), pg. 20. The rate of population growth was calculated for each country assuming exponential growth ((Pop2000/Pop1980)/(1/20)). GNP values were calculated by projecting GNP per capita to the year 2000, dividing GNP per capita by population, and calculating the implied exponential growth rate.

c Estimates from Kohler (1986), pg. 26. Growth rates were calculated assuming an exponential growth of automobile stock.

d Estimates from Kohler (1986), pg. 41. Growth rates were calculated assuming an exponential growth of domestic refrigerators stock

e Estimates from Kohler (1986), pg. 54. Growth rates were calculated assuming an exponential growth of domestic air conditioning stock.

EXHIBIT D-9

Scenario C: RAND GNP and Product-Consumption Annual Growth Rates in Selected LDCs: 1980-2000[a]

Country	Population[b]	GNP[b]	Cross-Section Model Automobiles[c]	Cross-Section Model (Point Estimate) Refrigerators[d]	Air Conditioning[e]
Brazil	2.1%	3.1%	3.2%	2.8%	3.5%
India	2.0%	3.0%	3.2%	3.6%	3.4%
Indonesia	1.8%	2.9%	3.5%	3.3%	3.2%
South Korea	1.5%	2.5%	2.8%	2.3%	2.9%
Algeria	3.7%	4.7%	5.3%	4.4%	5.1%
Argentina	1.3%	2.3%	2.7%	2.0%	2.7%
China	1.0%	2.0%	2.2%	2.6%	2.4%
Iran	3.0%	4.0%	4.3%	3.5%	4.4%
Mexico	2.2%	3.3%	3.3%	2.9%	3.7%
Nigeria	3.5%	4.5%	4.7%	4.7%	5.0%
Saudi Arabia	3.8%	4.8%	4.8%	4.0%	5.2%
South Africa	3.0%	4.0%	4.0%	3.6%	4.3%
Turkey	1.9%	2.9%	3.0%	2.8%	3.3%
Venezuela	2.8%	3.8%	4.1%	3.2%	4.2%

Source: D.F. Kohler, J. Haaga, and F. Camm, "Projections of Products Using Chlorofluorocarbons in Developing Countries", The RAND Corporation, prepared for U.S. Environmental Protection Agency, January 1986.

Notes: a RAND estimates based on projected GNP/capita growth rates of 1% for the years 1980 2000.

b Estimates from Kohler (1986), pg. 20. The rate of population growth was calculated for each country assuming exponential growth ((Pop2000/Pop1980)/(1/20)). GNP values were calculated by projecting GNP per capita to the year 2000, dividing GNP per capita by population, and calculating the implied exponential growth rate.

c Estimates from Kohler (1986), pg. 26. Growth rates were calculated assuming an exponential growth of automobile stock.

d Estimates from Kohler (1986), pg. 41. Growth rates were calculated assuming an exponential growth of domestic refrigerators stock.

e Estimates from Kohler (1986), pg. 54. Growth rates were calculated assuming an exponential growth of domestic air conditioning stock

Under Scenario A two sets of estimates are presented. The cross-sectional model projections are based on analyses of recent data (about 1980) across all the countries examined. The growth-rate model projections are based on time series analysis. Under Scenario A (Exhibit D-7) 13 out of 14 cross-section model projections for automobiles show product consumption growth rates greater than GNP growth rates. The exception was for Saudi Arabia.[17] The growth-rate model projections for automobiles, however, show only 3 out of 14 product consumption growth rates greater than GNP growth rates. For refrigerators the two models respectively show 3 and 5 (out of 14) product consumption growth rates greater than GNP growth rates. All 14 projections of air conditioning use growth rates were greater than GNP growth rates.

Under Scenario B (Exhibit D-8), only the cross-section model results were reported by Kohler. For automobiles, 12 out of 14 consumption growth rates are greater than the GNP growth rates. Estimates for refrigerators show only 4 out of 14 consumption growth rates greater than GNP growth rates. All projections of air conditioning use growth rates were greater than GNP growth rates.

In Scenario C (Exhibit D-9), 12 of the automobile, 4 of the refrigerator, and all of the air conditioning estimates exceed the GNP growth rates.

In sum, the Kohler estimates indicate the following for the products examined:

- Automobiles: The cross-section model shows the automobile stock growing more rapidly than GNP in nearly all the countries examined, and in all three GNP scenarios. The growth rate model (presented for Scenario A only) indicates that GNP growth may exceed automobile stock growth in most of the countries examined.

- Refrigerators: Both the cross-section and the growth rate models indicate that GNP is likely to grow more rapidly than the stock of refrigerators in most of the countries examined in all three scenarios.

- Conditioning Equipment: The results indicated that the growth in air conditioning equipment may exceed the rate of growth of GNP in all the scenarios examined. Compared to the automobile and refrigerator estimates, however, the air conditioning estimates are based on less complete data, and are considered (by Kohler) to be less reliable.

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[17] Of note is that Saudi Arabia has an unrealistically high GNP growth rate projection of 12.2 percent in this scenario.

Overall, these results imply that the rates of growth of the CFC-related products may be comparable to the rates of growth of GNP during the period 1980 to 2000.

3.4 Estimates of LDC CFC Growth Under Alternative Parameter Assumptions

This section presents a range of CFC use growth rates for the period 1985 to 2000 that are implied by a range of assumptions about future GNP growth and income elasticities of demand. The potential rate of GNP growth in LDCs through 2000 is uncertain, and will be influenced by various factors described in the previous section. A GNP growth range of 1.5 percent to 4.5 percent is used to explore the potential CFC growth rates during this period. The low rate would be consistent with very slow global economic growth, including significant recession. If the GNP growth rate is as low as 1.5 percent per year from 1985 to 2000, the implied GNP per capita level declines during this period because population is expected to grow more rapidly than 1.5 percent per year. A GNP growth rate of 4.5 percent is consistent with continued strong economic expansion in the LDCs.

Because the LDCs are diverse, some countries may be more likely to experience strong growth during the next 13 years (e.g., the newly industrialized countries), while others (e.g., those with large debt burdens) may be more likely to experience lower growth. A middle value of 3.0 percent per year is also presented.

A range of income elasticities of 0.5 (based on the Quinn scenario results) to 2.0 (based on the Gibbs scenario results) is used. A middle value of 1.0 (consistent with the indications from the Kohler analysis) is also presented.

Exhibit D-10 displays the implied CFC use growth rates for these ranges of assumptions. Not surprisingly the range of possible values is quite large, ranging from 0.75 percent to 9.0 percent. As mentioned above, it is unlikely that all of the LDCs will be in either extreme situation.

Of note is that the NICs and the large developing nations account for the largest portion of CFC use by the LDCs. The NICs will likely experience GNP growth on the high side of the range examined here, so that their CFC use growth rates will likely also be on the high side. Because the NICs have adopted CFC-intensive development strategies, their income elasticities may also be moderately high, meaning that the NICs may experience CFC use growth on the order of 3.0 to 9.0 percent.

The potential future GNP growth rates for the large developing nations (e.g, China and India) are less certain.[18] Also, although these nations have

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[18] The World Bank categorizes both China and India as "low-income countries." Although forecasts of GNP growth are not presented in the World Bank's 1987 World Development Report, "high" and "low" forecasts are presented for GDP and GDP/capita between 1986 and 1995 for the "low income countries." These range from a low GDP growth rate of 4.6 percent, to a high GDP growth rate of 6.7 percent; an average of 5.65 percent. Low and high forecasts of

EXHIBIT D-10

CFC USE GROWTH RATES FOR RANGES OF VALUES FOR INCOME ELASTICITIES AND GNP GROWTH, 1985-2000

	Income Elasticity 0.5	Income Elasticity 1.0	Income Elasticity 2.0
GNP GROWTH RATE			
1.5 Percent	0.75	1.5	3.0
3.0 Percent	1.50	3.0	6.0
4.5 Percent	2.25	4.5	9.0

Values computed assuming a constant income elasticity; values equal the GNP growth rate times the income elasticity.

GDP/capita for the period 1986-1995 are 2.8 percent and 4.8 percent respectively; an average of 3.8 percent.

generally not adopted export-led development strategies, the development of their internal markets may require increasing levels of CFCs (e.g., China has announced its desire to introduce refrigeration in significant amounts by 2000).[19] Therefore, these LDCs are unlikely to be in the lowest portion of the growth range presented in Exhibit D-10.

Overall, because the majority of current LDC CFC use is in countries that are not expected to be in the low portion of the range presented in Exhibit D-10, it indicates that CFC use growth across the LDCs may be on the order of the middle of the range in the exhibit (e.g., 3.0 percent) or higher.

3.5 Summary of CFC Growth Estimates

Each of the studies surveyed in this paper present estimates of the annual growth rate of CFC use to the year 2000. However, the studies are based on different methodologies, regional definitions, and scenarios of future economic growth. Comparisons of the estimates of future CFC use under these circumstances should be regarded with considerable caution. With these caveats in mind, some qualified comparisons are presented in this section.

In the Quinn study it was assumed that in the near term (through 2000) CFC use would grow at the same rate as GNP per capita. This assumption implies an income elasticity of less than 1.0. Using the Quinn population (and hence GNP) growth scenario, the implied income elasticity is on the order of 0.5.

The Gibbs study results are driven by the assumed level of market saturation achieved, and is strongly influenced by the large range of GNP and population projections examined. The Gibbs results imply larger income elasticities in the near term, ranging from 1.5 to 2.4. Of particular note is that the Gibbs values are for all non-OECD nations, including the East Bloc countries. The inclusion of these nations may be one reason why Gibbs' elasticity estimates exceed Quinn's estimates. In fact, if Quinn's estimates for East Bloc countries are combined with the results for the three Quinn regions identified above, an income elasticity of about 1.0 is implied for the period 1980 to 2000 for several of his scenarios, making his implied income elasticity closer to, but still lower than Gibbs.

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[19] It has been reported that China currently (1985) has about 4 million refrigerators, about one per sixty of its 240 million households. It has also been reported that by the year 2000, 50 percent of the households in China will have installed refrigerators. Assuming about 240 million households, this 50 percent saturation implies a 30-fold increase in refrigerators (from 4 million to 120 million) by the year 2000. The average annual growth rate in the stock of refrigerators is estimated at over 25 percent per year. See Gandhi, Sunita, Andrea Ketoff and Jayant Sathaye (July 1987), "Trends in Saturation of Refrigerators and Air Conditioners in Developing Countries: Potential for Chlorofluorocarbon Emissions," International Energy Studies, Energy Analysis Program, Lawrence Berkeley Laboratory, Berkeley, California, prepared for the U.S. Department of Energy.

The Kohler results indicate that the rates of growth may be expected to vary across the nations examined. Overall, however, the rate of growth in CFC-related products may be expected to be comparable to the rate of growth of GNP.

The parametric analysis displays the implications of the ranges of results reported in the three studies. Because most of the LDC CFC use is in NICs and large LDCs, it may be anticipated that near term CFC growth in LDCs will be in the middle to high end of the range of possible outcomes from the parametric analysis.

4. IMPACT OF CFC REGULATION IN INDUSTRIAL COUNTRIES ON FUTURE LDC USE OF CFCs

This section examines some of the potential implications of CFC regulation in industrial countries on future CFC use in developing countries. The disproportionate participation between industrial and developing countries in the Montreal Protocol negotiations to reduce CFC emissions, raises the possibility that while most (or all) industrial countries may join the protocol, many LDCs may not.

4.1 Potential Impacts on LDCs

Under each of the LDC groupings -- NICs, least developed countries, and large developing countries -- we discuss the potential impacts of the protocol's trade control provisions on LDC exports of CFCs, products containing CFCs, and products manufactured with but not containing CFCs. General conclusions are summarized in Exhibit D-11. We also examine current and potential future import costs of CFC-11 and CFC-12 for selected LDCs.

As noted in the exhibit, an import ban by parties to the protocol on exports of CFC bulk chemicals should have a very small negative impact on the non-party NICs; no effect on non-party least developed countries; and no-to-very small effect on non-party large developing countries. An import ban on products containing CFCs could have a large negative impact on the non-party NICs; a small negative effect on non-party least developed countries; and a medium-large effect on non-party large developing countries. An import ban on products manufactured with, but not containing CFCs could have a large-very large negative effect on non-party NICs; a small-medium effect on non-party least developed countries; and a medium-large negative effect on non-party large developing countries.

The Montreal Protocol contains trade control provisions that could involve the following:

a) signatory countries will ban imports of CFC and halon bulk chemicals from and exports of CFC and halon bulk chemicals to any state not party to the protocol;

b) imports of products containing CFCs and halons from non-signatory countries will also be restricted or banned;

EXHIBIT D-11

POTENTIAL NEGATIVE EFFECTS OF PROTOCOL TRADE CONTROLS ON CFC-RELATED EXPORTS OF SELECTED NON-PARTY LDCs a/

	Import Ban of CFC Chemicals	Import Ban by Parties of Products Containing CFCs	Import Ban of Products Manufactured with CFCs
NICs	Very small	Large	Large-very large
Least Developed Countries	None	Small	Small-medium
Large Developing Countries	None-very small	Medium-large	Medium-large

a/ This analysis assumes that many LDCs do not join the protocol and continue to implement current economic and industrial development policies. These potential effects are for illustrative purposes only and will differ among individual countries within each group.

c) the feasibility of banning or restricting imports of products manufactured with but not containing CFCs or halons from non-signatory countries will be determined;

d) exports to non-signatory countries of technologies which produce or use CFCs and halons will be discouraged; and

e) signatories will not provide new financial support for the export of technologies which facilitate production of CFCs or halons to non-signatory countries.

4.1.1 NICs

The newly industrialized countries (NICs) are the largest producers and users of CFCs and CFC-related products among the developing countries. NICs that currently produce CFCs include: Brazil, Mexico, Venezuela, Argentina, Korea and Taiwan, among others. Although CFC export data are unavailable, it appears that production of CFCs in these countries is mainly for domestic consumption rather than export. As such, the impact of an import ban by industrial countries party to the protocol of CFCs produced in non-signatory NICs, would have a limited negative impact on these industries or on the export earnings of these countries.

The NICs have become significant producers and exporters of manufactured goods containing CFCs, including: motor vehicles, air conditioners, and refrigerators. Although production of these goods serve, in part, domestic markets, recent industry production trends have been increasingly for export to industrialized country markets. As such, any restrictions on the export of these products by the NICs will have a strong negative impact on these industries, as well as the countries' export earnings. From the viewpoint of the NICs, restrictions on auto exports would pose the most serious detrimental effects. For example, in the event they do not join the protocol, Brazil and Korea would be most immediately affected.

The NICs are also the largest producers among developing countries of products manufactured with but not containing CFCs, notably electronics. Should the protocol's most severe trade control provisions be extended to such products, their domestic electronics industries and export earnings of the NICs would be greatly affected. In the event they do not join the protocol, NICs that could receive the most detrimental affects may include: Korea, Taiwan, Singapore, Malaysia and Mexico.

Another concern of the NICs is the potential increase in the cost of importing CFCs for industrial purposes, due to the protocol's restrictions on global production/use of CFCs. Current import costs of CFC-11 and CFC-12 for those NICs with available data are relatively small but cover a broad range. Import costs for Brazil, Hong Kong and Korea are, respectively, $18,000,[20] $2.5 million and $5.2 million (See Exhibit D-12). Given that these countries

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[20] Brazil's low import cost is due to self-sufficiency in CFC chemical production.

EXHIBIT D-12

ESTIMATED IMPORT COSTS OF CFC-11 AND CFC-12 FOR SELECTED LDCs (thousands of dollars)

Country	CFC Imports Amount	Current Import Cost (g)	Possible Future Range of Cost (h)
Brazil	.012 mill kg a/	$ 18	$ 36 - 1,800
Hong Kong	1.7 mill kg b/	2,500	5,000 - 30,500
India	.448 mill kg c/	672	1,344 - 6,720
Indonesia	5.4 mill kg d/	8,100	16,200 - 81,000
Korea	3.5 mill kg e/	5,200	10,400 - 52,000
Thailand	1.2 mill kg f/	1,800	3,600 - 18,000

Notes:

a/ "Carteira Do Comercio Exterior," Banco Do Brazil S.A., 1985.

b/ "Hong Kong Trade Statistics," Census & Statistics Department, Hong Kong, 1985.

c/ "Monthly Statistics of the Foreign Trade of India," Directorate General of Commercial Intelligence and Statistics, India, 1982.

d/ "Indonesia Foreign Trade Statistics," Biro Pusat Statistic, Jakarta, Indonesia, 1984.

e/ "Statistics Yearbook of Foreign Trade," Office of Customs Administration, Republic of Korea, 1985.

f/ "Foreign Trade Statistics of Thailand," Department of Customs, Bangkok, Thailand, 1985.

g/ This assumes an average cost of $1.50/kg for CFC-11 and CFC-12.

h/ This assumes a range of between two and ten times current import costs.

respectively import products and production inputs worth billions of dollars, current import costs represent a very small share of total import costs.

In the event that CFC prices increase between two and ten times their current cost, the import cost of CFCs should continue to represent a small share of total import costs, albeit larger than at present. For those countries with existing CFC production capacity, higher import costs may stimulate further import substitution of CFC chemicals. This would likely be the case for Brazil and some other Latin American NICs. For those NICs not currently producing CFCs, a ten-fold increase in CFC import costs would surely raise the possibility of initiating domestic CFC production. It is not currently known how much of a CFC import price increase would make CFC import substitution cost-effective.

In summary, the UNEP protocol's trade provisions could impair manufactured exports by non-party NICs which they have successfully increased in recent years. The costs to these countries of potentially lost export earnings could be high. Of all the developing countries, the NICs have the greatest interest in retaining access to the markets of the industrialized countries. As a result, it is likely that they will give due consideration to the potential costs and benefits of joining the protocol versus not joining. Protocol provisions to facilitate transfers of alternative technologies are an important incentive to join the protocol for the NICs.

4.1.2 LEAST DEVELOPED COUNTRIES

The least developed countries are the smallest users of CFCs among the developing countries. In general, the least developed countries do not have domestic production capacity for CFC chemicals. Domestic production of CFC-related products is largely non-existent, with the exception of a few countries that assemble air conditioners, refrigerators and electronics products. For example, Thailand is a net exporter of air conditioners, and several least developed countries, such as those in the Caribbean Basin, are attempting to establish electronics assembly industries for export. However, most of the least developed countries have no domestic production capacity for CFCs or CFC-related products. For these countries, CFC use is limited to imports of CFCs contained in or used to manufacture CFC end-user products.

The potential effects of the UNEP protocol's trade control provisions should be limited for the least developed countries as a group (see Exhibit D-11). Without exports of CFC-related products, the protocol's import restrictions are of little concern to these countries. They also should experience very limited balance of payments effects due to potential CFC price increases that might occur due to global reductions in CFC production. Because these countries have little need for industrial applications of CFCs, price increases should be limited to those incorporated in imported CFC end-user products. However, the value of CFCs represents such a small share of the total value of CFC end-user products (e.g., automobiles), that any increase in the final import cost of these products should be limited.

The trade control provisions of the UNEP protocol may have some negative effect on those few non-signatory least developed countries either currently attempting to, or considering, the development of domestic CFC end-user

industries, such as assembly of electronics or air conditioners. Because these industries would have the purpose of raising foreign exchange through exports to the industrial countries, restricting such exports may have detrimental effects. Since these countries would be able to export CFC end-user products to signatory industrial countries and obtain needed CFCs under the protocol, those considering CFC-related exports would be likely to join. Again, this would apply to very few countries in this least developed group.

4.1.3 LARGE DEVELOPING COUNTRIES

The large developing countries are significant users of CFCs. Indonesia and the Peoples Republic of China, for example, use larger amounts of CFC-11 and CFC-12 than some industrial countries (see Exhibit D-1). China and India are producers of CFCs. Although total use of CFCs in these countries is quite large, per capita use is much smaller than the industrial countries and slightly smaller than the NICs.

CFC use in the large developing countries has similar industrial applications as in the NICs. This is particularly true for India which has an impressive domestic electronics industry. China is also attempting to expand its electronics industry. Both countries also produce other CFC end-user products, such as automobiles, refrigerators and air conditioners. Production by these countries of most industrial goods, including CFC end-user products, is for the domestic market. However, in recent years, the large developing countries have attempted to increase their respective manufactured exports, spur the technological growth and sophistication of these industries, achieve greater economies of scale and production efficiencies, and, lastly, earn needed foreign exchange.

While the currently-earned foreign exchange that could be lost is relatively low, trade control provisions of the UNEP protocol could impair the continued near-term growth and, perhaps more importantly, the technical development of CFC end-user industries in the large developing countries that do not join the protocol. At the same time, however, the domestic markets of these countries probably can provide a major market for growth of CFC containing products.

The large developing countries would also feel the impact of any price increases for CFC chemical imports. For example, Indonesia currently imports about 5.4 million kilograms of CFC-11 and CFC-12, at a cost of roughly $8 million. A price increase from two to ten times could raise Indonesia's CFC import cost to between $16 million and $81 million (see Exhibit D-12). This could provide the incentive for Indonesia to initiate domestic production of CFCs. Once large capital investments are made in CFC producing facilities it will be harder to alter the growth of CFC dependent industries.

In summary, the trade control provisions of the protocol could, to a greater or lesser degree, impair future growth of CFC end-user industries in the large developing countries. Potential CFC price increases could significantly affect import costs in these countries and provide the economic incentive for them to substitute domestic production of CFCs for imports.

4.2 Potential LDC Responses and Alternatives

What alternatives will developing countries have regarding trade of CFC end-user products if they do not sign the protocol and are therefore frozen out of industrial country markets? Two options are apparent.

- Option 1: Increase south-south trade. One alternative to exporting to industrial country markets is increasing access to LDC markets. Although trade among developing countries increased at a faster pace than their trade with the rest of the world through the 1970s and early 1980s, much of this was trade in primary products. As noted in Exhibit 5 of Attachment D-1, manufactured exports between LDCs have declined as a percentage of total goods exported to developing countries. In addition, demand in LDCs for CFC end-user products such as automobiles, refrigerators and air conditioners is limited. This is due to both the luxury character of these products as well as the continued need of many LDCs to conserve foreign exchange and limit imports to necessary production inputs, capital goods and food. South-south trade may be a complement to north-south trade, but not a viable substitute, except in the case where the products are designed for the LDC market (e.g., inexpensive refrigerators without freezers). Although new south-south trade could reasonably exhibit a high rate of growth, it could not compensate for the loss of access to industrial country markets. Sales volumes would clearly decline as would LDC export earnings.

- Option 2: Alternative technologies. Because the protocol is only concerned with CFCs and products containing or made with CFCs, companies in non-signatory LDCs could continue producing and exporting to signatory industrial countries if CFC use was eliminated from the production of products currently using CFCs. Even if LDCs do not sign the protocol, companies will still have an incentive to assimilate CFC-free alternative technologies as they become available. Transnational corporations (TNCs), in turn, may be encouraged by non-party LDCs to use CFC-free technologies as they are developed in order for the LDCs to retain international market access for their products.

  However, it may be possible for LDCs to target CFC use to markets where there are no prohibitions, using alternative technologies only for exports to protocol members that enforce trade control provisions. The practicality of this depends on industry-specific factors and the economy of scale involved in this process.

In summary, the economic development of some LDCs (NICs) could be greatly impaired in the near-term if the full regulatory potential of current protocol trade control proposals -- banning imports of all products containing or manufactured with CFCs -- was implemented in the early 1990s and most LDCs decide not to join and continue to implement current industrialization policies. However, the development and adoption of alternative, non CFC-based technologies should limit the potential negative impacts on the long-term economic development and industrialization of these countries. If a protocol is structured so that LDCs can grow until alternatives are available, but lose export markets if they do not join, many LDCs will find it attractive to join. Those LCD's that are either dependent on exports for growth, or intend to greatly expand their exports of CFC-related products would have incentive to adopt such alternative technologies whether they join the protocol or not (assuming a strong trade control provision). This is particularly true for the NICs.

4.3 Impact of Changing CFC Technology on Future LDC Use of CFCs

The protocol provides developing countries with a Grace Period from regulations to freeze and reduce CFC and halon use for ten years if their per capita consumption of the controlled substances is below 0.3 kilograms.[21] The rationale for this exemption is that the economic and industrial development of these countries would be unfairly hampered if access to CFCs was immediately limited. Of note is that use of CFCs by developing countries may be affected by regulations imposed in industrial countries, whether they join the protocol with a regulatory Grace Period, or if they remain outside the protocol. In the long term (following the Grace Period), CFC and halon limits would apply to LDCs. By then, however, new technologies might be emerging which would allow LDCs to develop without CFCs. The question arises, however, whether the higher costs of these technologies will be a disincentive to their use, particularly in domestic markets. Protocol provisions to encourage transfers of alternative technologies, however, may limit these adjustment costs.

Once the regulations are imposed in the industrial countries, use of CFCs and CFC related products will be reduced. Technological development will begin to focus on other methods of providing the goods and services once made with CFCs. Instead of automatically searching to solve problems with CFCs, engineers will seek other alternatives. The potential future level of CFC use in developing nations will likely be influenced by the technological changes brought on by reductions in industrial nations; however, the extent of the influence in developing nations is uncertain.

5. RELATIVE ATTRACTIVENESS OF THE UNEP PROTOCOL FOR LDCs

In order to assess the likelihood of LDC participation in the UNEP protocol it is essential to identify the relative attractiveness for these countries of joining versus not joining. Whereas the preceding sections illustrated some

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[21] See Article 5: Special Situation of Developing Countries, Montreal Protocol on Substances That Deplete the Ozone Layer, United Nations Environment Programme, 1987.

types of costs LDCs may experience, this section examines these costs relative to the advantages of joining the protocol and suggests the likelihood that selected LDCs may join the protocol.

We discuss, in turn, the relative attractiveness of the protocol for newly industrialized countries, least developed countries, and large developing countries.

5.1 NICs

As noted above, the newly industrialized countries (NICs) are designated as such due to the significant and growing role of manufactured goods production, especially industrial products, in their respective economies. These industries include major CFC end-user products such as automobiles, electronics, refrigeration, and air conditioning equipment. The NICs are both largely self-sufficient in meeting domestic demand for these products as well as substantial exporters of these products. Markets in the industrial countries represent the major destinations for these exports. As such, the NICs have an interest in retaining access to these markets for their CFC end-user products.

NICs that participated in the Montreal Protocol negotiations included: Argentina, Brazil, Colombia, Korea, Malaysia, Mexico, Nigeria and Venezuela.[22] Mexico and Venezuela signed the protocol. Membership in the protocol would allow signatory NICs continued access to industrial country markets for their CFC end-user products. This is the main attraction that protocol membership would represent for these countries. Depending on protocol provisions, membership in the protocol would also allow the NICs to continue to expand their respective uses of CFCs for some specific period of time. Lastly, technology transfer provisions should provide additional incentive to join.

It should be noted that protectionist sentiment and actions pose a more serious threat to the NICs' access to industrial markets for their CFC end-user products than do protocol regulations to limit CFC use. Even without the provision of a time-based exemption, signatory LDCs would be able to maintain current (1986) levels of CFC use through 1992 or such, when use would be reduced 20 percent. However, there is no such guarantee that exports of automobiles, electronics, refrigerators, and air conditioners by the NICs to industrial countries will retain or exceed their current levels through 1992, absent any international CFC regulations.

Provision of a LDC Grace Period from the protocol's control measures to freeze and reduce CFC use for those LDCs that join would increase the relative attractiveness of joining for the NICs by reducing the near-term adjustment costs. Most significantly, such a Grace Period may allow continued CFC use for ten years. In and of itself, however, providing a Grace Period would not allow the LDCs to do anything that they do not and cannot already do, and could still result in lower LDC per capita CFC use than in OECD countries.

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[22] Colombia, Malaysia and Nigeria are included here as NICs, although they are relatively less developed than other countries in this group.

The incentive to join the protocol, besides a desire to protect the environment, is therefore provided by the protocol's trade control provisions which would ban or restrict exports of CFCs and some CFC end-user products by those countries that do not join.

The trade control provisions would restrict, to a greater or lesser degree, the ability of countries outside the protocol to export their CFCs and CFC end-user products to the markets of protocol signatories. It is this threat of losing market access to major export markets for major export products of the NICs that provides the greatest incentive for them to join the protocol.

The combination of the protocol's trade control provisions, LDC Grace Period and technology transfer assistance may be particularly attractive to the NICs. Together, these provisions would make joining the protocol significantly less costly than not joining. As such, it is more likely than not that the NICs will join the protocol rather than be subject to its trade control provisions. Some, however, may choose to simply comply with the protocol's central measures rather than officially join.

5.2 Least Developed Countries

There is little immediate economic incentive for most of the least developed countries to join the protocol. Their use of CFCs is low and should continue to be. Despite this, several least developed countries participated in the Montreal Protocol negotiations, including: Algeria, Burkina Faso, Chile, Congo, Costa Rica, Democratic Yemen, Egypt, Ghana, Kenya, Mauritius, Morocco, Panama, Peru, Philippines, Senegal, Thailand, Togo, Tunisia, and Uganda. Of these, Egypt, Ghana, Panama, Senegal, and Togo joined the protocol. The Dominican Republic, Ecuador and Kuwait were observers. These countries do not produce CFCs or CFC end-user products that would be subject to the protocol's trade control provisions, for either their respective domestic markets or export. A few of the least developed countries, such as Egypt, do have relatively high per capita CFC consumption levels.[23] For these countries, membership in the protocol may represent less cost than not becoming party to the agreement.

For most of the least developed countries, the economies of which are agricultural and primary resource-based, the incentive and attraction of joining the UNEP protocol may be largely indirect and political. That is, to the degree their participation in the protocol may contribute to these countries being favorably viewed by others, their participation may have intangible benefits. For some, public government support for an agreement of importance to industrial countries may result in strengthened relations between individual developing and industrial countries. Otherwise, the direct benefits of protocol membership are limited for most of the least developed countries. The costs of both protocol membership and abstention appear to be minimal.

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[23] See Exhibits D-1, D-2 and D-3.

5.3 Large Developing Countries

The attractiveness of joining the protocol for the large developing countries, such as the Peoples Republic of China, India and Indonesia,[24] is greatly dependent on whether these countries continue to implement development strategies with increasing emphasis on export of manufactured goods. China and Indonesia participated in the Montreal Protocol negotiations, while India was an official observer. None has yet joined the protocol.

China and India are both attempting to develop domestic production capabilities in CFC end-user industries such as motor vehicles and electronics. Expansion of these industries along current lines would require continued access to the markets of industrial countries. In this case, participation in the Montreal Protocol may be a key to continued export growth of such targeted industries. The ten-year Grace Period allowing continued growth of controlled substances use up to 0.3 kilograms per capita would further benefit the current development strategies of these countries, thus increasing their incentive to join. However, as with the NICs, the principal incentive to join the protocol is the threat of losing access to export markets in the industrial countries.

The size of domestic markets in the large developing countries gives them the option of basing their economic growth and development on increased domestic consumer demand.[25] With regard to CFC-related products, production for domestic consumption could continue to use CFCs, whereas, production for export could employ alternative technologies.

The ability of domestic markets to absorb current and foreseeable output of CFC-related products, however, has structural limitations. The character of these products and the vast poverty of the people in the large developing countries may constrain the ability of domestic markets to absorb these goods and fully substitute for exports. This will surely be a consideration in the decision of the large developing countries to join the protocol or not. For these countries, the choice of development strategy -- outward or inward looking -- will be an important factor. A decision to maintain or increase the outward orientation of their domestic economies should increase the probability that large developing countries will join the protocol.

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[24] Brazil could also be included in this group of developing countries given its large population and domestic market.

[25] Recent experience in Brazil showed the potential for this type of market shift. Although the causal factor was different, built-up consumer demand effectively siphoned off motor vehicles and other products made for export. Similarly, India's electronics may serve a domestic market.

ATTACHMENT D-1

The following is a series of development factors and indicators that will have affected the recent use and production of CFCs and CFC end-user products in nine developing countries[1] under three categories: newly industrialized countries -- Brazil, Hong Kong, and South Korea; least developed countries -- Egypt, Honduras, and Thailand; and large developing countries -- China, India, and Indonesia.

Exhibit 1 provides basic indicators which illustrate recent economic growth, population and projected population growth rates through the year 2000. There has been steady growth of GDP over the past decade ranging from a 4.1 percent increase in India to a 9.1 percent increase in Hong Kong. Population growth through the year 2000 is expected to range from a low of 1.2 percent in both China and Hong Kong, to a high of 3.0 percent in Honduras.

Social indicators are shown in Exhibit 2. Income distribution is weighted heavily towards the highest quantile of households. Urban population as a percentage of total population increased in eight out of the nine countries identified, the exception being Egypt. The number of cities with over 500,000 persons has, in most countries, more than doubled.

Exhibit 3 examines economic activity by sector. It indicates that agriculture represents a smaller portion of GDP than in the past. Manufacturing, services and, in most countries, industry have experienced strong growth in the past two decades, but a slowdown appeared in the 1973-1984 period from the preceding nine years. The sector breakdown illustrates that the economic growth indicated in Exhibit A-1 is unevenly based among economic sectors. CFC-related products are among the manufacturing and industry sectors that have had some of the strongest growth.

Production indicators in Exhibit 4 show a large increase in manufacturing since 1970. Of that increase, machinery and transport equipment grew at a faster pace than other sectors of manufacturing. For a majority of the countries, average annual energy production growth rates and per capita energy consumption increased tremendously due to improved infrastructure. This in turn is a precondition for increased CFC use in developing countries.

Exhibit 5 on structure of exports once again illustrates the growth of machinery and transport equipment as a share of merchandise exports. The destination of manufactured exports indicates a general decrease in the percentage of total goods exported to developing countries. The current trend is not toward increased trade of manufactured products between developing nations. This is significant as the trend indicates the problem some LDCs will have if they are banned from trading CFC end-user products with industrialized nations.

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[1] These countries were chosen because of the availability of data on CFC production/use (shown in Exhibits D-1, D-2, and D-3), the growth of which is influenced by the development indicators included in this Appendix.

Exhibit 6 on the structure of imports and capital flows demonstrates that with the exception of fuels, developing countries have, in most cases been importing much less than they did twenty years ago. This reflects in part, increasing domestic import substitution and production capacity. At the same time, all of the developing countries here have increased their external debt obligations, which in turn will restrict their available finances for productive investment and import purposes.

ATTACHMENT D-1

EXHIBIT 1

BASIC INDICATORS a/

	Population (millions) 1984	Population Growth Rate 1980-2000	GDP (billions $) 1965	GDP (billions $) 1984	Growth in GDP (%) 1973-1984	GNP Per Capita ($) 1984
Newly Industrialized Countries						
Brazil	132.6	2.0	19.3	187.1	4.4	1,720
Hong Kong	5.4	1.2	2.2	30.6	9.1	6,330
Korea	40.1	1.4	3.0	93.2	7.2	2,110
Least Developed Countries						
Egypt	45.9	2.2	4.6	30.1	8.5	720
Honduras	4.2	3.0	.5	2.8	3.8	700
Thailand	50.1	1.7	4.1	43.0	6.8	860
Large Developing Countries						
China	1,029.2	1.2	65.6	281.3	6.6	310
India	749.2	1.9	46.3	162.3	4.1	260
Indonesia	158.9	1.9	3.6	80.6	6.8	540

a/ The World Bank, (1986). World Development Report. Washington, D.C., pp. 180-184 and 228-229.

ATTACHMENT D-1

EXHIBIT 2

SOCIAL INDICATORS (1)

	Income Distribution(2) (% share of household income by groups of households)					Urban Population: As % of total Population		Urban Population: Average annual growth rate (%)		Cities Over 500,000 Persons	
	Lowest 20%	2nd Quantile	3rd Quantile	4th Quantile	Highest 20%	1965	1984	1965-73	1973-84	1960	1980
Newly Industrialized Countries											
Brazil	2.0	5.0	9.4	17.0	66.6	51	72	4.5	4.0	6	14
Hong Kong	5.4	10.8	15.2	21.6	47.0	89	93	2.1	2.6	1	1
Korea	5.7	11.2	15.4	22.4	45.3	32	64	6.5	4.6	3	7
Least Developed Countries											
Egypt	5.8	10.7	14.7	20.8	48.0	40	23	3.0	3.0	53	53
Honduras	NA	NA	NA	NA	NA	26	39	5.4	5.7	0	0
Thailand	5.6	9.6	13.9	21.1	49.8	13	18	4.8	3.1	1	1
Large Developing Countries											
China	NA	NA	NA	NA	NA	18	22	3.0	2.9	42	45
India	7.0	9.2	13.9	20.5	49.4	19	25	4.0	4.2	11	36
Indonesia	6.6	7.8	12.6	23.6	49.4	16	25	4.1	4.5	3	9

(1)

The World Bank, (1986). World Development Report 1986. Washington, D.C., pp. 226-227 and 240-241.

(2)

The income distribution data are current to 1976 for India, Indonesia, South Korea, and Thailand. The income distribution data for Brazil, Hong Kong, and Egypt are current to 1972, 1980, and 1974, respectively.

ATTACHMENT D-1

EXHIBIT 3

ECONOMIC ACTIVITY BY SECTOR (1)

	Distribution of gross domestic product (percent)								Average annual growth rate (percent)							
	Agriculture		Industry		Manufacturing(2)		Services		Agriculture		Industry		Manufacturing		Services	
	1965	1984	1965	1984	1965	1984	1965	1984	1965-73	1973-84	1965-73	1973-84	1965-73	1973-84	1965-73	1973-84
Newly Industrialized Countries																
Brazil	19	13	33	35	26	27	48	52	3.8	4.0	11.0	4.2	11.2	4.9	10.5	4.6
Hong Kong	2	1	40	22	24	NA	58	78	-0.6	0.8	8.4	8.0	NA	NA	8.1	9.6
S. Korea	38	14	25	40	18	28	37	47	2.9	1.7	18.4	10.9	21.1	11.5	11.3	6.8
Least Developed Countries																
Egypt	29	20	27	33	NA	NA	45	48	2.6	2 5	3.8	10.3	NA	NA	4.7	10.6
Honduras	40	27	19	26	12	15	41	47	2.2	3.6	5.7	4.4	6.5	4.2	5.8	3.8
Thailand	35	20	23	28	14	NA	42	52	5.2	3.7	9.0	8.7	11 4	10.0	9.1	7.5
Large Developing Countries																
China	39	36	38	44	NA	NA	23	20	2.8	4.9	12.1	8.7	NA	NA	11.7	5.0
India	47	35	22	27	15	15	31	38	3.7	2.3	3.7	4.4	4.0	5.9	4.2	6.1
Indonesia	59	26	12	40	8	NA	29	34	4.8	3.7	13.4	8.3	9.0	14.9	9.6	8.6

(1)
The World Bank, (1986). World Development Report 1986. Washington, D.C., pp. 182-185.

(2)
The distribution of manufacturing activity is shown separately in Exhibit A-4.

ATTACHMENT D-1

EXHIBIT 4

PRODUCTION INDICATORS (1)

	Value added in manufacturing (billions of 1980 dollars)		Distribution of manufacturing value added (percentage: 1980 prices) Food and agriculture		Textiles and clothing		Machinery and transport equipment		Chemicals		Other		Average annual energy production growth rate (percent)		Per capita energy consumption (kilograms of oil equivalent)	
	1970	1983	1970	1983	1970	1983	1970	1983	1970	1983	1970	1983	1965-73	1973-84	1965	1984
Newly Industrialized Countries																
Brazil	27.0	56.9	21	21	15	11	16	17	4	11	44	40	8.7	9.4	286	753
Hong Kong	3.1	6.9	4	NA	50	NA	16	NA	1	NA	28	NA	NA	NA	424	1,162
S. Korea	4.0	21.8	13	10	16	19	9	24	16	12	46	36	2.9	5.0	237	1,171
Least Developed Countries																
Egypt	3.3	4.8	22	20	35	26	5	13	7	9	32	32	10.0	15.6	313	562
Honduras	0.5	0.7	43	50	13	11	NA	1	2	5	41	33	15.6	9.9	111	205
Thailand	2.5	7.8	32	23	21	NA	6	12	6	8	36	56	11.0	17.4	80	205
Large Developing Countries																
China	69.1	134.9	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	11.8	5.6	178	485
India	16.3	27.1	11	13	37	27	14	18	8	11	30	32	3.7	7.9	100	187
Indonesia	2.4	9.6	18	21	7	7	5	7	7	6	62	60	12.7	3.3	91	205

(1) The World Bank, (1986) World Development Report 1986. Washington, D.C., pp. 192-195.

ATTACHMENT D-1

EXHIBIT 5

STRUCTURE OF EXPORTS (1)

	Percentage share of merchandise exports										Destination of manufactured exports (% of total)									
	Fuels, minerals, and metals		Other primary commodities		Textiles and clothing		Machinery and transport equipment		Other Manufacturers		Industrial market economies		East European nonmarket economies		High-income oil exporters		Developing economies		Manufactured exports (billions of dollars)	
	1965	1983	1965	1983	1965	1983	1965	1983	1965	1983	1965	1983	1965	1983	1965	1983	1965	1984	1965	1983
Newly Industrialized Countries																				
Brazil	9	15	83	44	1	3	2	14	6	23	40	52	1	1	0	3	59	43	.13	9 1
Hong Kong	2	2	11	6	43	33	6	22	37	36	71	64	0	0	1	4	28	32	1 01	20 1
S. Korea	15	3	25	6	27	25	3	32	29	34	68	66	0	0	0	10	32	24	10	22 2
Least Developed Countries																				
Egypt	8	70	71	22	15	4	NA	NA	5	5	20	38	46	40	4	8	30	14	.13	26
Honduras	6	7	90	84	1	1	NA	NA	3	7	2	28	0	0	0	0	98	72	.01	06
Thailand	11	6	84	62	0	11	0	6	4	15	39	60	0	0	0	9	61	31	03	2 06
Large Developing Countries																				
China	NA	22	NA	21	NA	19	NA	6	NA	32	NA	NA	NA	NA	NA	NA	NA	NA	NA	12 58
India	10	18	41	29	36	14	1	7	12	31	55	51	12	0	2	7	31	19	83	5 08
Indonesia	43	80	53	12	0	1	3	1	1	6	25	42	1	0	0	7	74	52	.03	1.62

(1) The World Bank, (1986). World Development Report 1986. Washington, D.C., pp. 198-199 and 204-205.

ATTACHMENT D-1

EXHIBIT 6

STRUCTURE OF IMPORTS AND CAPITAL FLOWS(1)

	Percentage share of merchandise imports										Net capital inflow (millions of dollars)				Total long-term debt service as percentage of			
	Food		Fuels		Other primary commodities		Machinery and transport equipment		Other Manufacturers		Public and publicly guaranteed		Private nonguaranteed		GNP		Exports of goods and services	
	1965	1983	1965	1983	1965	1983	1965	1983	1965	1983	1970	1984	1970	1984	1970	1984	1970	1984
Newly Industrialized Countries																		
Brazil	20	8	21	56	9	4	22	16	28	16	629	8,102	700	-416	1.6	5.5	21.7	35.8
Hong Kong	25	12	3	7	13	6	13	21	46	54	-1	69	NA	NA	NA	NA	NA	NA
S. Korea	15	8	7	27	26	14	13	29	38	22	242	2,999	25	807	3.2	6.6	20.3	15.8
Least Developed Countries																		
Egypt	26	30	7	3	12	6	23	29	31	30	97	995	NA	-50	NA	7.9	NA	34.1
Honduras	11	10	6	22	1	2	26	18	56	47	26	245	7	-33	1.5	6.0	5.2	20.4
Thailand	6	4	9	24	6	8	31	29	49	35	27	804	62	713	2.5	5.4	14.0	21.5
Large Developing Countries																		
China	NA	15	NA	1	NA	18	NA	19	NA	47	NA	NA	NA	NA	NA	NA	NA	NA
India	22	7	5	37	14	6	37	17	22	32	583	2,048	0	530	1.0	1.1	23.4	13.8
Indonesia	6	8	3	25	2	5	39	35	50	28	382	2,219	134	400	1.8	5.5	13.8	19.0

(1) The World Bank, (1986). World Development Report 1986. Washington, D.C., pp. 200-201, 210-211 and 212-213.

APPENDIX E

HUMAN HEALTH EFFECTS MODELING

This appendix presents the assumptions and calculations that underlie the estimates of cancer incidence and mortality and cataract incidence.

Each of the following topics is discussed in turn:

1. Baseline U.S. Population;

2. Ozone Depletion;

3. Changes in UV Radiation Flux;

4. Basal and Squamous Cell Skin Cancers:

   - Age- and sex-specific incidence rates assuming zero ozone depletion,

   - Dose-response relationship and assumptions, and

   - Mortality assumptions.

5. Melanoma Skin Cancers:

   - Age- and sex-specific incidence and mortality rates assuming zero ozone depletion,

   - Dose-response relationship and assumptions.

6. Cataract Prevalence and Incidence:

   - Age-specific prevalence rates assuming zero ozone depletion

   - Dose-response relationship and assumptions;

   - Method for computing incidence from prevalence.

7. Valuation of Human Health Effects

This appendix begins with a brief summary covering these areas.

SUMMARY

The key assumptions used to evaluate cancer risks include:

1. U.S. Population. The U.S. population is estimated to grow to 311 million by the year 2080 and to remain constant thereafter. The population is categorized by sex, race (white, non-white), age, and region (north, middle, south). The sex, race, and age pattern is assumed to change from 1985 to 2080, and to remain fixed thereafter. The current regional distribution of the U.S. population is assumed throughout.

2. Ozone Depletion. Global ozone depletion was evaluated using a parameterized representation of a 1-dimensional model of the atmosphere. Various scenarios of future production and emissions of ozone depleting compounds have been analyzed, ranging from a phaseout of CFCs to 5.0 percent growth per year from 1985 to 2050. In all scenarios, production after 2050 was assumed to be constant, and global ozone depletion was constrained not to exceed 50 percent.

3. UV Radiation Flux. The DNA-damage action spectrum and the erythema action spectrum are used to evaluate potential changes in UV radiation flux. Based on estimates from a UV model, for each 1.0 percent of ozone depletion, DNA-damage-weighted UV radiation flux is projected to increase from 2.1 to 3.2 percent, and erythema-weighted UV is projected to increase from 1.75 to 2.6 percent.

4. Basal and Squamous Cell Skin Cancers. Incidence rates (cases per 100,000 population per year) for white males and females for each U.S. region (north, middle, and south) were developed from incidence rates published in 1981. In the absence of ozone depletion, these rates are assumed to remain constant throughout the analysis, and rates for non-whites are assumed to be zero. A "power function" dose-response model is used which implies about a 1.0 percent increase in basal cell cancer (BCC) incidence and a 2.0 percent increase in squamous cell cancer (SCC) incidence for a 1.0 percent increase in DNA-damage-weighted UV radiation exposure. Changes in cumulative lifetime exposure are used in the dose-response equation. Mortality, which occurs in one percent of all current cases of nonmelanoma, is estimated to be 0.3 percent of additional basal cases and 3.75 percent of additional squamous cases.

5. Melanoma Skin Cancer. Incidence and mortality rates are developed for white males and females for each U.S. region

(north, middle, and south) based on incidence and mortality rates published in 1984. In the absence of ozone depletion, these rates are assumed to remain constant throughout the analysis, and rates for non-whites are assumed to be zero. A "power function" dose-response model is used which implies less than a 1.0 percent increase in both incidence and mortality for a 1.0 percent increase in DNA-damage-weighted UV radiation exposure (incidence and mortality are modeled separately). Changes in cumulative lifetime exposure are used in the dose-response equation.

6. Cataracts. Cataract prevalence for males and females are taken from rates published in 1983. In the absence of ozone depletion, these rates are assumed to remain constant throughout the analysis. A "power function" dose-response model is used which implies about a 0.2 percent increase in prevalence for a 1.0 percent increase in UV radiation exposure. Changes in cumulative lifetime exposure are used in the dose-response equation. Incidence is estimated as the rate of change of prevalence, assuming that mortality is not related to cataract prevalence.

7. Value of the Health Effects. To determine the amount of damages caused by the impacts on human health (and therefore, the size of the benefits to society for avoiding the damages), estimates of the costs to society for skin cancer and cataracts have been determined. Each additional case of nonmelanoma is assumed to cost society $5,000, melanoma -- $15,000, and cataracts -- $15,000.

1. BASELINE U.S. POPULATION

The U.S. population is described in terms of:

- total population over time;
- fraction of the total population that resides in each of three regions within the U.S.; and
- fraction of the population in each region that is white, non-white, male, female, and in each of nine age groups.

Exhibit E-1 shows the data used to describe the U.S. population. The top row shows the total U.S. population, which grows through the year 2080. After 2080, the total population remains constant.

Exhibit E-1 also displays the fraction of the U.S. population that resides in each of three regions: north, middle, and south. The three regions were chosen to divide the country into three sets of baseline nonmelanoma and melanoma incidence categories. The states included in each region are listed in Exhibit E-2. As shown in the exhibit, the regional population of the U.S. is assumed to remain constant after 1985, and therefore does not reflect regional migration and differences in birth and death rates among the regions after this time.

Exhibit E-1 also displays the fractions of the population projected to be white male and female and non-white male and female. These fractions shift slightly by 2000, and significantly by 2080.

Exhibit E-3 displays the fractions of the population projected to be in each of nine age groups. The age distributions are computed from projections for whites only, and the age group definitions were selected to correspond to the age groups for which nonmelanoma and melanoma skin cancer incidence rates are available. The age distributions show the general trend of the population getting older on average through the year 2080. Because skin cancer incidence rates increase with age, the shift in the age structure of the U.S. population toward older age groups has a large influence on estimates of skin cancer incidence and mortality; the older the population, the higher the population incidence and mortality.

To compute the number of people in each region by race, age, and sex over time, the total U.S. population is multiplied by the appropriate fractions displayed in Exhibits E-1 and E-3.

2. OZONE DEPLETION

Global ozone depletion can be evaluated for a wide range of future production and emissions of ozone depleting compounds and several sets of assumptions regarding future trace gas concentrations. The range of annual average growth rates for production through 2050 for the six scenarios presented in EPA's risk assessment are: (1) phasedown to 20 percent of the 1985 global emission levels by 2010, then constant thereafter; (2) lowest: 0.0 percent

EXHIBIT E-1

U.S. POPULATION ESTIMATES

	Year				
	1985	2000	2025	2050	2080
Total U.S. Population (millions)	239	266	301	310	311
Regional U.S. Population (Fraction of Total)					
North	0.2486	0.2486	0.2486	0.2486	0.2486
Middle	0.4607	0.4607	0.4607	0.4607	0.4607
South	0.2907	0.2907	0.2907	0.2907	0.2907
Population by Race and Sex					
White Male	0.4157	0.4063	0.3902	0.3732	0.3611
White Female	0.4355	0.4246	0.4087	0.3968	0.3843
Non-White Male	0.0710	0.0807	0.0961	0.1096	0.1213
Non-White Female	0.0778	0.0884	0.1050	0.1204	0.1333

Source: Computed from data presented in: Bureau of the Census, "Projections of the Population of the United States, by Age, Sex and Race: 1983 to 2080," U.S. Department of Commerce, Washington, D.C., Series P-25, No. 952.

EXHIBIT E-2

STATES INCLUDED IN THE THREE REGIONS OF THE U.S.

REGION 1: NORTH	REGION 2: MIDDLE	REGION 3: SOUTH
Alaska	California (N) *	Alabama
Connecticut	Colorado	Arizona
Idaho	Delaware	Arkansas
Maine	District of Columbia	California (S) *
Massachusetts	Illinois	Florida
Michigan	Indiana	Georgia
Minnesota	Iowa	Hawaii
Montana	Kansas	Louisiana
New Hampshire	Kentucky	Mississippi
New York	Maryland	New Mexico
North Dakota	Missouri	South Carolina
Oregon	Nebraska	Texas
Rhode Island	Nevada	
South Dakota	New Jersey	
Vermont	North Carolina	
Washington	Ohio	
Wisconsin	Oklahoma	
	Pennsylvania	
	Tennessee	
	Utah	
	Virginia	
	West Virginia	
	Wyoming	

* California is divided in half, one half being included in the Middle Region, and one half included in the South Region.

EXHIBIT E-3

AGE DISTRIBUTION OF THE U.S. POPULATION OVER TIME

	Age Group								
Year	0-14	15-24	25-34	35-44	45-54	55-64	65-74	75-84	85+
1985	0.2074	0.1619	0.1739	0.1360	0.0962	0.0973	0.0748	0.0403	0.0122
1990	0.2086	0.1381	0.1722	0.1532	0.1043	0.0879	0.0770	0.0444	0.0143
1995	0.2083	0.1275	0.1532	0.1627	0.1245	0.0838	0.0760	0.0470	0.0170
2000	0.1990	0.1303	0.1329	0.1633	0.1422	0.0925	0.0700	0.0498	0.0200
2005	0.1869	0.1360	0.1243	0.1472	0.1528	0.1120	0.0681	0.0502	0.0226
2010	0.1794	0.1334	0.1274	0.1286	0.1542	0.1286	0.0762	0.0469	0.0254
2015	0.1778	0.1246	0.1332	0.1207	0.1394	0.1387	0.0927	0.0463	0.0265
2020	0.1776	0.1177	0.1314	0.1243	0.1226	0.1406	0.1070	0.0527	0.0261
2025	0.1752	0.1168	0.1240	0.1310	0.1162	0.1282	0.1166	0.0651	0.0269
2050	0.1693	0.1151	0.1214	0.1236	0.1190	0.1229	0.1005	0.0723	0.0561
2075	0.1669	0.1147	0.1198	0.1212	0.1204	0.1189	0.1011	0.0778	0.0594
2080	0.1664	0.1146	0.1186	0.1219	0.1196	0.1174	0.1040	0.0757	0.0617

Source: Computed from data on the white population presented in: Bureau of the Census, "Projections of the Population of the United States, by Age, Sex, and Race: 1983 to 2080," U.S. Department of Commerce, Washington, D.C., Series P-25, No. 952.

globally (e.g., a true global freeze); (3) low: 1.2 percent globally; (4) central: 2.5 percent globally; (5) high: 3.8 percent globally; and (6) highest: 5.0 percent. Production is held constant after 2050. The annual average growth rates from 1985 to 2100 are therefore much lower than the rates listed above, which are for 1985 to 2050.[1]

Emissions lag production because a portion of the production of some chemicals (e.g., CFCs) is stored in products (e.g., refrigerators) before it is eventually released. The lag between production and emission is estimated based on the current mix of applications of ozone-depleting compounds, and is held fixed in the future. Exhibit E-4 displays the global ozone depletion[2] estimates in the "No Controls" scenario, reflecting no regulatory control of ozone-depleting substances.[3] These estimates in Exhibit E-4 are also based on trace gas concentrations that grow through 2100 as follows: CO2 -- approximately 0.6 percent per year; methane -- 0.017 ppm per year; and N20 -- 0.20 percent per year.

For several of the CFC scenarios, the ozone depletion estimates can exceed the valid range of the model. In these cases, the estimates of global ozone depletion are capped at 50 percent. The choice of the 50 percent cap has a large influence on the estimates of incidence and mortality. If a higher cap were chosen (e.g., 70 percent), estimates of effects would be much higher.

3. CHANGES IN UV RADIATION FLUX

Estimates of the ozone-depletion-induced changes in UV radiation reaching the earth's surface were based on the results of a UV model that relates UV flux to ozone concentrations.[4]

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[1] The annual growth rates from 1985 to 2100 for scenarios 3 to 6 are: (3) low: 0.7 percent; (4) central: 1.4 percent; (5) high: 2.1 percent; and (6) highest: 2.8 percent.

[2] In reality the extent of ozone depletion is expected to vary by latitude. However, different models (Sze and Isaksen, for instance) produce different gradients. Because it has not been resolved which model is most appropriate, unlike the draft risk assessment, the global depletion estimate is used here to project effects.

[3] In EPA's risk assessment, the middle case assumed an average annual rate of growth in global CFC production of 2.5 percent per year from 1985 to 2050. The assumed rate of growth in global CFC production for the No Controls scenario analyzed here is higher than 2.5 percent per year over the 1985-2000 period based on better information for the estimated CFC needs for several countries (e.g., the U.S.S.R. and other Eastern bloc countries are expected to increase CFC production 8 percent per year from 1986-1990) (see chapter 4). These changes result in an annual average rate of growth of 3.6 percent from 1986-2000; after 2000, the rate of growth is 2.5 percent per year.

[4] The UV model is described in G. Serafino and J. Frederick (1986).

EXHIBIT E-4

ANNUAL AVERAGE OZONE DEPLETION ESTIMATES -- NO CONTROLS SCENARIO*

Year	Global Ozone Depletion (%) Estimate
1985	0.00
2000	1.00
2025	4.64
2050	15.68
2075	50.00
2100	50.00
2150	50.00
2165	50.00

* Production of ozone-depleting compounds grows at 3.6 percent per year from 1985 to 2000, at 2.5 percent per year from 2000 to 2050, and remains constant thereafter. Trace gas concentrations grow as follows: CO2 -- approximately 0.6 percent per year; methane -- 0.017 ppm per year; and N20 -- 0.20 percent per year.

Source: Using a parameterized numerical fit to a 1-dimensional model of the atmosphere. The model is described in: Connell, Peter S., "A Parameterized Numerical Fit to Total Column Ozone Change Calculated by the LLNL 1-D Model of the Troposphere and Stratosphere," Lawrence Livermore National Laboratory, Livermore, California, November 1986. Of note is that a UNEP-sponsored model intercomparison found that compared with other models, this parameterization tends to under-estimate ozone depletion due to CFC-related perturbations.

The UV radiation values predicted by the model were weighted to derive biologically effective UV radiation fluxes using a weighting function based on the DNA-damage action spectrum developed by Setlow.[5] Exhibit E-5 shows the percent change in DNA-damage-weighted UV radiation flux for a wide range of changes in ozone levels. As shown in the exhibit, these values were estimated separately for each of the three U.S. regions. For example, a 10 percent ozone depletion over the north region results in a 22.9 percent increase in DNA-weighted UV radiation flux, and a 10 percent ozone depletion over the south region results in a 22.2 percent increase in UV radiation flux. Linear interpolation between values in the exhibit was used to estimate changes in UV radiation flux for changes in ozone ranging from increased levels of ozone of 10 percent to depletion of 30 percent.

The values shown in Exhibit E-5 for the DNA-damage action spectrum and the erythema action spectrum were used to estimate additional incidence and mortality risks. These values were estimated by: (1) simulating the UV radiation flux in 5 nm band widths with the UV Model; and (2) summing the energy across the 5 nm band widths using the appropriate action spectrum. The total UV radiation estimates for each level of depletion were used to compute the percent change in weighted UV radiation for the given percent changes in ozone.

Eight cities in each of the three U.S. regions were analyzed using this method (Exhibit E-6 lists the cities). Within each region, the results for the eight cities were weighted by their populations to produce average values used for each region. The relationship between ozone levels and weighted UV radiation flux shows only slight variation across the three U.S. regions.

4. BASAL AND SQUAMOUS CELL SKIN CANCER

4.1 Zero Ozone Depletion Incidence

Zero ozone depletion incidence of basal and squamous cell skin cancers is simply defined as the annual number of cases of these cancers expected over time in the absence of ozone depletion. This incidence was estimated by multiplying the region-, age-, and sex-specific incidence rates for whites shown in Exhibit E-7 by the number of whites (by age, sex, and region) in the U.S. over time. These rates in the exhibit are estimates of the expected number of cases per 100,000 people per year. The rates were estimated as the population-weighted averages of the incidence rates reported for 10 locations in the U.S.[6]

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[5] Setlow, R.B., "The Wavelengths in Sunlight Effective in Producing Skin Cancer: A Theoretical Analysis," Proceedings of the National Academy of Sciences, 71(9):3363-3366, 1974.

[6] Incidence rates for nonmelanoma skin cancer at 10 locations came from: Scotto, Fears, and Fraumeni (1981), "Incidence of Nonmelanoma Skin Cancer in the United States," U.S. Department of Health and Human Services, (NIH) 82-2433, Bethesda, Maryland, and were used to develop the population-weighted average incidence rates by region which were incorporated into the model as described above.

EXHIBIT E-5

PERCENT CHANGE IN WEIGHTED UV ENERGY AS A FUNCTION OF CHANGE IN OZONE ABUNDANCE FOR THREE U.S. REGIONS

	DNA-Damage Action Spectrum Change in UV (%)			Erythema Action Spectrum Change in UV (%)		
Change in Ozone	North	Middle	South	North	Middle	South
10% Increase	-17.3	-17.2	-16.7	-14.5	-14.4	-14.2
5% Increase	-9.3	-9.1	-8.9	-7.7	-7.6	-7.5
2% Increase	-3.8	-3.8	-3.8	-3.2	-3.2	-3.1
0 (No Change)	0.0	0.0	0.0	0.0	0.0	0.0
2% Depletion	4.2	4.3	4.2	3.5	3.5	3.5
5% Depletion	10.8	10.6	10.5	8.9	8.9	8.8
10% Depletion	22.9	22.8	22.2	18.8	18.7	18.5
20% Depletion	53.8	53.2	51.0	43.4	43.1	42.1
30% Depletion*	96.0	94.8	90.4	76.5	75.9	73.1

For depletion in excess of 30 percent, the following values are multiplied by the estimated depletion in order to compute changes in weighted UV radiation flux: DNA-damage: North -- 96.0/30 = 3.2; Middle -- 94.8/30 = 3.16; and South -- 90.4/30 = 3.013; Erythema: North -- 76.5/30 = 2.55; Middle -- 75.9/30 = 2.53; South -- 73.1/30 = 2.437. Given the fact that UV appears to increase non-linearly with ozone depletion, this extrapolation is an underestimate.

Source: Based on analyses using the UV Model developed by Serafino and Frederick (1986).

EXHIBIT E-6

CITIES USED TO EVALUATE CHANGES IN WEIGHTED UV FLUX FOR THE THREE REGIONS OF THE U.S.

REGION 1: NORTH	REGION 2: MIDDLE	REGION 3: SOUTH
New York	Chicago	Los Angeles
Detroit	Philadelphia	San Diego
Milwaukee	Baltimore	Houston
Boston	San Francisco	Dallas/Fort Worth
Seattle	Washington	Phoenix
Minneapolis	Denver	New Orleans
Portland	Salt Lake City	Miami
Buffalo	Kansas City	Atlanta

EXHIBIT E-7

INCIDENCE RATES FOR NONMELANOMA SKIN CANCERS: WHITE POPULATION ONLY
(Cases per 100,000 per year)

	Age Group								
	<15	15-24	25-34	35-44	45-54	55-64	65-74	75-84	85+
North Region									
Basal Cell Skin Cancer									
Male	0.1	2.9	22.1	91.1	259.2	465.8	761.0	1,162.8	1,311.3
Female	0.5	5.6	22.2	91.0	201.8	287.4	465.9	638.2	754.1
Squamous Cell Skin Cancer									
Male	0.2	0.3	1.6	7.4	32.6	87.4	147.4	349.7	431.8
Female	0.0	0.1	1.4	4.1	10.5	27.5	54.8	112.5	167.7
Middle Region									
Basal Cell Skin Cancer									
Male	0.8	2.6	29.4	120.0	297.4	556.7	871.9	1,149.0	1,139.0
Female	0.3	5.0	33.8	95.8	197.7	309.5	453 8	629.8	608.4
Squamous Cell Skin Cancer									
Male	0.1	0.8	3.3	22.2	67.7	170.4	295.1	489.9	624.2
Female	0.1	0.1	2.4	7.1	19.5	48.0	91.6	172.6	284.1
South Region									
Basal Cell Skin Cancer									
Male	0.3	3.8	49.4	236.1	595.9	1,075.0	1,786.0	2,331.0	2,295.0
Female	0.5	5.8	49.8	175.0	365.1	561.4	815.3	1,133.0	1,188.0
Squamous Cell Skin Cancer									
Male	0.0	0.3	11.2	43.0	168.6	377.3	640.0	965.7	696.0
Female	0.0	0.4	4.3	15.3	55.7	120.5	254.1	383.2	536.8

Source: Derived from data presented in: Scotto, Fears, and Fraumeni, 1981, "Incidence of Nonmelanoma Skin Cancer in the United States," U.S. Department of Health and Human Services, (NIH) 82-2433, Bethesda, Maryland.

The locations in each region for which incidence rates are available are:

North : Seattle; Minneapolis-St. Paul; Detroit;
Middle: Utah; San Francisco; Iowa; and
South : Atlanta; New Orleans; New Mexico; Dallas-Fort Worth.

In the absence of ozone depletion, the incidence rates (based on values published in 1981) are assumed to remain constant throughout the time horizon of the analysis.

Exhibit E-8 displays the estimated incidence of basal and squamous cell skin cancer from zero ozone depletion. Increases from zero ozone depletion incidence are due both to the increased size of the population and the changing population patterns with regard to race, age, and sex; the incidence rates (i.e., the values presented in Exhibit E-7) remain unchanged in the absence of ozone depletion. This incidence after 2080 remains constant because the population size is constant, and age, race, and sex patterns are assumed to remain constant.

The estimated incidence from zero ozone depletion can also be expressed in terms of the expected risk of developing nonmelanoma skin cancer. Three cohorts were analyzed: (1) people alive today; (2) people born between 1986 and 2029 (roughly, the children of the people alive today); and (3) people born between 2030 and 2074 (roughly, the grandchildren of the people alive today).

Exhibit E-9 displays the number of whites estimated to be in each cohort, and the number of cases expected for each. The risk is calculated by dividing the number of cases by the number of people in the cohort, and is expressed in the exhibit as a percent.

For the approximately 203 million white people alive today in the U.S., 61 million cases are anticipated <u>during the remainder of their lives</u> (in the absence of ozone depletion). On average, the risk is about 30 percent, although it should be noted that some people may get more than one case of nonmelonoma skin cancer during their lives. For the individuals born after 1985, the risk is estimated <u>over their entire lives</u>, and is estimated to be approximately 40 percent for people born from 1986-2029 and about 41 percent for people born from 2030-2074 (again, in the absence of ozone depletion).

4.2 Dose-Response Relationship and Assumptions

The additional incidence of nonmelanoma skin cancer associated with increased UV radiation flux due to ozone depletion was estimated by: (1) computing the expected percent increase in incidence; and (2) multiplying the percent increase by the incidence estimates assuming zero ozone depletion. The expected percentage increase in incidence is driven by: the estimated percent increase in exposure to UV radiation; the form of the dose-response equation; and the dose-response coefficient used in the equation. Each factor is discussed in turn.

The change in UV flux reaching the earth's surface is used as a proxy for the change in cumulative lifetime exposure for purposes of evaluating expected

EXHIBIT E-8

INCIDENCE OF NONMELANOMA SKIN CANCER IN THE ABSENCE OF OZONE DEPLETION

Year	U.S. Population (millions)	White U.S. Population (millions)	Incidence (thousands) BCC a/	SCC b/	Total
1985	239	203	462	125	587
2000	268	221	573	156	729
2050	310	237	839	250	1089
2075	311	232	838	252	1090
2100	311	232	839	252	1091
2150	311	232	839	252	1091
2165	311	232	839	252	1091

a/ BCC = Basal Cell Cancer.

b/ SCC = Squamous Cell Cancer.

Source: Population estimates derived from: Bureau of the Census, "Projections of the Population of the United States, by Age, Sex, and Race: 1983 to 2080," U.S. Department of Commerce, Washington, D.C., Series P-25, No. 952. Incidence estimates computed by multiplying zero ozone depletion incidence rates (see Exhibit E-7) by the population data. Incidence increases because the population structure shifts towards more elderly people.

EXHIBIT E-9

RISK OF NONMELANOMA SKIN CANCER IN THE ABSENCE OF OZONE DEPLETION

Cohort	U.S. Population a/ (millions)	U.S. Population: Whites Only a/ (millions)	Zero Ozone Depletion Cases: Whites Only (millions)	Risk: Whites Only (percent)
People Alive Today	239	203	61.1	30.1 b/
People Born 1986-2029	154	125	49.9	39.9 c/
People Born 2030-2074	156	119	49.1	41.3 c/

a/ Population estimates are approximate.

b/ Reflects the risk during the remaining lifetimes of the people alive today.

c/ Reflects the risk during the entire lifetimes of the people in the cohort. Differences between the latter two age cohorts are due to a small change in assumed age distribution which stabilizes in 2080.

Source: ICF Incorporated estimates.

changes in nonmelanoma incidence. For example, the percent change in a 40-year-old individual's lifetime exposure in year T (over a level of zero change) is estimated as the average percent change in DNA-damage-weighted UV radiation flux (due to ozone depletion) over the years T-39 to T. Changes in UV radiation prior to 1985 are assumed to be zero, meaning that people alive today are simulated to experience increased UV radiation exposure from ozone depletion only in the future. Note that estimated percent changes in UV radiation flux are assumed to translate directly into percent changes in exposure, so that no variations in exposure due to behavior are assumed (e.g., people are assumed not to change their exposure-related habits in response to the increased flux of UV radiation or to expected increases in their income).

The dose-response equation used was:

$$\text{Incidence} = a \times (\text{Exposure})^b$$

To estimate <u>changes</u> in incidence as a function of changes in exposure, this equation was rearranged as follows:

$$\text{Fractional change in incidence} = (\text{Fractional change in exposure} + 1)^b - 1.$$

The dose-response coefficient, b, for this equation is often referred to as a "biological amplification factor" or BAF; it equals the percent change in incidence associated with a one percent change in exposure.

As reported in EPA's risk assessment, various authors have estimated the BAF for basal and squamous cell skin cancer. Exhibit E-10 displays the coefficients used to evaluate increased risks due to ozone depletion. The coefficients were estimated using published estimates of basal and squamous cell skin cancer incidence rates and weighted annual UV radiation flux from the UV Model for 10 locations in the U.S. As shown in the exhibit, separate coefficients are used for basal and squamous cell skin cancers, and for males and females. Also shown in the exhibit are the coefficients used for the sensitivity analysis. These are the same seven locations analyzed in Scotto and Fears (in press). Then, the estimates of the incidence rates for each region were divided between: (1) Face, Head, Neck and Upper Extremities; and (2) Trunk and Lower. Exhibit E-11 displays the increased number of cases annually of basal and squamous cell skin cancers estimated based on the dose-response equation and the No Controls Scenario of production described above. As shown in the exhibit, the additional incidence is fairly small in the early years, reflecting the low level of increased exposure simulated to be experienced by most individuals alive in the near future. The risks of stratospheric modification can also be expressed on a percentage basis for the three cohorts analyzed. Exhibit E-12 displays estimated changes in risk for the three cohorts for the No Controls Scenario.

4.3 Mortality Assumptions

A dose-response relationship between UV exposure and mortality due to basal and squamous cell skin cancer has not been developed due to the poor quality of

EXHIBIT E-10

DOSE-RESPONSE COEFFICIENTS: NONMELANOMA SKIN CANCER (Whites only)

	DNA-Damage Action Spectrum			Erythema Action Spectrum		
	Low a/	Middle	High b/	Low a/	Middle	High b/
Squamous						
Male	1.42	2.03	2.64	1.54	2.21	2.88
Female	1.47	2.22	2.98	1.57	2.42	3.26
Basal						
Male	0.932	1.29	1.65	1.02	1.41	1.80
Female	0.316	0.739	1.16	0.346	0.809	1.27

a/ Middle minus one standard error.

b/ Middle plus one standard error.

Source: EPA (1987).

EXHIBIT E-11

ANNUAL INCIDENCE OF NONMELANOMA SKIN CANCER:
NO CONTROLS SCENARIO
(Whites only, -- DNA-Damage Action Spectrum)[a]

		Basal			Squamous		
Year	Ozone Depletion (%)	Zero Ozone Depletion (1,000s)	Additional (1,000s)	Additional Percentage	Zero Ozone Depletion (1,000s)	Additional (1,000s)	Additional Percentage
1985	0.00	462.0	0.0	0.0	125.0	0.0	0.0
2000	1.00	572.5	1.5	0.3	156.1	0.8	0.5
2050	15.68	838.6	93.8	11.2	249.7	52.8	21.1
2075	50.00[b]	838.0	470.1	56.1	251.5	313.9	124.8
2100	50.00	838.6	1,080.4	128.8	252.0	887.6	352.2
2150	50.00	838.6	1,756.4	209.4	252.0	1,813.8	719.8
2165	50.00	838.6	1,765.0	210.5	252.0	1,830.4	726.3

a/ The No Controls Scenario is one of several scenarios examined.

b/ Global ozone depletion constrained not to exceed 50 percent.

Source: ICF Incorporated estimates.

EXHIBIT E-12

CUMULATIVE INCIDENCE AND RISK OF NONMELANOMA SKIN CANCER BY COHORT: NO CONTROLS SCENARIO a/
(Whites only -- DNA-Damage Action Spectrum)

Cohort	Incidence			Risk		
	Zero Ozone Depletion (millions)	Additional (millions)	Additional Percentage Increase	Zero Ozone Depletion (%)	Additional (%)	Additional Percentage Increase
People Alive Today b/	61.09	3.51	5.7	30.1	1.7	5.7
People Born 1986-2029 c/	49.87	42.46	85.1	39.9	34.0	85.1
People Born 2030-2074 c/	49.09	132.02	268.9 d/	41.3	111.1	268.9 d/

a/ The No Controls Scenario is one of several scenarios examined.

b/ Reflects the risk during the remaining lifetimes of people alive today.

c/ Reflects the risk during the entire lifetimes of the people in the cohort.

d/ The total additional cases are so high that the incidence exceeds the size of the populations; this can happen because the percentage of deaths are low and a person can get two or more skin cancers.

Source: ICF Incorporated estimates.

the data on mortality due to these cancers. It is expected, however, that a fraction of basal and squamous cases will result in death, and it was assumed in this analysis that this fraction remains constant over time. It has been reported that:

(1) about one percent of all nonmelanoma skin cancer cases result in death;

(2) about 80 percent of all cases are basal, and 20 percent are squamous; and

(3) about 75 percent of the deaths from nonmelanoma skin cancers are attributable to squamous, and 25 percent to basal.[7]

Based on these approximate figures, the fraction of basal cases resulting in death is approximately 0.0031, and the fraction of squamous cases resulting in death is approximately 0.0375. In the risk assessment, these fractions were multiplied by the estimated additional cases of nonmelanoma skin cancer to compute additional mortality due to nonmelanoma skin cancer.

5. MELANOMA SKIN CANCER

5.1 Zero Ozone Depletion Incidence and Mortality

Zero ozone depletion incidence of melanoma skin cancer is simply defined as the number of cases expected over time in the absence of ozone depletion. This incidence was estimated using the age- and sex-specific incidence rates for whites shown in Exhibit E-13. These rates were derived from National Cancer Institute (NCI) incidence data for whites and data presented in Scotto and Fears (in press).[8] First, the NCI incidence data were population-weighted for each of the three U.S. regions using the following seven locations:

North : Seattle and Detroit;
Middle: Utah, San Francisco, and Iowa; and
South : Atlanta and New Mexico.

These incidence data were then divided into the two body locations (Face, Head, Neck and Upper Extremities; and Trunk and Lower Extremities) using data from Scotto (in press). Note that the data that describe the relative frequency of melanoma incidence between the two locations in Scotto and Fears (in press) do not vary by age group, and it was assumed that the relative frequency of incidence between the two locations is equal across ages. It was also assumed that the incidence among non-whites was zero. In the absence of ozone

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[7] Scotto, Fears, and Fraumeni, 1981, "Incidence of Nonmelanoma Skin Cancer in the United States," U.S. Department of Health and Human Services, (NIH) 82-2433, Bethesda, Maryland, pp. 2, 7, and 13.

[8] National Cancer Institute SEER Report, 1984, and Scotto and Fears (in press), "The Association of Solar Ultraviolet Radiation and Skin Melanoma Among Caucasians in the United States," Cancer Investigations.

EXHIBIT E-13

INCIDENCE FOR MELANOMA SKIN CANCER IN THE ABSENCE OF OZONE DEPLETION WHITE POPULATION ONLY (Cases per 100,000 population per year)

	Age Group								
	10-14	15-24	25-34	35-44	45-54	55-64	65-74	75-84	85+
NORTH REGION									
Face, Head, Neck and Upper Extremities									
Males	0.0	0.8	2.4	5.3	5.5	8.4	10.4	9.2	9.1
Females	0.1	0.9	3.2	4.2	5.3	5.4	4.5	4.6	4.9
Trunk and Lower Extremities									
Males	0.0	1.2	3.4	7.5	7.9	12.0	14.9	13.2	13.0
Females	0.1	1.4	5.3	6.9	8.6	8.9	7.4	7.4	8.0
MIDDLE REGION									
Face, Head, Neck and Upper Extremities									
Males	0.0	1.0	3.4	5.5	7.3	10.6	11.7	13.7	16.2
Females	0.0	1.7	4.3	5.7	6.5	5.8	6.6	7.1	11.9
Trunk and Lower Extremities									
Males	0.0	1.1	3.8	6.1	8.2	11.9	12.9	14.9	17.9
Females	0.1	2.2	5.8	7.6	8.6	7.7	8.8	9.4	15.7
SOUTH REGION									
Face, Head, Neck and Upper Extremities									
Males	0.1	1.2	4.3	6.7	9.5	11.4	11.4	15.9	23.8
Females	0.0	1.6	6.0	7.2	8.8	8.8	8.1	10.3	15.0
Trunk and Lower Extremities									
Males	0.1	1.4	5.1	7.8	11.1	13.3	13.5	18.9	27.3
Females	0.0	1.7	6.6	8.0	9.6	9.6	8.8	11.1	16.4

Sources: Derived from Scotto and Fears, "The Association of Solar Ultraviolet Radiation and Skin Melanoma Among Caucasians in the United States," Cancer Investigation, in press, and the National Cancer Institute SEER Report, 1984.

depletion, the incidence rates reported in Exhibit E-13 are assumed to remain constant throughout the time horizon of the analysis.

The incidence of melanoma skin cancer assuming zero ozone depletion among whites in the United States was computed by multiplying the age- and sex-specific rates reported in Exhibit E-13 by the number of individuals in the appropriate segments of the U.S. population. Exhibit E-14 displays the annual incidence of melanoma skin cancer over time assuming zero ozone depletion. Increases in incidence from 1985 to 2080 are due both to the increased size of the population and the changing population patterns (race, age, and sex). Incidence after 2080 assuming zero ozone depletion remains constant because the population size is constant.

The estimated incidence from zero ozone depletion can also be expressed in terms of the expected risk of developing melanoma skin cancer. For the three cohorts analyzed in the risk assessment, Exhibit E-15 displays the number of whites in each cohort, and the number of cases expected for each. The risk is calculated by dividing the number of cases by the number of people in each cohort. For the approximately 203 million whites alive today in the U.S., 1.53 million cases are expected during the remainder of their lives (in the absence of ozone depletion). On average, risk is about 0.8 percent. For individuals born after 1985, the risk is estimated over their entire lives, and is estimated to be about 1.1 percent (again, in the absence of ozone depletion).

Exhibit E-16 displays the mortality rates for melanoma skin cancer assuming zero ozone depletion, also derived from seven locations reported in the NCI data. These data do not identify the anatomical sites of the melanomas (Face, Head and Neck versus Trunk and Lower Extremities); consequently, the mortality figures are not divided by body site.

Similar to the incidence rates, these mortality rates are assumed to remain constant over time in the absence of ozone depletion. Exhibit E-17 displays the mortality over time assuming zero ozone depletion, and Exhibit E-18 displays the estimated risk for the three cohorts analyzed.

5.2 Dose-Response Relationship and Assumptions

The additional incidence and mortality of melanoma skin cancer associated with increased UV radiation flux due to ozone depletion was estimated by: (1) computing the expected percent increase in incidence; and (2) multiplying the percent increase by the zero ozone depletion incidence estimates. The expected percentage increase in incidence is driven by: the estimated percent increase in exposure to UV radiation; the form of the dose-response equation; and the dose-response coefficient used in the equation. Each factor is discussed in turn.

The change in UV flux reaching the earth's surface is used as a proxy for the change in cumulative lifetime exposure for purposes of evaluating expected changes in melanoma incidence and mortality (the change in incidence may actually be the result of a change in peak exposure, which is highly correlated to the change in cumulative exposure, and therefore, for purposes of this analysis, would not change the outcome by a large amount). For example, the

EXHIBIT E-14

ANNUAL INCIDENCE OF MELANOMA SKIN CANCER IN THE ABSENCE OF OZONE DEPLETION

Year	U.S. Population (millions)	White U.S. Population (millions)	Incidence (thousands)
1985	239	203	20.2
2000	268	221	24.2
2050	310	237	30.0
2075	311	232	29.6
2100	311	232	29.6
2150	311	232	29.6
2165	311	232	29.6

Source: Population estimates derived from: Bureau of the Census, "Projections of the Population of the United States, by Age, Sex, and Race: 1983 to 2080," U.S. Department of Commerce, Washington, D.C., Series P-25, No. 952. Incidence estimates computed by multiplying zero ozone depletion incidence rates (see Exhibit E-13) by the population data.

EXHIBIT E-15

RISK OF MELANOMA SKIN CANCER IN THE ABSENCE OF OZONE DEPLETION

Cohort	U.S. Population a/ (millions)	U.S. Population Whites Only a/ (millions)	Zero Ozone Depletion Cases: Whites Only (millions)	Risk: Whites Only (percent)
People Alive Today	239	203	1.53	0.8 b/
People Born 1986-2029	154	125	1.37	1.1 c/
People Born 2030-2074	156	119	1.33	1.1 c/

a/ Population estimates are approximate.

b/ Reflects the risk during the remaining lifetimes of the people alive today.

c/ Reflects the risk during the entire lifetimes of the people in the cohort.

Source: ICF Incorporated estimates.

EXHIBIT E-16

MORTALITY RATES FOR MELANOMA SKIN CANCER IN THE ABSENCE OF OZONE DEPLETION WHITE POPULATION ONLY
(Rate per 100,000 population per year)

	Age Group								
	10-14	15-24	25-34	35-44	45-54	55-64	65-74	75-84	85+
NORTH REGION									
Male	0.0	0.5	1.0	2.9	4.6	5.6	8.0	7.9	10.3
Female	0.0	0.0	0.8	1.6	2.8	2.9	3.3	5.3	5.5
MIDDLE REGION									
Male	0.0	0.4	1.5	3.4	4.2	5.9	10.3	13.3	9.7
Female	0.0	0.4	0.7	2.1	2.1	3.5	5.1	5.6	10.2
SOUTH REGION									
Male	0.0	0.2	1.3	3.5	6.1	7.7	12.8	10.2	11.1
Female	0.0	0.0	1.2	0.8	3.9	3.7	5.4	10.2	15.8

Source: Derived from National Cancer Institute SEER Report, 1984.

EXHIBIT E-17

MORTALITY FROM MELANOMA SKIN CANCER IN THE ABSENCE OF OZONE DEPLETION

Year	U.S. Population (millions)	White U.S. Population (millions)	Mortality (thousands)
1985	239	203	4.97
2000	268	221	6.11
2050	310	237	8.32
2075	311	232	8.27
2100	311	232	8.28
2150	311	232	8.28
2165	311	232	8.28

Source: Population estimates derived from: Bureau of the Census, "Projections of the Population of the United States, by Age, Sex, and Race: 1983 to 2080;" U.S. Department of Commerce, Washington, D.C., Series P-25, No. 952. Incidence estimates computed by multiplying zero ozone depletion incidence rates (see Exhibit E-16) by the population data.

EXHIBIT E-18

RISK OF MORTALITY FROM MELANOMA SKIN CANCER IN THE ABSENCE OF OZONE DEPLETION

	U.S. Population a/ (millions)	U.S. Population: Whites Only a/ (millions)	Zero Ozone Depletion Cases: Whites Only (millions)	Risk: Whites Only (percent)
People Alive Today	239	203	0.45	0.2 b/
People Born 1986-2029	154	125	0.38	0.3 c/
People Born 2030-2074	156	119	0.37	0.3 c/

a/ Population estimates are approximate.

b/ Reflects the risk during the remaining lifetimes of the people alive today.

c/ Reflects the risk during the entire lifetimes of the people in the cohort.

Source: ICF Incorporated estimates.

percent change in a 40-year-old individual's lifetime exposure in year T (over a level of zero change) is estimated as the average annual percent change in DNA-damage-weighted UV radiation flux (due to ozone depletion) over the years T - 39 to T. Changes in UV radiation prior to 1985 are assumed to be zero, meaning that people alive today are simulated to experience increased UV radiation exposure only in the future. Note that estimated percent changes in UV radiation flux are assumed to translate directly into percent changes in exposure, so that no variations in exposure due to behavior are assumed (e.g., people are assumed not to change their exposure-related habits in response to the increased flux of UV radiation or as a result of expected increases in income).

The form of the dose-response equation used for both incidence and mortality was:

$$\text{Incidence} = a \times (\text{Exposure})^{b}$$

To estimate changes in incidence as a function of changes in exposure, this equation was rearranged as follows:

$$\text{Fractional change in incidence} = (\text{Fractional change in exposure} + 1)^{b} - 1.$$

The dose-response coefficient, b, for this equation is often referred to as a "biological amplification factor" or BAF; it equals the percent change in incidence associated with a one percent change in exposure.

Exhibit E-19 displays the coefficients used to assess the risks of ozone depletion in conjunction with the DNA-damage action spectrum and the erythema action spectrum. As shown in the exhibit, separate coefficients are used for Face, Head and Neck Melanomas, Trunk and Lower Extremities Melanomas, and for males and females. Also shown in the exhibit are the coefficients used for the sensitivity analysis presented in the risk assessment. Of note is that these coefficients were developed using Robertson-Berger (R-B) meter measures of annual UV radiation flux as the surrogate measure of exposure, and that the coefficients were then used with the DNA-damage action spectrum and erythema action spectrum estimates of changes in UV flux due to ozone depletion. Use of R-B meter-derived coefficients for the dose-response relationship coupled with estimates of changes in DNA-damage-weighted and erythema-weighted UV radiation flux in response to ozone depletion may result in overestimating the increase in melanoma incidence in response to ozone depletion.[9]

Exhibit E-20 displays the increased number of cases per year of malignant melanoma estimated using the dose-response equation and the No Controls Scenario of production described above. As shown in the exhibit, the additional incidence is fairly small in the early years, reflecting the low level of

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[9] This potential upward bias is not present in the analysis of nonmelanoma skin cancers because the dose-response coefficients for nonmelanoma were computed using estimates of DNA-damage-weighted UV radiation flux.

EXHIBIT E-19

DOSE-RESPONSE COEFFICIENTS: MELANOMA SKIN CANCER INCIDENCE (Whites Only)

	Low a/	Middle	High b/
Face, Head and Neck			
Male	0.398	0.512	0.624
Female	0.477	0.611	0.744
Trunk and Lower Extremities			
Male	0.200	0.310	0.420
Female	0.268	0.412	0.553

a/ Middle minus one standard error.

b/ Middle plus one standard error.

Source: Derived from: Scotto and Fears, "The Association of Solar Ultraviolet Radiation and Skin Melanoma Among Caucasians in the United States," Cancer Investigation, in press.

EXHIBIT E-20

ANNUAL INCIDENCE OF MELANOMA SKIN CANCER:
NO CONTROLS SCENARIO*
(Whites only -- DNA-Damage Action Spectrum)

Year	Ozone Depletion (percent)	Zero Ozone Depletion (thousands)	Additional (thousands)	Additional Percentage Increase
1985	0.00	20.2	0.00	0.0
2000	1.00	24.2	0.03	0.1
2050	15.68	30.0	1.60	5.3
2075	50.00	29.6	6.97	23.5
2100	50.00	29.6	13.18	44.5
2150	50.00	29.6	17.26	58.3
2165	50.00	29.6	17.30	58.4

* The No Controls Scenario is one of several scenarios examined.

Source: ICF Incorporated estimates.

increased exposure simulated to be experienced by most individuals alive in the near future.

The risks of stratospheric modification can also be expressed on a percentage basis for the three cohorts analyzed. Exhibit E-21 displays estimated changes in risks for the No Controls Scenario. Exhibit E-22 displays the coefficients used to evaluate the increased mortality due to melanoma skin cancer. Exhibit E-23 displays the increases in melanoma mortality computed with changes in UV flux from the No Controls Scenario and the dose-response coefficients presented in Exhibit E-22. Exhibit E-24 displays the increase in risks.

6. CATARACT PREVALENCE AND INCIDENCE

Epidemiological studies have identified a correlation between the prevalence of various types of cataracts in humans and the flux of sunlight or ultraviolet radiation reaching the earth's surface (Hiller, Giacometti and Yuen 1977; Zigman, Datiler, and Torczynski 1979; Taylor 1980; Hollows and Moran 1981). Hiller, Sperduto and Ederer developed a multivariate logistic risk function that describes the correlation found between the prevalence of senile cataracts and the flux of UV-B and other risk factors.[10] The results of this study were used to indicate the magnitude of change in the prevalence of senile cataracts that could be associated with changes in UV-B flux due to ozone depletion.

The study by Hiller, Sperduto, and Ederer included HANES data on a total of 2,225 persons between the ages of 45 and 74 years who had resided in the state where the HANES examination took place for at least one-half of their lives. Of these 2,225 people, 413 (18.6 percent) were placed in the cataract or aphakia outcome category.

UV-B flux data were developed by NOAA for the 35 HANES locations used in the study based on a statistical analysis of UV-B data collected at 10 locations using Robertson-Berger meters. The statistical analysis incorporates season, latitude, elevation, weather (clouds), and haze. Subsequent validation of the estimates at six locations indicated that the differences between the estimated and observed mean daily flux average about seven percent.

These data on UV-B and outcome (i.e., cataract) were used by Hiller, Sperduto, and Ederer in conjunction with demographic and medical history data to estimate the following multivariate logistic risk function:

$$P = \frac{1}{1 + \exp(-a - b_i X_i - \ldots - b_k X_k)}$$

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[10] Hiller, Sperduto, and Ederer, "Epidemiologic Associations with Cataract in the 1971-1972 National Health and Nutrition Examination Survey," American Journal of Epidemiology, Vol. 118, No. 2, pp. 239-249, 1983.

EXHIBIT E-21

CUMULATIVE INCIDENCE AND RISK OF MELANOMA SKIN CANCER BY COHORT: NO CONTROLS SCENARIO a/
(Whites only -- DNA-Damage Action Spectrum)

Cohort	Incidence			Risk		
	Zero Ozone Depletion (millions)	Additional (millions)	Additional Percentage Increase	Zero Ozone Depletion (%)	Additional (%)	Additional Percentage Increase
People Alive Today b/	1.53	0.02	1.3	0.8	0.01	1.3
People Born 1986-2029 c/	1.37	0.22	16.1	1.1	0.18	16.1
People Born 2030-2074 c/	1.33	0.65	48.9	1.1	0.54	48.9

a/ The No Controls Scenario is one of several scenarios examined.

b/ Reflects the risk during the remaining lifetimes of people alive today.

c/ Reflects the risk during the entire lifetimes of the people in the cohort.

Source: ICF Incorporated estimates.

EXHIBIT E-22

DOSE-RESPONSE COEFFICIENTS: MELANOMA SKIN CANCER MORTALITY (Whites Only)

	DNA-Damage Action Spectrum			Erythema Action Spectrum		
	Low a/	Middle	High b/	Low a/	Middle	High b/
Male	0.39	0.42	0.46	0.42	0.46	0.50
Female	0.25	0.29	0.33	0.28	0.32	0.36

a/ Middle estimate minus one standard error.

b/ Middle estimate plus one standard error.

Source: Pitcher, H.M., "Examination of the Empirical Relationship Between Melanoma Death Rates in the United States 1950-1979 and Satellite-Based Estimates of Exposure to Ultraviolet Radiation." U.S. EPA, Washington, D.C., March 17, 1987, draft.

EXHIBIT E-23

MELANOMA SKIN CANCER MORTALITY: NO CONTROLS SCENARIO*
(Whites-only -- DNA-Damage Action Spectrum)

Year	Ozone Depletion (percent)	Zero Ozone Depletion (thousands)	Additional (thousands)	Additional Percentage Increase
1985	0.00	4.97	0.0	0.0
2000	1.00	6.11	0.01	0.2
2050	15.68	8.32	0.33	4.0
2075	50.00	8.27	1.43	17.3
2100	50.00	8.28	2.77	33.5
2150	50.00	8.28	3.80	45.9
2165	50.00	8.28	3.81	46.0

* The No Controls Scenario is one of several scenarios examined.

Source: ICF Incorporated estimates.

EXHIBIT E-24

RISK OF MORTALITY FROM MELANOMA SKIN CANCER BY COHORT: NO CONTROLS SCENARIO a/
(Whites only -- DNA-Damage Action Spectrum)

Cohort	Mortality			Lifetime Risk		
	Zero Ozone Depletion (thousands)	Additional (thousands)	Additional Percent Increase	Zero Ozone Depletion (percent)	Additional (percent)	Additional Percent Increase
People Alive Today b/	449.3	6.0	1.3	0.22	0.003	1.3
People Born 1986-2029 c/	380.9	57.6	15.1	0.30	0.045	15.1
People Born 2030-2074 c/	372.7	147.7	39.6	0.31	0.123	39.6

a/ The No Controls Scenario is one of several scenarios examined.

b/ Reflects the risk during the remaining lifetimes of people alive today.

c/ Reflects the risk during the entire lifetimes of the people in the cohort.

Source: ICF Incorporated estimates.

where P is the probability (or risk) of having a cataract, and X_i are risk factors. In addition to UV-B, the following risk factors were analyzed: age; race; sex; education; diabetes; systolic blood pressure; and residence (urban, rural).

Exhibit E-25 displays the standardized regression coefficients estimated for each of the risk factors. Positive coefficients indicate factors that are correlated with increased risk; negative coefficients indicate factors that are correlated with decreased risk. The coefficients presented in the exhibit are "standardized," meaning that they represent the expected change in the logit of P (equal to ln (P/1-P)) for a one standard deviation change in the risk factor. Standardization of the coefficients allows the relative importance of the risk factors to be identified by the relative size of the standardized coefficients.

As shown in Exhibit E-25, three risk functions were estimated: (1) univariate (outcomes as a function of the risk factor); (2) bivariate (outcome as a function of the risk factor and age); and (3) outcome as a function of all the risk factors simultaneously. For all three formulations, UV-B is statistically significant, and positively correlated with the increased risk of being in the cataract outcome category.

Using the multivariate risk function coefficients, and the mean values for all the risk factors other than UV-B, the change in the prevalence of cataract for each 1.0 percent change in UV-B is estimated to be approximately 0.5 percent. This relationship holds for changes in UV-B as large as minus 20 percent to plus 30 percent. Outside of this range, reductions in UV-B are associated with less of a reduction in cataract prevalence, and increases in UV-B are associated with larger increases.

Of note is that this estimated relationship between UV-B and cataract prevalence varies with age; UV-B has a larger effect on prevalence (on a percentage basis) among younger individuals. Exhibit E-26 displays the percent increase in cataract prevalence due to increases in UV-B for persons of different ages. As shown in the exhibit, the percentage increase in prevalence due to changes in UV-B are estimated to be larger for 50 year olds than for 70 year olds.

Although the effect of UV-B on prevalence is estimated to be larger at younger ages (on a percentage basis) using the multivariate risk function, the prevalence of senile cataracts is known to increase substantially with age. Leske and Sperduto report the prevalence of senile cataracts in both sexes found in the Framingham Eye Study to be as follows: 52 to 64 years old -- 4.5 percent; 65 to 74 years old -- 18.0 percent; 75 to 85 years old -- 45.9 percent.[11] These prevalence estimates use the same definition of cataracts as used by Hiller, Sperduto, and Ederer. Because cataracts are more prevalent in older individuals, increases in the actual number of cases of cataracts would likely be larger for older individuals, even though the percentage increase in risk has been estimated to be larger for younger individuals.

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[11] Leske and Sperduto, "The Epidemiology of Senile Cataracts: A Review," American Journal of Epidemiology, Vol. 118, No. 2, pp. 152-165, 1983.

EXHIBIT E-25

STANDARDIZED REGRESSION COEFFICIENTS FOR CATARACT

Risk Factor a/	Mean b/	Univariate c/	Bivariate d/	Multivariate e/
Age	61.97	1.22 f/	-	1.20 f/
Race	1.22	0.18 f/	0.20	0.13 g/
Sex	1.52	0.07	0.08	0.08
Education	2.87	-0.43 f/	-0.25 f/	-0.14 g/
Diabetes	0.08	0.25 f/	0.23 f/	0.21 f/
Systolic Blood Pressure	146.3	0.33 f/	0.15 g/	0.08
UV-B	3.59	0.19 f/	0.20 f/	0.13 g/
Residence	1.37	0.18 f/	0.21 f/	0.19 f/

a/ Values for categorical risk factors: race: 1 = white, 2 = black; sex: 1 = male, 2 = female; education 1 = <5 grades, 2 = 5-8 grades, 3 = 9-11 grades, 4 = 12 grades, 5 = college; diabetes: 0 = absent, 1 = present; residence: 1 = urban, 2 = rural.

b/ Mean value for the risk factor in the 2,225 persons in the study.

c/ Each risk factor analyzed separately.

d/ Each risk factor analyzed with age only.

e/ All risk factors analyzed simultaneously.

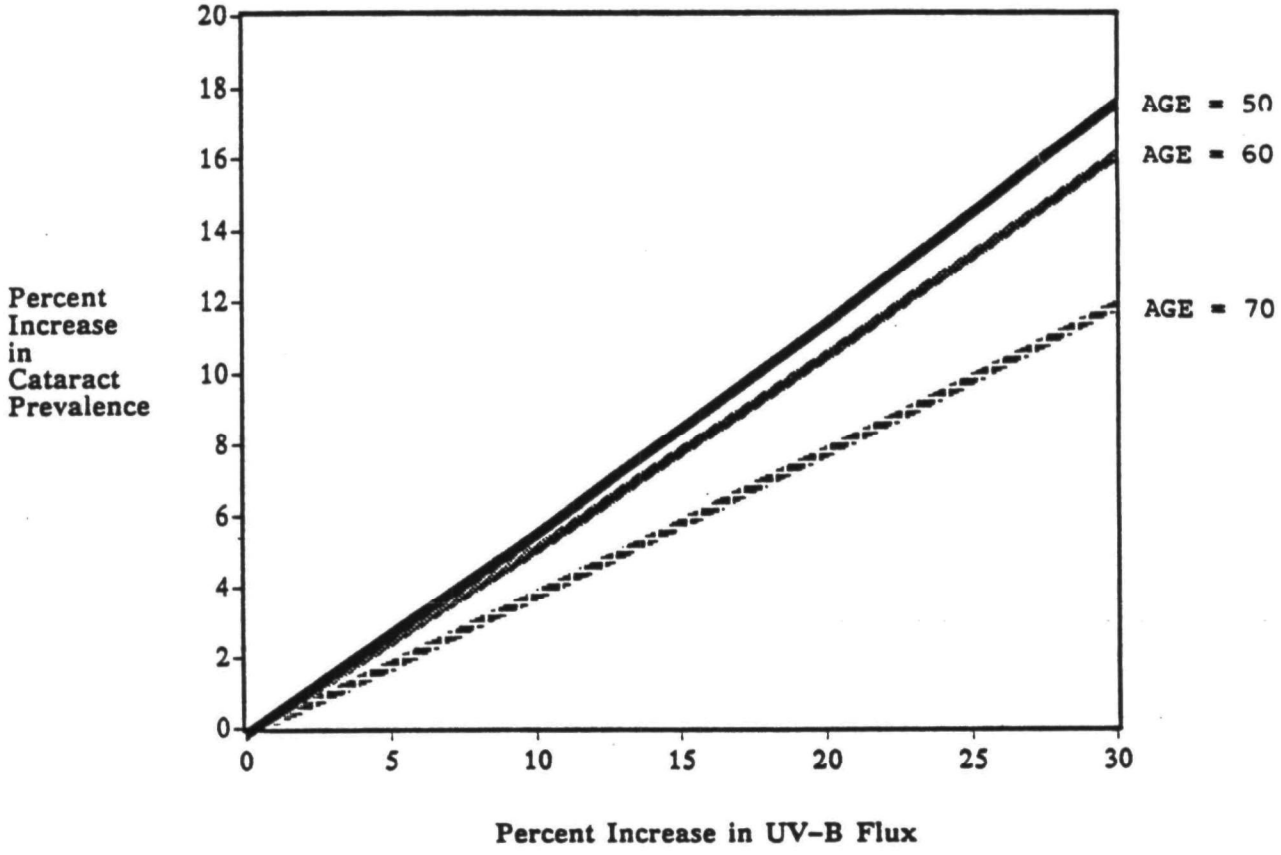
f/ p(two sided) <0.005.

g/ p(two sided) <0.05.

Source: Hiller, R., R. Sperduto, and F. Ederer, "Epidemiologic Associations with Cataract in the 1971-1972 National Health and Nutrition Examination Survey," American Journal of Epidemiology, Vol. 118, No. 2, pp. 239-249, 1983.

EXHIBIT E-26

ESTIMATED RELATIONSHIP BETWEEN RISK OF CATARACT AND UV-B FLUX



Increased UV-B flux (measured with an RB-meter) is associated with increased prevalence of cataract. The percent change in prevalence varies by age.

Source: Developed from data presented in R. Hiller, R. Sperduto, and F. Ederer, "Epidemiologic Associations with Cataract in the 1971-1972 National Health and Nutrition Examination Survey," American Journal of Epidemiology, Vol. 118, No. 2, pp. 239-249, 1983.

To assess the potential implications of ozone depletion for cataract incidence, the prevalence reported by Sperduto and Ederer was used as the prevalence in the absence of ozone depletion. These prevalence values were used to compute incidence estimates (again, in the absence of ozone depletion) under the assumption that mortality and cataract prevalence are not related, and that the people in each age group (e.g., 55 to 64 year olds) are distributed uniformly across the ages. Based on these assumptions, the incidence rates assuming zero ozone depletion are as follows: 55 to 64 years old -- 450 per 100,000; 65 to 74 years old -- 1,350 per 100,000; 75 to 85 years old -- 2,750 per 100,000. Because (in the absence of ozone depletion) prevalence of cataracts in those 85+ years old is assumed to be equal to the prevalence in those 75 to 85 years old, there is no incidence among those over 85. The incidence over time assuming zero ozone depletion and for the three cohorts is presented in Exhibits E-27 (number of cases per year) and E-28 (cumulative number of cases), respectively.

To evaluate the impact of ozone depletion on cataract incidence, a "power model" was used to relate increases in prevalence to changes in lifetime UV radiation exposure. The use of the power model is justified because the percent change in prevalence divided by the percent change in UV radiation is fairly constant over a wide range of changes in UV. Exhibit E-29 displays the age-weighted coefficients used in the analysis. The age-weighting was performed because the dose-response coefficient varies by age.

Of note is that these coefficients were developed using Robertson-Berger (R-B) meter measures of annual UV radiation flux as the surrogate measure of exposure, and that the coefficients were then used with the DNA-damage action spectrum and erythema action spectrum estimates of changes in UV flux due to ozone depletion. Use of R-B meter-derived coefficients for the dose-response relationship coupled with estimates of changes in DNA-damage-weighted and erythema-weighted UV radiation flux in response to ozone depletion may result in <u>overestimating</u> the increase in cataract incidence in response to ozone depletion.

Using the coefficients in Exhibit E-29, estimates of increased prevalence due to ozone depletion were computed. These prevalence values were then translated into increased incidence estimates, as above. Exhibits E-30 and E-31 display the increased incidence over time and by cohort for the No Controls Scenario.

There are various important limitations in the use of these estimates and data. The correlation between UV-B and cataracts reported by Hiller, Sperduto, and Ederer does not prove a causal connection -- other (unknown) factors could be playing a role. These (unknown) factors would have to be correlated with UV-B flux. Also, the study does not have estimates of individual lifetime UV-B exposure, thereby limiting the strength of the evidence for the association between UV-B exposure and cataracts. Additionally, the sample population analyzed may not be representative of the entire U.S. population. Finally, the outcome category used in the study does not differentiate between different types of cataracts, some of which may be more strongly related than others to UV-B exposure.

EXHIBIT E-27

ANNUAL INCIDENCE OF CATARACTS IN THE ABSENCE OF OZONE DEPLETION

Year	U.S. Population (millions)	Incidence (millions)
1985	239	0.603
2000	268	0.724
2050	310	1.194
2075	311	1.242
2100	311	1.234
2150	311	1.234
2165	311	1.234

Source: Population estimates derived from: Bureau of the Census, "Projections of the Population of the United States, by Age, Sex, and Race: 1983 to 2080," U.S. Department of Commerce, Washington, D.C., Series P-25, No. 952. Incidence estimates computed by multiplying incidence rates assuming zero ozone depletion by the population data.

EXHIBIT E-28

RISK OF CATARACTS IN THE ABSENCE OF OZONE DEPLETION

Cohort	U.S. Population a/ (millions)	Zero Ozone Depletion Cases (millions)	Risk (percent)
People alive today	239	70.7	29.6 b/
People born 1986-2029	154	56.0	36.4 c/
People born 2030-2074	156	55.5	35.6 c/

a/ Population estimates are approximate.

b/ Reflects the risk during the remaining lifetimes of the people alive today.

c/ Reflects the risk during the entire lifetimes of the people in the cohort.

Source: ICF Incorporated estimates.

EXHIBIT E-29

DOSE-RESPONSE COEFFICIENTS -- CATARACTS

Low a/	Middle	High b/
0.127	0.225	0.296

a/ Middle minus one standard error.

b/ Middle plus one standard error.

Source: Derived from data presented in: Heller, Sperduto, and Ederer, "Epidemiologic Associations with Cataract in 1971-1972 National Health and Nutrition Examination Survey," American Journal of Epidemiology, Vol. 118, No. 2, pp. 239-249, 1983.

EXHIBIT E-30

ANNUAL INCIDENCE OF CATARACTS: NO CONTROLS SCENARIO*
(DNA-Damage Action Spectrum)

Year	Ozone Depletion (Percent)	Zero Ozone Depletion (millions)	Additional (millions)	Percent Increase
1985	0.00	0.603	0.000	0.00
2000	1.00	0.724	0.001	0.14
2050	15.68	1.194	0.027	2.26
2075	50.00	1.242	0.134	10.79
2100	50.00	1.234	0.224	18.15
2150	50.00	1.234	0.274	22.20
2165	50.00	1.234	0.273	22.12

*The No Controls Scenario is one of several scenarios examined.

Source: ICF Incorporated estimates.

EXHIBIT E-31

RISK OF CATARACTS BY COHORT:
NO CONTROLS SCENARIO a/
(DNA-Damage Action Spectrum)

Cohort	Incidence			Risk		
	Zero Ozone Depletion (millions)	Additional (millions)	Additional Percentage Increase	Zero Ozone Depletion (%)	Additional (%)	Additional Percentage Increase
People Alive Today b/	70.7	1.02	1.4	29.6	0.41	1.4
People Born 1986-2029 c/	56.0	7.08	12.6	36.3	6.57	12.6
People Born 2030-2074 c/	55.5	11.85	21.6	35.6	7.62	21.4

a/ The No Controls Scenario is one of several scenarios examined.

b/ Reflects the risk during the remaining lifetimes of people alive today.

c/ Reflects the risk during the entire lifetimes of the people in the cohort.

Source: ICF Incorporated estimates.

Confidence in the estimates developed here are strengthened by several considerations. The correlation between UV-B flux and sunlight flux is high, and a correlation between sunlight and cataracts has also been found in Australia (Taylor 1980) and in China (Mao and Hu 1982). An association between UV-B exposure and cataracts has also been demonstrated in laboratory animals. Therefore, although considerable investigation remains to be performed, indications are that the association between UV-B and cataracts is a reasonable basis for evaluating potential impacts due to increased UV-B flux associated with ozone depletion.

7. VALUATION OF HUMAN HEALTH EFFECTS

The previous sections have discussed the physical impacts on human health that can result from stratospheric ozone depletion. In this section the costs associated with these human health effects are discussed. The first part of this section discussed the costs associated with skin cancer; the second part discusses the costs due to cataracts.

7.1 Costs of Skin Cancer

As discussed previously in this appendix, there is a substantial amount of information on the specific types of cancer that can occur and the rates at which the incidence of skin cancers may change. However, there is little available information on the costs to society associated with a potential increase in the number of skin cancer cases.

To overcome this problem, EPA sponsored a Skin Cancer Focus Group, which was comprised of medical specialists in the skin cancer field. The purpose of this Skin Cancer Focus Group was to identify the major cost components incurred by society for different types and severity of skin cancer. These cost components include the medical costs associated with treatment, the amount of work lost due to treatment, costs due to preventive measures recommended for those people that have skin cancer, costs of caregiving and chores performed by others, pain and suffering incurred by skin cancer patients, etc.

The major costs identified by the Skin Cancer Focus Group are presented in Attachment A to this appendix, along with a summary of the key elements addressed by the Skin Cancer Focus Group. Based on the results from this process, the costs assumed for skin cancer are $5000 for a "typical" case of nonmelanoma and $15,000 for a "typical" case of melanoma. (In this context "typical" is used to imply a weighted average of the costs incurred for the different types of cases that are treated. Because many cases are less serious and some are more serious, the "typical" case does not represent the modal case, but the weighted average based on the frequency of each type of case.)

For the increase in mortality expected from an increase in skin cancer, the value of each life lost is assumed to be three million dollars; this value is assumed to increase at the rate of 1.7 percent annually (i.e., the value of a human life increases at the same rate of growth in per capita income). For a more complete discussion of these issues, see Appendix G.

It should be noted that the results obtained to date from the Skin Cancer Focus Group process are preliminary. The information is undergoing continuing peer review to ensure that all issues have been properly addressed and all costs adequately represented. As this review process continues, the results may change as well. However, it should be emphasized that the cost estimates presented above are conservative estimates of the actual costs incurred by society for skin cancer. This is because the costs currently include only those items directly attributable to the medical treatment required for skin cancer patients, i.e., the cost of medical treatment, follow-up visits, preventive measures, etc. Other costs, such as pain and suffering and costs of caregiving and chores performed by others, have not been included because cost estimates have not been readily available. Inclusion of these costs would more closely reflect society's willingness to pay to avoid all of the costs associated with additional skin cancer cases.

These costs also do not include the costs associated with potential increases of actinic keratosis, i.e., pre-cancerous lesions that occur as a result of excessive exposure to the sun. As discussed further in Attachment A to this Appendix, the increase in incidence of actinic keratosis may be quite substantial, perhaps even greater than the increase in incidence of nonmelanoma. The costs to treat actinic keratosis may be several thousand dollars per case. Due to a lack of information on the potential increase in incidence of actinic keratosis from higher levels of UV radiation, this illness has not been included in this analysis. It should be noted, however, that the costs to society for actinic keratosis may be large.

In one respect the cost estimates developed from the Skin Cancer Focus Group discussion in Attachment A may overestimate costs for individuals that develop more than one case of skin cancer in their lifetime. The cost estimates include certain activities, such as follow-up visits and application of sunscreen, that skin cancer patients are recommended to do for the rest of their lives. However, in some instances a single individual may develop two or more cases of skin cancer. For these people with recurring skin cancer, additional medical treatment will be required, but their costs do not increase for follow-up visits to the doctor or for sunscreen applications. To the extent that some individuals do develop more than one case of skin cancer, total costs will be overestimated. As an example, if a second case of nonmelanoma affects the same individual five years after treatment for the first nonmelanoma, about $1500 of the costs incurred would already be accounted for by the costs associated with the first case. No correction has been made for this potential double-counting. Since many other potential costs are not included in the cost estimates, however (as discussed above), the cost estimates of $5000 for nonmelanoma and $15,000 for melanoma likely do not overestimate society's willingness to pay to avoid the skin cancer in the first place.

7.2 Costs of Cataracts

The costs of cataracts have been determined from Rowe, Neithercut, and Schulze (1987). In this study, Rowe et. al. evaluated society's willingness to pay to avoid the damages incurred from cataracts. These impacts on the well-being of the affected individual and others in society included:

1. Increased Medical Costs,

2. Increased Work Loss,

3. Increased Cost for Paid Chores, Caregiving, etc.,

4. Increased Disutility Related to Reduced Leisure Activities,

5. Increased Disutility Related to Discomfort,

6. Increased Unpaid Caregiving and Chores, and

7. Other Effects, such as risk premiums.

To estimate these costs, Rowe et. al. (1987) used three basic methods -- a review of the literature to determine the amount and type of information available on the costs, contacts with health providers to obtain their estimates of the costs of treating cataract patients, and a survey of actual cataract patients to determine the types of costs they incur as a result of the medical illness.

Rowe et. al. (1987) investigated several different measures for evaluating the costs of cataracts. These measures included costs incurred by the affected individual only versus those costs incurred by society in general; they also included the costs of the illness only (i.e., the actual medical costs) versus estimates of the willingness to pay to avoid the damages. For purposes of this analysis, the most appropriate cost measure is assumed to be the social willingness to pay. Based on the costs reported by Rowe et. al. (1987), each cataract case that results from increased UV-B radiation is assumed to cost $15,000.

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ATTACHMENT A

SUMMARY OF MEETING WITH THE SKIN CANCER FOCUS GROUP (Held on July 23, 1987, in New York City, New York)

In attendance were Drs. Darrell Rigel and Robert Friedman, skin cancer specialists practicing in New York City, and Craig D. Ebert, M.P.P., and Dr. Janice Longstreth of ICF Incorporated of Washington, D.C.

Craig Ebert of ICF began the meeting with an overview of the current efforts to achieve an international protocol for the control of ozone- depleting substances. Mr. Ebert explained that the U.S. Environmental Protection Agency was currently working on a Regulatory Impact Analysis to evaluate the benefits and costs associated with various control programs to avoid the potential health and non-health impacts that could result from stratospheric ozone depletion. The purpose of this meeting was to evaluate the costs due to increased incidences of skin cancer that could occur as a result of increased ultraviolet radiation from ozone depletion. The objective was to identify all of the social costs incurred from skin cancer (not just the costs to the individual), including not only the medical costs, but the costs due to loss of work, caregiving and chores performed by others for the patient,and unpaid costs incurred by the patient and others (such as family members) during and after treatment.

Dr. Rigel indicated that although basal and squamous cell carcinoma and cutaneous malignant melanoma are the different types of skin cancer on which to focus, there would be large costs due to significant increases in the incidence of actinic keratosis, pre-cancerous lesions that occur as a result of excessive exposure to the sun. For purposes of discussion, these cases were divided into "less serious" cases, where only a few lesions at most are present, to "more serious" cases, where hundreds of lesions may be present. About 90 percent of all cases are in the first category, with ten percent considered "more serious." It was estimated that the prevalence rate in the U.S. for actinic keratosis is about 1 in 50 to 1 in 100. About three percent of all keratoses were estimated to become squamous cell carcinoma.

In the "less serious" cases, the lesions would be treated by either scraping or freezing them off. The initial visit would cost about $125, followed by another visit in six months, with annual follow-up visits thereafter as a precaution. Follow-up visits average about $50 per visit.

In the "more serious" cases, the typical treatment would be application of a topical cream over the exposed areas of the body suffering from the sun exposure, i.e., the face, neck, hands, and perhaps, the arms and shoulders. The purpose of the cream is to remove the sun-damaged cells by burning them off. The patient typically undergoes treatment for 10-14 days, with the cream applied twice a day. If the patient's hands are being treated, it is often necessary to apply the cream for 6 weeks due to the toughness of the skin on the back of the hands. During this treatment, the patient will look very much like a burn patient. Once the 10-14 days have elapsed, the patient is often given steroids

to ease the pain and help in the recovery. While this treatment is going on, the patient will have burning and itching around the clock. For 2-3 weeks after the cream has been applied, the patient will have scabs and oozing as the skin heals that many have compared to a very bad case of poison ivy. This is followed by about 2-3 weeks of redness. It is quite common for these patients to stay home during this period of time, particularly during the first 2-3 week period after the cream has been initially applied.

The cost for the cream alone with this treatment is about $75-$100. The patient is seen by the doctor 2, 4, and 6 weeks from the time the treatment is first begun. The effectiveness of the treatment lasts only two years so in some cases it may be necessary to go through the treatment again after this period of time. For all forms of keratosis, regardless of severity, it was estimated that the average cost of treatment was $300 per year per case.

Basal Cell Carcinoma

For purposes of discussion. basal cell carcinoma was divided into three categories:

1. Small--about 80% of all cases.
2. Large--about 15% of all cases.
3. Recurring--about 5% of all cases.

Small BCC are typically treated in the doctor's office by (1) burning and scraping or (2) freezing. In these cases the cost of the biopsy plus the pathology fee would be about $200. This would be followed by the treatment itself at a cost of about $250, plus the costs of follow-up. These patients would be seen every six months for two years, then once a year thereafter for the rest of their lives. (Estimated average age at first discovery is 56; estimated years of follow-up is 15.) These follow-up visits would cost about $50 per visit and take from no more than one-half hour to maybe an hour. In these types of cases there is about a 50% chance of a second recurrence; if a second BCC is found, there is about a 70% chance that a third BCC will be found.

Large BCC may be treated either in the doctor's office or the hospital, depending on the location of the BCC. The cost to treat each case (one case is one treatment, not necessarily one patient; one patient may undergo multiple treatments) ranges from $500 to $1500, with an average of $1000 per case. Patients are likely to be out of work for at least a week. Large BCC are similar to recurring BCC, except that they do not recur.

Recurring BCC are typically treated with microscopic surgery at a cost of about $1200 per treatment. These patients will be out of work for at least a week. About 80-90% of all cases are single lesion: 10-20% are multiple lesions. The costs of treatment do not go up linearly for multiple lesion patients -- a patient with three tumors would incur costs about twice as great as a single lesion patient, not three times as great.

Drs. Friedman and Rigel indicated that current estimates of 500,000 cases of skin cancer per year was a significant underestimate of the number of nonmelanoma skin cancers. The reported statistics are based on information

obtained from hospitals, but many of these cases are treated in the doctor's office. This approach probably understates cases by at least sixfold, e.g., they estimated 3 million cases was probably more reasonable.

Many cancer patients are elderly who may no longer be employed and, as a result, do not miss work when treatment is required. However, in many of these cases, friends or relatives take time off from their jobs to bring the patient in and to assist the patient during the treatment process. For these patients insurance costs often go up, including medical and life insurance. A common reaction for patients once they discover they have cancer is fear and depression -- doctors spend some of their time consoling and educating the patient to allay these fears. Very few patients are thought to seek psychotherapy, so few that no estimate on the number of patients was provided.

Squamous Cell Carcinoma

The procedures and costs to treat squamous cell carcinoma (SCC) are the same as those incurred for basal cell carcinoma unless the SCC is on the lip or it metastasizes. These cases often require a lip resection at a cost of $2-3,000.

About 4-5% of all SCC metastasize. If a SCC metastasizes, the patient can often expect multiple hospital stays, chemotherapy, surgery, and being out of work for an indefinite period of time. In cases where the patient dies, the average cost for these cases ranges from $25,000 to $50,000 per case over the life of the treatment (these costs are medical costs only). In cases where the patient does not die, the average cost per case is $5,000 to $10,000 per case.

Sunscreens

For patients that have skin cancer, doctors typically recommend a number of steps that can affect the patient's lifestyle. These recommendations usually do not change a person's vacation or career plans, but they do tend to change the patient's habits. For one thing, patients are told to wear sunscreen whenever they are likely to get a significant amount of exposure to the sun. This amount is roughly defined as anything more than 10-15 minutes in the sun, and includes any activities when they are outdoors. The time of year when these applications are required varies by latitude -- in New York recommended practice is often five months of the year (from mid-April to mid-October); in Florida sunscreen use is recommended year-round.

For a patient exposed to the sun on a casual basis during the day, applications are recommended twice a day. For more serious exposure, such as the amount of sun one may receive at the beach, more frequent applications may be necessary. Sunscreens with a sun protection factor (SPF) of 15 or higher are strongly recommended. It is estimated that it takes one full ounce to cover the entire human body correctly. At a cost of about $10 per bottle, annual sunscreen costs were put at a minimum of $100, probably higher, especially in the South. In 1936 about $100 million was spent in the U.S. on sunscreens with a SPF of 15 or higher.

In addition to sunscreen, patients are told to wear hats and sunglasses, to avoid the sun between 10 A.M. and 2 P.M., to use umbrellas, and to stay out of

the direct sun whenever possible. For people involved in careers that require a substantial amount of time outdoors, doctors rarely recommend a change of careers, but they do strongly urge that these types of precautions be taken to minimize the degree of risk.

Cutaneous Malignant Melanoma

Cutaneous malignant melanoma (CMM) was divided into four different classifications, depending mainly on where the CMM is treated, for purposes of discussion:

1. Office -- about one-third of all cases

2. Outpatient -- about one-third of all cases

3. Hospital

   A. Low risk -- two-thirds to three-fourths of all hospital cases

   B. High risk (lymph nodes are affected) -- about one-third to one-fourth of all hospital cases.

The location for where the CMM is treated has been changing rapidly in recent years. The general shift has been to more outpatient care due to better medical procedures and the tendency to catch the skin cancer at an earlier stage than in previous years. In some cases, however, insurance considerations may result in in-hospital treatment.

For all types of CMM, a biopsy and pathology fee will be incurred at a cost of about $200-$250 per case. Total medical costs for an office visit are likely to run about $500 to remove the CMM.

For an outpatient case, total medical costs are likely to average about $1500 per case.

For hospital cases, costs will vary depending on whether it is a low risk or high risk case, with the degree of risk depending on whether the lymph nodes are affected. About 30% of all cases metastasize. For low risk patients, a hospital stay of 5 to 7 days is required, averaging about $400-$700 per day. Surgery costs will run about $2500-$3000. Anesthesiology costs would run about $1500, and medicine costs would be about $300-$500. In the first year, these patients would see the doctor eight times, four times the second and third year, twice a year for about six years, and once a year thereafter at a cost of about $50 per visit if no recurrence is diagnosed.

For high risk patients where the lymph nodes are affected, another $2000 to $3000 would be spent to have the lymph nodes removed. For these patients, follow-up visits would be required monthly for 6 months, every three months for year 2, every four months for years 3 and 4, every six months through year 7, followed by once a year visits thereafter. These patients would typically incur about $300-$400 in laboratory costs per year.

Despite the different types of cancer, if the cancer metastasizes, the treatment (and hence, the incurred costs) is likely to be quite similar. As indicated above, for patients who will eventually die from the cancer these medical costs run about $25,000 to $50,000 per case; costs are $5,000 to $10,000 per case for patients that survive.

Skin cancer patients are taught to examine themselves once a month to make sure no visible changes have occurred. Once they have been taught how to do it, this procedure takes no more than a few minutes each month.

SUMMARY ESTIMATES OF COSTS FOR SKIN CANCER

ACTINIC KERATOSIS

1. Less Serious--90% of cases
   - Initial visit--$125
   - Six-month follow-up--$50
   - Annual follow-up--$50 per visit; assume 15 years--$750
   - Sunscreen costs (see below)--$1,550-$3,050

   Total: $2,475-$3,975

2. More Serious--10% of cases
   - Initial visit--$125
   - Topical Cream--$75-$100
   - Follow-up visits at 2, 4, and 6 weeks from initial visit--$150
   - Work loss (4 weeks at $30,000/year)--$2300
   - Annual follow-up--$50 per visit; assume 15 years--$750
   - Sunscreen costs (see below)--$1,550-$3,050

   Total: $4,950-$6,475

BASAL CELL CARCINOMA

1. Small--80% of cases
   - Biopsy plus pathology fee--$200
   - Treatment cost--$250
   - Follow-up visits--once every six months for two years, then annually at $50 per visit--$850 assuming 15 years of visits.
   - Sunscreen costs (see below)--$1,550-$3,050

   Total: $2,850-$4,350

2. Large--20% of cases (recurring cases were considered "large" cases)
   - Biopsy plus pathology fee--$200
   - Treatment cost--about $1000 (±$500)
   - Follow-up visits--once every six months for two years, then annually at $50 per visit--$850 assuming 15 years of visits.
   - Loss of work--one week at $30,000/year--$575
   - Sunscreen costs (see below)--$1,550-$3,050

   Total: $4,175-$5,675

SQUAMOUS CELL CARCINOMA

1. Small--80% of cases
   - Biopsy plus pathology fee--$200
   - Treatment cost--$250
   - Follow-up visits--once every six months for two years, then annually at $50 per visit--$850 assuming 15 years of visits.
   - Sunscreen costs (see below)--$1,550-$3,050

   Total: $2,850-$4,350

2. Large--15% of cases
   - Biopsy plus pathology fee--$200
   - Treatment cost--about $1000 (±$500)
   - Follow-up visits--once every six months for two years, then annually at $50 per visit--$850 assuming 15 years of visits.
   - Loss of work--one week at $30,000/year--$575
   - Sunscreen costs (see below)--$1,550-$3,050

   Total: $4,175-$5,675

3. Metastasize cases--4-5% of all SCC cases
   A. Death does not result--$5/10,000 in medical costs per case
   - Work loss--assume two years at $30,000 per year-- $60,000

   Total: $65,000-$70,000

   B. Death--$25-50,000 per case, medical costs only
   - Work loss--assume two years at $30,000 per year-- $60,000

   Total: $85,000-$110,000

CUTANEOUS MALIGNANT MELANOMA

1. Office--one-third of all cases
   - Total medical costs--$500 per case
   - Follow-up visits--four times first year, three times second year, twice thereafter (assume 13 more years)--$1650
   - Work loss--assume 2 hours per visit, or about 1-1/2 weeks at $30,000 per year--$850
   - Transportation to and from doctor's office--assume $10 per visit--$330
   - Sunscreen costs (see below)--$1,550-$3,050

   Total:$4,880-$6,380

2. Outpatient--one-third of all cases
   - Total medical costs--$1500 per case
   - Follow-up visits--four times first year, three times second year, twice thereafter (assume 13 more years)--$1650
   - Work loss--assume 2 hours per visit, or about 1-1/2 weeks at $30,000 per year--$850
   - Transportation to and from doctor's office--assume $10 per visit--$330
   - Sunscreen costs (see below)--$1,550-$3,050

   Total: $5,880-$7,380

3. Hospital--one-third of all cases
   A. Low risk--2/3 to 3/4 of all hospital cases
   - Hospital stay--$2000-$3500
   - Surgery--$2500-$3000
   - Anesthesiology--$1500
   - Medicine--$300-$400
   - Follow-up visits--eight times first year, four times second and third year, twice a year for six years, and once thereafter (assume 6 more years)--$1700

3. Hospital--one-third of all cases (continued)
   - Work loss due to surgery--assume three weeks at $30,000 per year--$1,730
   - Work loss due to office visits--assume 2 hours per visit, or about 1-1/2 weeks at $30,000 per year--$850
   - Transportation to and from doctor's office--assume $10 per visit--$340
   - Sunscreen costs (see below)--$1,550-$3,050

Total: $12,470-$16,070

B. High risk--1/3 to 1/4 of all hospital cases
- Hospital stay--$2000-$3500
- Surgery--$2500-$3000
- Lymph node removal--$2,000-$3,000
- Other laboratory costs--$300-$400 per year
- Anesthesiology--$1500
- Medicine--$300-$400
- Follow-up visits--monthly for 6 months, every three months through year 2, every 4 months for years 3 and 4, twice a year/through year 7, and annually thereafter (assume 8 years)-/$1600
- Work loss due to surgery--assume three weeks at $30,000 per year--$1,730
- Work loss due to office visits--assume 2 hours per visit, or about 1-1/2 weeks at $30,000 per year--$850
- Transportation to and from doctor's office--assume $10 per visit--$320
- Sunscreen costs (see below)--$1,550-$3,050

Total: $14,670-$19,370

4. Metastasize cases
   A. Death does not result--$5-10,000 per case
   B. Death results--$25,000-$50,000

SUNSCREEN REQUIREMENTS--APPLIES TO ALL SKIN CANCER PATIENTS

- Annual sunscreen costs in New York--$100/year; assuming 15 years--$1500
  -- In the South, about $200 per year--$3000
- Wear hats and sunglasses--$50

Total Suncreen Costs: $1,500-$3,050

F

APPENDIX F

APPROACHES USED FOR ESTIMATING THE ENVIRONMENTAL IMPACTS OF STRATOSPHERIC OZONE DEPLETION

This appendix presents the approaches used to estimate the environmental (non-health) impacts that could result from stratospheric ozone depletion. The dose-response relationships used to assess the likely physical impacts associated with increases in ultraviolet (UV) radiation due to ozone depletion and the methods used to quantify and value the potential damages are described. Throughout this appendix reference is often made to EPA's Risk Assessment: Assessing the Risks of Trace Gases that Can Modify the Stratosphere, final report by the Office of Air and Radiation, EPA, December 1987 (EPA 1987). The Risk Assessment reviews in detail the current state of knowledge on the potential risks posed by stratospheric ozone depletion.

This appendix presents overviews of the environmental risks associated with ozone depletion, including:

- risks to marine organisms;
- risks to crops;
- increased concentrations of ground-based ozone (smog); and
- degradation of polymers.

It is important to emphasize that this analysis focuses exclusively on the above environmental effects, all of which have anticipated, direct economic consequences. Damage to other aspects of the natural environment and to ecosystems are not estimated herein, although their long-term economic consequences could be highly significant, perhaps catastrophic. Therefore, these potential additional environmental consequences should be considered in interpreting the results of this analysis.

This appendix also presents estimates of the potential impacts of sea level rise associated with the global warming impacts of CFCs. The health impacts of ozone depletion (including skin cancers and cataracts) are described in Appendix E.

1. RISKS TO AQUATIC ORGANISMS

1.1 Physical Effects

Increased flux of UV radiation due to ozone depletion is anticipated to adversely affect aquatic organisms. According to the Risk Assessment (EPA 1987):

> Various experiments have demonstrated that UV-B radiation causes damage to fish larvae and juveniles, shrimp larvae, crab larvae, copepods, and plants essential to the aquatic food web. These damaging effects include decreased fecundity, growth, survival, and other reduced functions in these organisms. In natural marine plant communities a change in species composition

rather than a decrease in net production is the probable result of enhanced UV-B exposure. The change in community composition may introduce instabilities to ecosystems and would likely have an influence on higher trophic levels. A decrease in column ozone could diminish the near-surface season of invertebrate zooplankton populations. Whether the population could endure a significant shortening of the surface season is unknown.

The direct effect of UV-B radiation on food-fish larvae closely parallels the effect on invertebrate zooplankton. Information is required on seasonal abundances and vertical distributions of fish larvae, vertical mixing, and penetration of UV-B radiation into appropriate water columns before effects of incident or increased levels of exposure to UV-B radiation can be predicted. However, in one study involving anchovy larvae, a 20% increase in incident UV-B radiation (which would accompany about a 9% decrease in the atmospheric ozone column) would result in the death of all of the larvae within a 10-meter mixed layer in April and August after 15 days. It was calculated that about 8% of the annual larval population throughout the entire water column would be directly killed by a 9% decrease in column ozone.

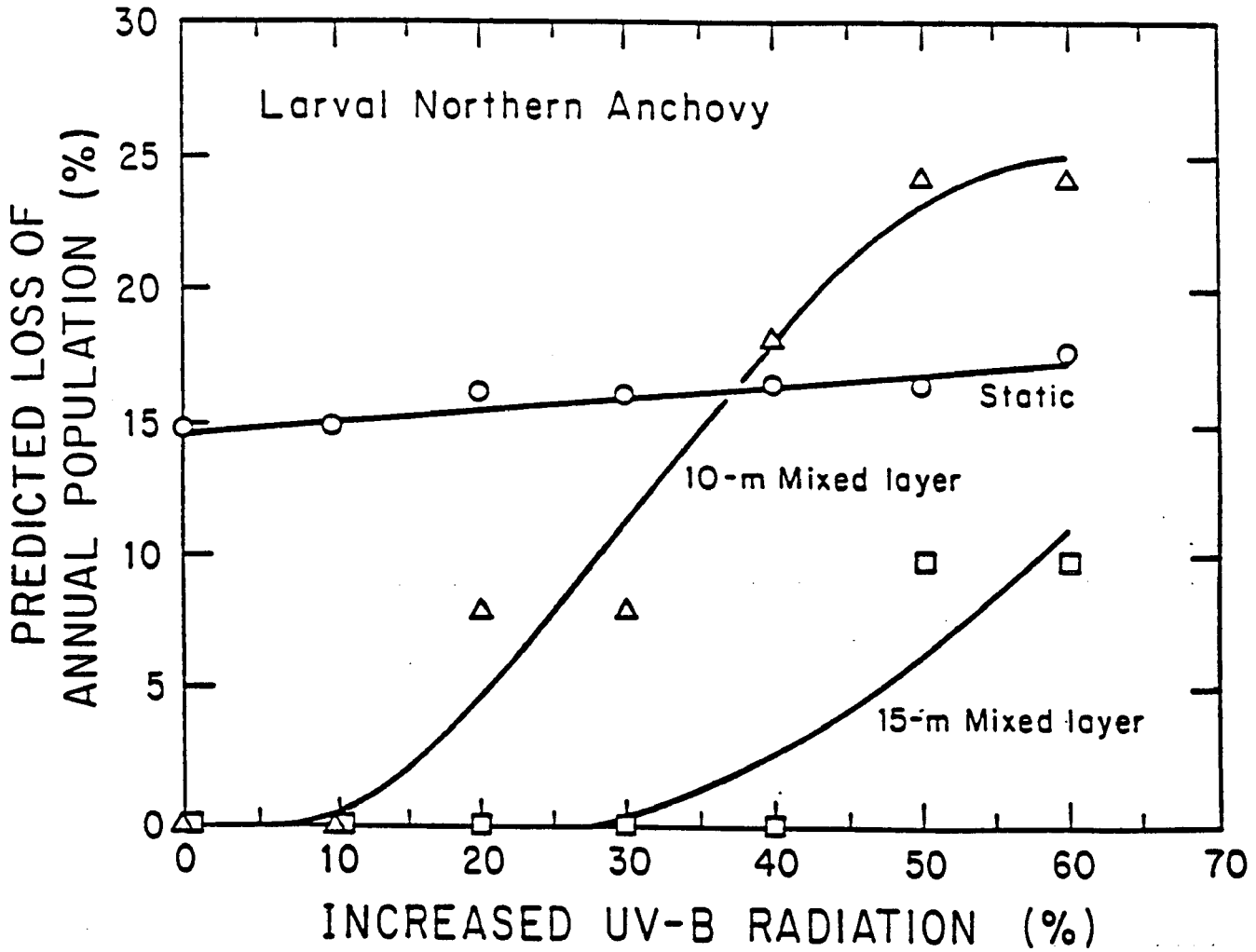
Effects induced by solar UV-B radiation have been measured to depths of more than 20 m in clear waters and more than 5 m in unclear water. The euphotic zone (i.e., those depths with levels of light sufficient for positive net photosynthesis) is frequently taken as the water column that reaches down to the depth at which photosynthetically active radiation is reduced 99%. In marine ecosystems, UV-B radiation penetrates approximately the upper 10% of the marine euphotic zone before it is reduced to 1% of its surface irradiance. Penetration of UV-B radiation into natural waters is a key variable in assessing the potential impact of this radiation on any aquatic ecosystem.

Although the scientific literature generally supports the hypothesis that UV radiation can inflict potentially adverse impacts on marine organisms, there is a limited amount of information from laboratory studies to indicate the appropriate dose-response relationships between UV radiation increases and impacts on aquatic organisms in the natural environment. In a study by Hunter, Kaupp, and Taylor (1982), analyses were conducted on anchovy larvae to estimate the potential effects of increased UV-B radiation on anchovy populations. They found that several factors influence the potential for UV-B radiation to affect anchovy larvae, including seasonal abundance and vertical distribution of the larvae, degree of vertical mixing, and the amount of UV-B penetration into the anchovy-populated seawater. The results of their study are summarized in Exhibit F-1.

As indicated in Exhibit F-1, anchovy larvae losses were estimated for three different models of mixing within the top layer of the oceans -- static, mixing within the top ten meters, and mixing within the top 15 meters. For purposes

EXHIBIT F-1

EFFECT OF INCREASED LEVELS OF SOLAR UV-B RADIATION ON THE PREDICTED LOSS OF LARVAL NORTHERN ANCHOVY FROM ANNUAL POPULATIONS, CONSIDERING THE DOSE/DOSE-RATE THRESHOLD AND THREE VERTICAL MIXING MODEL



Based on data of Hunter, Kaupp, and Taylor 1982.

of this analysis, the dose-response relationship demonstrated by the ten-meter mixed layer model was assumed to be the most representative of likely impacts due to increased UV-B radiation. These impacts on anchovy larvae were assumed to apply to the adult anchovy population, i.e., a 10 percent decline in anchovy larvae would translate into a 10 percent decline in the adult populations. Our understanding of the relationship between larvae populations and adult populations is not good; it is possible that the impacts on the adult population might not occur or might be larger. Obviously, actual impacts would also vary depending on the ocean mixing depth assumed. Additionally, these impacts were limited to a maximum of 25 percent of the population levels to avoid extrapolating outside the bounds of the available (limited) information.

1.2 Valuation of Physical Impacts

To estimate the potential impact of increased UV-B radiation on the natural environment, the dose-response relationships indicated by the ten-meter mixing depth for anchovy larvae in Exhibit F-1 were assumed to be representative of the effects on the natural anchovy population. These effects were assumed to be reflected in commercial harvest levels, which would decline by the amount indicated by the dose-response relationships, e.g., if an increase in UV-B resulted in a 25 percent decline in anchovy larvae survival, then commercial harvest levels would also decline by 25 percent.

The value of a decline in the commercial anchovy harvest was determined by using the average 1981-1985 anchovy harvest levels (9,111 tons) and market value ($4.9 million) as reported by the U.S. Department of Commerce.[1] These 1981-1985 market levels were assumed to represent the average amount and value of each annual anchovy harvest through 2075 from which UV-B impacts are measured. For example, if a 25 percent decline in the anchovy harvest were estimated to occur, the value of this impact would be 25 percent of the average 1981-1985 harvest level multiplied by the average value of anchovies from 1981-1985 (as determined by its market price). Future harvest amounts and market value could differ from average 1981-1985 levels; to the extent that they do so, the values estimated herein will be incorrect. However, because future market value and production levels cannot be easily estimated, the average 1981-1985 levels were used as a reasonable approximation.

Exhibit F-2 summarizes the estimated value of avoiding declines in anchovy harvests for the baseline (i.e., no controls) scenario.[2] The dollar values in Exhibit F-2 are net present values based on cumulative impacts on anchovy harvests for all years 1985-2075 (all values are in 1985 dollars). The estimated percentage decline in the amount of anchovies harvested by 2075 is

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[1] Fisheries of the United States, 1985. United States Department of Commerce, National Oceanic and Atmospheric Administration, Washington, D.C., April 1986.

[2] The baseline scenario used throughout this appendix assumes about 3.6 percent annual CFC growth from 1985 to 2000 and 2.5 percent annual CFC growth from 2000 to 2050, with constant production thereafter. See Chapter 4 for a discussion of the baseline.

EXHIBIT F-2

POTENTIAL IMPACTS ON ANCHOVY HARVESTS DUE TO INCREASED UV RADIATION (billions of 1985 dollars)

Scenario	Harvest Decline by 2075 (%)	2% Discount Rate		
		0.5	1.0	2.0
No Controls	>25.0%	0.004	0.009	0.018

Source: ICF estimates based on Hunter, Kaupp, and Taylor (1982).

shown. The value of the change in anchovy harvest levels has been calculated for a discount rate of two percent. Also, to reflect the uncertainty associated with the crude manner used to value these benefits, values have been quantified for three different levels of impacts -- one level assuming that the impact on harvests is equal to the dose-response relationships shown in Exhibit F-1, another level assuming impacts are one-half that amount, and a third level assuming that impacts are doubled. These sensitivity analyses help to capture the potential range of impacts that could result depending on the ability of thenatural environment to compensate for potentially adverse impacts or the possibility that impacts could be more severe than currently thought due to currently unforeseen ripple effects (e.g., other aquatic species that rely on anchovies for survival also experience harmful impacts).

In addition to the potential impacts on anchovy harvests, increases in UV-B radiation would likely have deleterious effects on a wide variety of marine organisms. Much of the evidence for these effects has been reviewed by Worrest (1983). Unfortunately, the reactions of other marine organisms to increases in UV-B radiation have not been adequately quantified. To estimate the potential range of impacts of UV-B radiation on other marine organisms, the dose-response relationships used for anchovies were applied to all other major commercial fish species. That is, if UV-B increases were estimated to cause a 25 percent decline in anchovy harvests, the same percentage decline would occur for all other commercial fish species. Future scientific research would be needed to validate the reasonableness of this assumption.

Exhibit F-3 summarizes the estimated value of avoiding declines in commercial fish harvests for the baseline scenario. These values have been estimated using the same methodology used for valuing the impacts on anchovies. Impacts were determined from average commercial harvest levels (5.9 million tons for all species considered) and average market values from 1981-1985 ($3.65 billion) and are based on the net present value of impacts over the 1985-2075 period. A discount rate of two percent was used, and sensitivity analyses are shown assuming that impacts range from one-half to twice the level estimated by the dose-response relationships. Also, the potential benefits have been separated according to the type of commercial fish evaluated:

- Fin fish include menhaden, Pacific trawlfish, anchovies, halibut, sea herring, jack mackerel, Atlantic mackerel, sablefish, and tuna.

- Shell fish include clams, crabs, American lobster, spiny lobster, oysters, shrimp, scallops, and squid.

While clearly speculative, these estimates dimension the problem. Real damages could be significantly larger or smaller.

2. RISKS TO CROPS

2.1 Physical Effects

UV radiation may potentially affect crops and other managed or naturally-occurring plants. According to the Risk Assessment (EPA 1987):

EXHIBIT F-3

POTENTIAL IMPACTS ON FIN FISH AND SHELL FISH HARVESTS DUE TO INCREASED UV RADIATION (billions of 1985 dollars)

Scenario	Harvest Decline by 2075 (%)	2% Discount Rate 0.5	1.0	2.0
No Controls	>25.0%			
-- Fin Fish		1.1	2.2	4.4
-- Shell Fish		2.3	4.5	9.0
Total		3.4	6.7	13.4

Source: ICF estimates based on Hunter, Kaupp, and Taylor (1982).

In making an assessment of the risk to crops and ecosystems of increased ultraviolet-B (UV-B) radiation, it must be recognized that existing knowledge is in many ways deficient. The effects of enhanced levels of UV-B radiation have been studied in only four of the ten major terrestrial plant ecosystems. Most of our knowledge is derived from studies focused upon agricultural crops and conducted at mid-latitudes, not in the tropics or at more poleward latitudes. Trees have not been subject to experimentation. Experimental protocols often have had flaws; too often, single-year studies have been done, rather than long-term ones, and too much of the existing data comes from growth chambers, in which plants grow under unrealistic conditions, rather than from field studies. Therefore, the full extent of the potential impacts of enhanced levels of UV-B radiation on a global basis cannot be adequately assessed.

Despite these limitations, a broad range of experimental results demonstrated that, in nearly half of the plant species examined, UV-B radiation deleteriously affected crop yield and quality. Data exist that indicate that it may be reasonably anticipated that if UV-B radiation increases, crop yield and quality will decline for at least some cultivars. Existing data also suggest that increased UV-B radiation will alter the distribution and abundance of plants and potentially disrupt ecosystems. Unfortunately, a qualitative prediction of how these ecosystems would be altered cannot be determined from the current knowledge base.

Despite the potential for UV-B radiation to adversely affect crop yield and quality, there is a very limited amount of information to indicate the extent to which damage may occur. Although scientific studies have been carried out on a number of different types of crops, reliable dose-response relationships are difficult to obtain. Some of the most detailed work has been conducted by A.H. Teramura on soybean cultivars.[3] His greenhouse and field studies have helped to determine the dose-response relationship between UV-B radiation and soybean yield. There has been some variation in results from one study to the next. As a general approximation of the overall dose response relationship, for this analysis each one percent decrease in ozone is assumed to cause a 0.3 percent decline in soybean yield.[4] This relationship is assumed to hold for ozone

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[3] For example, see Teramura, A.H. and N.S. Murali, "Intraspecific Differences in Growth and Yield of Soybean Exposed to Ultraviolet-B Radiation Under Greenhouse and Field Conditions." Env. Exp. Bot. In press, 1986, and Teramura, A.H., "Effects of Ultraviolet-B Radiation On The Growth and Yield of Crop Plants." Plant Physiology, 58:415-427, 1983.

[4] This value was based on the average of all statistically significant data points in Teramura's work (non-drought years). This result was reported in Analysis of Economic Impacts of Lower Crop Yields Due to Stratospheric Ozone Depletion, Robert Rowe and Richard Adams, draft report to EPA, August 18, 1987.

depletion estimates up to 25 percent. At this point, declines in soybean yield would be 7.5 percent. For ozone depletion estimates exceeding 25 percent, declines in soybean yield were limited to 7.5 percent. This limit was applied because the scientific research conducted to date has not analyzed effects on soybean yield for ozone depletion estimates exceeding 25 percent. The 7.5 percent limit avoids extrapolating dose-response relationships outside the range of the available scientific analyses. However, this assumption may be a very limiting assumption; in reality, very high UV-B increases might have more than a proportional effect.

2.2 Valuation of Physical Impacts

The dose-response relationship discussed above, i.e., a 0.3 percent decline in soybean yield for each one percent decrease in ozone, is assumed to apply to all future years of agricultural production. This assumption does not take into account possible measures to plant more UV-B resistant soybean varieties, the substitution of other crops that are more resistant to UV-B for soybeans, or other possible mitigating factors. Sensitivity analyses to consider these types of impacts are discussed below.

To determine the value of future declines in soybean yield, a study by Rowe and Adams (1987) that analyzed the economic impacts of stratospheric ozone depletion on crop yields was used. In their analysis, Rowe and Adams used the National Crop Loss Assessment Network (NCLAN) to evaluate the economic impacts. NCLAN was originally developed to assist EPA in the evaluation of various National Ambient Air Quality Standards (NAAQS) for tropospheric ozone. For their analysis Rowe and Adams used information supplied by EPA from Teramura (1987) to estimate the percentage decline in soybean yield due to increased UV radiation. NCLAN was then used to determine the annual changes in economic surplus that would occur for the estimated changes in soybean yield. They developed the following relationship between soybean yield and economic damage:

$$D2 = 0.1068 * SOY - 0.00029 * SOY^2$$

where

D2 = annual change in economic surplus, in billions of 1982 dollars, resulting from changes in soybean yield due to UV-B.

SOY = percent change in soybean yield due to UV-B, which was defined as 0.30 times the percentage decrease in stratospheric ozone.

Using this equation, annual decreases in economic surplus can be calculated for assumed levels of stratospheric ozone depletion. To estimate the impact of potential changes in soybean yield over time, the following additional steps are taken:

This may be a conservative (low) estimate of actual impacts since Teramura's work intentionally examined one cultivar sensitive to UV (Essex) and one cultivar that was not sensitive (Williams); earlier work by Teramura indicated that about two-thirds of all soybean cultivars are sensitive to UV.

- All values are expressed in 1985 dollars.
- Impacts are cumulative from 1985-2075, i.e., the annual soybean impacts have been expressed on a net present value basis.
- A discount rate of two percent was used.
- Dollar values have been calculated for three different levels of impacts: (1) the level indicated by the dose-response relationship discussed above; (2) one-half the rate of impact implied by the dose-response relationship; and (3) double the rate of impact. These three levels are shown as sensitivity analyses to reflect potential improvements in crop breeding and management practices or future differences in production levels or market value.

The results of this valuation procedure are summarized in Exhibit F-4, along with the estimated decline in soybean yield by 2075 in the baseline scenario.

Although the dose-response information for the effects of UV-B radiation on plant species is most reliable for soybeans, UV-B radiation has been shown to affect other plants as well. However, detailed dose-response information is not available for the other plants. Because reliable dose-response data do not exist for other plant species, the dose-response relationship for soybeans is assumed to apply to other plant types. That is, for each one percent decrease in stratospheric ozone, plant yield is assumed to decline by 0.3 percent. In this analysis only the major grain crops are assumed to be affected: wheat, rye, rice, corn, oats, barley, sorghum, and soybeans.[5] Potential impacts on other crops, including fruits and vegetables, trees, and non-commercial plant species have not been evaluated.

To estimate the value of potential impacts on the major grain crops, the estimated impacts on soybeans only were increased by a factor that reflected how much larger the size of the market for these crops was compared to the size of the market for soybeans. This comparison was done by using average annual production levels and market values from 1981-1985 to represent average future levels of annual production and market value. During this period the average annual amount of soybeans produced in the U.S. was valued at about $13 billion, while all major grains crops had an average annual value of $50 billion.[6] This comparison indicates that the market for all major grain crops is about 3.85 times greater than the market for soybeans only. This factor was used to increase the estimated impacts on soybean yield only to a level commensurate

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[5] Other minor grain crops, particularly feedstuffs such as cottonseed and linseed meal, are not included here.

[6] Jewell, C. Duane (1986). Agricultural Statistics 1986. U.S. Department of Agriculture, Washington, D.C., 1986.

EXHIBIT F-4

POTENTIAL IMPACTS ON SOYBEAN YIELD DUE TO UV RADIATION (billions of 1985 dollars)

Scenario	Harvest Decline by 2075 (%)	2% Discount Rate 0.5	1.0	2.0
No Controls	>7.5%	4.4	8.7	17.4

Source: ICF estimates based on Teramura (1987).

with potential impacts on all major grain crops. Also, there are a variety of factors beyond the scope of this analysis that could cause the dose-response relationships for grain crops to be different. To take the potential impact of these factors into account, sensitivity analyses similar to those discussed above for soybeans were conducted. Exhibit F-5 summarizes the results of the valuation for the baseline scenario. While speculative in nature, these estimates again provide some dimensioning of the potential problem.

3. TROPOSPHERIC OZONE

3.1 Physical Effects

Due to increases in the flux of UV radiation that may occur due to stratospheric ozone depletion, levels of tropospheric ozone (ground-based ozone, or smog) may increase. According to the Risk Assessment (EPA 1987):

> Tropospheric or ground-based ozone, 03(T), is an air pollutant formed near the earth's surface as a result of photochemical reactions involving ultraviolet radiation, hydrocarbons, nitrogen oxides, oxygen, and sunlight. At high concentrations, often found during warmer months, tropospheric ozone can adversely affect human health, agricultural crops, forests, and materials. To protect public health, the U.S. Environmental Protection Agency (EPA) has established a primary standard of 0.12 ppm (one-hour average), which is not to be exceeded more than one day per year. In 1979, EPA also determined that a secondary welfare standard, more stringent than the primary standard, was unnecessary for the protection of vegetation. Currently, EPA is reviewing available scientific and technical information to determine whether these standards are adequate to protect health and welfare.
>
> This chapter reviews preliminary scientific information that suggests that increases in UV-B radiation may affect the rate of tropospheric ozone formation in urban areas. The results from these analyses suggest that increased ultraviolet radiation increases the rate of ground-based ozone production and acid rain precursors. Moreover, global warming, associated with ozone-depleting substances, may enhance these reactions. Further analyses of additional cities are being conducted. If these analyses confirm these results, it would appear likely that in the future more cities and regions would violate the ambient air standards and that more restrictive measures to control hydrocarbons and nitrogen oxides may be required in order to comply with current standards.

Very little analysis has been conducted to date on the relationship between UV radiation increases and potential increases in the level of tropospheric (ground-based) ozone. Whitten (1986) has conducted a preliminary investigation into the potential relationships between UV radiation and ground-based ozone in urban areas. This analysis focused on the potential impacts in three cities:

EXHIBIT F-5

IMPACTS ON YIELD OF MAJOR GRAIN CROPS DUE TO UV RADIATION (billions of 1985 dollars)

Scenario	Harvest Decline by 2075 (%)	2% Discount Rate		
		0.5	1.0	2.0
No Controls	>7.5%	16.9	33.7	67.4

Source: ICF estimates based on Rowe et al. (1987).

Los Angeles, Philadelphia, and Nashville. These three cities were selected to represent the likely range of atmospheric conditions that could be encountered in the U.S. -- Nashville is nearly in compliance with the 0.12 parts per million Federal ozone standard; Philadelphia is moderately out of compliance (a 30-50 percent reduction in organic precursors would be required); and Los Angeles has one of the most severe ozone problems in the U.S. The average increase in tropospheric ozone is based on the results from these three areas.[7] The maximum increase in tropospheric ozone has been limited to 30.9 percent, the average of the maximum values reported for Nashville, Philadelphia, and Los Angeles, to avoid extrapolating beyond the range of impacts reported in Whitten (1986).

Increases in tropospheric ozone could cause a number of adverse impacts on human health. In a recent study by EPA/OAQPS (1986),[8] a review of the available evidence indicated that tropospheric ozone could have the following health effects:

- During periods of heavy exercise, alterations in pulmonary function[9] have been demonstrated among healthy individuals. Controlled exposure studies have reported decreases in pulmonary function among intermittently, heavily exercising, healthy children exposed for two hours to 0.12 ppm O3 and among continuously heavily exercising, healthy adults exposed for one hour to 0.16 ppm O3. Field studies have also noted similar responses.

- Pulmonary function can also be impaired during lighter periods of exercise. Exposure to 0.2 ppm O3 for two hours was shown to decrease pulmonary function by 1.6 percent during intermittent light exercise, 2.4 percent during moderate exercise, 2.8 percent during heavy exercise, and 4.7 percent during very heavy exercise.

- Some fraction of individuals appears to be more affected by ozone than others. In tests on healthy exercising adult

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[7] See Whitten, G. Z. and M. Gery, "Effects of Increased UV Radiation on Urban Ozone," presented at EPA Workshop on Global Atmospheric Change and EPA Planning, edited by Jeffries, H., EPA Report 600/9-86016, July 1986. The dose-response relationship between UV radiation and ozone levels may be linear or non-linear depending on the interplay between several factors, including temperature, local conditions, and other factors.

[8] Review of the National Ambient Air Quality Standards for Ozone: Preliminary Assessment of Scientific and Technical Information, staff paper, prepared by Office of Air Quality Planning and Standards (OAQPS), U.S. Environmental Protection Agency, March 1986.

[9] Pulmonary function is measured by the forced expiratory volume in 1.0 second, i.e., the volume of air that can be expelled in the first second of a maximal expiration.

males, pulmonary function decreased by more than 10 percent when exposed to 0.12 ppm O3.

- Preliminary results indicate that acute and chronic exposures to ozone may cause longer term effects on pulmonary function and lung structure, although the data do not yet establish a statistically significant relationship.

- Work performance may be limited by exposure to ozone, although the magnitude of this impairment has not been quantified.

- Changes in pulmonary function due to exposure to ozone may cause other respiratory and non-respiratory symptoms, such as throat dryness, chest tightness, difficulty or pain in inspiring deeply, cough, wheeze, headache, etc.

- People with asthma may be more likely to have an asthmatic attack due to ozone; people with preexisting respiratory diseases are also more likely to be at risk.

- Exposures to ozone could affect host defense systems by possibly decreasing resistance to bacterial and viral infections.

- Extrapulmonary effects may be more likely to occur due to ozone exposure, e.g., alterations in red blood cell structure and enzyme activity, liver metabolism effects, etc.

In addition to human health effects, increases in tropospheric ozone may also affect agricultural yields, forests, other plant species, ecosystems, and materials. As summarized in the Risk Assessment (EPA 1987), these effects are:

(1) The mechanisms by which O3 may injure plants and plant communities include (a) absorption of O3 into leaf through stomata followed by diffusion through the cell wall and membrane, (b) alteration of cell structure and function, as well as critical plant processes, resulting from the chemical interaction of O3 with cellular components, and (c) occurrence of secondary effects including reduced growth and yield and altered carbon allocation;

(2) The magnitude of the O3-induced effects depends upon the physical and chemical environment of the plant, as well as various biological factors (including genetic potential, the developmental age of the plant and interaction with plant pests);

(3) Effects of O3 on vegetation and ecosystems have been demonstrated to occur from both short-term and long-term exposures. Although there are a limited number of studies in which short-term (1-2 hour) exposures have resulted in

growth and yield reduction, there is a growing body of evidence that repeated peaks above a given level are important in eliciting plant response;

(4) Concerning long-term exposures, the bulk of the evidence indicates that growth and yield losses occur in several plant species exposed to seasonal concentrations of O3, typically characterized as the daily daylight mean over the growing season. In addition, evidence indicates that forests experience cumulative stress as a result of chronic exposure to O3. Exhibit 14-1 [See Exhibit F-6] summarizes the range of O3 levels and exposure times required to induce 5% and 20% foliar injury. Exhibit 14-2 (EPA 1986) [See Exhibit F-7] provides a more complete survey; and

(5) Damage to materials is another effect of O3. There appears to be no threshold level below which material damage will not occur; the slight acceleration of the aging processes of materials occurs at the level of the proposed standard. The materials known to be most susceptible to ozone attack are elastomers, textile fibers and dyes, and certain types of paint.

3.2 Valuation of Impacts

As discussed in the previous section, tropospheric ozone can affect human health, agricultural yields, forest productivity, other plant species, ecosystems, and materials. In this section, only the agricultural impacts are quantified because insufficient information exists to attempt to value the other impacts. These data limitations include little or no information on dose-response relationships for some of the impacts and an inability to place a meaningful dollar value on the impact, e.g., decreases in pulmonary function as a result of ozone exposure.

One should not conclude from this inability to quantify the value of some potential impacts due to tropospheric ozone that these impacts are not important. In fact, the human health impacts may be the most important, e.g., the Primary National Ambient Air Quality Standard (NAAQS) for ozone is based on human health considerations. Unfortunately, appropriate methods were not available to quantify the value of several effects, including those relating to human health. These effects do raise, however, significant concerns over increases in tropospheric ozone. Their importance should not be overlooked.

3.2.1 AGRICULTURAL IMPACTS

To determine the economic impact of tropospheric ozone on agricultural crops, a study by Rowe and Adams (1987) that analyzed the economic impacts of stratospheric ozone depletion on crop yields was used. In their analysis, Rowe and Adams used the National Crop Loss Assessment Network (NCLAN) to evaluate the economic impacts. NCLAN was originally developed to assist EPA in the evaluation of various National Ambient Air Quality Standards (NAAQS) for tropospheric ozone. For their analysis Rowe and Adams used information supplied

EXHIBIT F-6

OZONE CONCENTRATIONS FOR SHORT-TERM EXPOSURE THAT PRODUCE 5% or 20% INJURY TO VEGETATION GROWTH UNDER SENSITIVE CONDITIONS*

Exposure Time, Hour	Ozone Concentrations (ppm) that may Produce 5% (20%) Injury: Sensitive Plants	Intermediate Plants	Less Sensitive Plants
0.5	0.35 to 0.50 (0.45 to 0.60)	0.55 to 0.70 (0.65 to 0.85)	≥0.70 (0.85)
1.0	0.15 to 0.25 (0.20 to 0.35)	0.25 to 0.40 (0.35 to 0.55)	≥0.40 (0.55)
2.0	0.09 to 0.15 (0.12 to 0.25)	0.15 to 0.25 (0.25 to 0.35)	≥0.30 (0.40)
4.0	0.04 to 0.09 (0.10 to 0.15)	0.10 to 0.15 (0.15 to 0.30)	≥0.25 (0.35)
8.0	0.02 to 0.04	0.07 to 0.12	≥0.20 (0.30)

* The concentrations in parenthesis are for the 20% injury level.

Source: EPA (1987), p. 14-6.

EXHIBIT F-7

OZONE CONCENTRATIONS AT WHICH SIGNIFICANT YIELD LOSSES HAVE BEEN NOTED FOR A VARIETY OF PLANT SPECIES EXPOSED UNDER VARIOUS EXPERIMENTAL CONDITIONS

Plant Species	Exposure Duration	Yield Reduction, % of Control	O_3 Concentration, ppm	Reference
Alfalfa	7 hr/day, 70 days	51, top dry wt	0.10	Neely et al., 1977
Alfalfa	2 hr/day, 21 day	16, top dry wt	0.10	Hoffman et al , 1975
Pasture grass	4 hr/day, 5 days/wk, 5 wk	20, top dry wt	0.09	Horsman et al., 1980
Ladino clover	6 hr/day, 5 days	20, shoot dry wt	0.10	Blum et al., 1982
Soybean	6 hr/day, 133 days	55, seed wt/plant	0.10	Heagle et al., 1974
Sweet corn	6 hr/day, 64 days	45, seed wt/plant	0.10	Heagle et al., 1972
Sweet corn	3 hr/day, 3 days/wk, 8 wk	13, ear fresh wt	0.20	Oshima, 1973
Wheat	4 hr/day, 7 day	30, seed yield	0.20	Shannon and Mulchi, 1974
Radish	3 hr	33, root dry wt	0.25	Adedipe and Ormrod, 1974
Beet	2 hr/day, 38 days	40, storage root dry wt	0.20	Ogata and Maas, 1973
Potato	3 hr/day, every 2 wk, 120 days	25, tuber wt	0.20	Pell et al., 1980
Pepper	3 hr/day, 3 days/wk, 11 wk	19, fruit dry wt	0.12	Bennett et al., 1979
Cotton	6 hr/day, 2 days/wk, 13 wk	62, fiber dry wt	0.25	Oshima et al., 1979
Carnation	24 hr/day, 12	74, no. of flower buds	0.05-0.09	Feder and Campbell, 1968
Coleus	2 hr	20, flower no.	0.20	Adedipe et al., 1972
Begonia	4 hr/day, once every 6 days for a total of 4 times	55, flower wt	0.25	Reinert and Nelson, 1979
Ponderosa pine	6 hr/day, 126 days	21, stem dry wt	0.10	Wilhour and Neely, 1977
Western white pine	6 hr/day, 126 days	9, stem dry wt	0.10	Wilhour and Neely, 1977
Loblolly pine	6 hr/day, 28 days	18, height growth	0.05	Wilhour and Neely, 1977
Pitch pine	6 hr/day, 28 days	13, height growth	0.10	Wilhour and Neely, 1977
Poplar	12 hr/day, 5 mo	+1333, leaf abscission	0.041	Wilhour and Neely, 1977
Hybrid poplar	12 hr/day, 102 days	58, height growth	0.15	Patton, 1981
Hybrid poplar	8 hr/day, 5 day/wk, 6 wk	50, shoot dry wt	0.15	Patton, 1981
Red maple	8 hr/day, 6 wk	37, height growth	0.25	Dochinger and Townsend, 1979
American sycamore	6 hr/day, 28 days	9, height growth	0.05	Kress and Skelly, 1982
Sweetgum	6 hr/day, 28 days	29, height growth	0.10	Kress and Skelly, 1982
White ash	6 hr/day, 28 days	17, total dry weight	0.15	Kress and Skelly, 1982
Green ash	6 hr/day, 28 days	24, height growth	0.10	Kress and Skelly, 1982
Willow oak	6 hr/day, 28 days	19, height growth	0.15	Kress and Skelly, 1982
Sugar maple	6 hr/day, 28 days	12, height growth	0.15	Kress and Skelly, 1982

Source: EPA (1987), p. 14-7.

by EPA that indicated the percentage increase in tropospheric ozone due to decreases in stratospheric ozone. Given these assumed levels of increase in tropospheric ozone, NCLAN was then used to determine the annual changes in economic surplus that would occur for the estimated changes in crop yield.

In their analysis Rowe and Adams estimated crop losses for soybeans, corn, wheat, cotton, rice, barley, sorghum, and forage. They developed the following relationship between tropospheric ozone changes and economic damage:

$$D1 = -0.0678 * T - 0.000195 * T^2$$

where:

D1 = annual change in economic surplus, in billions of 1982 dollars, due to tropospheric ozone.

T = percent change in tropospheric ozone.

Using this equation, annual decreases in economic surplus can be calculated for assumed increases in tropospheric ozone. To estimate the impact of potential changes in crop yields over time, the following additional steps are taken:

- Average values from 1980-83 on market prices and quantity of agricultural production were used to establish a baseline from which all changes were measured. Other actual agronomic, meteorological, and economic variables for the 1980-83 period were included to model conditions over this period as closely as possible. The type of information available from one of these years--1980--is summarized in Exhibit F-8.

- Dose-response relationships between tropospheric ozone levels and crop yield were specified. Exhibit F-9 provides these relationships by state for a 25 percent increase in tropospheric ozone for the major agricultural crops.

- Differences in economic surplus between the NCLAN baseline and alternative ambient ozone levels defined the benefits or costs associated with changes in tropospheric ozone.

- All results are converted to 1985 dollars.

The changes in economic surplus reported by Rowe and Adams (1987) for alternative tropospheric ozone levels were reported as annual cost impacts, i.e., they were based on economic surplus changes that would occur each year whenever ozone levels differed from the baseline. For example, Rowe and Adams estimated that a 15 percent decrease in stratospheric ozone levels would cause about a $1.0 billion decrease (1985 dollars) annually in economic surplus.

To determine the potential cost impacts of increased tropospheric ozone levels due to stratospheric ozone depletion, the annual cost impacts for each

EXHIBIT F-8

1980 CROP PRODUCTION QUANTITIES USED IN NCLAN a/

Commodity	1980 Prices b/ $/unit	1980 Quantities (million units)
Cotton	366.72	17.45
Corn	3.25	7,339.85
Soybeans	7.74	1,778.07
Wheat	3.71	2,633.94
Sorghum	3.00	700.88
Rice	12.79	164.78
Barley	2.91	335.50
Oats	1.93	472.91
Silage	19.46	91.24
Hay	70.90	141.58
Soybean Meal	0.11	46,180.80
Soybean Oil	0.24	10,755.81

a/ Average values from 1980-1983 were actually used in this analysis. Documentation for these average values was not publicly available in time for this study, so just 1980 data is shown here.

b/ Units are as follows: 500 pound bales for cotton; bushels for corn, soybeans, wheat, barley, oats, and sorghum; hundredweight for rice; tons for hay and silage; pounds for soybean meal and oil.

Source: Adams (1984).

EXHIBIT F-9

DECLINES IN CROP YIELD ASSUMING A 25 PERCENT INCREASE IN TROPOSPHERIC OZONE

STATE	CORN	SOYBEANS	COTTON	SPRING WHEAT	WINTER WHEAT	GRAIN SORGHUM	BARLEY
ALABAMA	.990	.958	.947	.000	.971	.993	.000
ARIZONA	.977	.000	.840	.974	.957	.967	.996
ARKANSAS	.984	.952	.933	.000	.969	.978	.000
CALIFORNIA	.976	.000	.837	.973	.958	.987	.996
COLORADO	.978	.000	.000	.975	.951	.987	.996
CONNECTICUT	.964	.000	.000	.000	.000	.000	.000
DELAWARE	.994	.954	.000	.000	.964	.000	.999
FLORIDA	.996	.974	.971	.000	.000	.000	.000
GEORGIA	.960	.962	.952	.000	.973	.993	.000
IDAHO	.985	.000	.000	.981	.951	.000	.997
ILLINOIS	.988	.955	.000	.000	.973	.992	.998
INDIANA	.986	.945	.000	.000	.979	.990	.000
IOWA	.992	.961	.000	.000	.975	.994	.000
KANSAS	.985	.953	.000	.000	.975	.992	.999
KENTUCKY	.990	.957	.000	.000	.976	.993	.999
LOUISIANA	.989	.944	.939	.000	.973	.992	.000
MAINE	.994	.000	.000	.000	.000	.000	.000
MARYLAND	.986	.951	.000	.000	.973	.000	.998
MASSACHUSETTS	.988	.000	.000	.000	.000	.000	.000
MICHIGAN	.993	.951	.000	.000	.975	.000	.999
MINNESOTA	.994	.963	.000	.991	.975	.000	.999
MISSISSIPPI	.986	.953	.938	.000	.966	.992	.000
MISSOURI	.986	.985	.940	.000	.967	.992	.000
MONTANA	.986	.000	.000	.982	.951	.000	.998
NEBRASKA	.989	.954	.000	.000	.970	.992	.999
NEVADA	.978	.000	.846	.975	.957	.000	.996
NEW HAMPSHIRE	.991	.000	.000	.000	.000	.000	.000
NEW JERSEY	.982	.950	.000	.000	.974	.000	.997
NEW MEXICO	.985	.000	.880	.000	.962	.990	.997
NEW YORK	.991	.957	.000	.000	.974	.000	.998
NORTH CAROLINA	.982	.950	.924	.000	.962	.990	.996
NORTH DAKOTA	.994	.964	.000	.992	.973	.000	.993
OHIO	.988	.943	.000	.000	.978	.000	.998
OKLAHOMA	.988	.956	.973	.000	.985	.992	.998
OREGON	.996	.000	.000	.993	.981	.000	.999
PENNSYLVANIA	.986	.939	.000	.000	.966	.990	.998
RHODE ISLAND	.978	.000	.000	.000	.000	.000	.000
SOUTH CAROLINA	.980	.945	.919	.000	.954	.989	.996
SOUTH DAKOTA	.991	.956	.000	.988	.973	.994	.998
TENNESSEE	.987	.950	.938	.000	.966	.991	.998
TEXAS	.992	.966	.978	.000	.978	.993	.999
UTAH	.975	.000	.000	.972	.940	.000	.995
VERMONT	.988	.000	.000	.000	.000	.000	.000
VIRGINIA	.972	.924	.884	.000	.953	.985	.994
WASHINGTON	.998	.000	.000	.996	.984	.000	.999
WEST VIRGINIA	.987	.000	.000	.000	.969	.000	.998
WISCONSIN	.986	.963	.000	.991	.970	.000	.999
WYOMING	.983	.000	.000	.979	.951	.000	.997

Source: Adams (1984).

scenario were estimated using the function cited above. For example, if tropospheric ozone levels were forecast to increase 10 percent in each year, then annual costs would be about $0.8 billion. For each scenario a stream of annual impacts was determined over time, then the present value of these annual impacts was calculated using a specified discount rate. A summary of these cost impacts is provided in Exhibit F-10 for the baseline scenario for a discount rate of two percent.

4. EFFECTS OF UV-B ON POLYMERS

4.1 Physical Effects

Many polymers currently used are sensitive to UV radiation. In many instances, steps are taken to protect polymeric materials from current UV levels. If UV radiation levels were to increase, many polymeric materials would be at greater risk than they are currently. As reported in the Risk Assessment (EPA 1987):

> Several polymers (and largely the impurities present in the polymers) readily absorb the ultraviolet (UV) radiation. One effect of increased UV-B radiation, resulting from possible future depletion of the ozone layer in the stratosphere, will be accelerated degradation of the polymeric materials. Energies associated with the UV radiation are large enough to initiate reactions in polymers, which lead to their degradation by affecting their mechanical and optical properties and thus reducing their service life. Several methods are used to stabilize the polymers to maintain a useful service life in their various important applications.
>
> While much is known about the physical processes of degradation, little research has focused to date on the potential costs and responses to such degradation. Initial studies suggest that one likely response to increased UV-B induced damage is to increase the amount of light stabilizer in the polymers. Because of the lack of relevant data, only approximate estimation methods are available to determine the extent of light-induced damage and the degree of stabilization required to minimize it. The effect of increased UV-B radiation is manifested in increased costs of production, including raw material costs, energy costs, and maintenance costs.

The available evidence on the molecular structure of polymers indicates that the chemical bonds in the polymer can be broken by different types of energy, particularly heat, mechanical energy, and radiation. It is the UV component of sunlight that is the most common form of radiant energy that causes degradation. Different polymeric materials are most sensitive to degradation at different wavelengths of UV radiation (Kelen, 1983).

The exposure of polymeric materials to radiation can affect their properties in a number of ways. For example, mechanical properties such as tensile strength, elongation, modulus, and impact strength can be affected, as well as

EXHIBIT F-10

POTENTIAL IMPACT ON U.S. AGRICULTURAL OUTPUT DUE TO INCREASED TROPOSPHERIC OZONE LEVELS (billions of 1985 dollars)

Scenario	Tropospheric Ozone Increase by 2075 (%)	2% Discount Rate
No Controls	>30.9%	18.3

Source: ICF estimates based on Rowe and Adams (1987).

optical properties such as transparency, color, chalking or cracking of surfaces, and yellowing. The most likely areas where these effects may be observed are in outdoor applications, primarily the use of plastics in the building industry and in paints and coatings. There are other applications where radiation exposure may occur, but the length of exposure tends to be on a more limited, possibly intermittent, basis (e.g., packaging, outdoor furnishings, housewares, and toys). Exhibit F-11 indicates a number of applications where exposure of the material to sunlight might be expected.

In many of these applications some degradation of product quality due to UV exposure is expected under current atmospheric conditions. The most common technique employed to counteract these effects is the addition of a light stabilizer to the polymer product. The purpose of these light stabilizers is to absorb the light in the UV-B range of the spectrum in a manner that is more efficient than the polymeric material itself. Light stability can be achieved in three ways: (1) the use of UV-absorbing compounds to dissipate the light without degrading the polymer; (2) light-shielding techniques that prevent light from reaching the polymer by including a light-absorbing or reflecting pigment; or (3) the addition of substances to deactivate or quench the excited molecular state caused by the interaction of the light with the polymer before degradation can occur.

From the available information it is not easy to determine when polymers may require additional protection from increases in UV radiation. Exhibit F-11 indicates the types of polymer products that may be more likely to be exposed to UV radiation. Of note is that not enough is known about the use of polymer products to conclude that even polymers with a relatively low degree of exposure to UV radiation would not require additional protection. Furthermore, the limited amount of dose-response information available in the literature is difficult to apply here because "... (a) the action spectra, where available, are often related to properties of little practical interest, (b) the polymer systems used in the studies do not represent those compounds typically used in outdoor applications, and (c) the light sources used in early experiments had spectra quite different from that of sunlight."[10]

To date, data for assessing the potential future markets and potential damages due to UV have only been developed for the portion of the PVC market used in construction (siding, window profiles, rainwater systems, and pipe and conduit). This PVC market accounts for about 26 percent of all polymers subject to exposure to UV (measured by production volume); consequently, any damage estimates based on these products only are underestimates of the potential risks of polymer degradation due to ozone depletion.

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[10] Research Triangle Institute, Analysis of Technical Issues Related to the Effect of UV-B on Polymers, draft final report, EPA Contract No. 68-01-7033. March 1986.

EXHIBIT F-11

PLASTICS USED IN APPLICATIONS WHERE EXPOSURE OF THE MATERIAL TO SUNLIGHT MIGHT BE EXPECTED

Type of Plastic	Application	Usage 1000 m.t.	Exposure
	Building Industry		
Poly(vinyl chloride) (rigid)	siding	410	high
	door/window	284	high
	other	33	high
	conduit	493	moderate
	irrig. pipe	247	high
	other pipe	1912	low
Poly(vinyl chloride) (plasticized)	roofing	22	high
	liners	25	moderate
	wire-cable	410	-
	weatherstrip	38	moderate
	garden hose	48	high
Unsaturated Polyester	glazing	41	high
	panels/siding	122	high
	pipe	237	low
Polycarbonate	glazing	90	high
	fixtures	9	low
Acrylic	glazing	84	high
	Packaging		
Polyethylene	film	696	-
	containers	2990	-
Polypropylene	film	375	-
	containers	325	-
Thermoplastic Polyester	containers	635	-

EXHIBIT F-11 (continued)

PLASTICS USED IN APPLICATIONS WHERE EXPOSURE OF THE MATERIAL TO SUNLIGHT MIGHT BE EXPECTED

Type of Plastic	Application	Usage 1000 m.t.	Exposure
	Housewares and Toys		
Polyethylene		954	-
Polystyrene		378	-
Polypropylene		176	-

Source: Andrady, A., Research Triangle Institute, Analysis of Technical Issues Related to the Effect of UV-B on Polymers, Draft final report, submitted to EPA, Contract No. 68-01-7033, March 1986, p. 22.

4.2 Valuation of Impacts on Polymers

As indicated above, there are a number of actions that polymer manufacturers can take to protect their products from exposure to UV radiation. In one case study that analyzed the costs to protect rigid PVC products used in building and construction from increases in UV radiation, Horst (1986) assumed that polymer manufacturers would need to increase the amount of titanium dioxide added to their products as a UV stabilizer.[11] To determine the costs that would be incurred to protect rigid PVC products from UV radiation, Horst used three basic steps:

1. Projected the size of the market for rigid PVC in construction applications that may be subject to degradation due to UV.

2. Assessed the damage that increases in UV (due to ozone depletion) may have on the polymers.

3. Assessed the costs of the damage to the polymers.

Each step is described in turn.

STEP 1 -- MARKET FOR POLYMERS

The future market for PVC polymers in construction will be influenced by construction activity and the costs and performance of substitute materials. Horst (1986) developed several approaches for projecting the expected production and use of PVC over the next 90 years. The approach used here reflects expected market saturation and is of the following form:

$$Q = A\ (1-\exp\ (-k(T - To)))$$

where:

Q = quantity per person per year in pounds;

A = a constant;

k = a constant;

T = the current year of the projection; and

To = a base year identified for the polymer type.

The constants and base year computed for PVC by Horst (1986, p. 4A-3) using statistical analyses of historical data are as follows: A = 63.0308; k = 0.01265; and To = 1966. These values are used along with the U.S. population projections to compute a middle estimate of the size of the future market for

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[11] Horst, et al., The Economic Impact of Increased UV-B Radiation on Polymer Materials: A Case Study of Rigid PVC, draft final report prepared by Mathtech, Inc., for EPA, June 1986.

PVC in pounds. By using the same population estimates used in other parts of the analysis, the estimates of the PVC market will be consistent with the values used to develop the scenarios of production of CFCs and the other trace gases, and the evaluation of human health effects.

Because there is uncertainty in the expected future market for PVC, low and high estimates of future demand were also calculated. The low and high estimates are based on the statistical uncertainty in the estimates of A and k. These low and high values (along with the middle value described above) are used in step 3 to evaluate the costs associated with the degradation of these polymers.

STEP 2 -- POLYMER DAMAGE

A damage index that indicates the level of degradation of polymer characteristics was developed by Andrady (1986). When there is no degradation, the index value equals 1.0. Degradation is indicated by increasing values of the index, such as 1.1. This index is used here to describe the potential damage to polymers due to increased UV flux associated with ozone depletion.

Andrady (1986) developed an estimate of how the damage index may vary as a function of ozone depletion. Due to uncertainties in the relationship between ozone depletion and UV, and UV and polymer characteristics, the relationship between ozone depletion and the damage index is represented as a range. These ranges are displayed in Exhibit F-12.

To evaluate the damage index in each year, the ozone depletion estimate for that year is used to get a range of values in the damage index table. The result of this method is a range of damage index values for each year (low, middle, and high).

STEP 3 -- ASSESS DAMAGE COSTS

The costs of polymer degradation depend on the manner in which the characteristics of the polymers degrade, and the steps that are taken in response to the degradation. Horst (1986) developed an approach for evaluating the costs associated with the production of new PVC each year. These costs represent the implications of changing the formulation of PVC during manufacture in order to maintain its characteristics in light of increased UV exposure. These costs do not include the potential damages to PVC already in place. Additionally, these estimates do not reflect the losses that may be associated with polymer degradation in the absence of changes in the polymer formulation. Therefore, these estimates are an underestimate of the damages resulting from exposure of polymers to UV radiation.

Horst (1986) identified the costs of changing the formulation of PVC as a function of the increased amount of stabilizer that needs to be added to the polymer to maintain its characteristics. A 25 percent increase in stabilizer was estimated to lead to a 1.86 percent increase in the price of PVC, from its

EXHIBIT F-12

DAMAGE INDEX AND INCREASE IN STABILIZER FOR RANGES OF OZONE DEPLETION

Ozone Depletion (percent)	Damage Index			Stabilizer Increase (%)		
	Low	Middle	High	Low	Middle	High
0-5	1.01	1.015	1.02	1.0	3.0	5.0
5-10	1.01	1.025	1.04	1.0	5.0	9.0
10-20	1.03	1.105	1.18	3.0	20.5	38.0

Source: Derived from Horst (1986), p. 6-10.

current cost of $0.604 per pound.[12] (Horst 1986, p. 5-16 and 6-8). The increased amount of stabilizer required as a function of ozone depletion was identified by Andrady (1986) and is also presented in Exhibit F-12.

To estimate the costs of increasing the stabilizer in response to ozone depletion, Horst recommends using a ten year lag between the increase in stabilizer required and the increase in the price of PVC. This lag reflects the time needed for the industry to respond to changing environmental conditions and the fact that the current stabilizer concentrations include a margin of safety. This ten year lag has been assumed for purposes of this analysis.

To compute the costs in year T, the following computations are performed:

- compute the increased amount of stabilizer required, based on the ozone depletion in year T - 10;
- compute the increase in price by interpolating between no increase in price, and a 1.86 percent increase in price for a 25 percent increase in stabilizer;
- given the increase in price, compute the cost as follows:

$$C(T) = (D(T)/Po^{b})/(1+b) * [Po^{(1+b)} - P1^{(1+b)}]$$

where

C(T) = cost in year T;

D(T) = demand in year T;

Po = price of PVC in the absence of changes in the formulation of the polymer;

b = price elasticity of demand for PVC;

P1 = the new price for PVC given the change in the formulation of the polymer.

This equation represents the annual loss in consumer surplus associated with the estimated changes in price. The price elasticity of demand estimated by Horst (1986) is -1.956. This value represents (in part) the estimated availability of appropriate substitutes for PVC.

This equation is evaluated for each year to generate low, medium, and high estimates of the costs. The low estimate uses the low demand value (from step 1) and the estimate of the change in price associated with the low estimate of the increase in stabilizer associated with ozone depletion. The middle and high estimates use the middle and high values for these components respectively. If there is an increase in ozone abundance, the damage index is set to zero and

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[12] Ibid, pp. 5-16 and 6-8.

there are no estimated costs. The maximum price increase (1.86 percent) estimated by Horst is associated with a 25 percent increase in stabilizer. Price increases are capped at this value (1.86 percent) even when an increase in stabilizer exceeding 25 percent may be required to provide sufficient protection.

Using the Horst (1986) damage estimates as a reference point for potential damages to rigid PVC products, damage estimates for the baseline scenario can be calculated as summarized in Exhibit F-13. These damage estimates are shown for a discount rate of two percent.

The damage estimates summarized in Exhibit F-13 were estimated only for extruded PVC products used in building and construction. However, these materials represent only a portion of all polymer materials that could be damaged by increased UV-B radiation. The Horst (1986) case study focused on products that comprise about 1.2 million metric tons of annual plastic consumption.[13] As shown in Exhibit F-11, however, the building industry alone consumed approximately 4.5 million metric tons of plastics in 1985 that Andrady (1986) estimated could be exposed to UV radiation. Studies have not been conducted to determine how other polymers would respond to increased UV radiation. However, if one assumes that all of these materials require the same level of additional protection identified by Horst (1986) for PVC products at the same incremental cost per pound, the costs to protect all of these products could be substantially higher. Exhibit F-14 summarizes the potential magnitude of these additional costs.

Furthermore, Andrady (1986) identified an additional 6.5 million metric tons of plastic applications in the packaging, housewares, and toys industries that may be subject to intermittent doses of UV radiation. These materials may also require additional UV protection, but information is not available to determine whether such protection would be necessary.

It should also be noted that the estimates in Exhibit F-14 have been adapted from the Horst (1986) case study analysis as a means to approximate the potential costs due to damage from UV radiation. However, it is not clear whether the methodology employed by Horst (1986) for extruded PVC products in the building and construction industries can be easily extrapolated to all other plastic applications. The method used to protect the products from increased UV radiation -- the addition of titanium dioxide to the product -- may not be appropriate. It is also not known whether additional protection may be warranted for these other products. These determinations could not be made with a higher level of confidence without substantial additional analytic efforts.

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[13] Horst, p. 7-3.

EXHIBIT F-13

POTENTIAL IMPACTS ON RIGID PVC DUE TO OZONE DEPLETION
(billions of 1985 dollars)

Scenario	Ozone Depletion by 2075 (%)	2% Discount Rate
No Controls	50.00%	1.37

Source: ICF estimates based on Horst (1986).

EXHIBIT F-14

POTENTIAL IMPACTS ON PLASTICS IN THE BUILDING INDUSTRY DUE TO OZONE DEPLETION (billions of 1985 dollars)[a]

Scenario	Ozone Depletion by 2075 (%)	2% Discount Rate
No Controls	50.00%	5.14

a/ Horst (1986) estimated only the cost of potential damages to rigid PVC products in the building and construction industries, as shown in Exhibit F-11. These estimates have been extrapolated from the Horst (1986) case study.

Source: ICF estimates based on Horst (1986).

5. SEA LEVEL RISE IMPACTS

5.1 Physical Effects

Increased concentration of CFCs are expected to contribute to global warming, of which one impact is the rise in the level of the seas. According to the Risk Assessment (EPA 1987):

> One of the most widely examined impacts of the projected global warming is the possible rise in sea level. Researchers have identified at least four mechanisms that might cause a significant rise: the warming and resulting expansion of the upper layers of the ocean, the melting of alpine glaciers, the melting of polar ice sheets in Greenland and Antarctica, and the disintegration of these land-based ice sheets. Estimates of the rise through the year 2100, in the absence of efforts to limit the greenhouse warming, range from 50 cm to over 2 m. Even the most conservative estimate implies a substantial acceleration over the 10-15 cm rise of the last century.
>
> A rise in sea level in that range would permanently inundate wetlands and lowlands, accelerate coastal erosion, exacerbate coastal flooding, and increase the salinity of estuaries and aquifers. Although wetlands have kept pace with sea level rise in the last several thousand years, a 1- to 2-m rise would destroy a majority of U.S. coastal marshes and swamps. River deltas, such as those of the Mississippi, Ganges, and Nile Rivers, appear to be particularly vulnerable.
>
> Along the open coast, beach erosion could reach 1 to 2 m for every 1-cm rise in sea level, in addition to whatever erosion might be caused by other factors. Because buildings are generally found within 50 m of the shore, even the 30-cm rise projected for the next 40 years could threaten coastal property and the recreational use of beaches, unless additional remedial measures are implemented.
>
> Sea level rise would also increase the vulnerability of coastal areas to flooding from storm surges and rainwater. In the area of Charleston, S.C., for example, the area now flooded once every 100 years would be flooded every 10 years if sea level rises 1.6 m. Protecting against increased flooding would require improvement or construction of levees, seawalls, and drainage facilities.
>
> Higher water levels would also increase the salinity of estuaries and aquifers. For example, Philadelphia's drinking water intake on the Delaware River would be threatened by a 73-cm rise, as would adjacent aquifers in New Jersey that are recharged by the (currently) fresh part of the river. Construction of additional reservoirs might be necessary to offset salinity increases.

> Few studies have estimated the economic significance of future sea level rise. One study suggests that the impacts of a 0.9- to 2.4-m rise by 2075 could be as great as 17% to 35% of total economic activity in the Charleston, South Carolina, area and 5% to 16% of the activity around Galveston, Texas. No one has yet estimated the potential nationwide cost of defending shorelines and other resources from the projected rise in sea level.

For purposes of evaluating the impact of CFC emissions on global sea level, a statistical representation of a one-dimensional box model of the atmosphere and oceans was used.[14] This model evaluates the expected change in average global air temperature as a function of: (1) the changing atmospheric concentration of trace gases (including CFCs); (2) an assumed level of climate sensitivity of greenhouse-gas forcings; and (3) an assumed rate of diffusion of heat into the oceans. Based on these calculations, the change in global sea level due to the following components is estimated:

- thermal expansion;
- Alpine meltwater; and
- Greenland meltwater.

Exhibit F-15 displays the estimates of the contribution to sea level rise for the period 1985 to 2075 for the No Controls scenario. A value of 3.0°C is used for climate sensitivity based on the middle of the range recommended by the National Academy of Sciences.[15]

Also shown in the exhibit is a potential range of sea level rise due to Antarctic ice discharge. The model used to evaluate the other components of sea level rise does not incorporate this factor in a manner that is sensitive to rates of change of temperature. Therefore, there are no estimates of how this component of sea level rise may vary with alternative CFC emission scenarios. The range of sea level rise contribution from Antarctic ice discharge displayed in Exhibit F-15 was presented in Thomas (1985). A middle value of 42 cm is used in this analysis. Of note is that Exhibit F-15 shows that potential Greenland Ice Discharges and Antarctic meltwater are not evaluated.

To evaluate the sea level rise associated with alternative CFC emission scenarios, the model was run using the alternative scenario emission estimates, resulting in alternative scenario estimates of sea level rise due to thermal expansion, Alpine meltwater, and Greenland meltwater. As mentioned above, the Antarctic ice discharge estimates do not vary across the scenario, and a middle value of 42 cm is used throughout for this component.

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[14] The model developed by Lacis et al. (1981), and subsequently modified by Hoffman, Keyes, and Titus (1983), and Hoffman, Wells, and Titus (1986).

[15] Climate sensitivity refers to the equilibrium increase in global average surface air temperature expected for a doubling of carbon dioxide concentrations in the atmosphere. The entire range recommended by the National Academy of Sciences was 1.5°C to 4.5°C. See NAS (1983).

EXHIBIT F-15

FUTURE SEA LEVEL RISE FOR THE NO CONTROLS SCENARIO: 1985-2075 (centimeters)

Sea Level Rise Component	Global Climate Sensitivity of 3.0°C
Thermal Expansion	32.9
Alpine Meltwater	15.1
Greenland Meltwater	6.5
Antarctic Ice Discharge a/	(10 cm to 107 cm)
Antarctic Meltwater	Not Evaluated
Greenland Ice Discharged	Not Evaluated

a/ Estimates are not a function of trace gas concentration and global warming in this analysis. Range is taken from Thomas (1985).

Source: Based on sea level use model described in Hoffman, Wells and Titus (1986).

5.2 Valuation of Sea Level Rise Impacts

As discussed above, sea level rise can have a number of impacts, including loss of coastal wetlands, higher storm surges, flooding, and beach erosion. There have been very few studies that have examined the economic costs associated with sea level rise impacts. In one study by Gibbs (1984), the potential impacts of a 0.75 to 2.2 meter rise by 2075 were evaluated for two coastal communities -- Charleston, South Carolina and Galveston, Texas. Gibbs concluded that the major impact would be due to increased storm damage.

To evaluate the economic impacts of sea level rise, Gibbs measured changes in net economic services (NES) that could result over time due to sea level rise. Net economic services were defined as the returns to a set of investments (referred to as gross services) minus the costs of the investments. For any community, net economic services were determined using the following equation:

$$NES = S - H - NI + CS$$

where:

NES = net economic services

S = returns generated by a set of investments (also called gross services)

H = costs to individuals to maintain their investments

NI = new investment by a community to serve the growing population

CS = value of the capital stock at the end of a finite period of time (the remaining useful life at the end of the period of analysis, e.g., in the year 2075).

The aggregate value of NES over a period of time was calculated by estimating the present value of the time stream of NES values for each year using a specified discount rate. The cost impacts associated with sea level rise were evaluated by determining the changes in the present value of NES as a result of increasing sea levels.

In addition to analyzing the impacts of different levels of sea rise, (as determined by changes in NES), Gibbs also estimated the impacts for two different types of community response -- damages if anticipatory actions were taken and damages if they were not. If communities do not anticipate the problems of higher sea levels, this study estimated that costs in Charleston would range from $1.3 to $2.6 billion (depending on the level of sea rise) and costs in Galveston would range from $0.6 to $2.0 billion (all costs in 1985

dollars).[16] If measures were taken in anticipation of the higher sea levels, then costs in Charleston would range from $0.5 to $1.2 billion and costs in Galveston would range from $0.3 to $0.8 billion.

Detailed estimates of the potential amount of damage that could occur to U.S. ports due to sea level rise could be done most reliably by conducting site-specific analyses for each port. However, since this approach was not feasible for this study, estimates of the amount of damage that could occur due to sea level rise have been estimated for the major ports in the U.S. using the potential damage estimates from the Gibbs study to represent the potential range of impacts due to sea level rise. The list of ports evaluated is shown in Exhibit F-16. The potential range of cost impacts due to sea level rise at these ports is summarized in Exhibit F-17 for the baseline scenario. The steps taken to provide these estimates were:

- The cost estimates for Galveston and Charleston were divided by the total tonnage shipped annually from the port to determine damage costs for each ton shipped through the port. This value was used to represent the relative severity of impacts due to sea level rise. The higher the dollar per ton value, the greater the impact due to sea level rise. This approach assumes that port size can be related to the amount of tonnage shipped through the port and that potential cost impacts can be directly related to the total amount of tonnage. Based on the cost estimates in Gibbs (1984), the costs per ton shipped for a 98 cm rise in sea level were $66 to $181 per ton for Charleston and $8 to $16 per ton for Galveston.

- Because Charleston had higher estimated impacts and lower tonnage shipped than Galveston, the Charleston cost estimates represent the upper end of the range of cost impacts with Galveston representing the lower end. A medium range value was estimated by examining maps of each coastal port to determine whether the port tended to be protected (like Galveston, and therefore would tend to incur costs more similar to Galveston than to Charleston) or unprotected (like Charleston).

- Cost estimates are based on cumulative impacts from 1985-2075.

- A discount rate of three percent was assumed. (Data were unavailable from the Gibbs study to calculate costs using other discount rates.)

The impacts summarized in Exhibit F-17 are estimated for all damages expected in major U.S. coastal ports if the sea level were to rise by the amount indicated.

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[16] Gibbs, M., "Economic Analysis of Sea Level Rise: Methods and Results," in Barth, M. C. and J. G. Titus (editors), Greenhouse Effect and Sea Level Rise: A Challenge for this Generation, New York, Van Nostrand Reinhold, 1984.

EXHIBIT F-16

MAJOR SHIPPING PORTS VULNERABLE TO SEA LEVEL RISE

Port	1985 Tonnage Shipped (thousand short tons)
New York, NY	161,676,654
New Orleans, LA	154,220,218
Houston, TX	96,777,619
Valdez Harbor, AK	92,047,493
Baton Rouge, LA	66,198,761
Tampa Harbor, FL	46,517,226
Norfolk Harbor, VA	44,897,403
Corpus Christi Ship Channel, TX	44,081,109
Long Beach, CA	42,848,658
Texas City Galveston, TX	42,409,947
Corpus Christi, TX	42,281,512
Baltimore Harbor, MD	37,306,504
Mobile, AL	35,718,226
Beaumont, TX	33,004,372
Los Angeles, CA	31,242,369
Philadelphia, PA	28,509,784
Portland, OR	27,302,664
Lake Charles, LA	27,238,993
Pascagoula, MS	24,153,100
Seattle, WA	20,327,874
Boston, MA, Port of	19,888,675
Paulsboro, NJ	18,197,352
Tacoma Harbor, WA	17,383,225
Port Arthur, TX	16,430,368
Richmond, CA	16,341,341
Newport News, VA	15,552,908
Freeport, TX	15,122,761
Charleston Harbor, SC	8,086,893
U.S. Total	1,225,764,009

Source: The World Almanac and Book of Facts 1987, p. 161.

EXHIBIT F-17

POTENTIAL IMPACTS OF SEA LEVEL RISE ON MAJOR COASTAL PORTS (billions of 1985 dollars)[a]

Scenario	Sea Level Rise by 2075	Anticipated			Unanticipated		
		Low	Medium	High	Low	Medium	High
No Controls	99.6 cm	13.0	55.1	106.2	26.1	145.7	290.7

a/ Assuming a discount rate of three percent.

Source: Based on Gibbs (1984).

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G

APPENDIX G

THE VALUE OF MORTALITY RISK REDUCTIONS FROM THE PREVENTION OF STRATOSPHERIC OZONE DEPLETION

1. INTRODUCTION

The benefits of environmental protection include the avoidance of detrimental effects on human health and welfare plus reductions in damages to the natural environment and ecosystems. Many of these benefits, such as the avoided impacts of crop losses from the prevention of ozone depletion, can be translated into monetary values. Other benefits however, such as avoided deaths, are not readily translated into monetary terms.

Efforts to quantify and monetize such nonmonetary benefits must rely on implicit valuation and other economic analytical techniques. The most widely pursued, and the most controversial, of these efforts involves the attempt to determine the value of reducing risks of premature mortality resulting from adverse environmental conditions.

In markets for ordinary consumer goods and services, a demand function could be estimated to reveal a consumer's willingness to pay for that good or service. From observed prices and.quantities on the demand curve, monetary benefits to the consumer could be derived. For instance, to derive monetary benefits in the case of crop losses from damage due to photochemical oxidants, the price of the commodity and the value of the lost output can be determined through the existing market. If production of that particular commodity is affected by photochemical oxidants, an estimate of that loss could be determined by the different price/quantity combinations in that market. Eliminating the crop loss by attempting to control the cause of ground-based oxidants can be expressed as a monetary benefit to society.

However, a market structure of this type does not exist for reductions in risk of mortal injury. Such risks are different from other commodities our society produces and exchanges through markets. Therefore, there is no discernible set of market prices for mortality risk reductions.

Without such direct, market-based, monetary value for mortality risk reduction, environmental regulatory analysts are confronted by a difficult problem. Executive Order 12291 requires that potential benefits of major regulation must be shown to outweigh potential costs before enactment. In order to make such a demonstration, it would be desirable to be able to express all of the costs and benefits of the regulatory alternatives in common units. However, dollars[1] are the most commonly used units of value for cost-benefit analysis and, as discussed previously, many environmental protection benefits cannot be readily expressed in monetary terms.

Some analysts have suggested that this dilemma is best resolved by applying economic valuation techniques to derive a value for a unit of mortality risk

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[1] Actually, most economists prefer using "uncommitted foreign exchange in government hands" as the common unit of value, or numeraire, for cost-benefit analysis.

reduction. These values are then applied within the framework of traditional cost-benefit analysis. However, other analysts have pointed out that "such a value, given the current state of knowledge in this area, might not be analytically discoverable."[2] Some of the considerations underlying this conclusion are discussed later in this appendix.

These latter analysts have suggested that the best way to approach the problem of evaluating and comparing regulatory effects is to develop, and present to decisionmakers, some type of structured representation of regulatory costs and benefits which avoids reducing these effects to a single net benefit value. Approaches which have been suggested include (1) a balance sheet format which shows nonmonetary benefits plus monetary benefits on one side and nonmonetary costs plus monetary costs on the other side, and (2) an impact matrix, or cost-benefit trade-off chart.[3] Using one of these methods, the decisionmakers are thus presented with cost and benefit information distilled to the lowest non-controversial level, and potential distortions in the comparison of costs and benefits created by imprecise monetary valuation of factors such as mortality risk reduction benefits are avoided.

The approach taken in this appendix is to develop and apply a range of monetary values for the mortality risk reduction benefits achieved by alternative stratospheric ozone protection strategies. This approach is taken with some trepidation, however, given the severe theoretical and empirical limitations of implicit valuation of risk reductions resulting from environmental regulation. As stated by Zeckhauser and Shepard, "(t)here is no unambiguous procedure for valuing human life; indeed, evidence suggests that life valuation should not be approached for an elusive number."[4] To partially mitigate the potential distortions resulting from reliance on imprecise values for environmentally-related mortality risk reductions, a range of values is used in the present analysis.

The principal advantages of incorporating monetized values for nonmonetary benefits such as mortality risk reductions are that this approach satisfies the requirements of E.O. 12291 and satisfies those who prefer to examine single net benefit estimates. Others who prefer to rely on other approaches, such as the balance sheet approach described above, will find the basic estimates of nonmonetary costs and benefits retained in the document.

The remainder of this appendix consists of, first, an examination of the human capital approach to valuing mortality risk reductions and its potential for providing reliable estimates for use in the present analysis. Second, the willingness to pay approach to obtaining such values is similarly treated. The third section of the appendix presents, and describes the basis for, the values chosen for the present analysis. The final section presents a justification for adjusting, over time, the mortality risk reduction value based on income effects.

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[2] Ashford and Stone (1988), p. 38.

[3] Ashford and Stone (1988) pp. 54-59.

[4] Zeckhauser and Shepard (1981).

2. HUMAN CAPITAL APPROACH

The human capital method defines a person's worth to society as their future earnings. It is assumed that the value of an individual's life is measured by future production potential often calculated as the present discounted value of expected labor earnings. A variation to this approach reduces the estimated value of human life by subtracting medical and other costs of supporting life. The following aspects make the use of the human capital approach to the valuation of life attractive:

- The human capital approach is easily calculated and provides reliable and consistent methods of estimating foregone earnings.[5]

- Estimates derived by using the human capital approach may have the expected value over the range of human ages.[6]

- The human capital approach is considered an appropriate although partial, measure of certain economic impacts, such as the economic burden of cancer in a given (past) year, the resources that would be saved by preventative measures that reduce the incidence of cancer, and the economic impact of improved survival rates.[7]

While the human capital approach to valuing life has some attractive features and was a widely used method of calculating health benefits in the past, it is no longer considered an acceptable measure of estimating the benefits of reductions in mortal risk. The following are serious drawbacks to the use of the human capital approach:

- The perspective that the value of human life depends solely on earnings is highly controversial. The human capital approach implies that the average white is more valuable than the average black, men more valuable than women, the rich more valuable than the poor, the educated more valuable than the uneducated, etc.

- The human capital approach ignores other dimensions of illness and death as well as nonmarket activities that may be more important to an individual than economic loss. These include pain, suffering, aversion to risks and loss of leisure.[8]

- Because the human capital approach measures the value of a human life as the additional dollar amount of wages a person could have earned had he or she not died prematurely, it undervalues the lives of the elderly, mentally or physically incapacitated or any other people not expected to earn substantial wages in the future.[9]

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[5] Rice and Hodgson (1982); Vaupel (1981).

[6] Vaupel (1981).

[7] Rice and Hodgson (1982).

[8] Landefeld and Seskin (1982).

[9] DeMocker (1986).

While the human capital approach may be an appropriate measure of benefits in some instances, it has drawbacks which make this procedure inadequate to use when trying to determine the benefits of a specific government regulation which could save many lives in the future.

The benefit of a health and safety regulation is not merely the monetary value of earnings, rather it is the avoidance of risks of premature death, injury, or illness. The benefits are a reduction in the probability that all members of some population group will encounter some specific form of suffering.[10] For the reasons described above and because there are more promising alternative approaches, the human capital approach is not used herein as the basis for estimating the value of environmentally-related mortality risk reductions.

3. WILLINGNESS TO PAY APPROACH

Today, most analysts attempting to estimate the value of health risk reductions have focused on alternative approaches based on empirical examinations of individuals' willingness to pay to avoid risk. Using the willingness to pay approach overcomes some of the limiting factors of the human capital approach. The values derived from the willingness to pay approach are ex ante measures of the monetary values individuals attach to changes in welfare that would accompany changes in the probability of a death occurring. Willingness to pay is basically the algebraic sum of the amounts all affected persons are willing to pay for a change in the status quo, such as a regulation that has life saving potential. Analysts such as Rice and Hodgson argue that, through valuation by the willingness to pay method, individual preferences, freedom of choice, and maximum social welfare are reflected.[11]

However, the willingness to pay approach is not universally approved. The principal criticisms against this approach include:

- The willingness to pay approach is only concerned with the aggregate level of welfare and does not adequately consider distributional and equity effects.
- The willingness to pay approach assumes that individuals have adequate information and make rational decisions regarding their own welfare, both of which have been shown in the literature to be frequently unfounded.
- The willingness to pay approach is biased if the expressed values are limited by an individual's ability to pay due to constraints on health, wealth, or income.[12]

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[10] Ferguson and Figge (1981), preface.

[11] Rice and Hodgson (1982).

[12] See Zechkauser and Shepard (1981); also see Rice and Hodgson (1982).

- There is evidence in the literature that willingness to pay valuations are context-dependent, in that "an individual's willingness to pay for reduced risk to life is a function of the level of risk ... and that person's life expectancy and quality of life after removal of the incremental risk."[13]

- There is evidence in the literature that willingness to pay valuations of mortality risk reduction may reflect an oversimplification of the true measures of change in individual and social welfare, in that the potential differences between compensating variation and equivalent variation are often ignored.[14]

- Frequently, valuations based on the willingness to pay approach ignore potentially significant externalities associated with the welfare effect in question. Specifically, an individual's willingness to pay to avoid an increment of job-related mortal risk may not adequately reflect the willingness to pay of his/her family and friends to reduce this risk.[15]

Notwithstanding these criticisms, there are two distinct procedures which have been used to calculate willingness to pay estimates of the value of mortality risk reductions: direct surveying of individuals, and estimation of individuals' preferences as revealed through consumer behavior or labor market behavior.[16]

3.1 Direct Surveys

Surveys asking people what they would pay for stated risk reductions have been used to attempt to value mortality risk reductions.[17] Individuals are asked open-ended questions about their willingness to pay for a program or service designed to reduce a probable risk of death.

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[13] Ashford and Stone (1988), p. 4.

[14] There are two symmetrical concepts which are used in determining changes in individual or social welfare: the compensating variation and the equivalent variation. According to Ashford and Stone (1988, p. 10), there is "evidence ... from a variety of sources which shows consistent and sizable differences between the compensation individuals demand to give up good ... and the amount they are willing to pay to acquire it. Compensation demanded regularly exceeds willingness to pay by 100 percent, but the disparity is sometimes a five-fold, ten-fold, and even a fifteen-fold difference in value ..." Ashford and Stone (1988, p. 11) further state that, if the basis for this difference is that individuals must be compensated for their entitlement to the commodity, such an interpretation "has implications for valuing reductions in risk to life, since an individual's valuation then depends on his entitlements to health and safety as far as the risk-generating activity is concerned."

[15] Ashford and Stone (1988), p. 13.

[16] Landefeld and Shepard (1982).

[17] Bailey (1980).

The survey method provides an estimate of an individual's willingness to pay; however, the validity of such estimates has been questioned.[18] One problem with the application of this methodology is that sometimes what an individual says they will do under a hypothetical survey situation and what they actually do when confronted with an actual situation differs. Also, individuals may not be able to respond rationally and consistently to the abstract and complex questions involving hypothetical risk.[19]

Procedures that reflect an individual's actual behavior, or revealed preferences in risk reduction choices, are more acceptable to some economists.[20] This can be done in two ways: analysis of markets for products that affect health and safety, and labor market data. Neither of these approaches, however, overcomes the fundamental problem of estimating a value for a risk reduction for a future generation since, until recently, people did not realize that these choices were necessary and therefore have little experience in these decisions.

3.2 Consumer Behavior Studies

Consumer behavior studies use markets for products that affect health and safety to estimate the value of mortality risk reduction. Estimates by the use of this method will show the amounts people are willing to pay directly for reductions in risk, i.e., the purchase of smoke detectors to reduce the likelihood of death and injury in case of fire.[21]

The criticisms of this procedure are that, among others, data constraints may bias the statistical estimates, and the quantitative information on the risk reducing potential of various activities is scarce.[22]

3.3 Labor Market Studies

Another approach to estimating the value that individuals are willing to pay for a reduction in health risk is to examine the wage premiums that must be paid to induce people to take more risky jobs.[23]

The following are some of the problems associated with using the estimates of the value of mortality risk reductions derived from labor market studies in environmental cost-benefit studies:[24]

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[18] Bailey (1980).

[19] Landefeld and Shepard (1982).

[20] Bailey (1980).

[21] DeCanio and Woodward (1987).

[22] Landefeld and Shepard (1982).

[23] Viscusi (1986).

[24] Landefeld and Shepard (1982); Ashford and Stone (1988); DeMocker, (1986); Bailey (1980).

- Wage premiums may not accurately reflect worker risk preferences if workers have incomplete information regarding risks to which they are exposed or if workers are so desperate for income that they cannot refuse available, but dangerous, jobs. One potential analytical consequence of the latter point is that, as Graham, Shakow and Cyr have demonstrated, such labor market conditions may lead to labor market segmentation which distorts derived wage risk premiums.[25]

- Even if the risk is perfectly known and the acceptance of the wage premium is by choice, it is a voluntary risk. Estimates of the value of voluntary risk reductions would underestimate the value of involuntarily incurred risks, such as environmental risks.[26]

- People may accept wage premiums for self-incurred risk substantially lower than the amount they would pay to protect others, including children and grandchildren, from future risk.

- Statistical problems arise in attempting to isolate a value for reductions in mortal risk from the entire range of health risks, including risk of illness and risk of injury.

- Life and health insurance policies can distort the wage premium workers will accept for more risky jobs. Moore and Viscusi concluded that, if death benefits from workers compensation are eliminated, age risk premiums more than double.[27]

- Labor market studies may suffer from sampling errors resulting in the underrepresentation of actual job fatalities discovered in the frequently used Bureau of Labor Statistics (BLS) data. Moore and Viscusi relied on NIOSH data to conclude the wage premiums derived from BLS data should be more than doubled.[28]

- Risk valuations based on labor market studies frequently omit the willingness to pay of family members and friends to reduce risks faced by workers. This externality may or may not be adequately compensated by the wage premium.[29]

- Other externalities not reflected in the worker risk wage premium are the employers' productivity losses and the societal psychic loss resulting from worker death, injury, or illness.[30]

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[25] Graham, Shakow and Cyr (1983).

[26] Mishan (1971).

[27] Moore and Viscusi (1987).

[28] Moore and Viscusi (1987).

[29] Ashford and Stone (1988), p. 21.

[30] Ashford and Stone (1988), p. 21.

There have been a number of empirical studies which have attempted to estimate the value of mortality risk reductions using the labor market approach. These studies have consistently found a significant relationship between on-the-job risks and wages. Given that the results of consumer market studies have not been validated by repeated estimation in the same market, the results derived from labor market studies are considered more credible.[31]

It should be noted that while some of the wage-risk premium studies may be relatively credible statistically, many of the above-described deficiencies in this approach have not been satisfactorily managed. There have been a number of articles written[32] which attempt to identify the value of a reduction in unit mortality risk based on the wage-risk premiums. The ranges of estimates derived in each of these review are presented in Exhibit G-1.

An examination of this exhibit shows that the range of values derived can vary significantly, sometimes by an order or magnitude, and even to the point that one author's lower end value approximates another author's upper end value.

The next section attempts to develop a range of values for mortality risk reduction which can be used to estimate the monetary benefits of preventing stratospheric ozone depletion.

4. BASIS FOR RANGE OF ESTIMATED VALUES FOR REDUCTION IN RISK FROM STRATOSPHERIC OZONE DEPLETION

Before an estimate of the value of unit mortality risk reduction is determined, it is important to reiterate that this value should not be thought of as an amount of money an individual would accept in exchange for his or her life. Rather, it is the summation of small reductions in life-threatening risk imposed on a large number of people.[33]

The risk of premature death from skin cancer occurring from a depletion of stratospheric ozone is an involuntary environmental risk which will affect people and their descendants for generations to come. A depletion of stratospheric ozone will prevent or disrupt people's attempts to pursue enjoyable leisure and sport activities. A depletion of stratospheric ozone will also affect people who make their living working outdoors, such as construction workers, gardeners and landscapers, painters, farmers, and others.

This Regulatory Impact Analysis selects as one value for mortality risk reductions resulting from stratospheric ozone protection, an estimate of $3 million per unit mortality risk reduction.[34] This value is in the range of

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[31] ERC (1983).

[32] Landefeld and Shepard (1982); Bailey (1986); Viscusi (1986); Miller (1986); and ERC (1983).

[33] ERC (1983).

[34] This unit of risk is also referred to by some analysts as "a statistical life saved," although such a term is less favorable since it tends to connote a risk of an individual death, rather than the sum, over large numbers of people, of small increments of mortal risk.

EXHIBIT G-1

WILLINGNESS TO PAY ESTIMATES OF THE VALUE OF MORTALITY RISK REDUCTIONS

	Value Per Unit Mortality Risk	
Reviewer	Low Range($)	High Range($)
ERC a/	400,000	7,500,000
Bailey b/	170,000	584,000 to 715,000
Viscusi c/	580,000	11,000,000
Landefeld and Shepard d/	277,000	5,900,000
Miller e/	0	3,462,000

NOTE: All studies were based on wage-risk premiums.

a/ Values in 1982 dollars. Studies reviewed included R. Smith (1974 and 1976); Thaler and Rosen (1975); Viscusi (1978); Dillingham (1979); Olson (1981); V.K. Smith (1982); Arnould and Nichols (1983).

b/ Values in 1978 dollars. Studies reviewed included Thaler and Rosen (1975); R. Smith (1974); Viscusi (1978); and Dillingham (1979).

c/ Values in 1982 dollars. Studies reviewed included Brown (1980); Leigh (undated); Olson (1981); Smith (1965); Thaler and Rosen (1976); Viscusi (1979 and 1981); Viscusi and O'Conner (1984).

d/ Values in 1977 dollars. Studies reviewed included Dillingham (1979); Thaler and Rosen (1975); Viscusi (1978); Smith (1974); and Olson (1981).

e/ Values reported in 1985 dollars and adjusted by Miller from author's original estimates to reflect after tax dollars. Studies reviewed included Viscusi (1978 and 1980); Brown (1980); V. Smith (1983 and 1984); Dillingham (1985); Dillingham and Smith (1984); Gegax, Gerking and Schultze (1985); Dickens (1984); Melinek (1974); Marin and Psacharopoulos (1982); Butler (1983); Viscusi (1986).

values identified by Viscusi for small, involuntary, life threatening risks.[35] This $3 million estimate is selected as one of the values for the present analysis primarily because the risk associated with depletion of stratospheric ozone, as was previously shown, is small and involuntary.

The RIA also tests the impact of a second value for a unit mortality risk reduction equal to $12 million. This value is based on the $3 million value, with adjustments to take account of risk sampling error[36] and insurance effects,[37] each of which lead to a rough doubling of the unit mortality risk reduction value. However, most runs use the $3 million dollar value.[38]

The analysis recognizes that the values for mortality risk reduction presented in this appendix, and used in the calculation of the cost-benefit ratios for stratospheric ozone protection options, are crude and still reflect many of the problems with wage-based risk valuation described in the previous section.

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[35] Viscusi stated: "If a regulation affects individuals who have voluntarily put themselves into high risk activities, a value of life around $600,000 seems appropriate. For risks that are more modest or have been incurred involuntarily, the appropriate value of life will be that of a more representative worker, which is in the range of $2 million to $3 million or more. Very small, involuntary risks, such as those associated with nuclear or airline safety, may command much higher values." (For a description of the analytical linkages leading to these conclusions, the reader is referred to Viscusi's studies.) However, later work by Viscusi raises serious questions about the $2 to $3 million estimates and suggests $5 to $6 million as more likely.

[36] The adjustment for risk sampling error is made to account for the apparent underrepresentation of actual job fatalities discovered in Bureau of Labor Statistics (BLS) data. Moore and Viscusi (1987) relied on National Institutes for Occupational Health and Safety (NIOSH) data to conclude that wage premiums derived from BLS data should be more than doubled. (For a more complete discussion of risk sampling error and the appropriate adjustment to wage-risk estimates, the reader is referred to Ashford and Stone (1988), p. 34).

[37] The adjustment for insurance effects is made to account for the effects of life and health insurance on wage-risk premiums. Moore and Viscusi (1987) concluded that, if death benefits from worker's compensation are eliminated, wage risk premiums more than double. (For a more complete discussion of the insurance adjustment to wage-risk estimates, the reader is referred to Ashford and Stone (1988), p. 35.)

[38] As discussed, establishing a value of preventing risks to human life is context dependent. Use of $3 million dollars was the most commonly shown case should not be taken by readers as an indication that the analytical questions have been addressed to support $3 million rather than the higher values suggested by Viscusi and Ashford for nonvoluntary risks.

5. BASIS FOR ADJUSTMENT OVER TIME TO MORTALITY RISK VALUES BASED ON INCOME EFFECTS

This section presents a basis for adjusting the value for mortality risk reductions in the future. This adjustment addresses one of the problems with intergenerational valuation of health and environmental effects.

It is primarily future generations that will be adversely affected by stratospheric ozone depletion. The value which future society is willing to pay to reduce the risk of death from skin cancer is not expected to be the same as what society is willing to pay today. The future value will be dependent upon many factors, including education, values, and income. As these factors change over time, the actual amount paid for risk reduction will change as well.

Generally, as income rises, the amount of money people are willing to expend for a given commodity increases. In some instances, however, it has been shown that people will actually buy less of a good as their income rises. Economists have defined three types of goods to describe these various responses to consume goods as incomes rise: inferior goods, neutral goods, and superior goods. Inferior goods are ones which people would buy proportionally less of as income rises. For a neutral good, people would buy more in the same proportion as the rise in income. In the case of superior goods, people would buy proportionally more than the rise in income. For example, tickets to the movies might be a good that rises proportionally to income; education might be a superior good; potatoes an inferior good. The amount of risk reduction a person would purchase with a rise in income would vary according to the type of good it was perceived to be.

A simple measure of this responsiveness of the quantity demanded of a particular good from changes in income is the income elasticity of demand. For example, a superior good is referred to as income elastic, because it is more responsive to a change in income. To calculate the income elasticity of a particular good, it is necessary to know the percentage change in income and the corresponding percentage change in the quantity demanded of that good.

It is a generally accepted assumption that real income will rise in the future. Historically, total disposable, personal income has followed an increasing trend, rising from $791.8 billion in 1950 to $2,603.7 billion in 1986 (in constant 1982 dollars). In that same time period, income rose from $5,220 to $10,780 on a per capita basis (1982 dollars).[39] In the present analysis of ozone depletion, per capita income was assumed to continue to increase, albeit at a diminishing rate. Of note is that if the historical rate of growth of per capita income had been assumed, CFC demand would have grown faster, and greater ozone depletion would have occurred earlier.

It is expected that as per capita income increases, the calculated values of mortality risk reductions will also increase. According to DeCanio and Woodward, "both evidence and intuition indicate that 'willingness to pay' to reduce risk has a high income elasticity."[40] In other words, the value of risk reduction is very responsive to changes in income. This theory is evident by

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[39] Economic Report of the President, Jan. 1987, Table B.27.

[40] DeCanio and Woodward (1987).

looking at the many areas in which increases in spending have recently occurred to achieve additional safety and reductions in mortal risks. The mandatory requirements for seat belt installation and use in automobiles, purchases of home fire detectors, and purchases of life insurance polices are all examples of increased payments by a wealthier society to reduce the risks or consequences of death. These examples show that risk reduction is expected to be income elastic and a superior good.

In order to predict the value in which a future society would be willing to pay for risk reduction, two key pieces of information are necessary: the income elasticity of risk reduction and the expected rate of future per capita income increases. While the values of these factors are unknown, it is possible to make assumptions and develop scenarios which show that the estimated values of a mortality risk reductions will increase.

Given that per capita income is projected to increase into the future, the increased value of risk reduction will vary depending upon its income elasticity. If the value of risk reduction had an income elasticity of one, then it is unitary with respect to income and the value will increase in proportion to the expected rise in per capita income. If the income elasticity is 1.5 (an elastic good has a value greater than one), then the value of risk reduction is a "superior" good. In this instance, the value increases by 1.5 times the amount of the rise in income. If the income elasticity were 0.5 (an inelastic good has a value less than one), risk reduction would be considered "inferior" and the value would increase at one half the rate of the rise in income. For the standard case, we shall assume risk reduction is a neutral good (i.e., an elasticity of 1.0).

No matter what income elasticity is associated with risk reduction, the result is still an increase in its value. This then indicates that the values chosen in this analysis for mortality risk reductions resulting from stratospheric ozone protection probably underestimate the value(s) which a future wealthier society would be willing to pay to reduce the same risks.

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H

APPENDIX H

SELECTION OF DISCOUNT RATE FOR VALUING FUTURE COSTS AND BENEFITS FROM THE PREVENTION OF STRATOSPHERIC OZONE DEPLETION

1. INTRODUCTION

Control of potential ozone depleting substances, like many environmental regulations, offers benefits and imposes costs over several years, sometimes extending into the quite distant future. Indeed, some of the benefits conferred by the proposed regulations of chlorofluorocarbons (CFCs) may extend for many decades (or even centuries) and span several generations. The method used in this Regulatory Impact Analysis (RIA) to compare these benefits and costs accruing at different points in time is to convert both the benefit stream and the cost stream into a single measure of benefits and costs (as discussed in more detail in Appendix G, there are other numerous problems with applying this method to evaluate the costs and benefits of environmental regulation). This is accomplished by discounting each of the streams at the appropriate discount rate and summing the resulting discounted values. This yields a present value measure for each of the two streams. Given the extended period of time over which the benefits and costs of CFC controls may accrue, the choice of discount rate can have an important impact on the relative magnitude of the present value of the benefits and costs.

This appendix presents, and describes the basis for, the choice of discount rates for evaluating the costs and benefits for CFC control. It is important to note that the process of choosing a discount rate described in this appendix is based on the methodology and assumptions made in the preceding appendix on the valuation of nonmonetary costs and benefits. If some of the costs and/or benefits incorporated in a cost-benefit analysis are not measurable in dollars, then the entire process associated with identifying the time value of these costs and benefits must be re-examined. For example, if one assumes that the value of environmentally-related, life-threatening risk reductions cannot be expressed in monetary terms, then a different rate of time preference would apply to these reductions than would apply to the monetary valuation of the same reductions. Nevertheless, the present analysis of the costs and benefits of stratospheric ozone depletion control options assumes that all relevant costs and benefits can be translated into monetary values, although this is controversial.[1]

This appendix briefly summarizes a number of ethical, analytical, and empirical issues associated with discounting future costs and benefits. Many of these issues remain unsolved or are at least in dispute in the academic literature. Because of the depth, scope and complexity of these issues, this appendix does not attempt to resolve them. Instead, its more modest goals are: (1) to raise these different sets of concerns in a coherent fashion; (2) to indicate which discount rates may be appropriate under alternative

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[1] For a more detailed discussion of the issues associated with monetary valuation of nonmonetary costs and benefits, see Appendix G.

viewpoints; and (3) to select a discount rate from the various rates suggested by the different approaches to be used in this RIA.

The remainder of this appendix is organized into four sections as follows:

- Section 2 discusses some ethical concerns associated with discounting future costs and benefits;
- Section 3 presents alternative economic perspectives on the appropriate discount rate and the estimates of the discount rate they generate; and
- Section 4 concludes the appendix with a brief discussion of the reference discount rate chosen for the analysis and of the range of rates selected for the sensitivity analysis.

2. ETHICAL AND ANALYTICAL ISSUES IN DISCOUNTING

There is a substantial body of economic literature concerning discounting and public project evaluation which ranges from discussions of theoretical aspects of the appropriate rate to analyses of how various complications such as risky costs and benefits, should be addressed.[2] Behind this literature, however, are ethical frameworks which motivate the various theoretical and empirical discussions. These ethical foundations are logically prior to the specific suggestions for discount rates in the literature. Hence, this section of the appendix reviews these ethical issues and concerns. The following section then presents the various suggestions in the literature for the appropriate rate of discount for use in evaluating public policies and regulations.

2.1 The Ethical Underpinnings of Cost-Benefit Analysis

Cost-benefit analysis, in general terms, is a branch of applied economics in which the overall goal is to define and measure the consequences of regulatory (and other) actions, to value these consequences, and then to compare the costs with the benefits. Clearly, from an analytical perspective, the basic idea behind cost benefit analysis is straightforward. If the benefits of a regulation or other intervention in the private economy exceed the costs, the policy is deemed to be desirable from the perspective of cost-benefit analysis.

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[2] The modern literature on project evaluation and discounting from a social perspective began in the late 1950s with Eckstein (1958), Steiner (1959), and Bailey (1959). Subsequently, Feldstein (1964) and Marglin (1963a, 1963b) sparked a lively controversy resulting in, to date, a two decade exchange of views. See e.g., Diamond (1963), Lind (1963), Tullock (1963), Baumol (1968), Kay (1972), Harberger (1972), Feldstein (1970), Dreze (1974), Arrow (1966), Arrow and Lind (1970), Hirschleifer (1966), Bradford (1970, 1975), and Lind (1982).

Although this rule appears to be a simple and intuitive guide for evaluating policies, it nonetheless relies on several ethical tenets with which one does not necessarily have to agree. First, there are some cost-benefit analysts who choose to assume that the social value of costs or benefits is independent of the identity of the individual experiencing them. Thus, one dollar's worth of benefit to a rich individual is worth the same to society as a dollar's worth of benefit to a less advantaged person. Other analysts have argued that benefits and costs should be weighted differently depending on the identities and circumstances of the parties that experience them. The present cost-benefit analysis weighs the welfare of individuals equally.

A second, and perhaps more important, assumption made by some cost-benefit analysts is that a policy can be considered to be desirable if its benefits exceed its costs <u>even if particular individuals in society are made worse off by the policy</u>. That is, as long as the "winners" under a particular policy could compensate the "losers" for their losses and still be better off, then the policy enhances social welfare. This is a significant assumption because classical economic literature refers to a change that makes at least one person better off and no one worse off as a "Pareto improvement" in social welfare terms. In such a case, in the absence of strategic behavior, a vote on the proposed change would be unanimously favorable.

The link between the Pareto improvement's intuitive prescription for determining whether a policy enhances social welfare (i.e., that everyone would agree that the change either confers a positive benefit or is indifferent about the change) and the aggregate benefits-greater-than-cost rule pursued by some cost-benefit analysts is the <u>possibility</u> that the gainers could compensate the losers and remain better off under the policy. Some refer to such situations as "potential Pareto improvements." The fact that the compensation does not have to take place for the policy to be judged to improve social welfare is a value judgment not to be ignored in understanding and evaluating the prescriptions of cost-benefit analyses conducted from this perspective. Indeed, as the analysis in the following subsection indicates, the fact that the compensation is <u>not</u> made in cases in which the benefits and costs are distributed through time introduces a host of ethical and economic issues.

The basic cost-benefit framework used in the present analysis requires that costs and benefits be quantified and expressed in the same units (e.g., dollars) so that it is meaningful to inquire whether the costs are greater or less than the benefits. This is not always an easy task because, in many instances, the benefits and costs may not be quantifiable and/or monetizable.[3] Whether or not one assumes that the values of the costs and benefits can be quantified, a residual problem remains for policies or regulations that impose costs and offer benefits in different time periods. This problem is that the costs and benefits occurring at different times must be expressed in relation to a common point in time by applying the analytical constructions of discounting (or compounding).

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[3] See more detailed discussion of these issues in Appendix G.

2.2 Ethical Issues in the Choice of a Discount Rate

The choice of appropriate discount rates to apply to the various streams of future costs and benefits can significantly affect resultant net benefit estimates. Choosing lower or higher rates of discount for evaluating public policies implies a systematic weighting for or against future welfare versus present welfare. Consequently, selecting particular discount rates for use in public policy evaluation requires an ethical stance on the relative value of future versus present current benefits.

Establishing this relative value, however, is difficult. A number of ethical positions and problems have been discussed in this connection:

i. In many cases, the parties who will bear costs or enjoy benefits may not yet exist. In these cases, one can hardly argue that one has measured their preferences and assigned values for these costs and benefits in a scientific fashion. Moreover, it is possible to argue that applying the entire "potential" Pareto improvement framework (in which compensation could be paid by the gainers to compensate the losers, but is not) to cases in which many of the parties do not yet exist is too much of a strain on the ethical underpinnings of the framework.[4] Valid though these criticisms may be, policymakers nevertheless must make decisions that inevitably affect future generations. Acknowledging the limitations inherent in these situations does not absolve one of the necessity of choosing.

ii. If currently living individuals attach a positive value to additional saving for future generations, including members of future generations that are not their direct descendants, then the unregulated market will probably not result in the optimal level of saving for the future.[5] The mechanism producing this outcome results from a market failure caused by a "free rider" situation (i.e., one in which an individual who bears no costs is potentially able to receive a benefit). Suppose that the welfare of future generations enters the utility functions of currently living individuals and that this is sufficiently important to them that each person saves for these future generations. Each individual will save up to the point at which the marginal value of his or her own consumption equals the value to that individual of marginal future consumption by future generations. However, if each person does not account for the "external" increase in welfare of other currently living individuals attributable to his or her own saving, then too few resources may be allocated to these future generations.

If the empirical conditions underlying this view are correct, then some argue that the rate of discount for use in evaluating public policies ought to be lower than the private rate of discount to reflect this failure of the private market to provide the optimal level of resources for the future. This line of reasoning implies that all public policies, including environmental

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[4] Mishan (1981) discusses this problem in considerable depth.

[5] See, e.g., Marglin (1963a) for arguments along these lines.

regulations, should be viewed in the context of this "underprovisioning" of future generations. Hence, costs and benefits imposed on future generations should receive greater weight in public decisions and this can be accomplished through reducing the discount rate.

iii. Irreversibility of the consequences of some policies is sometimes advanced as a reason for adopting a more cautious attitude toward imposing burdens on future generations.[6] In the context of regulating potential ozone depleters, this line of reasoning would run as follows. In the absence of controls on potential ozone depleters, a number of possible harmful effects could occur and the source of these harmful effects may not be easily reversed; indeed, it may be impossible to reverse them in any reasonable time frame. Of course, by itself irreversibility does not necessarily imply that society should operate differently than in other circumstances. Many actions may have irreversible consequences (e.g., mining minerals irreversibly reduces the stock), but they are nonetheless undertaken.

However, if there is some uncertainty concerning the magnitude or severity of the harmful effects of ozone depletion and some or all of this uncertainty may be resolved during the future, this may have implications for the choice of whether and to what extent to control potential ozone depleters. In this case, even if society is risk neutral (in the sense that only expected values of costs and benefits motivate choices), the optimal degree and timing of controls for potential ozone depleters may appear to be based on risk aversion. That is, if only the currently expected values of costs and benefits were inspected, controls on potential ozone depleters might be too few and too late relative to the actual optimal choice. This is because there is always the opportunity to reverse the controls on potential ozone depleters but not the reverse. Hence, ozone depletion in the future might be larger than now projected (and thus possibly alter one's choice concerning optimal controls on ozone depleters), then the irreversibility of ozone depletion may play a role in the selection of the optimal extent and timing of controls on potential ozone depleters. This influence could be translated into using a lower discount rate for evaluating the benefits of controlling potential ozone depleters, thereby raising the present value of benefits of protection to encourage this more cautious attitude.

iv. Future generations may be richer than existing ones.[7] Hence, if the government is considering policies that involve altering the relative distribution of welfare between current and future generations, either explicitly or implicitly, then it should place more weight on offering benefits to (or avoiding costs on) current generations. In essence, this view argues for the desirability of (or at least provides the moral justification for) borrowing from future generations to benefit the present. Using higher

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[6] This section follows Arrow and Fisher (1974).

[7] Indeed, Tullock (1963) and Stiglitz (1982) argue that the more likely market failure is one concerning transfers to poor members of existing society, not transfers to future members of society.

rates of discount for evaluating public policies that have costs and benefits that accrue over time serves this goal.

v. The current generation should treat future generations as they treat themselves.[8] Thus, this view recommends that current society make decisions about regulations and intertemporal resource allocation involving yet-to-be-born generations as if they themselves were both the current and the future generations. This recommendation, consequently, argues for a discount rate equal to the rate at which the current generations trade with themselves over time.

vi. The current generation should treat future generations so as to improve their life from current conditions. Many U.S. Presidents have held this view and it is part of the American Dream. This argues for a low discount rate vis-a-vis projects affecting future welfare.

vii. The current generation should not discount future lives, since human life is not fungible. Many people would find the discounting of future life ethically unacceptable.

The ethical issues and considerations discussed above are not easy to resolve. The resolution of some of the issues depends on empirical information that is not available (such as the free rider problem, whose existence depends on the nature and strength of existing individuals' preferences concerning the welfare of future generations), and the fact that the preferences of future generations is inherently unknowable. Similarly, the irreversibility problem may have some factual basis, but it is not entirely clear that adjusting the discount rate to account for this problem is the theoretically correct, much less empirically precise, solution. The "let's borrow from our richer descendants" position rests on assertions about facts (the rate of increase of wealth over time) and attitudes concerning intertemporal welfare maximization. Finally, the approach of valuing future generations' welfare over time at the same rate as the current generation has been criticized since it ignores the consequences of intergenerational distributional inequities and externalities, the undesirability of which is presumably embedded in whatever social welfare function the current society subscribes to.[9]

After considering these difficulties, many cost-benefit analysts choose to ignore them as intractable and unresolvable and adopt the approach in which current members of society are assumed to treat future generations in the same way that they treat themselves. The disadvantages of this (non)resolution of these problems is that some of the other ethical considerations raised may be true or applicable (although this is unknown or, in some cases, unknowable). In this case, cost-benefit analyses which incorporate an unrealistic discount rate may themselves be inaccurate and, therefore, potentially unreliable. On

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[8] Lind (1982) implicitly adopts this approach, although he discusses these ethical issues in some detail.

[9] Ashford and Stone, 1988, p. 51.

the other hand, bypassing these "top level" ethical issues offers the advantage of allowing the search for the appropriate rate of discount for public policy evaluation to proceed to other analytical issues and empirical research. In this analysis, the position of ethical position "v" is used in most cases, but the sensitivity of this assumption is analyzed by considering results with different discount rates.

3. ALTERNATIVE PERSPECTIVES ON THE APPROPRIATE DISCOUNT RATE

Some of the remaining analytical issues underlying the selection of a discount rate are complex and have been approached in different ways in the literature, not all of which can be reconciled. In view of this complexity, this section does not attempt to reconcile the various approaches suggested in the literature. The purpose of this appendix is only to report these approaches and the discount rates implied under each. This review then serves as the basis for selecting the range of discount rates to be used in the regulatory analysis of potential ozone depleters. Therefore, this section presents these various approaches, their underlying motivations and indicates the relationships between them. Computations based on the different approaches are presented in the following section.

3.1 Consumption Rate of Interest -- Shadow Price of Capital Approach

Much of the economic literature concerning the appropriate rate of discount for public policy evaluation focuses on the implications of pre-existing "distortions"[10] such as taxes on investment earnings for the selection of the discount rate.[11] In simple and stylized terms, the problem raised by the existence of distortions in the economy is as follows. Suppose that investments in the private economy are taxed so that the pre-tax rate of return on these investments exceeds their post-tax rate of return, the latter of which is received by private investors. In this event, some of the proceeds of these private investments accrue to the government in the form of tax revenues and the remainder accrues to the owners of the investments.

The problem that this situation poses for determining the appropriate discount rate for public decision making stems from two observations. First, if a public project (e.g., dams, military expenditures, regulations) diverts funds from private investments into the public project, then it may be reasonable, assuming all costs and benefits can and have been appropriately valued and incorporated, to require that the value of the public project be high enough to compensate both for the loss of private returns and the loss of tax revenues that would have been generated by the foregone private investments. Second, the fact that private individuals "trade" between the

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[10] In the economics literature, a distortion refers to something that prevents conditions from being optimal. Taxes, for example, make society's and an individual's points of view diverge because the prices faced by individuals are not necessarily the same as prices faced by society.

[11] See, e.g., Bradford (1970, 1975), Feldstein (1970), Harberger (1972), and Stiglitz (1982).

present and the future at the post-tax rate of return on private investments means that their discount rate is not the pre-tax rate on private investments; it is the post-tax rate. Because public decisions concerning policies that affect both the present and the future should mimic (according to this approach) the way that private individuals are willing to trade consumption through time, clearly this post-tax rate should be relevant as well. Combining these two considerations yields the "Consumption Rate of Interest -- Shadow Price of Capital" approach to public project evaluation.

According to this approach, the correct discount rate for evaluating public policies is the rate that individuals use to determine the present value of future consumption, which the literature refers to as the "consumption rate of interest." The consumption rate of interest is identified with the post-tax real rate of return that private investors receive on their investments precisely because individuals trade between the present and the future at that rate. Accordingly, this approach recommends that the consumption rate of interest be used as the discount rate for evaluating public policies.

Before discounting, however, the costs and benefits associated with the policy must be examined to determine whether they displace or encourage private investment. This is crucial because of the gap between the pre-tax, or social rate of return on private investments, and the post-tax rate of return received by individuals. This gap implies that the social value of private investments exceeds the private or market value of these investments. The term "shadow price of capital" is used to denote this distinction between the private value of investments and the social value. A marginal dollar's worth of private investment is worth one dollar to the private market, but it is worth more than one dollar to society, implying that the shadow price of capital is greater than unity. The shadow price of capital may be greater than unity for two interrelated reasons. First, the rate of return to society on private investments may be greater than that received by individuals because of taxes on income. Second, if the proceeds from private investments are reinvested in yet more private sector capital (which also has a social rate of return in excess of the private rate of return), then this causes the shadow price of capital to be even higher because a dollar's worth of private capital represents even more private capital to be created in the future.

The result of this approach is that any costs that displace private capital must be multiplied by the shadow price of capital prior to discounting them to the present at the consumption rate of interest. Similarly, if some of the benefits of the public policy or project encourage private investments, then these too must be appropriately multiplied by the shadow price of capital to arrive at the actual social value of these benefits. These adjusted cost and benefit estimates then should be discounted to the present using the consumption rate of interest. This method, consequently, accounts for the pre-existing distortion issue by directly measuring the social values of all of the benefit and cost flows generated or caused by a change in public policy. After doing so, these are all discounted at the consumption rate of interest, reflecting the fact that this is the rate at which individuals trade between the present and the future.

One final aspect of this approach is the treatment of riskiness of the public project's costs or benefits. Whether or not any adjustments to the measured benefits and costs are required to account for this depends on several factors. First, if the benefits and costs are small relative to income and are uncorrelated with other income, then no adjustment is required. Other income is defined broadly here to include not only income that can be translated into private consumption goods, but also "income" from non-market sources, such as public goods and other forms of consumption not explicitly purchased in the market. Only if the costs or benefits are large relative to other income or if they are correlated with other income would any adjustments be required.

For example, if the public project produces costs and benefits that are extremely large relative to other income, then the attitudes of those who bear these costs or enjoy these benefits must be considered. In this case, one should estimate the "certain monetary equivalent"[12] (CME) of the risky costs or benefits, rather than their expected values. For large and uncertain positive (negative) outcomes risk averse individuals, CME will be less (more) than the expected value of the outcomes. On the other hand, if the project's costs and benefits are not large, but are correlated with other income, then they should be adjusted to reflect either the added riskiness they impart to the portfolio (if they are positively correlated with other income) or the "insurance" function they offer (if they are negatively correlated with other income). For the most part, however, adjustments for risk are not common because most public projects are not obviously large or correlated with other income.

The data required to conduct public project evaluation using this method exceed those associated with more limited cost-benefit analyses because additional features of these project's consequences beyond the gross costs and benefits are important. Thus, in addition to the standard measurement of costs and benefits and their timing, the sources of the funds for the costs and the degree to which the benefits encourage or discourage private capital formation are also required. If the funds for the project are raised through simple income taxation, the social costs of the project could be lower than if the funds are drawn predominantly from private investments via deficit finance (assuming that funds drawn from taxes displace primarily current consumption). Similarly, the social benefits of the project could be higher if they tend to encourage some additional saving (as might any source of additional income) than if, on the other hand, the benefits tend to be viewed as substitutes for private investments (so that saving and investment might be discouraged). Furthermore, the social costs of a project resulting from the displacement of private investment in an industry subject to new, more costly environmental controls may be offset to some extent by increased private investment in the pollution control industry.

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[12] The certain monetary equivalent is the perfectly certain sum of money that an individual would view as equivalent (in utility terms) to an uncertain prospect. For example, one might view a perfectly certain payment of $400 as equivalent to an even chance of receiving nothing or $1,000. Hirschleifer (1966) provides a good exposition of this concept.

In addition to the information on the source of the funds and the secondary effects of the public project on private investment, this approach also requires information on the level of taxation of private investments (both corporate and individual), the level of nominal returns on private investments, the expected rate of inflation, and the risk class of the public investment under consideration. Finally, to calculate the shadow price of capital the pre-tax and post-tax rates of return on private capital, the level of reinvestment of returns from private capital, and the duration of a typical private investment project are required.

Lind (1982) presents some estimates of both the consumption rate of interest and the shadow price of capital using a variety of rates of return and other information. Although his estimates for both the consumption rate of interest and the shadow price of capital depend on the specific estimates of the rates of return, reinvestment rates, and tax rates required to compute them, he finally settles on a set of estimates which he deems to be reasonable.

The most plausible measures of the consumption rate of interest are the post-tax real rate of return on "safe" government securities such as Treasury bills and long-term government bonds. The pre-tax, nominal rate of return on Treasury bills over the period 1956-1986 was 5.8 percent.[13]. Assuming a modest 20 percent individual marginal tax rate, this yields a post-tax nominal rate of return of about 4.6 percent. Given an inflation rate of 4.7 percent over the same period, the post-tax, real rate of return on Treasury bills was about -0.1 percent.

For long-term government bonds, the pre-tax, nominal rate of return for 1956-1986 was 4.7 percent. Once again using a 20 percent marginal tax bracket and 4.7 percent inflation rate, the post-tax, real rate of return on long-term government bonds was -0.9 percent.

Both measures indicate a negative consumption rate of interest. It has been argued, however, that these measures slightly underestimate the true consumption rate of interest because it is likely that on the average, actual inflation has exceeded anticipated inflation, especially during the 1970s. For this reason, Lind suggests a post-tax real rate of return on a "safe" asset such as Treasury bills, of 1 percent, and 2 percent as the rate of return on safe, long-term assets such as long-term government bonds.[14] Thus, Lind's recommendation is that if one is discounting the costs and benefits of

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[13] The data on Treasury bills, long-term government bonds, and inflation rates are from Ibbotson Associates (1987), Exhibits A-4, A-5, and A-6. Data for only the last three decades were used in order to exclude the effects of World War II and the depression. In addition, these data are likely to reflect better the consumption rate of interest of current generations.

[14] Of course, other portfolios yielded higher historical rates of return. Lind estimates that the "market portfolio" (which reflects risk as well as time discounting) yielded about 4.6 percent.

a project with returns that are small and uncorrelated with the market portfolio, then one should use 1 percent to 2 percent as the consumption rate of discount.

Baumol suggests values in this same range in stating: "The approximate range in rates of return of from zero to 5.0 percent ... brackets the real, after-tax rate of return that individual consumers are likely to receive on their savings. Discount rate values on the lower end of this range -- zero to 2 percent -- should be used for government projects or regulations that are regarded as risk-free, whereas discount rates on the upper end should be used for those government actions that are regarded as risky."[15] Baumol justifies the zero value by pointing out that "(z)ero or even negative rates of return are consistent with rational consumer behavior. Some individuals are willing to forego some real income for the certainty of assuring consumption at a future time, such as the period after retirement."[16]

For the shadow price of capital, Lind performs a number of calculations, finally resulting in an estimate of 3.8 (i.e., the social value of one dollar's worth of private capital is actually $3.80). He bases this estimate on a rate of reinvestment of earnings from private capital of 20 percent, on an average private project life of 15 years, an average pre-tax rate of return of 12.41 percent, and a post-tax rate of return of 5.77 percent. Lind argues, furthermore, that the inconsistency between the rate of return estimates used in the shadow price of capital estimate and the calculations of the consumption rate of interest is not critical since the shadow price of capital is sensitive to the ratio of the pre-tax and post-tax rates of return, and not particularly to their levels.

There continues to be disagreement among economists with regard to the appropriate definition and measurement of the shadow price of capital. Nonetheless, some measure must be selected if evaluation of time streams of benefits and costs is to proceed using a Consumption Rate of Interest -- Shadow Price of Capital approach. Our review suggests that most reasonable values for these parameters are a 1.5 percent consumption rate of discount with benefits and costs (to be varied in a sensitivity analysis) adjusted by Lind's estimate of the shadow price of capital (3.8).

3.2 Consumption Rate of Interest Approach

A modification of the Consumption Rate of Interest -- Shadow Price of Capital approach discussed above is to use the consumption rate of interest for discounting purposes, but not to adjust any of the costs and benefits by the shadow price of capital. The rationale for using the consumption rate of interest as the discount rate in this approach is identical to the reasoning outlined in the previous approach. The absence of adjustments of the costs

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[15] Baumol, W.J. (1982); Baumol (personal communication) does note that higher rates of social discount can be defended in cases where public projects may result in environmental damages, the costs of which have not been assessed.

[16] Baumol, W.J. (1982), ibid., p. 12, footnote 12.

and benefits by the shadow price of capital, on the other hand, could be justified in two ways. First, if there is no gap between the pre-tax, or social rate of return, and the post-tax, or private rate of return, then the shadow price of capital will be unity. Hence, no special adjustments are required.

An alternative justification for this approach is as follows. Even if the shadow price of capital is greater than unity, under certain conditions, no adjustments may be required because the policy under consideration may not displace private investments on net.[17] For example, if a regulation causes some investment to be channelled into projects required for compliance rather than into other private sector projects, but the regulated entities have the option of exiting the industry rather than bearing compliance costs, then the rate of return on the compliance-related investments pre-tax must be equal (in long-run equilibrium) to the pre-tax rate of return elsewhere in the economy. In this event, there may be no net change in the amount of investment in the economy, only a redirection. If the welfare effects of the regulation are correctly calculated, no adjustments will be required for the shadow price of capital.

All other aspects of this approach are the same as the previous one, including the adjustments required, if applicable, for risky costs and benefits. Hence, the data requirements for implementing this approach are similar, but fewer than those for the Consumption Rate of Interest -- Shadow Price of Capital approach precisely because the shadow price of capital is irrelevant. That is, information on the degree to which private investment is encouraged or discouraged by the public project are not required. All that is required is an estimate of the consumption rate of interest, which is identified as the real rate of interest at which individuals trade between the present and the future.

If the consumption rate of interest approach alone is adopted (because either one believes that the shadow price of capital is unity or if one is merely redirecting private investments), then the estimates of the consumption rate of interest presented in the previous section are appropriate. Some analysts argue that this approach may be more appropriate for discounting the effects of regulations to project stratospheric ozone. Their rationale is that, rather than displacing private investment, "private investments are redirected into product and process redesign and control technologies which permit regulatory compliance."[18] If correct, this conclusion would argue for a limited use, or elimination of, the shadow price of capital multiplier.

3.3 Gross Rate of Return on Private Capital Approach

Another approach for determining the discount rate for public policy evaluation arrives at a different recommendation based on the observation that

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[17] This argument is made in ICF Incorporated (1986). See also the qualifications discussed there, but not in this appendix.

[18] Ashford and Stone (1988), p. 50.

the pre-tax, or social rate of return to private investment, is greater than the post-tax or private rate of return. The argument is that if government actions are funded for the most part by displacing private investments, then the rate of return required for public projects to be considered to be desirable must be at least as great as this pre-tax or social rate of return.[19] Thus, this approach argues that the "hurdle" internal rate of return below which public project should be rejected equals the pre-tax real rate of return on private investments (assuming that marginal funds for the government displace private investments). An alternative justification for this approach is that if the relevant alternative use of the funds for the project under investigation is understood to be government investment in the private sector, then the opportunity cost of using the funds in the project itself is again the pre-tax social rate of return on private investments.[20]

According to this "Gross Rate of Return on Private Capital" approach, the post-tax private rate of return (i.e., the consumption rate of interest) is irrelevant for discounting public sector policies and projects. Thus, all that is required for this approach is an estimate of the pre-tax real rate of return for typical private sector projects. Of course, actually deciding which of the many rates of return that coexist in the economy to use makes the practical application of this approach, as well as the two previous approaches, somewhat less straightforward than they seem from a theoretical perspective.

There are several estimates in the literature of the historical pre-tax, real rate of return on private capital. In virtually all cases, these rates are calculated as a weighted average of the rates of return on various tangible assets, where the weights are the shares of the assets in the total capital stock. The estimates differ in terms of the assets included in the calculations and the time period for which data are used.

Stockfish (1982) reports estimates of the real overall private sector rate of return of 10.6 percent and 12.8 percent for the period 1961-1965. These estimates are weighted averages of the returns in both the corporate and noncorporate sectors. Stockfish suggests that the "true" average rate of return is likely to be between 8 and 12 percent. Another estimate is provided by Holland and Myers (1979). They calculate a real pre-tax rate of return in the corporate sector of 12.4 percent for the period 1946 to 1976.

Two rough, but more up-to-date estimates of the real, pre-tax rate of return on private capital were calculated as part of this study. The estimates are a weighted average of the returns to common stocks, long-term

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[19] The Office of Management and Budget's 10 percent real rate of discount for public projects (Circular A.94) appears to be based on this line of reasoning.

[20] Defining the appropriate scope of opportunity cost in this context is extremely important. Feldstein (1970), for example, argues that the relevant definition is what would be done with the funds, not what could be done with them.

corporate bonds, and residential real estate over the past three decades. Both estimates are derived from data on post-tax nominal returns.[21] The two estimates differ in terms of the assumed relationship between inflation and the marginal tax rate on capital income.

In calculating the first estimate, it is assumed that the tax rate on capital income is exogenous (i.e., the tax rate has not changed over time in response to inflation). Therefore, the average tax rate for the period in question is applied to nominal rather than real returns. Thus, in calculating the pre-tax, real rate of return from the data, taxes on capital income are put back in before expressing returns in real terms. Given an estimated weighted average, post-tax, nominal rate of return of 8.1 percent, and an average marginal tax rate on capital income of 34.5 percent, the pre-tax, nominal rate of return is 12.4 percent. Subtracting the 4.7 percent average annual inflation rate over the period, the estimated pre-tax, real rate of return on private capital is 7.7 percent.

The second estimate is calculated under the assumption that the tax rate on capital income is endogenous. Hence, the average tax rate for the period in question is applied to real rather than nominal returns. This implies that there has been de facto indexing of taxes on capital income during periods of high inflation. There is some evidence that during the 1970s, changes in deduction and depreciation provisions in the tax code did in fact dampen the effects of inflation. Under this assumption of an endogenous tax rate, taxes on capital income are put back in after expressing returns in real terms. Given the 4.7 percent inflation rate, the post-tax, nominal rate of return of 8.1 percent translates to a post-tax, real rate of return of 3.4 percent. Applying the 34.5 percent marginal tax rate, yields an estimated pre-tax, real rate of return on private capital of 5.2 percent. This estimate is considerably lower than the estimate derived under the assumption of an exogenous tax rate.

Two points regarding the above estimates should be noted. First, the estimates are for the average rate of return, whereas the quantity that is actually being sought is the marginal rate of return. If, as is commonly argued, the schedule for the marginal efficiency of capital is downward sloping, the average rate of return will exceed the marginal rate of return. Hence, the above estimates represent upper bounds on the marginal rate of return to private capital. Second, the estimates undoubtedly include returns to risk since the underlying assets are risky. Thus, they do not represent

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[21] Returns on common stocks and long-term corporate bonds as well as the inflation rate are the (geometric) averages for the period 1956-1986 and are taken from Ibbotson Associates (1987), Exhibits A-1, A-3, and A-6. The return to residential real estate is the (geometric) mean for the period 1947-1982 and is from Ibbotson and Siegel (1984). The weights for the three assets are from Stambaugh (1982). The average of the weights reported in Table 1 of Stambaugh for common stocks, government bonds, and residential real estate were re-scaled to sum to unity. The estimate of the average marginal tax rate on capital income is from the Council of Economic Advisers (1987), Table 2.6, p. 91.

the "riskless" rate of return to private capital, which, it would be argued, is the relevant quantity if the riskiness of the proposed public investment is relatively small.

One possible measure of the riskless rate of return to private capital is the pre-tax, real rate of return to long-term corporate bonds. The nominal, post-tax rate of return to these bonds over the period 1956-1986 was 5.7 percent. Using the marginal tax rate on capital income of 34.5 percent and the inflation rate of 4.7 percent, the implied pre-tax, real rate of return is 4.0 percent when the tax rate is assumed to be exogenous. Under the assumption of an endogenous tax rate, the pre-tax, real rate of return is 1.5 percent.

In summary, the estimates of the pre-tax, rate of return to private capital range from about 2 percent to 12 percent with the lower end of the scale reflecting returns to risk-free assets and the higher end reflecting returns to risky assets. Within this range, we believe a value toward the lower end is most appropriate (to reflect the factors relating to the marginal and riskless rate of return). Thus, for this approach, a central value might be 5 percent, with sensitivity values of 2 percent and 12 percent.

3.4 "Implicit" Consumption Rate of Interest Approach

Another approach is closely related to the consumption rate of interest approaches discussed in subsections 3.1 and 3.2 in the sense that its analytical focus is on rates at which individuals and society are willing to trade consumption through time. However, this approach assumes that for a variety of possible reasons, the interest rates produced in the market (net of inflation and taxes) are not adequate guides to how people currently alive and those yet to be born would actually trade consumption over long periods of time.[22] Hence, market rates are not, according to this approach, an acceptable guide for discounting from a social point of view. Thus, although the goal is to determine the consumption rate of interest from society's point of view, this approach ignores market rates of interest and instead attempts to build the consumption rate of interest from another direction, hence the term "implicit."

Deriving the consumption rate of discount under this approach is somewhat more complex than the market-based approaches. Indeed, in many formulations, the consumption rate of interest for a particular project depends on the identities of the parties involved and the timing of the benefits and costs, making general statements about the level of consumption rate of interest for discounting public benefits and costs impossible. For purposes of illustrating the fundamentals of this approach, however, many of the complications will be ignored.

The first step in defining the consumption rate of interest under this approach is to note that an individual's (or society's) rate of discount for

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[22] A recent summary of this approach, with citations to the relevant literature, is Ray (1984).

consumption, in general, equals the sum of two terms. The first is a "global" utility discount factor which reflects the individuals' or society's general weighting of current versus future utility. This factor may be positive, negative, or zero and different authors choose various values. From a social perspective, the value of this global utility discount factor reflects one's resolution of some of the ethical considerations discussed above. A zero utility discount factor weights current and future utilities equally. A positive (negative) value weights future utilities lower (higher) than current utility).

The second term defining the consumption rate of interest under this approach is the product of two factors -- the rate of growth of consumption over time and the elasticity of marginal utility with respect to consumption (defined positively). This term, consequently, is designed to measure the degree to which marginal utility of additional consumption in the future falls depending on the expected growth of consumption over time. The higher the expected rate of growth of consumption over time (ceteris paribus), the higher the consumption rate of interest. Similarly, the higher the elasticity of marginal utility with respect to consumption (again, ceteris paribus), the higher the consumption rate of interest. These observations should be fairly intuitive. Because the object is to determine how to value future benefits and costs from the perspective of today, the utility to be derived from marginal amounts of consumption in the future given expected increases (or decreases) in consumption over time should be relevant.

Finally, this approach defines the consumption rate of interest as the global utility rate of discount plus the product of the elasticity of marginal utility with respect to consumption and the expected rate of growth of consumption. Intuitively, the formulation is appealing. If one wants to know what the value is today of some future benefit, one would consider both the marginal utility to be generated in the future (which depends on the sensitivity of marginal utility and the growth of consumption over time) and the inherent discount (if any) of future utility. Together, these determine the rate at which consumption in the future should be discounted.

In addition, there is an implicit linkage of this approach to market rates of interest in the following sense. In the event that individuals today are assumed to maximize their consumption patterns intertemporally (which generally is assumed not to take place perfectly under this approach), then the market rate at which they trade consumption through time equals their global utility rate of discount plus the product of their elasticity of marginal utility and their expected growth of consumption. If they are assumed not to maximize or if there are other reasons why the individuals' perspective does not define the social perspective, then this equality will not hold and the better guide to discounting from a social perspective is this "implicit" component approach to defining the consumption rate of discount.

The data requirements for this approach are reasonably simple to state, but much harder to measure. It requires the elasticity of marginal utility, the expected rate of growth of consumption, the global social utility discount rate, and in more complex formulations, the time and interpersonal distribution of costs and benefits. In most applications of this framework,

the interpersonal distribution of costs and benefits is ignored. The rate of growth of consumption is generally derived from historical data. However, the values of the global utility discount rate and the elasticity of marginal utility can only be assumed. Moreover, as is evident from the definition of the consumption rate of discount according to this approach, these two factors can be varied independently. Indeed, even for an individual who is assumed to maximize intertemporal consumption, so that his or her consumption rate of interest (as defined by this approach) equals the market rate of interest, these two utility-function related factors can take on an infinite number of pairs, all of which produce an equality between the market rate and this estimated consumption rate of interest. Thus, there is virtually no guide to specifying these two factors correctly. In the application of this approach in the following section, values for these factors in the literature will be used.

The data required for estimating the implied consumption rate of interest under this approach are not easy to obtain. Although the rate of growth of consumption over time is observable, both the "global" utility rate of discount and the elasticity of marginal utility are not. Ray (1984) cites a number of different studies that used this approach for determining the discount rate for public projects, mostly in developing countries. The range of assumptions for the global utility rate of discount in these studies is zero to 5 percent. For the value of the elasticity of marginal utility, Ray reports a range of 1 to 3. Finally, the rate of growth of consumption is generally assumed to be around 2 percent, although this can vary with individual countries' experiences. Together, these imply that the range for the estimated consumption rate of interest is 2 to 11 percent, although the higher end of the range is overstated because studies that use higher estimates for the elasticity of marginal utility appear to use lower estimates for the global utility rate of discount and vice versa.

Ray also reports the results of a study by Scott (1977), in which an econometric "search" for the pair of global utility discount factor and elasticity of marginal utility times the rate of growth of consumption that best "fit" the observed market rate of interest. Ray reports that the pair that produced the best fit was a global rate of .5 percent and an elasticity of marginal utility of 1.5. If consumption is assumed to grow at about 2 percent, then this would imply an estimated consumption rate of interest of 3.5 percent.

3.5 Growth Theory Approach

A final approach suggested by the economics literature is based on the optimal economic growth literature. Broadly speaking, this literature discusses intertemporal optimization of consumption under a variety of assumptions and circumstances. Various propositions are advanced and explored using both single- and multi-sector models. The distinguishing feature of all of this literature, however, is a reliance on steady state growth, or optimal paths which approach steady state conditions. Steady state growth occurs when all relevant economic variables, e.g., capital output, etc., grow at constant rates so that in per capita (or similar) terms, these economic variables do not change over time.

One special case of steady state economic growth is referred to as the "Golden Rule."[23] In its simplest form, this occurs when population is growing at a constant rate and consumption per person is at its highest constant and sustainable level. This requires that capital, output, and all other relevant economic variables grow at the same rate as population. In more complex formulations, if productivity is rising over time, then all relevant economic variables must grow at the sum of the rate of population and productivity growth (often referred to as the growth rate of labor in efficiency units). In all formulations, however, if a steady state growth path could be chosen, this "Golden Rule" path is optimal given that a steady state path must be maintained.[24]

If the economy were growing along this steady state "Golden Rule" path, then certain other conditions also hold. Most relevant for the search for the appropriate discount rate for evaluating public policies is the level of the consumption rate of discount. In a "Golden Rule" situation, the interest rate equals the marginal productivity of capital (the rate of return on investments) which also equals the rate of growth of population (or of population plus productivity in more complicated formulations), all of which, in turn, equal the rate of output growth. Thus, if the economy were in a steady state "Golden Rule" path, then the interest rate appropriate for discounting public policies or projects would equal the long-run rate of output growth, which also would equal the long-run constant rate of growth of population plus the long-run rate of growth of productivity.

Although casual inspection suggests that growth has been neither constant nor always positive if one were to assume (1) that the current population and productivity growth rates will continue forever, (2) that steady state growth at these rates for all other variables would now obtain, and (3) that this steady state is the "Golden Rule" steady state, then the implications for the discount rate would follow. Thus, if these assumptions were made and this approach were adopted, one would need only the long-run rate of output growth to calculate the discount rate for public policy evaluation.

The observed real rate of output growth over the period 1929-1986 was 2.9 percent annually.[25] Over the past three decades (1956-1986), the rate was slightly higher at 3.0 percent. Thus, the growth theory approach implies a discount rate on the order of 3 percent.

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[23] The seminal article is Phelps (1961).

[24] The fact that the steady state must be maintained is crucial for this argument. Clearly, one generation could improve it's position by failing to save enough output to equip future generations with sufficient capital. However, this would mean reduced welfare for future generations, implying that the improved welfare of the current generation is not sustainable.

[25] The estimates are based on GNP data for the U.S. from the Council of Economic Advisors (1987), Table B-2, p. 246.

4. CHOOSING A DISCOUNT RATE FOR THE PRESENT ANALYSIS

The range indicated is from about zero percent to about 8 percent (if one ignores the high ends of the "Implicit" Consumption Rate of Interest approach and the Gross Rate of Return on Private Capital approach), where the lowest estimate is based on the Consumption Rate of Interest approach and the highest on the Gross Rate of Return on Private Capital approach.

For the purposes of the present analysis, a value of 2 percent for discounting future monetary costs and benefits is selected for the reference case, and values of one and 6 percent are selected for the sensitivity analysis. The use of these estimates is based on the conclusion that not all of the different approaches to determining the social rate of discount are equally applicable to the regulatory options for controlling potential ozone depleters. That is, the logical and economic underpinnings of some of the approaches reviewed in this appendix may not correspond to those inherent in regulating potential ozone depleters.

First, the "Gross Rate of Return on Private Capital" approach reviewed above. The intuitive appeal of this approach has its roots in the view that the government "projects" being evaluated displace private capital formation by reducing the amount of private investment in order to fund dams, social programs, and other government undertakings. This view of government programs, however, does not really correspond to the character of regulating potential ozone depleters. Under these regulations, private capital is not really displaced. Instead, investments are redirected into control technologies to reduce emissions of these substances. Thus, the level of private capital formation is not obviously reduced, only its composition is changed. This means that the redirected investments still earn the pre-tax return, just as they would have in their original deployment. (This might be marginally lower, but, given the likely investment flow affected, the decrease could hardly be significant.) Consequently, the intuitive justification for using the pre-tax social rate of return on private investments as the social rate of discount (i.e., that a stream of government revenues from the displaced private investments is lost) does not really apply for these regulations.

Second, the "Implicit Consumption Rate of Interest" approach is very difficult to apply in practice. As the discussion of this approach indicated, little economic or ethical guidance exists for choosing the global discount factor, and no reliable empirical evidence exists for the magnitude of the elasticity of marginal utility. Furthermore, the range of discount rates generated using this approach includes relatively high rates only when the global discount factor is positive, which implies a systematic bias against the welfare of future generations. It is not at all clear that such an ethical stance is appropriate in the context of regulating potential ozone depleters.

Third, the "Golden Rule" approach for determining the social rate of discount assumes economic conditions that may not apply at present in the case of regulations on potential ozone depleters. In particular, this approach assumes that the economy is in steady state growth and that the rate of saving

equals the golden rule. Causal observation suggests that these conditions may not be true presently. In fact, the long-term growth rate of the economy used to generate emissions and ozone depletion estimates is lower in the scenarios used to generate emissions and ozone depletion estimates than past rates of economic growth. In those scenarios (upon which damage estimates are based), the growth rate of the economy starts off in 1985 at 2.8 percent and declines to 1.9 percent by 2050, a reduction of 30 percent. By 2100, it is assumed that no growth is occurring. Not only would this lower growth rate imply a lower discount rate for the "Golden Rule" approach, but it would also indicate that the shadow price of capital or the consumption rate of interest would also decrease with time. Thus, the slowing growth would significantly decrease the discount rates since, in essence, it rejects the approach of extrapolating the past indefinitely into the future (which is what usually is done for discounting problems of shorter duration).

In conclusion, it is possible to make a more refined selection of the rate to use in evaluating the effects of controlling potential ozone depleters. First, the regulations under study have effects in a future later in time than usually considered in evaluating typical regulations. Second, there is an asymmetrical character to the uncertainties that characterize costs and benefits that cannot be quantitatively estimated, but could be large. For example, the possibility exists that damage to aquatic systems could destroy the food chain in some regions leading to catastrophic failure of fisheries and the functioning of that part of the ocean in the biogeochemical cycle. Because ozone depletion would be quasi-irreversible, there is a high insurance premium on avoiding both potentially projected damages and the possibility of large disruptions not encompassed in the standard estimation of discount factors. A discount rate in the lower end of the range indicated above follows from such a view. Finally, the regulations on potential ozone depleters do not obviously displace private investments; rather they tend merely to redirect private capital formation. Thus, the approaches that argue for higher discount rates (or for adjusting costs by the shadow price of capital) are less relevant for the regulations under study here.

Based on this analysis, a social rate of discount in the lower portion of the range suggested by all of the approaches seems appropriate. This is the basis for the previously mentioned estimates used in the present analysis: a rate of two percent is adopted as the reference value, and zero, one and six percent are used in the sensitivity analyses.

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I

APPENDIX I

FRAMEWORK AND METHOD FOR ESTIMATING COSTS OF REDUCING THE USE OF OZONE-DEPLETING COMPOUNDS IN THE U.S.

This paper describes the analytical framework and methods used to estimate the costs of reducing the use of potential ozone-depleting compounds. The emphasis of the approach is on estimating the net social costs of reducing the use of the compounds. An essential step in estimating these social costs is assessing potential industry responses to regulations which would be implemented to achieve the desired reductions. This assessment, in turn, calls for estimates of the private costs faced by the affected industries of complying with the regulations. These private compliance costs are also required for performing a Regulatory Flexibility Act analysis.[1] Hence, the approach employed provides estimates of both private and social costs.

The framework for estimating social costs essentially consists of measuring the changes in consumer surplus caused by the regulations in the markets for chlorofluorocarbon (CFC) and halon compounds (hereafter referred together as CFCs). Hence, a major component of the analysis is characterizing these CFC markets and, in particular, estimating the derived demand schedules for each.

The appendix is organized as follows:

- Section 1 presents the economic framework for estimating costs. It discusses the assumptions employed in the analysis and the economic justification for measuring changes in consumer surplus in the CFC markets.

- Section 2 discusses the analysis of the four basic regulatory alternatives -- auctioned rights, allocated quotas, regulatory fees, and engineering controls and product bans.

- Section 3 describes the methods used to estimate derived demand schedules for CFCs using the engineering and financial data collected by EPA. It also describes the procedure for estimating changes in consumer surplus using the estimated derived demand schedules.

- Section 4 discusses some of the inherent limitations of the analytic methods used.

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[1] The methods and results of the Regulatory Flexibility Act analysis are presented separately in Appendix L.

1. CONCEPTUAL APPROACH FOR ESTIMATING REGULATORY COSTS

This section discusses the economic theory that underlies the approach used to estimate the private and social costs of regulations that restrict the use of CFCs. The basic method for estimating costs is to measure changes in producer and consumer surplus in the relevant markets that result from restrictions on CFC use required by regulation.

The section initially identifies the relevant markets, establishes the relationships between these markets, and characterizes the supply and demand schedules that underlie them. The section then turns to the issue of measuring changes in producer and consumer surplus in these markets due to exogenously imposed restrictions on CFCs. The section ends with a discussion of the differences between private and social costs.

1.1 Affected Parties and Relevant Markets

To analyze the costs of the proposed regulations it is necessary, first, to identify the parties that are likely to be significantly affected by the regulations and the markets in which the changes in the welfare of these parties can be measured.

The parties likely to be affected by the regulations are:[2]

- firms producing CFCs;
- owners of factors employed in the production of CFCs;
- firms in the CFC-using industries;
- owners of factors employed in the CFC-using industries; and
- final consumers of goods manufactured using CFCs.

To determine the costs borne by each of these parties it is generally necessary to measure changes in consumer and producer surpluses in two sets of markets:

- the markets for the various CFC compounds, i.e., the markets in which CFCs are sold by producers of these compounds to the various CFC-using industries; and
- the markets for the outputs of the CFC-using industries, i.e., the markets in which the products of the CFC-using industries are sold to consumers.

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[2] It is assumed that the markets for complements and substitutes for the outputs of CFC-using industries would not experience price changes as the result of reductions in CFC use. Therefore, these markets do not experience gains or losses.

It is possible, however, to measure the net costs of the proposed regulations by measuring changes in surpluses in the CFC markets alone. Here net costs are defined to be the sum of the costs borne by the affected parties minus any transfers (e.g., to the government) in the form of revenues generated by the regulations (e.g., fees collected). The rationale for measuring these costs entirely in the CFC markets is explained in the following sections.

1.2 General Analysis of the Relationships Between the Relevant Markets

A general overview of the relationships between the markets for CFCs and the markets for the outputs of the CFC-using industries is presented in this section. The overview is a stylized one in that it employs very general assumptions about the shapes of the various supply and demand curves. This allows a derivation of the full range of relationships that may exist between the relevant markets.

An important assumption maintained throughout the analysis is that all relevant markets are competitive.[3] Furthermore, it is assumed that the various "application categories" discussed in Section 3 of this appendix roughly correspond to distinct industries. Hence, the term application category and industry are used synonymously in this appendix.

Note, finally, that the discussion in this and subsequent sections is couched frequently in terms of a single ozone-depleting compound (e.g., CFC-11). Thus, reference is made to a single market. However, the analysis applies to the markets for all of the CFC and halon compounds subject to the proposed regulations.

Before examining the relationships between the relevant markets, the supply and demand schedules underlying these markets are briefly characterized.

1.2.1 DEMAND SCHEDULES

Three sets of relevant demand schedules can be identified:

- the derived demand for CFCs of a single CFC-using industry;
- the demands for the outputs of the CFC-using industries; and
- the aggregate derived demand for CFCs of all CFC-using industries.

The relationship among these demands is best explained by means of an example. An important use of CFCs is in manufacturing air-conditioners. This industry has a derived demand schedule for CFCs that specifies the quantity of CFCs it

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[3] The assumption of competitiveness is probably reasonable for the CFC-using industries. However, the CFC-producing industry is highly concentrated, potentially leading to a non-competitive situation. The implications of a non-competitive CFC-producing industry are described below.

would buy at various CFC prices. This industry derived demand schedule is obtained by horizontally summing the derived demand schedules of the firms in the air-conditioner industry.[4] The shape of this derived demand schedule for this industry is influenced, in part, by the demand for air-conditioners (i.e., by the demand for the outputs of the CFC-using industry).

The aggregate derived demand schedule for CFCs is obtained by horizontally summing the derived demand schedules of all the CFC-using industries (air-conditioning, foam blowing, etc.). Thus, the aggregate derived demand schedule for CFCs is obtained via a two-stage procedure:

- First, the derived demand schedules of firms in a given industry are summed to obtain the derived demand schedule for CFC of that industry. This is carried out for each CFC-using industry.

- Then, the derived demand schedules for CFC of all CFC-using industries are summed to obtain the aggregate derived demand schedule for CFC.

Typically, derived demand schedules for an input to production assume that factors influencing the demand for the input other than its price are held constant. Most important among these factors are the prices of other inputs and the price of the output produced using the input in question. The relationship between other input prices and the demand for CFC inputs depends on whether other inputs complement or substitute for the use of CFCs in the production process.

The relationship between output price and CFC input demand hinges on the link between output price and output quantity. The price a competitive firm receives for its output determines the level of output that it produces. The higher the price the firm receives; the larger is the quantity of output it produces (provided that marginal production costs are increasing, as is commonly assumed). This output level, in turn, determines the quantity of input that is needed by the firm. Higher output levels imply higher demands for the input. Thus, there is a positive relationship between output price and input demand.

Although derived demand schedules are commonly specified with output <u>price</u> held constant, this need not be the case. Derived demand schedules can also be specified holding output <u>quantity</u> constant, requiring only the removal of the intermediate link between output price and output quantity. In later sections, derived demand schedules are specified in this manner. However, in this section we adhere to economic convention and assume output price is held constant.

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[4] It is assumed throughout that external effects of scale are negligible so that industry demand and supply curves can be approximated by horizontally summing individual firm demand and supply curves. An example of an external effect of scale is factor prices rising as industry output expands.

1.2.2 SUPPLY SCHEDULES

Two sets of relevant supply schedules can be identified:

- the supply schedule for CFCs of the CFC-producing industry; and
- the output or product supply schedules of the CFC-using industries.

The supply schedule for CFCs gives the total amount of CFCs that would be supplied by CFC producers for various prices of CFCs. This supply schedule is obtained by horizontally summing the supply schedules of the individual CFC-producing firms.

Turning to the CFC-using industries, each industry has an output supply schedule that specifies the level of output it supplies for different output prices. The output supply schedule for each industry is obtained by horizontally summing the supply curves of the firms in the industry. These firm-level supply schedules are based on firms' marginal costs of production. Thus, along a supply schedule, the prices of inputs are held constant.[5] The effect of a change in the price of an input, such as CFCs, is to shift the output supply schedules because of its effect on the marginal cost of production.

1.2.3 RELATIONSHIPS BETWEEN THE CFC (INPUT) MARKET AND THE OUTPUT MARKET

Exhibit I-1 shows an illustrative supply schedule and an illustrative aggregate derived demand schedule for a CFC. Along the aggregate derived demand schedule, the prices of the outputs of the various CFC-using industries are held constant at their current equilibrium values. The equilibrium price and quantity of the CFC are determined by the intersection of the supply schedule and the aggregate derived demand schedule. The equilibrium price p_t^0 is the price of the CFC faced by all the firms in CFC-using industries. The equilibrium quantity q_t^0 is the total quantity of the CFC demanded by the CFC-using industries at this price.

Exhibit I-2 shows the output supply curve of one of the many CFC-using industries as well as the demand schedule it faces for its output. Along the output supply curve, the price of the CFC is held constant at its current equilibrium value, p_t^0. The equilibrium price and quantity in the output market, P_t^0 and Q_t^0, are given by the intersection of the supply and demand schedules.

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[5] It is assumed that supplies of all inputs (other than CFCs) are perfectly elastic.

EXHIBIT I-1

MARKET FOR A CFC

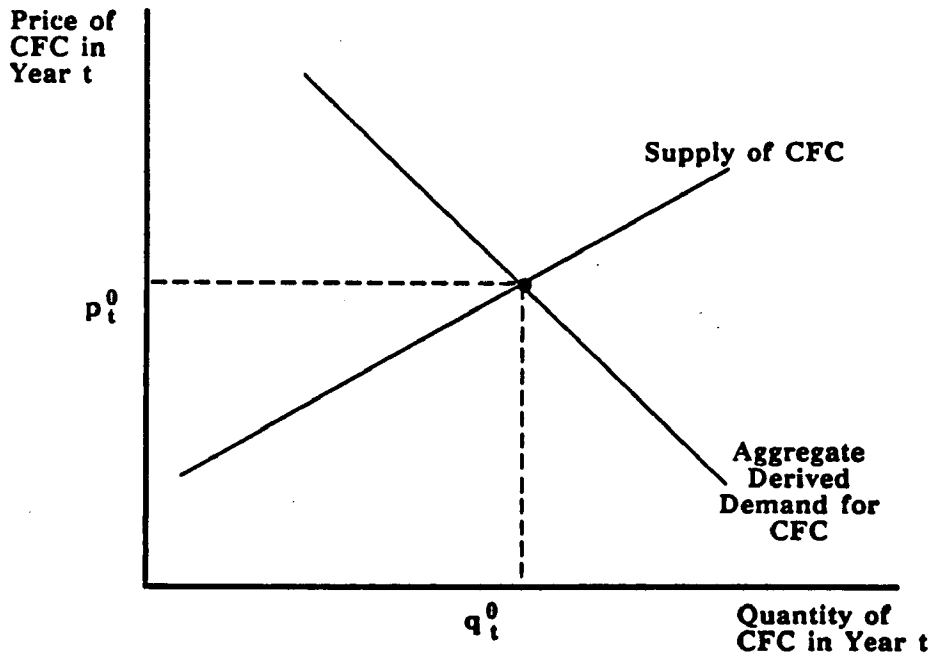
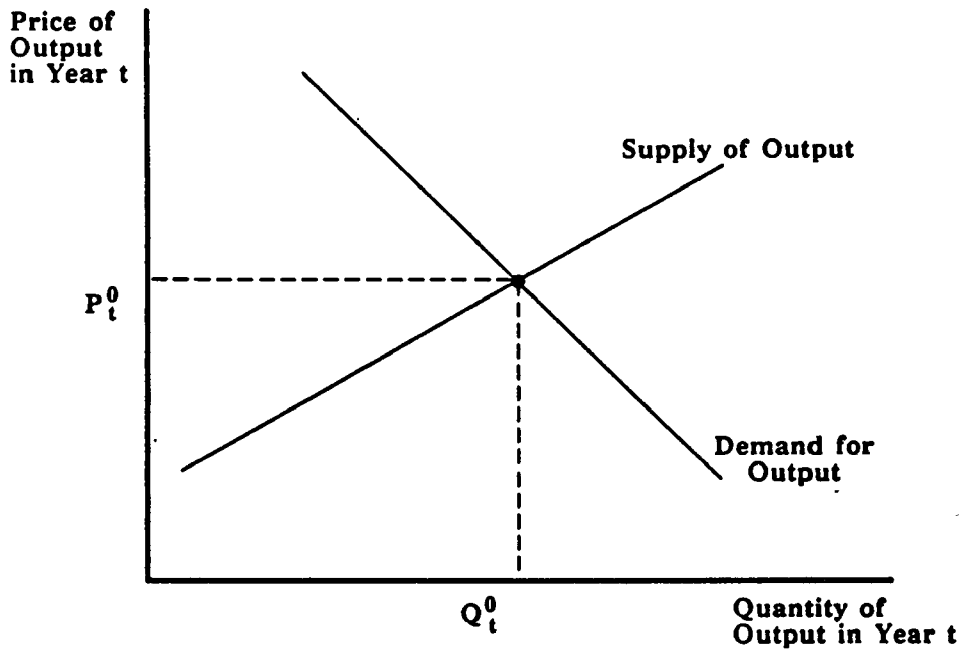


EXHIBIT I-2

MARKET FOR THE OUTPUT OF A CFC-USING INDUSTRY



The relationships between the CFC market and the output markets can be identified by tracing the effects of an increase in CFC price due to an upward shift in the supply schedule for CFC. The initial effect of the higher CFC price is to shift up the output supply schedules of the CFC-using industries. This shift would eventually result in a higher equilibrium output price and a lower equilibrium quantity in each output market.

Given the dependence of the derived demand schedule for CFCs on the level of output produced, the lower equilibrium output quantities would cause a contraction in the aggregate derived demand for CFCs. This contraction would lower the equilibrium price of CFCs, assuming the supply curve for the CFCs is upward sloping, and initiate a new round of shifts in the two markets.

The above interaction between the input and output markets would continue until a new equilibrium is established in both markets. This new equilibrium is illustrated in Exhibit I-3. Panel (a) shows the input market and panel (b) shows one of the many output markets. The equilibrium CFC price in panel (a) rises from p_t^0 to p_t^1 and the equilibrium quantity falls from q_t^0 to q_t^1. In panel (b), the equilibrium output price rises from P_t^0 to P_t^1 and the equilibrium output quantity falls from Q_t^0 to Q_t^1. Along the new output supply schedule, labeled S_1^1, the price of the CFC is held constant at its new equilibrium level p_t^1.

To summarize, the key relationships between the market for a CFC and the markets for outputs are: (1) the dependence of the derived demand for the CFC on the demand for the outputs of the CFC-using industry; and (2) the relationship between the equilibrium price of the CFC, which is determined in the input (i.e., CFC) market, and the positions of the output (i.e., CFC-using industry) supply curves. In the general setting examined, an upward shift in the CFC supply curve triggers a series of linked adjustments in each of the markets before a new equilibrium is achieved.

1.3 Assumptions Regarding CFC Supply and CFC-Using Product Demands

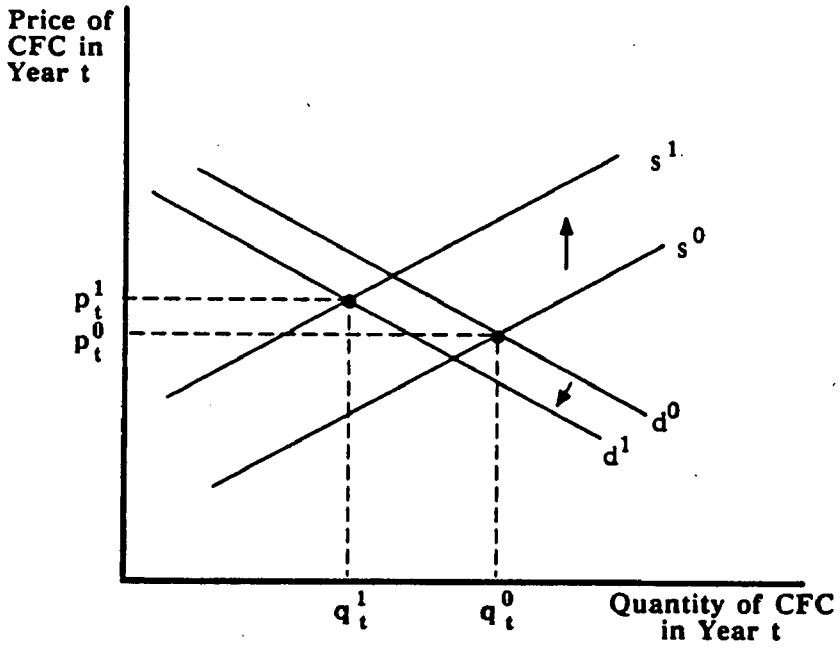
The discussion contained in the previous section is based on very general assumptions about the characteristics of the various supply and demand schedules. This section presents the specific assumptions we make about the supply curve for CFCs and the output demand curves faced by the CFC-using industries, and the justification for these assumptions.

Given the assumption that all relevant markets are competitive, the supply schedule for CFCs reflects the marginal costs of producing CFCs. A survey of the available literature on the CFC industry revealed no engineering data on marginal production costs. Moreover, data suitable for econometric estimation of CFC supply schedules are also not available. Therefore, empirical derivation of CFC supply curves is not possible.

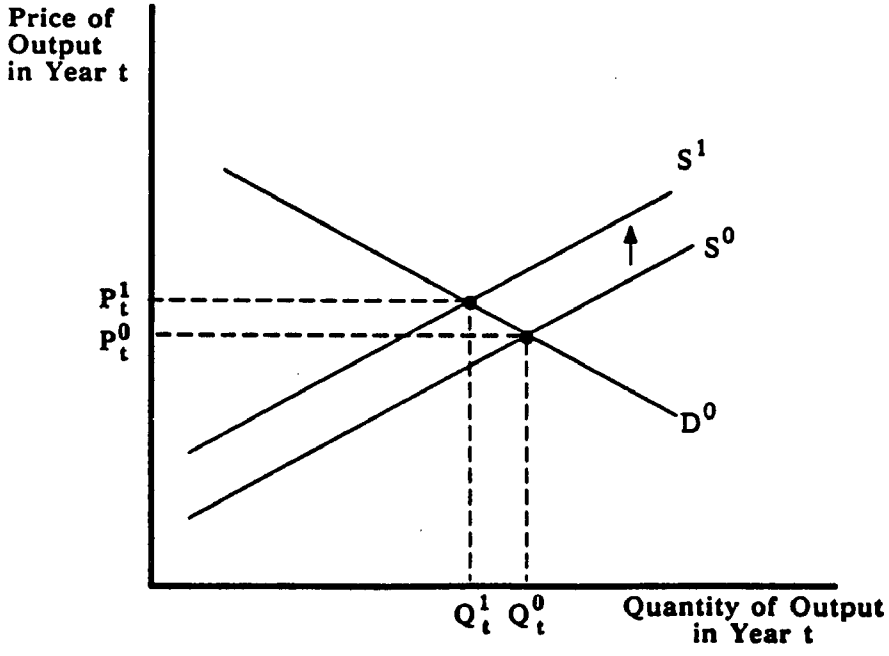
EXHIBIT I-3

EFFECTS OF A SHIFT IN THE CFC SUPPLY CURVE: GENERAL CASE

(a) Market for CFC



(b) Market for Output of a CFC-Using Industry



An examination of the CFC production process, and those of similar chemicals, suggests, however, that the marginal costs of production are likely to be constant over a very large range of output. This implies that the supply schedule for CFCs is perfectly elastic (i.e., horizontal) over a large range of output. For purposes of this analysis, it is assumed that the supply curve is perfectly elastic over its entire range.

Because the CFC-producing industry is highly concentrated in the U.S., it may not exhibit all the necessary characteristics of a competitive market. In such cases, price may exceed marginal costs. Due to the lack of empirical data, the extent to which the price of CFCs exceeds the marginal cost of production has not been assessed.

A review of the available data on production costs for the CFC-using industries indicates that CFC costs account for only a small fraction (under 5 percent) of total production costs for a majority of the outputs examined. This implies that even substantial increases in the price of CFCs would cause only small increases in the marginal costs of production in the CFC-using industries. Hence, the shifts in the output supply curves for these industries caused by higher CFC prices will be small. This, in turn, implies that higher CFC prices will induce only small changes in equilibrium prices and quantities in the output market if demand is not very elastic.

Therefore, for outputs that have low CFC cost shares and low demand elasticities, a simplifying assumption is made that, over the relevant range, demand for outputs is perfectly inelastic. That is, the demand schedules for these outputs are assumed to be vertical so that changes in output price have no effect on the quantity of output demanded. This approximation is acceptable given the small changes in output price and output quantity associated with higher CFC prices. In terms of the final social cost estimates derived, the approximation generates a small upward bias in the estimates.

For the few outputs that have relatively large CFC cost shares and possibly higher demand elasticities, the potential for output substitution is accommodated by interpreting the demand for output in terms of the services provided by the CFC-based output. This services-provided demand is then assumed to be perfectly inelastic.

For example, CFC costs account for roughly 16 percent of the total costs of making rigid polyurethane foam, a material used as insulation in building construction. The services provided by this foam consist of insulation (measured as an R-value) over the expected life of the foam. Because substitute insulation materials are available at reasonable prices, it would be inappropriate to assume that the quantity of rigid foam demanded is constant when there are large increases in the price of CFCs. Thus, in modeling the demand for rigid polyurethane foam, the price of the foam is compared to the cost of using substitute insulation materials. (The costs of using substitutes include the costs of higher energy bills given their inferior insulation properties). If the price of rigid polyurethane foam exceeds the cost of using a substitute (including the increased energy costs), consumers are assumed to switch to the substitute and to stop buying rigid polyurethane foam.

1.4 Characteristics of Derived Demand Schedules for CFCs

The smooth derived demand schedules drawn in Exhibits I-1 and I-3 are consistent with the assumption, traditional in economic theory, that production processes are such that inputs can be continuously substituted for one another. In other words, it is always possible to reduce use of an input and keep the level of output constant by increasing the use of other inputs. This assumption implies that increases in the price of an input invariably result in a lower quantity demanded of that input (assuming other input prices are constant).

Engineering data on production processes indicate, however, that substitution possibilities are limited for any given production technology.[6] In general, these data imply that, for a specific production technology, no substitution of inputs is possible. In other words, it is not possible to reduce use of one input and keep the quantity of output constant by raising the use of other inputs. Production technologies of this type are called fixed-proportions technologies. For these technologies, the quantity of input used per unit of output is a constant.

The data collected on options for reducing CFC use in the various application categories imply that the portions of the overall production processes related to CFC use are characterized by fixed proportions. Thus, for a given production technology, the quantity of CFCs used per unit of output is a constant. It follows that the quantity of CFCs demanded for a given level of output is constant over some range of CFC price. This implies that the derived demand schedule for CFCs of a single CFC-using firm or industry (along which output is held constant) is a series of vertical line segments or a step function. As shown in Exhibit I-4, the quantity of output (rather than the price of output) is constant along each of these segments.

Although substitution of inputs is not possible within any given fixed-proportions technology, it is possible across fixed-proportions technologies. For instance, in the context of CFC use, the quantity of CFCs used per unit of output is constant for a given fixed-proportions production technology, but the quantity may be changed by "switching" to a different fixed-proportions production technology. As used here, switching technologies encompasses replacing CFCs with less ozone depleting chemicals, modifying production processes, and recycling or recovering CFCs.

CFC-using firms will choose the production technology that minimizes production costs given prevailing input prices. Changes in input price, if sufficiently large, will induce firms to switch technologies and alter their levels of input use for a given level of output.

For example, if the price of CFC rises sufficiently, CFC-using firms will switch to less CFC-intensive production technologies (assuming these exist) and

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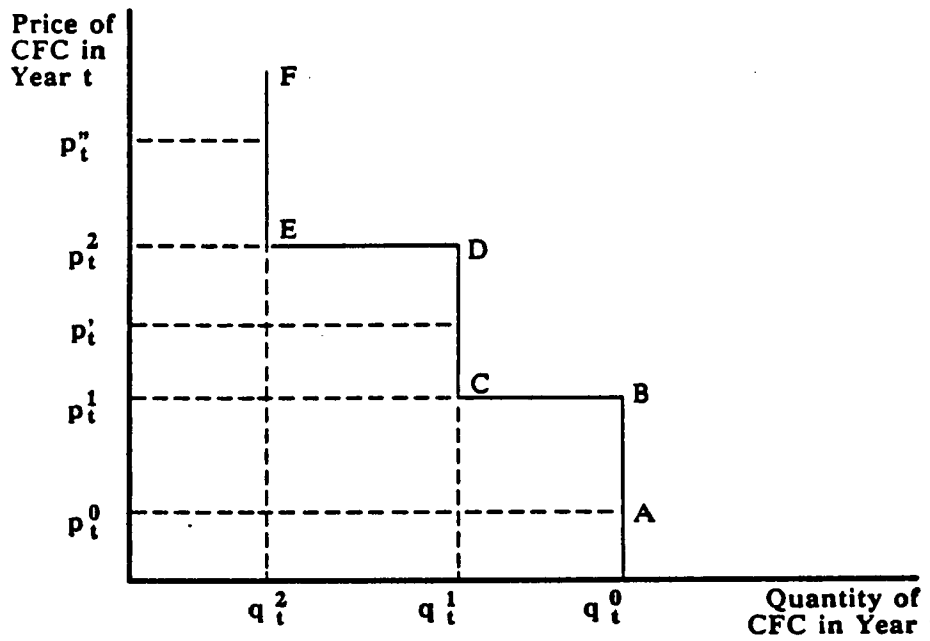
[6] See P.R.G. Layard and A.A. Walters, Microeconomic Theory, McGraw-Hill, 1978, Chapter 10 for a general discussion of this issue. For a good case study, see J.M. Griffin, "The Process Control Alternative to Statistical Cost Functions: An Application to Petroleum Refining," American Economic Review, March 1972, Vol. 62, pp. 46-56.

EXHIBIT I-4

CHARACTERIZING THE DERIVED DEMAND SCHEDULE FOR CFCs AS A STEP FUNCTION



reduce their use of CFCs per unit of output. This is reflected in Exhibit I-4 by a switch from line segment AB to the line segment labeled CD. For a CFC price above p_t^1 but below p_t^2, the switch to a less CFC-intensive production technology implies a reduction in the quantity of CFC demanded from q_t^0 to q_t^1. The derived demand schedule in Exhibit I-4 further implies that if the CFC price rises above p_t^2, firms switch to an even less CFC-intensive production technology that reduces their CFC use from q_t^1 to q_t^2.[7]

Thus, each vertical "step" in the derived demand schedule corresponds to a different fixed-proportions production technology. As the price of CFCs increases, firms "climb up" the demand schedule and switch to less CFC intensive technologies. Along the entire demand schedule, the quantity of output produced by the firm or CFC-using industry in question is constant, as are the prices of other inputs.

Although there are three steps in Exhibit I-4, the actual number of steps in a derived demand schedule may be smaller or larger. The number of steps depends on the number of suitable production technologies: more technologies imply more steps in the schedule. For derived demand schedules that are obtained by horizontally summing demand schedules for different firms or different industries, such as the aggregate derived demand schedule for CFC defined above, the number of steps is likely to be large.

1.5 Relationships Between the Relevant Markets

Given the assumptions regarding the shapes of the relevant supply and demand schedules, the relationships between the CFC market and the various output markets are simpler than those described in Section 1.2. This can be established by once again tracing the effects of an increase in CFC price due to an upward shift in the supply curve for CFC.

Panel (a) of Exhibit I-5 shows the CFC market with a perfectly elastic supply schedule and a step aggregate derived demand schedule for CFC. Along this demand schedule, the level of output of each of the CFC-using industries is held constant.

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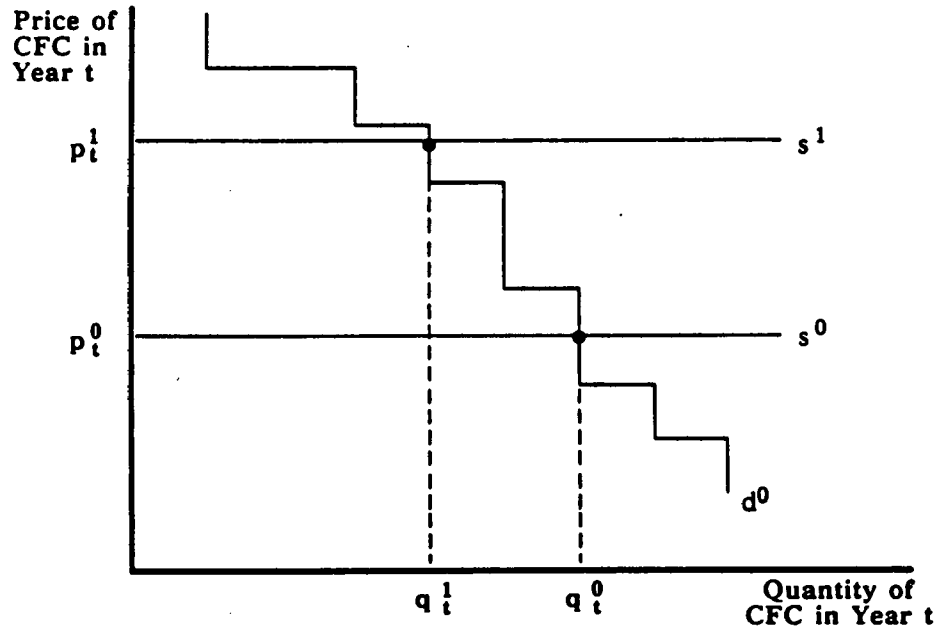
[7] For "switch" prices such as p_t^1 and p_t^2, the quantity of CFCs demanded is indeterminate. For example, at a price of p_t^1, the quantity of CFCs demanded may range from q_t^0 to q_t^1. At prices other than these switch prices, however, the quantity of CFC demanded is determinate.

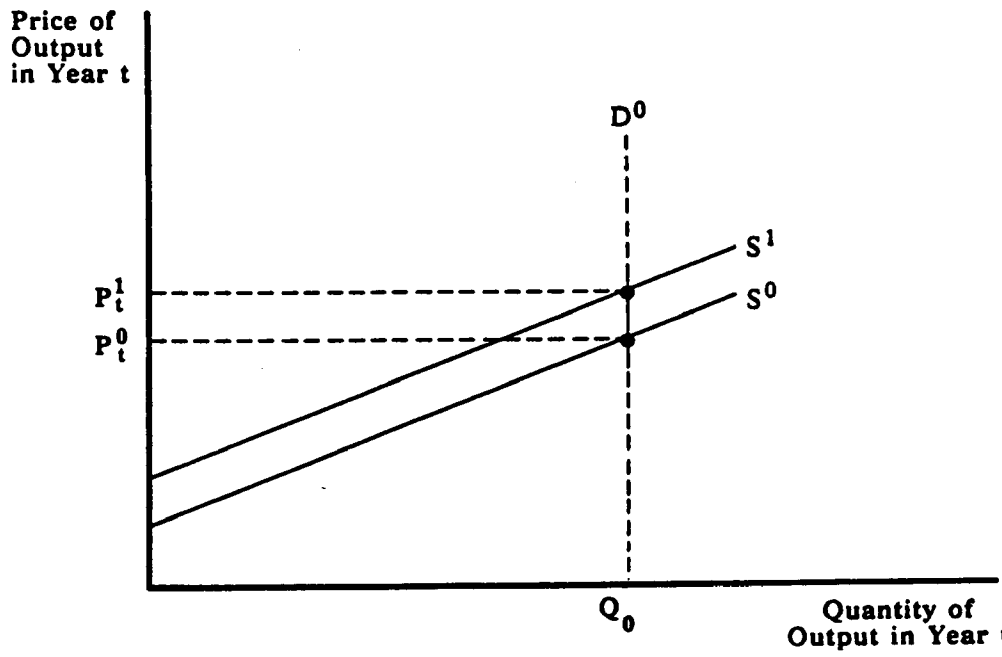
EXHIBIT I-5

EFFECTS OF A SHIFT IN THE CFC SUPPLY CURVE

(a) Market for CFC



(b) Market for Output of a CFC-Using Industry



Panel (b) shows the output market of a single CFC-using industry (recall that there are many such industries). The demand curve for the output is drawn as being vertical over the relevant range. The dashed portions of the demand schedules are those outside the relevant range and no assumptions are made about the shape of the demand schedule over these ranges. As before, the output supply schedules are drawn as upward sloping.[8]

The effect of the higher CFC price due to the upward shift in the CFC supply curve is to push up the output supply curve from S^0 to S^1. This raises the equilibrium price of output from P_t^0 to P_t^1, but, given the shape of the relevant portion of the demand curve, it does not alter the equilibrium quantity of output, which remains at Q_t^0. Because the aggregate derived demand schedule for CFC in panel (a) is specified holding output levels constant, there is, therefore, no "feedback" contraction of the derived demand schedule. Thus, the new equilibrium in the input market is simply given by the intersection of S^1 and the existing aggregate derived demand schedule, while the new equilibrium in the output market is given by the intersection of S^1 and the output demand schedule.

1.6 Measuring Social Costs in the Input and Output Markets

The welfare measures relevant to the calculation of the economic costs of a regulation are producer surplus and consumer surplus:

- Consumer surplus is a measure of the difference between what consumers are willing to pay for a good and what they have to pay for it. As such, it indicates the net gain to consumers of being able to buy all units of the good at the prevailing price. In graphical terms, consumer surplus is given by the area under a demand curve above the price line.

- Producer surplus is a measure of the difference between the price firms received for their output and the price at which they are willing to supply the output. Thus, it is a measure of the net gains to firms of being able to sell all of their output at the prevailing price. In graphical terms, the aggregate producer surplus of a competitive industry is given by the area above the industry's supply curve under the price line.

Panel (a) of Exhibit I-6 shows consumer surplus under the aggregate derived demand schedule for CFCs. There is no producer surplus in the CFC market because of the assumption that price equals marginal cost and that CFC supply is perfectly elastic. Panel (b) shows consumer and producer surpluses in the

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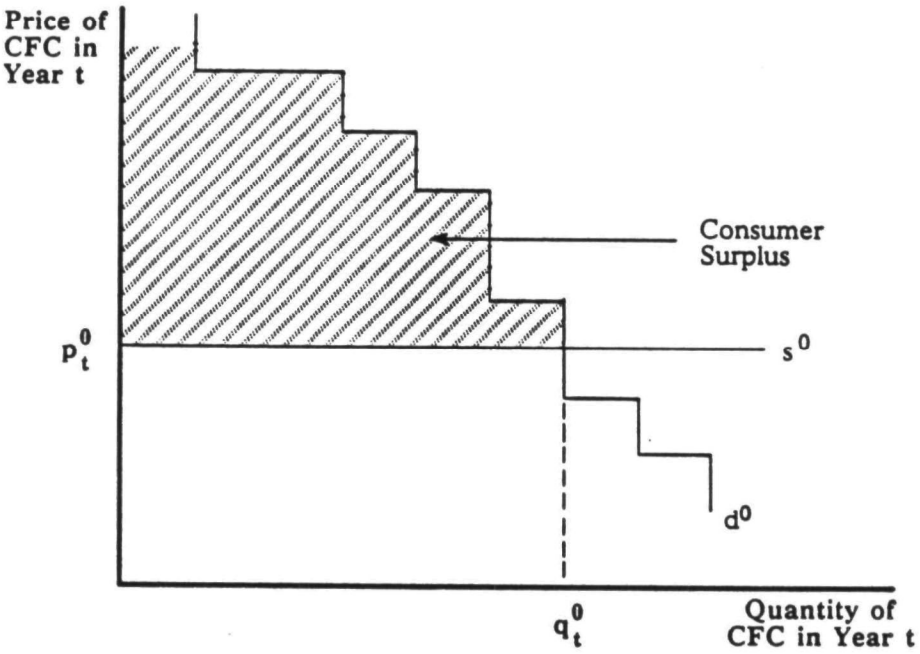
[8] We do not have data on the shapes of these output supply curves. But upward sloping curves are not inconsistent with the assumption that the CFC-related portion of the production process is of the fixed-proportions variety.

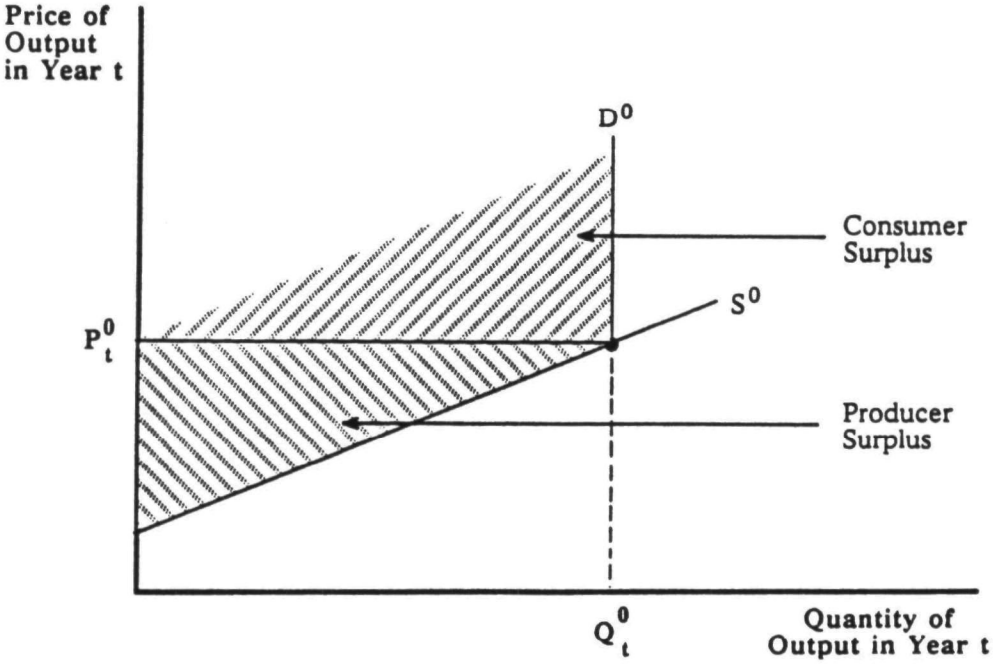
EXHIBIT I-6

ILLUSTRATION OF CONSUMER AND PRODUCER SURPLUS IN THE CFC AND CFC-USING PRODUCT MARKETS

(a) Market for CFC



(b) Market for Output of a CFC-Using Industry



output market of a CFC-using industry. Consumer surplus is not well-defined in this panel since the shape of the demand curve is specified over only a small range.

The social costs of an increase in the price of CFCs due to higher production costs can be measured in terms of the changes in consumer surplus in the CFC market or the changes in producer and consumer surplus in the output markets. Panel (a) of Exhibit I-7 shows the effect in the CFC market of an increase in CFC price from p_t^0 to p_t^1. Consumer surplus under the aggregate derived demand schedule falls by an amount equal to the irregularly-shaped area C. Thus, the net social cost of the CFC price increase is given by area C.[9] Panel (b) of Exhibit I-7 shows the change in producer and consumer surplus due to the CFC price increase in an output market. Consumer surplus in this market falls by an amount equal to the rectangular area D+E. The change in producer surplus is equal to the difference between the lower triangular area F+G and the upper triangular area D+F; this difference is area G-D. If the higher CFC price simply results in a parallel shift in the output supply curve, area D is equal to area G and there is no change in producer surplus.

The net change in the sum of producer and consumer surpluses in the output market is equal to area D+E plus area G-D, which is areas E+G. Thus, the cost of the CFC price increase in this particular output market is equal to area E+G.

Given the links between the CFC market and the output markets of the CFC-using industries, we would expect some relationship between the social cost measures in the two sets of markets. In fact, area C in the CFC market is equal to the sum of the E+G areas in all the output markets of the CFC-using industries.[10] Thus, the social cost of a change in CFC price can be measured in either the CFC market or the relevant output markets. Given the nature of the data collected as part of this analysis, it is far easier to measure costs in the CFC market.

1.7 Social Versus Private Costs

In the discussion thus far, no distinction has been made between the private costs of undertaking an action to reduce CFC use and the social costs of such an action. The distinction is unnecessary if private and social costs are identical. However, there are two reasons why the two costs measures diverge:

- businessmen are concerned only with their profits after taxes while society is concerned with total costs including taxes and

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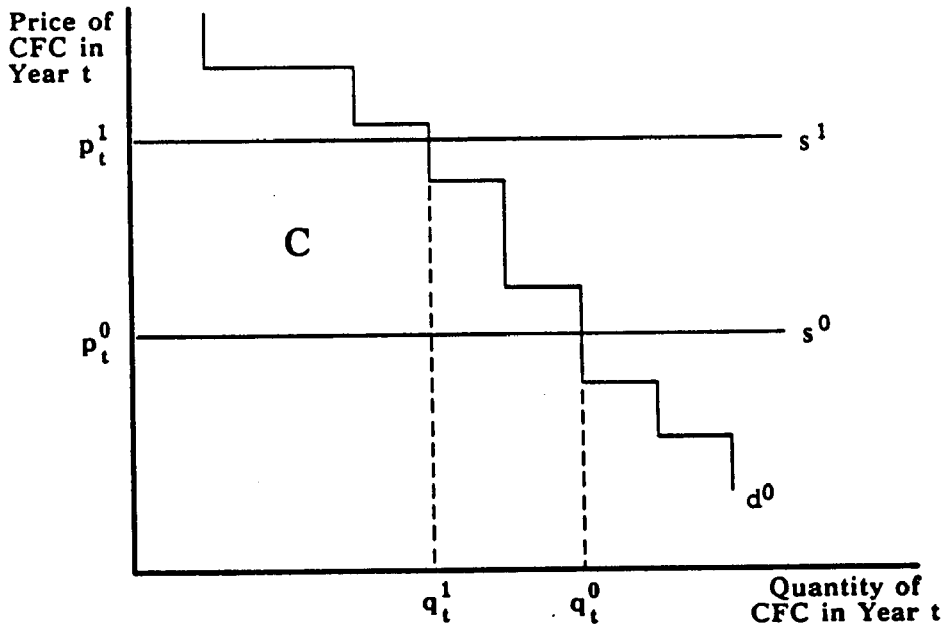
[9] If the price exceeds marginal cost in the CFC-using industry, then additional social costs are incurred, equal to the reduction in CFC production times the amount by which price exceeds marginal cost.

[10] See R. E. Just, D.L. Hueth, and A. Schmitz (1982), Applied Welfare Economics and Public Policy, Prentice-Hall, Englewood Cliffs, New Jersey, Chapters 4 and 9.

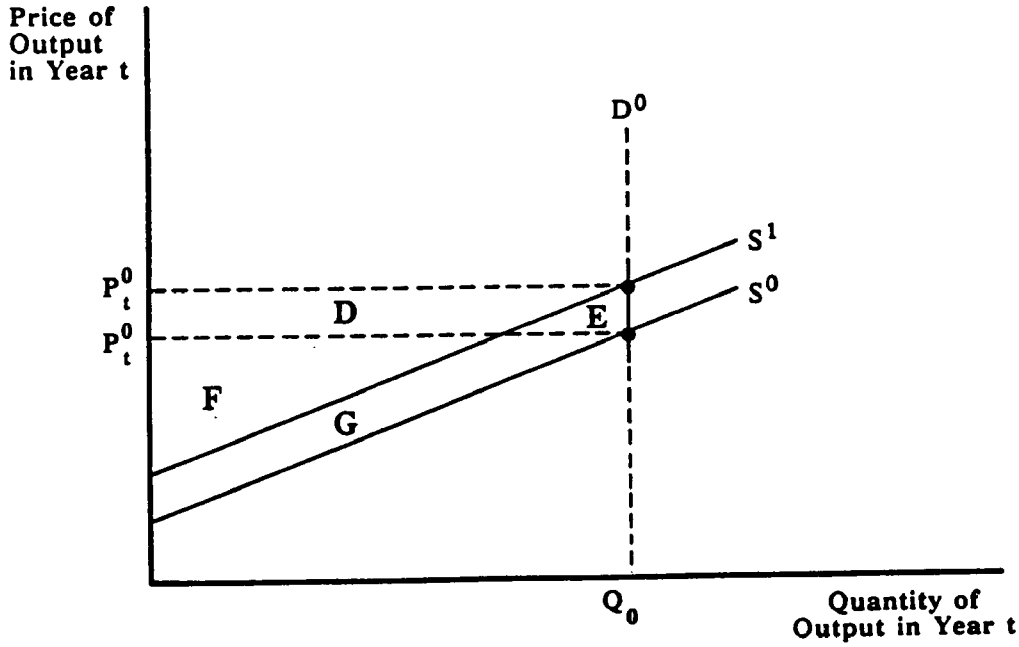
EXHIBIT I-7

CHANGES IN CONSUMER AND PRODUCER SURPLUS DUE TO AN INCREASE IN CFC PRICE

(a) Market for CFC



(b) Market for Output of a CFC-Using Industry



- the private discount rate exceeds the social discount rate.

The first factor implies that social costs exceed private costs if the firm's tax burdens are reduced by the CFC regulations. The second factor implies relatively higher private costs because the amortized value of capital expenditures increases with a higher discount rate.

Because the primary purpose of the cost analysis described in this appendix is to determine the social costs of the proposed regulations, the relevant cost measure is the social one. Thus, the final cost estimates are based on the real before-tax costs of industry responses to the proposed regulations. However, to assess potential industry responses, private costs are the relevant measure because they determine the choice of control options by CFC-using firms. In evaluating alternative control options, these firms will compare the private (rather than the social) costs of the options.

In terms of the supply and demand relationships discussed earlier, the divergence between private and social costs is accommodated in the following manner:

- The ordering of technologies along the steps of the derived demand schedules for CFC is always based on private costs. This is consistent with firms choosing technologies on the basis of private costs.

- The aggregate derived demand schedule used to determine equilibrium prices and quantities in the CFC market is based on private costs.

- The aggregate derived demand schedule under which changes in consumer surplus are measured is expressed in terms of social costs. That is, for each of the underlying derived demand schedules, the heights of each of the steps in the demand schedules reflect social rather than private costs.

Thus, for each CFC compound there are two sets of derived demand schedules: one reflecting private costs and another reflecting social costs. The two sets of demand schedules differ only in terms of the heights of the steps; the correspondence between technologies and steps is identical for the two sets.

2. ANALYSIS OF THE REGULATORY ALTERNATIVES

There are four basic regulatory alternatives for controlling the use of CFCs: a regulatory fee on CFCs; auctioned rights for CFC use; quotas on CFC production; and engineering restrictions and product bans on the use of CFCs in particular applications. Combinations of these alternatives may also be used. Each of these alternatives is analyzed below in terms of the framework developed in Section 1. For purposes of exposition, a stylized version of each of the regulatory alternatives is analyzed. The actual alternatives being considered are considerably more complex, but their salient features are captured by the constructs employed here.

2.1 Regulatory Fees on CFCs

The regulatory fee alternative under consideration is simply a constant fee imposed on producers of virgin (i.e., non-recycled) CFCs. The fee may differ across CFC compounds depending on their ozone depletion potential.

The basic effect of a fee is to raise the price of CFC faced by users. This is illustrated in Exhibit I-8. The fee pushes up the supply curve for CFC by an amount equal to the fee itself. The effect of this shift is to raise the equilibrium price of CFCs and to lower the equilibrium quantity. As shown, the equilibrium price rises from p_t^0 to p_t^1 and the equilibrium quantity falls from q_t^0 to q_t^1. At the new equilibrium, the price paid by users of CFC is p_t^1 and, given the horizontal supply curve, the price received by sellers is p_t^0. The difference between the two prices is the regulatory fee per unit of CFCs.

The rectangular area A in the exhibit represents the revenue generated by the fee. It is equal to the difference between the price paid by users at the new equilibrium and the price received by suppliers times the new equilibrium quantity. The revenue generated comes out of the producer surplus of the CFC-using industries and the consumer surplus of the buyers of the outputs of these industries.[11] However, the revenue generated offsets some of the losses experienced by these parties, hence the revenue is a transfer from the affected parties to the government. It does not represent a net social cost.

The net social cost of the fee is given by the irregularly shaped area B in Exhibit I-8. The costs captured by this area are borne by the same set of parties as those identified above. Because of the horizontal supply curve for CFCs and the assumption that price equals marginal cost, there are no losses (in terms of producer surplus) experienced by the producers of CFCs or the owners of the factors used in its production.

2.2 Auctioned Rights for CFC Use

The auctioned rights alternative would require firms to purchase rights in order to use CFCs. The total number of rights available would be set by EPA. The rights would initially be allocated via an auction, but firms would subsequently be allowed to buy and sell rights from one another. The rights would not be defined by CFC compound, but in terms of ozone depletion equivalents. For example, if the ozone depletion potential of CFC-11 is taken as the base, then using ten kilograms of CFC-11 would require purchasing rights worth 10 kilograms. Fewer rights would be needed to use ten kilograms of a CFC

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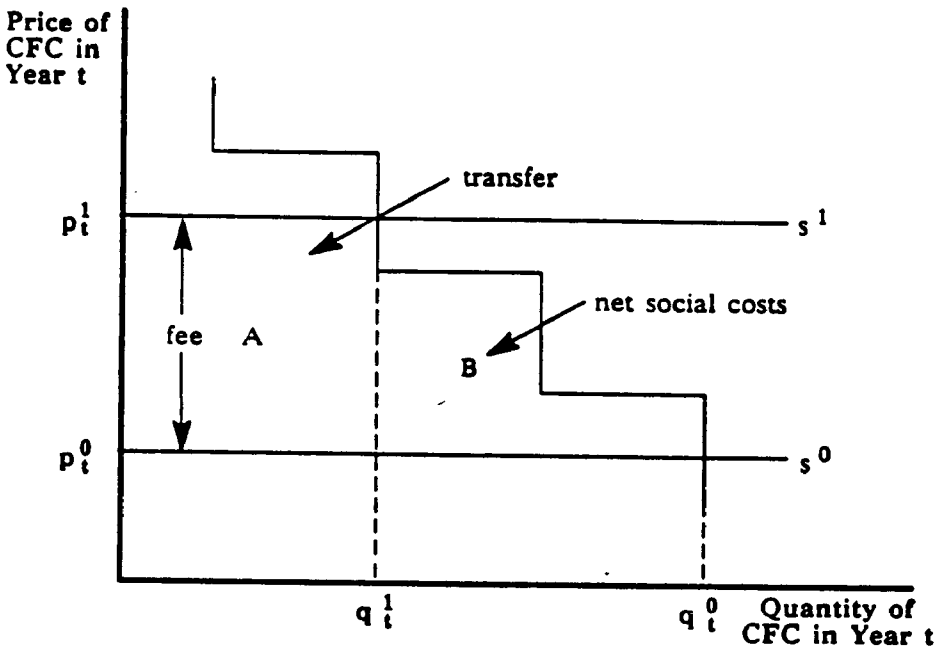
[11] Losses in producer surplus occur to the extent that the higher CFC price induces consumers to switch to substitute non-CFC based outputs. Given the assumption that the supplies of all inputs are perfectly elastic, no losses accrue to the owners of the factors employed in the CFC-using industries.

EXHIBIT I-8

SOCIAL COSTS OF A REGULATORY FEE ON CFC



that is less ozone depleting than CFC-11, and more rights would be needed to use one that is more ozone depleting. Thus, there would be a single right market for all CFC compounds instead of separate markets for each compound.

To model the market for rights that would develop under this regulatory alternative, it is necessary, first, to specify the conduct of the market. Given the large numbers of firms that use CFC compounds and would participate in the market, it may be reasonable to assume that the market is a competitive one. Although this is the assumption adopted in the analysis, alternative assumptions are possible.[12]

The second step is to determine the aggregate demand for rights. Because the rights are based on ozone depletion equivalents, it is necessary to translate the demands for the various CFC compounds into ozone depletion equivalents and then sum these translated demands. Conceptually, this is accomplished by multiplying the vertical and horizontal scales on the aggregate derived demand schedule for each CFC compound by its corresponding ozone depletion index. The individual aggregate derived demand schedules for different CFCs are then measured in the same units. These aggregated derived demand schedules can then be horizontally summed to obtain a single "composite" aggregate derived demand schedule for rights defined in terms of ozone depletion equivalents.

This composite demand schedule is depicted in Exhibit I-9 along with a vertical line representing the total number of rights available at a given time.[13] The intersection of this line with the demand schedule gives the composite "full" price, r_t^1, paid for CFCs in terms of their ozone depletion equivalents. This composite full price can be translated back to a full price for each CFC compound (in standard units) by dividing the composite full price by the ozone depletion index for the compound.

The result is illustrated in Exhibit I-10 for a single CFC market. In addition to the standard aggregate demand and supply schedules, a line representing the full price for this CFC compound is presented. The full price, p_t^1, is the price paid by users of the CFC for both the compound itself

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[12] The highly-concentrated CFC-producing industry could lead to a highly-concentrated market for permits. In such a case, the observed market price for the permits would be below their true value, and the transfer payments would flow to the holders of the permits instead of to the permit-issuing agency (presumed to be the government). Assuming that the same non-competitive market behavior exists both before and after the permits are auctioned, the assumption of a competitive market for permits does not bias the estimates of net social costs.

[13] The above discussion implicitly assumes that the number of permits issued is binding. In other words, the level of CFC use allowed under the permit scheme is lower than that in the absence of regulations. The permit scheme would otherwise be redundant and permits would have no value.

EXHIBIT I-9

MARKET FOR PERMITS IN OZONE DEPLETION EQUIVALENTS

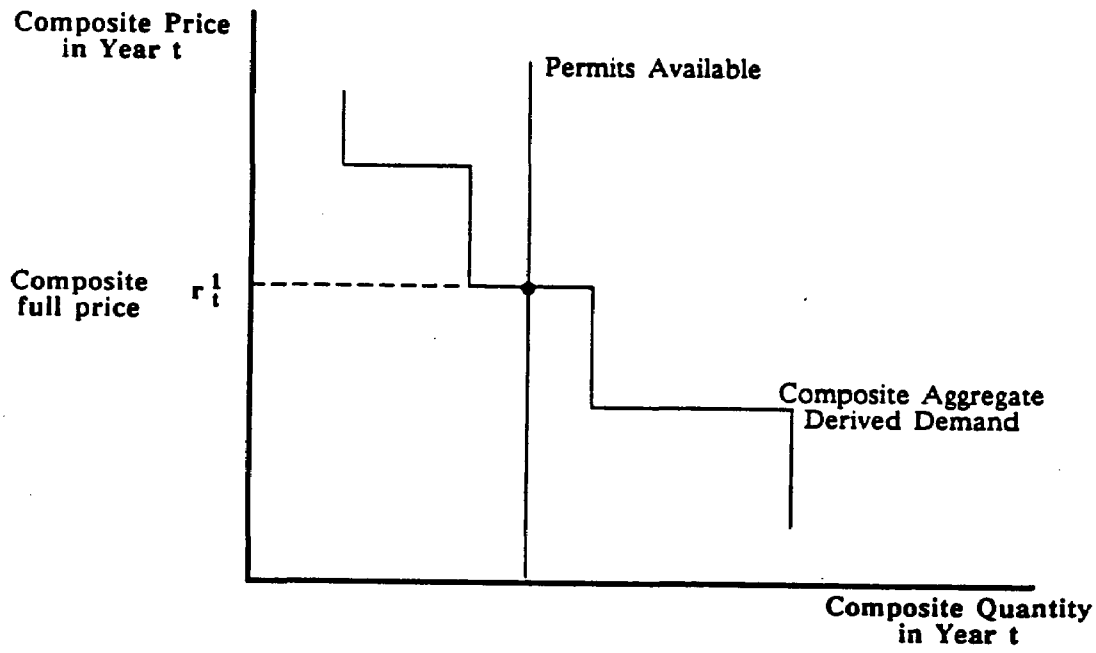
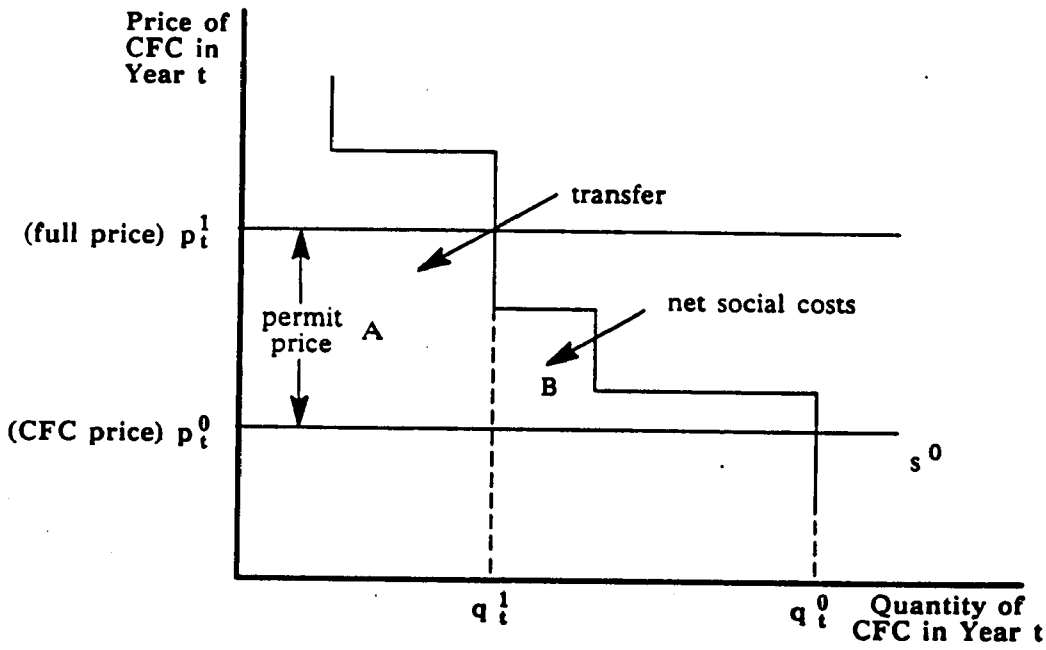


EXHIBIT I-10

SOCIAL COSTS OF AUCTIONED PERMITS FOR CFC USE



and the rights required to use it. The price of the CFC is given by p_t^0; this is the price received by the producers of the compound. The price of a right is equal to the difference between the full price and the price received by the producers.

The total amount spent on rights is given by the rectangular area A. This area is simply equal to the right price times the quantity of the CFC demanded at the full price. As in the case of a regulatory fee, the right payments represent a transfer from one firm to either another firm or to the government. As such, right payments are not counted as net social costs.

The net social costs of the right scheme are given by the irregularly shaped area B. These costs are borne by the same set of parties as those in the regulatory fee case. Once again, because of the horizontal supply curve for CFC and the assumption that price equals marginal cost, there are no losses experienced by the producers of CFC or the owners of the factors used in its production.

2.3 Allocated Quotas

Under the allocated quota alternative, producers and importers of CFCs would be issued quotas based on their historical market shares. They would then be allowed to trade these quotas among themselves. Like the auctioned rights, these quotas would be defined in terms of ozone depletion equivalents.

Conceptually, the allocated quota and auctioned rights alternatives are very similar. The major differences between them are: (1) allocated quotas are targeted specifically at producers/importers, whereas auctioned rights are also bought and sold by CFC users; and (2) quotas are initially issued free, whereas auctioned rights are auctioned off by EPA.

Because the allocated quotas can be traded, the analytical procedure for determining the social costs of allocated quotas is identical to that for auctioned rights. The differences noted above only affect the magnitude of the transfers under the two alternatives, and the parties across which they take place. In terms of the framework outlined in the previous section for measuring the costs of a auctioned rights scheme, the total number of quotas issued corresponds to the available number of rights and the quota price corresponds to the right price.

2.4 Command and Control Alternatives

The two major command and control alternatives being considered are:

- mandatory adoption by some industries of specific engineering controls; and

- bans on the use of CFCs in selected products.

The procedure for calculating the costs associated with the first alternative is straightforward. Because it is not necessary to first determine the response of the CFC-using industries to the regulations (unlike the case for the economic incentive based alternatives), the cost analysis entails tabulating and summing the social costs of implementing the required engineering controls.

The method for determining the costs of bans on CFC use in specific products is also straightforward. The costs can be determined by measuring the consumer surplus under the derived demand schedule of the industry producing the banned output. Exhibit I-11 depicts the derived demand schedule and associated consumer surplus for an industry manufacturing a banned product. To reduce CFC use in the product to zero, the industry must implement all the control options to the left of the one employed in the baseline. Hence, all consumer surplus in this market is lost. None of this loss is a transfer. Therefore, the costs of the regulation are equal to the baseline consumer surplus, represented by area A in Exhibit I-11.[14] As in the previous cases, the loss comes out of the producer surplus of the CFC-using industries and the consumer surplus of the buyers of their output.

3. EMPIRICAL APPROACH FOR ESTIMATING COSTS OF REGULATION

This chapter describes the manner in which the framework presented in the previous chapter was implemented to estimate the social and private costs of U.S. regulations aimed at reducing the domestic use of CFCs. To compute the social and private costs of regulations, demand schedules for CFCs were estimated that define the amount of CFCs that would be demanded in each of the major CFC applications (i.e., industries) at higher CFC prices. With these schedules, the costs of regulations that restrict domestic CFC use were estimated as changes in consumer and producer surplus.

The demand schedules were estimated from engineering cost data developed for EPA.[15] These engineering data describe the capital and operating costs of options for modifying the manner in which products are produced and/or used in order to reduce the use and/or emissions of CFCs. These options for reducing CFC use and/or emissions have been variously referred to as "control options, control possibilities, technical possibilities, and alternative technologies." In the previous sections of this appendix, the opportunities for reducing CFC use were discussed in terms of alternative "fixed proportion production technologies." In this chapter, all the above terms are considered to be interchangeable.

The data upon which the derived demand schedules are based describe the steps that firms may take in response to increased CFC prices. These steps include using alternative production methods, using alternative chemicals,

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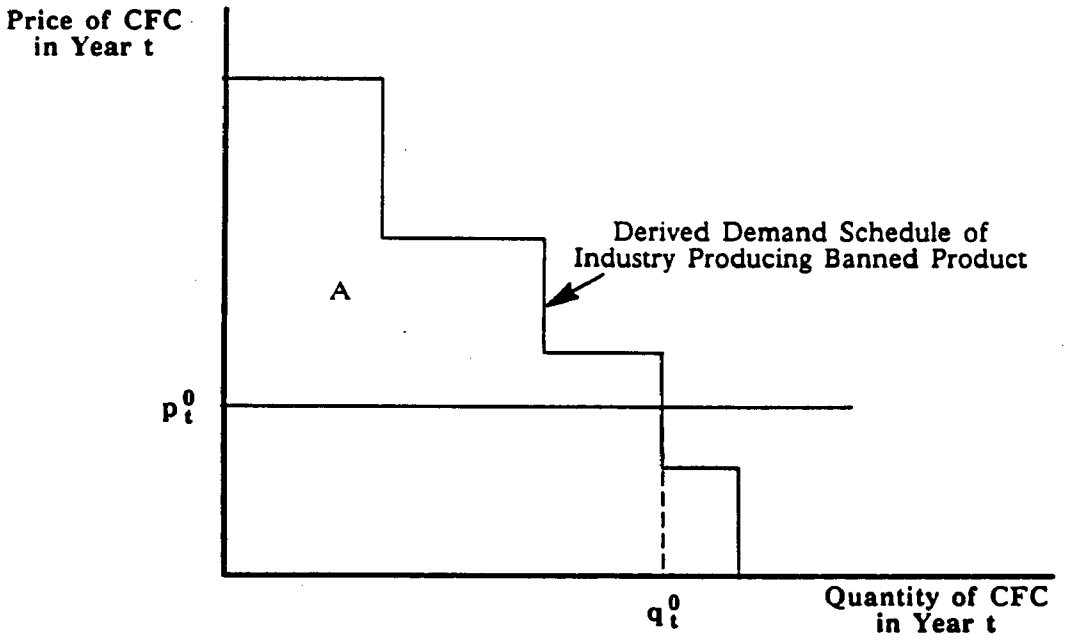
[14] Because the supply curve for CFCs is perfectly elastic, the price of CFCs does not change in response to the lower demand for CFCs resulting from the ban. Hence, there are no changes in non-banned markets. This would not be true if the supply curve for CFCs were upward sloping. It would then be necessary to examine non-banned markets.

[15] The engineering data are described separately in a series of addenda to the RIA, found in Volume III.

EXHIBIT I-11

SOCIAL COSTS OF A PRODUCT BAN



installing equipment to collect and recycle CFCs, and switching to non-CFC products. The increased prices of CFCs (caused by the restrictions imposed by the regulation) are assumed to drive the adoption of these steps by firms.

Based on the derived demand curves developed from the engineering data, social costs are evaluated using pre-tax costs discounted at a social discount rate. Private costs are evaluated using after-tax costs discounted using a private after-tax discount rate.

The steps used to estimate costs are as follows:

1. Identify Major CFC Applications. The major CFC applications were identified and divided into key product areas. The patterns of CFC use in each application were defined.[16]

2. Specify Control Possibilities Applicable in Each Application. A wide range of control possibilities was identified for each of the application categories. Some controls are available today, while others are expected to become available in the future. For each of the control possibilities, the potential cost of undertaking the control and the influence that the control may have on CFC use and emissions was defined.

3. Estimate CFC Use Reductions Achievable with Each Control Possibility. The annual reduction in CFC use that can be achieved if the control possibility were implemented was estimated for each control individually, using the 1985 pattern of use.

4. Estimate Annualized Costs of the Control Possibilities. Social and private annualized costs of the control possibilities were estimated from the capital and operating data provided. One-time costs (such as capital costs) were converted into equivalent annual costs using a standard annualization factor. The annualized costs were expressed in terms of dollars per kilogram of CFC use avoided by dividing the annualized cost estimate by the number of kilograms of CFC use that are avoided by implementing the control.

5. Construct Derived Demand Schedules for Each Application. Derived demand schedules were constructed for each application using subsets of the control possibilities. The subsets of the control possibilities were selected to represent groups of options that may be undertaken over time in response to increased prices of CFCs. The groups represent internally consistent sets of steps that may be undertaken within each of the applications.

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[16] The definitions of the CFC applications and their products are presented separately in addenda to the RIA, found in Volume III.

The general shape of these schedules is shown in Exhibit I-4. The height of each vertical step in the schedules represents the annualized costs of each control possibility (on a per kilogram basis). The width of each horizontal step represents the reduction in annual CFC use associated with the controls. Different schedules were developed for: (1) social and private costs, and (2) each year in the analysis period reflecting the expected future availability of control possibilities over time.

6. Aggregate Derived Demands for CFCs. The derived demand schedules for each of the applications were summed horizontally to estimate aggregate derived demand.

7. Estimate Private and Social Costs. The social and private costs of regulatory alternatives were computed by comparing the required reduction in CFC use to the aggregate derived demand schedule. The changes in consumer surplus were estimated using both the private and social derived demand schedules, resulting in estimates of the private and social costs of the required reduction.

Each of these steps is described below, followed by a description of major limitations.

3.1 Identify Major CFC Applications

The major uses of CFCs are in:

- refrigeration;
- foam blowing;
- fire extinguishing;
- solvent cleaning;
- sterilization; and
- miscellaneous applications.

For this analysis, these broad end-uses were divided into more detailed application categories that differentiate the types of products made with CFCs. A list of these applications is shown in Exhibit I-12 along with estimates of the 1985 CFC use in each.

The applications were defined as products (e.g., insulating foam) or services (e.g., metal cleaning). In some cases a single product is divided into separate applications. For example, two applications are defined for boardstock rigid polyurethane foams -- construction and industrial. Although the manufacturing processes and firms producing foams for both applications are similar, a division between the two was kept in order to capture possible differences in control options available for each.

EXHIBIT I-12

LIST OF CFC APPLICATIONS USED IN THE ANALYSIS

Application	Compound	1985 Use (million of kilograms)
FOAM BLOWING		
Rigid Polyurethane Foam		
Laminated-Construction	CFC-11	12.8
Boardstock-Construction-Bldg.	CFC-11	2.7
Boardstock-Construction-Ind.	CFC-11	0.2
Poured-Refrigeration	CFC-11/CFC-12	9.2
Poured-Packaging	CFC-11/CFC-12	3.4
Poured-Transportation	CFC-11/CFC-12	3.4
Poured-Construction-Bldg.	CFC-11/CFC-12	3.2
Poured-Construction-Ind.	CFC-11/CFC-12	0.5
Poured-Construction-Bldg.	CFC-11/CFC-12	8.0
Poured-Construction-Ind.	CFC-11/CFC-12	3.0
Sprayed-Transportation	CFC-11/CFC-12	1.3
Flexible Polyurethane Foam		
Slabstock	CFC-11	11.5
Molded	CFC-11	3.3
Phenolic Foam	CFC-11/CFC-113	1.4
Polypropylene Foam	CFC-11/CFC-114	1.9
Polyethylene Foam	CFC-11/CFC-114	3.1
PVC Foam	CFC-11/CFC-12	<0.1
Extruded Polystyrene Foam		
Sheet	CFC-12	6.3
Boardstock	CFC-12	3.0

EXHIBIT I-12 (continued)

LIST OF CFC APPLICATIONS USED IN THE ANALYSIS

Application	Compound	1985 Use (million of kilograms)
REFRIGERATION		
Mobile Air Conditioners	CFC-12	54.1
Retail Food	CFC-12	4.7
Cold Storage	CFC-12	2.6
Centrifugal Chillers	CFC-12	2.0
Refrigerators	CFC-12	1.8
Transport	CFC-12	0.7
Process Refrigeration	CFC-12	0.7
Freezers	CFC-12	0.5
Reciprocating Chillers	CFC-12	0.4
Dehumidifiers	CFC-12	0.3
Ice Machines	CFC-12	0.2
Water Coolers	CFC-12	<0.1
Vending Machines	CFC-12	<0.1
Centrifugal Chillers	CFC-11	5.5
Centrifugal Chillers	CFC-114	0.8
Centrifugal Chillers	CFC-500	0.9
Retail Food	CFC-502	6.2
Cold Storage	CFC-502	3.0
SOLVENTS		
Conveyorized Vapor Degreasing	CFC-113	18.1
Open Top Vapor Degreasing	CFC-113	15.9
Cold Cleaning	CFC-113	4.6
Dry Cleaning	CFC-113	1.4
STERILIZATION		
Hospitals	CFC-12	6.9
Medical Equipment	CFC-12	3.1
Contract Sterilization	CFC-12	1.3
Pharmaceutical	CFC-12	0.6
Spice Fumigant	CFC-12	0.2
Commercial R&D Labs	CFC-12	0.1
Libraries	CFC-12	<0.1
Non-commercial R&D Labs	CFC-12	<0.1
Animal Labs	CFC-12	<0.1
Bee Hive Fumigant--DOA	CFC-12	<0.1

EXHIBIT I-12 (continued)

LIST OF CFC APPLICATIONS USED IN THE ANALYSIS

Application	Compound	1985 Use (million of kilograms)
FIRE EXTINGUISHING		
Total Flooding Systems		
Civilian Electronic	Halon 1211	<0.1
Military	Halon 1211	<0.1
Civilian Flammable Liquid	Halon 1211	<0.1
Civilian Other	Halon 1211	<0.1
Civilian Electronic	Halon 1301	2.2
Military	Halon 1301	0.5
Civilian Flammable Liquid	Halon 1301	0.4
Civilian Other	Halon 1301	0.3
Portable Systems		
Civilian Electronic	Halon 1211	1.3
Military	Halon 1211	0.8
Civilian General	Halon 1211	0.2
Civilian Residential	Halon 1211	0.2
Civilian Flammable Liquid	Halon 1211	0.1
Military	Halon 1301	0.1
Locally Applied Systems	Halon 1211	<0.1
Locally Applied Systems	Halon 1301	<0.1
MISCELLANEOUS		
Skin Chiller/Cleaner	CFC-113	<0.1
Liquid Food Freezing	CFC-12	3.0
Blower Cleaner	CFC-12	0.9
Warning Devices	CFC-12	0.6
Heat Detectors	CFC-12	0.9
Whipped Topping Stabilizer	CFC-115	<0.1
Aerosol Propellant	CFC-11/CFC-12	9.5

Source: See addenda to the RIA, Volume III.

The applications cover all CFC use associated with manufacturing, installation, and use of the application.[17] Mobile air conditioners, for example, require CFCs during manufacturing, installation, and for replacing CFCs lost during product use. Manufacturing, installation and service use of CFCs are each analyzed within this application, recognizing that the control possibilities may influence each portion of the use separately from the other portions.

For some applications, the output produced can best be described as a "service." Examples include solvent and sterilization uses. For service uses, applications were defined by the entity performing the service (e.g., hospitals sterilizing surgical equipment) or the type of service being performed (e.g., conveyorized vapor degreasing).

3.2 Specify Control Possibilities Applicable in Each Application

Having identified the primary applications of CFCs, the next step was to define the set of control possibilities that may be undertaken for purposes of reducing CFC use within each application. The following types of control possibilities were identified:

- Product substitutes -- replace CFC-consuming products with non- (or less-) CFC-consuming substitute products. An example is substituting packaging materials manufactured using CFC-blown foam with paper-based packaging materials..

- Chemical substitutes -- replace CFCs used in the manufacture, installation, or use of products with less ozone depleting chemicals.

- Process substitutes and other controls -- process changes, use of add-on recovery/recycling equipment, and other kinds of controls for reducing CFC use or emissions (e.g., recovery of CFCs from existing products).

For the 74 applications identified in this analysis, a total of nearly 900 control possibilities were identified.[18] These controls form a "menu" of actions from which firms within each of the applications may choose to reduce their consumption of CFCs. Although the identification of control possibilities was designed to be as comprehensive as possible, additional options may be available that are not included in the data available for this analysis.

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[17] The available application data do not account for the total amount of CFC produced, imported, and exported in the U.S. The difference between the sum of the use across all the application data and the total amount produced is referred to as "unallocated use."

[18] The data on the control possibilities are documented separately in addenda to the RIA, found in Volume III.

Of note is that not all of the options identified are available immediately. For each control option an estimate was made of its expected future availability over time. The following definitions were used:

- short term -- available in 0 to 3 years;
- medium term -- available in 4 to 7 years; and
- long term -- available in more than 7 years.

Of the nearly 900 control possibilities identified, about 350 were excluded from further analysis because of factors that make the controls unacceptable for use by industry, including:

- risk/toxicity;
- technical feasibility;
- cost;
- effectiveness at reducing CFC use;
- enforceability; and
- insufficient data to evaluate the costs and reduction achieved by the substitute.

For the remaining approximately 550 control options identified, detailed estimates were prepared concerning the cost of undertaking the control and the possible reduction in annual CFC use achievable with the control over time. These factors were used to estimate the annualized cost of the control per kilogram of use avoided, which is used to estimate the appropriate derived demand schedules.

3.3 Estimate CFC Use Reductions Achievable with Each Control Possibility

The potential effectiveness of each control possibility to reduce CFC use was estimated within its application category based on three factors:

- the portion of the application for which the control is effective;
- the reduction potential of the control; and
- 1985 U.S. CFC use and emissions within the application.

The portion of the application for which the control is effective defines the segment of the application that may reduce its CFC use through the implementation of the control. For example, the mobile air conditioning application includes several types of use, including service use. The control being analyzed may be applicable for the service use segment of the application, but may not be applicable for the other segments. In this case, the control is analyzed as being capable of reducing only the climate service use, and the

other uses are assumed to be unaffected. This case is further refined in that the control may apply only to a portion of the service use segment (e.g., only larger automotive repair shops). In this case, the control is analyzed as being capable of reducing only a portion of the service use, and the remaining service use is assumed to be unaffected.

An alternative example is the case where a chemical substitute is estimated to be applicable to only a portion of the total application's use of CFCs. The portion for which the chemical substitute is not applicable may have certain product characteristics or manufacturing requirements that preclude the use of the substitute. In this case, the chemical substitute is assumed to be capable of replacing only the applicable segment of the application, and the non-applicable segment is assumed to be unaffected.

Reduction potential refers to the extent to which a control reduces CFC use in its applicable segment of the application. For example, recovery equipment used during mobile air conditioning servicing may result in a fraction of service use being recycled, thereby reducing total use in the application. In this example, only the fraction of the use that is recovered is counted as a potential reduction in compound use. The reduction potential is generally less than 100 percent for engineering controls. The reduction potential for chemical substitutes was assumed to be 100 percent (within the applicable segment of the application) because chemical substitutes generally result in a complete replacement of a CFC.[19] Similarly, the reduction potential for product substitutes is 100 percent.

The final factor considered is the use and emissions of the compound in the applications. The 1985 use in the application is divided into manufacturing use, installation use, service use, other use, and unallocated use. The total use in the application equals the sum of these component uses. The total use in some applications could not be allocated to manufacturing, installation, or service. In this case, an amount was identified as "other or unallocated," and unless specifically assumed otherwise, this portion of the use was assumed to be controllable to the same extent as the allocated portion of CFC use in that control option.

Emissions in 1985 are divided into emissions during manufacturing, installation, product use and servicing, product disposal, and "other" emissions. Engineering controls are assumed to reduce CFC emissions in these categories. As with unallocated use, "other" emissions were assumed to be controllable to the same extent as allocated emissions.

Given these definitions, the approach used to estimate the potential for control options to reduce CFC use differed by the type of control as follows:

- Product substitutes were assumed to reduce CFC use during the manufacturing and installation of CFC-consuming products they replaced. Therefore, the use reduction of product substitute controls was estimated by multiplying the 1985 compound use

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[19] Some of the chemical substitutes are themselves potential ozone depleters. The increase in the use of these compounds as a consequence of the undertaking of the control option is identified as well.

during manufacturing and installation in the application category by the estimated portion of the manufacturing and installation use to which the product substitute applies.

- Chemical substitutes may be capable of replacing CFC use in: (1) manufacturing and installing new products (e.g., making a new refrigerator) and/or (2) servicing existing products (e.g., replacing CFCs while servicing an old refrigerator). Therefore, separate use reductions were estimated for chemical substitutes in new products and in existing products. The use reduction associated with chemical substitute in new products was estimated by multiplying the portion of new production that may adopt the chemical substitute by the 1985 CFC use during manufacturing and installation. Similarly, for existing products, the reduction potential was estimated by multiplying the portion of existing products for which the substitute may be applicable by the 1985 CFC use for service existing products.

- For process substitutes, add-on engineering controls, and other kinds of controls, use reduction potentials were calculated as the sum of the reductions possible in each of the emissions categories. The separate emissions reductions estimates for the emissions categories (i.e., manufacturing, etc.) were multiplied by the 1985 emissions estimates to estimate the total.

The estimates of the portion of the application to which each control applies were allowed to change over time. A maximum level was defined, indicating the likely full extent to which the control would be implemented in the application, given time for the firms in the application to implement the controls. The time required to implement the controls was also estimated (and is generally on the order of 3 to 10 years), so that the estimated use reduction changes over time as the level of applicability of the control increases. For purposes of this analysis the increase in the applicability of the control over time is modelled using linear interpolation, so that the maximum likely penetration is reached in the time required for firms to adopt the control.

3.4 Estimate Annualized Costs of the Control Possibilities

For each control possibility, both social and private annualized costs were estimated. These annualized costs reflect the capital, operating, and other costs that are incurred when the control is undertaken. These costs are based on engineering estimates and are defined as the costs that are incremental relative to continuing to manufacture and use the CFC-related products in their current forms. The social costs reflect the total resource costs to society, and the private costs reflect the costs faced by firms, including appropriate adjustments for tax liabilities and costs of capital.

To enable the controls to be compared and analyzed in relation to a policy of restricting the use of CFCs, the annualized costs are expressed on a per kilogram of use avoided basis. This "per kilogram" estimate is made by dividing the annualized cost of undertaking the control by the amount of the compound use that may be reduced by the control. The resulting value (based on private

costs) is taken as an indication of the increase in the price of CFCs that would be required in order for firms to be indifferent between undertaking the control or continuing to use the CFCs. If the price of the CFCs exceeds this annualized value, the firm would be better off to reduce its use of CFC and undertake the control. Consequently, the cost estimates are designed to be used in the analysis framework described in the previous chapter, where derived demand schedules form the basis of the analysis.

The following types of costs were reported (where applicable) for each control possibility:[20]

- capital costs -- such as the acquisition cost of equipment required to convert production capacity to use substitute chemicals. Capital costs are one-time costs that are subject to depreciation.

- non-recurring costs -- transitional, one-time costs such as research and development, reformulation, or training required to implement a control. For purposes of computing private annualized costs, non-recurring costs were considered not to be depreciable.

- annual operating costs -- incremental materials, and labor required to implement the control.

- salvage of capital equipment -- residual value of equipment used to implement a control.[21]

- annual offsetting savings -- reduced expenditures due to lower use of CFCs and other factors.

In addition to the costs identified above, several special costs were reported for product and chemical substitutes:

- Product substitutes.

  -- the price differential between the CFC-using product and its replacement product was included as a cost (or possibly a savings); and

  -- for insulating foams, an estimate was made of the potential stream of annual energy losses caused by the use of less-well-insulating products.

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[20] Not all of these cost categories apply to all of the controls. Some chemical substitutes, for example, can be used without additional capital investment.

[21] A salvage value for necessary capital equipment was included in only a few instances.

- Chemical substitutes -- the expected future price per kilogram of CFC-replacing chemicals was estimated along with the amount of the substitute needed to replace a single kilogram of CFC.

All of these reported engineering-based cost estimates are on a before-tax, real basis in 1985 U.S. dollars.

3.4.1 METHODS FOR COMPUTING SOCIAL ANNUALIZED COSTS

Estimates of capital and non-recurring costs were annualized by multiplying these costs by:

$$\frac{r}{1 - [1/(1+r)]^t}$$

where r is the real social discount rate and t is the estimated economic life of capital. This factor is used to spread capital and non-recurring costs over the economic life of the capital to which a control is applied. The economic life of the capital equipment for each control was estimated, and ranged between 5 to 20 years.

Non-recurring costs (such as research and development costs) represent one-time costs which, in practice, will not be replicated in future years. Using this interpretation, such non-recurring costs should not be included in annualized costs because they will not recur at a constant scale (i.e., the costs only occur once, regardless of how long the control is undertaken). Nonetheless, non-recurring costs were included with capital costs so that the annualized cost estimates would reflect the full social costs of controls.

To compute total annualized costs, annualized capital and non-recurring costs were added to estimates of other annual pre-tax costs as follows:

- annual operating costs -- annual operating costs such as labor and utilities were added directly.

- salvage of control equipment -- few controls were expected to have salvageable capital. The present value of the salvage value of control equipment was estimated as:

  $$S * C/(1+r)^t$$

  where S is the percentage of capital costs estimated to be recoverable on salvage, C is the original capital cost, t is the useful life of capital, and r is the real social discount rate. This present value salvage amount was annualized in the same manner as described above for capital and non-recurring costs. The resulting annualized salvage value was then deducted from total annualized costs.

- annual savings -- the estimated annual savings due to reduced CFC use, operating efficiencies, or other factors associated with implementing a control were subtracted from total annualized costs.

In addition to these cost components, adjustments are required for product substitute and chemical substitute controls. For product substitutes, the differential costs of the products and their differences in lifetimes must be reflected.[22] The annualized cost associated with replacing one CFC-related product was estimated as:

$$-Pc + Ps * \frac{r/(1-(1/(1+r)^{ts}))}{r/(1-(1/(1+r)^{tc}))}$$

where: Pc = the 1985 price of the CFC-based product;
Ps = the 1985 price of the product substitute;
tc = the average useful life of the CFC-based product;
ts = the average useful life of the product substitute; and
r = real social discount rate.

This annualized cost was added to the annualized costs computed above.

For substitute insulating materials, the costs of reduced insulating capacity was reported in terms of the annual incremental energy costs experienced per metric ton of CFC-blown foam replaced. Because these energy costs occur during each year for which alternative insulating materials are used, annual energy costs were aggregated to reflect the stream of costs incurred over the useful life of the product as follows:

$$PV(E) = E * \frac{1-1/(1+r)^{t}}{r}$$

with r representing the real social discount rate, t the life of the CFC-blown foam product, and E the real before-tax annual energy penalty. This energy cost value was added to the annualized cost estimates described above.

The adjustment to the annualized cost estimate for chemical substitute controls was based on two factors: (1) the price of the chemical substitute compared to the price of the CFC it replaces and (2) the amount of substitute required to replace a unit of the CFC. These factors were combined to estimate the relative cost of replacing one kilogram of the CFC with the substitute as:

$$Ps * R - Pc$$

where Ps is the price of the chemical substitute, R is the number of kilograms of substitute required to replace one kilogram of the CFC, and Pc is the price of the displaced CFC. Separate estimates of R were made for chemical

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[22] The difference in the lifetimes of the CFC-related product and the substitute product must be incorporated so that the relative cost of switching to the substitute can reflect the costs over the full lifecycle of the products. If the substitute product lasts longer than the current CFC-related product, then the cost of switching is reduced; if the product life of the substitute is shorter, then the cost of switching is increased. In general, the reported lifetime differences were small, so that the lifetime adjustment had a small impact on the cost estimate.

substitutes in new and existing products. Annual chemical replacement costs were added to annualized capital, operating, and other costs of chemical substitutes (if any). As a final step, the annualized costs were adjusted to reflect differences in the basis for expressing the engineering cost estimates, which included:

- Costs reported for the maximum fraction of the application expected to take the control. In this case the cost estimates are based on the segment of the application expected to implement the control, and consequently no adjustment was required.

- Costs reported per unit of application (e.g., per metric ton of foam produced). In this case the costs had to be multiplied by the number of units (e.g., the number of metric tons of foam) expected to be affected by the control. The number of units was estimated as the total units in the application times the expected fraction of the application that could undertake the control.

- Costs reported as if the entire application adopted the control. In this case the costs were multiplied by the maximum fraction of the application expected to implement the control (if the entire application was expected to implement the control, then no adjustment was required).

Once these adjustments are made, the total annualized costs for the control are divided by the reduction potential for the control to produce a social annualized cost per kilogram of use avoided. Detailed examples of social annualized cost calculations are shown in Exhibits I-13 through I-15 for product substitute, chemical substitute, and add-on engineering control options.

3.4.2 METHODS FOR COMPUTING PRIVATE ANNUALIZED COSTS

For purposes of assessing firms' potential reactions to restrictions on CFCs, the costs faced by the firms must be estimated. These costs are referred to as private costs. As discussed in Section 1, private costs will differ from social costs because of tax effects, differences in discount rates, and possible differences in the kinds of costs incurred.

To estimate private costs, a discounted cash flow analysis was used. This cash flow analysis: (1) computes annualized before-tax costs using a before-tax private discount rate, (2) estimates incremental cash flows incurred by private entities including the effects of depreciation and taxes on cash flows, and (3) computes an annual cost as the net of all annualized cash flows.

In general, the methods used to compute private annualized costs follow those described to compute social annualized costs. The methods used to estimate private annualized costs are comprised of the following steps:

1. The magnitude and timing of pre-tax costs (i.e., capital and operating costs) were specified. Assumptions regarding the timing of the costs and expenses (relative to the initiation of the control) are:

EXHIBIT I-13

EXAMPLE SOCIAL COST ESTIMATE FOR A PRODUCT SUBSTITUTE

Control Description: Fiberglass Batts -- Use Fiberglass as an alternative insulating material

Application Category: Rigid Polyurethane Foam -- Boardstock Building Construction

Ozone-Depleting Compound: CFC-11

1. Estimated Use Reduction Potential for Application Category

	CFC-11 Use in 1985 (Metric Tons) *	Market Penetration (Percent) =	Use Reduction For Application (Metric Tons)
During Manufacturing	2,700	10	270
During Installation	0	10	0
During Product Use or Servicing	0	--	--
Other Use	0	--	--
Unaccounted For	0	--	--
TOTAL	2,700		270

2. Estimated Annualized Costs per Metric Ton of Foam Replaced

				Annualized Costs ($)
Capital Cost	0	* 0.062 a/	=	0.00
Annual Operating Cost			=	0.00

a/ Represents annualization factor used to spread capital costs. Calculated as:

$$0.02/(1-(1/(1+0.02)^{20})) = 0.062.$$

EXHIBIT I-13 (continued)

EXAMPLE SOCIAL COST ESTIMATE FOR A PRODUCT SUBSTITUTE

				Annualized Costs ($)
Salvage of Capital				
	0 %	Salvageable Capital		
x	$ 0	Capital Cost		
x	0.673 b/			
x	0.062 c/		=	0.00
Product Substitution Costs				
+	$11,820	Price of Fiberglass Required to Replace One Metric Ton of Rigid PU Foam		
x	1.0 d/			
=	$11,820			
-	$4,600	Price per Metric Ton of Rigid PU Foam	=	$7,220
Present Value Energy Cost				
	$0	Annual Energy Cost		
x	31.42 e/		=	$ 0
	TOTAL ANNUALIZED COST			$7,220

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b/ Present value factor calculated as: $1/(1+0.02)^{20} = 0.673$

c/ See footnote a/.

d/ Factor that accounts for differences in useful lives of fiberglass and rigid polyurethane foam in this application. In this case, the lives are the same, so the factor equals 1.0.

e/ Annuity factor calculated as: $(1-1/(1+0.02)^{50})/0.02 = 31.42$ where 50 years is the estimated useful life of fiberglass board.

EXHIBIT I-13 (continued)

EXAMPLE SOCIAL COST ESTIMATE FOR A PRODUCT SUBSTITUTE

3. Cost Adjustment to Industry-Wide Values

	19,100	1985 U.S. Consumption of Rigid PU Foam for Application (Metric Tons)
X	10%	Estimated Market Penetration for Fiberglass
=	1,910	Metric Tons of Rigid PU Foam Potentially Replaced
X	$ 7,220	Annualized Cost Per Metric Ton of Foam
=	$13.8 Million	

4. Annualized Cost Per Kilogram of CFC Use Reduction

$13.8 Million	Adjusted Annualized Costs
270,000	Use Reduction for Application (Kilograms)

Social Annualized cost Per Kilogram = $51

EXHIBIT I-14

EXAMPLE SOCIAL COST FOR A CHEMICAL SUBSTITUTE

Control Description: FC-123

Application Category: Rigid Polyurethane Foam Boardstock -- Building Construction

Ozone-Depleting Compound: CFC-11

1. Estimated Use Reduction Potential for Application Category

	CFC-11 Use in 1985 (Metric Tons)	*	Market Penetration (Percent)	=	Use Reduction For Application (Metric Tons)
During Manufacturing	2,700		90 a/		2,430
During Installation	0		90 a/		0
During Product Use or Servicing	0		0 b/		0
Other Use	0		0 b/		0
Unaccounted For	0		--		--
TOTAL	2,700				2,430

2. Estimated Annualized Costs per Metric Ton of Foam Replaced

					Annualized Costs ($)
Capital and non-recurring Cost	92	*	0.062 c/	=	5.70
Annual Operating Cost				=	0

a/ Estimated market penetration for new products.

b/ Estimated market penetration for existing products. Not relevant for foams.

c/ Annualization factor used to spread capital and non-recurring costs. Calculated as:

$$0.02/(1-(1/(1+0.02)^{20}))=0.062.$$

Note in this example all costs are non-recurring reformulation costs, and no capital costs are expected.

EXHIBIT I-14 (continued)

EXAMPLE SOCIAL COST FOR A CHEMICAL SUBSTITUTE

				Annualized Costs ($)
Salvage of Capital				
	0 %	Salvageable Capital		
x	$ 0	Capital Cost		
x	0.673 d/			
x	0.062 e/			0.00

Chemical Substitution Costs

	New Products	Existing Products	
	4.14	NA	Price of FC-123
x	1.25	NA	Kilograms of FC-123 Blowing Agent Needed to Replace 1 Kilogram of CFC-11
=	5.18	NA	
-	1.41	NA	Price of CFC-11 ($/kg)
=	3.77	NA	Cost of Substituting 1 kg of CFC-11
x	1.41 f/	NA	
=	531.57	NA	

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d/ Present value factor calculated as: $1/(1+0.02)^{20} = 0.673$

e/ See footnote c/

f/ Estimated number of kilograms of CFC-11 used per metric ton of foam.

EXHIBIT I-14 (continued)

EXAMPLE SOCIAL COST FOR A CHEMICAL SUBSTITUTE

Total Annualized Costs (New Products)	537.27
Total Annualized Costs (Existing Products)	NA

3. Cost Adjustment to Industry-Wide Values (New Products Only)

	19,100	1985 U.S. Consumption of Rigid PU Foam for Application (Metric Tons)
x	90%	Market Penetration for FC-123
=	17,190	Metric Tons of Foam
x	$537.27	Annualized Cost Per Metric Ton of Foam
=	$9.2 million	

4. Annualized Cost Per Kilogram of CFC Use Reduction

	$9.2 million	Adjusted Annualized Costs
	2,430,000	Use Reduction for Application (Kilograms)
=	$3.80	Social Annualized Cost per Kilogram

EXHIBIT I-15

EXAMPLE SOCIAL COST ESTIMATE FOR AN ADD-ON ENGINEERING CONTROL OPTION

Control Description: Vertical Foam Chamber with Carbon Absorption and Recovery*

Application Category: Flexible Polyurethane Foam -- Slabstock

Ozone-Depleting Compound: CFC-11

1. Estimated Use Reduction Potential for Application Category

	CFC-11 Emissions in 1985 (Metric Tons)	x	Market Penetration (Percent)	x	Estimated Control Effectiveness (Percent)	=	Use Reduction For Application (Metric Tons)
During Manufacturing	11,500		2		60		138
During Installation	0		0		0		0
During Product Use or Servicing	0		0		0		0
During Product Disposal	0		0		0		0
Other Use	0		0		0		0
Unaccounted For	0		--		--		--
TOTAL	11,500						138

2. Estimated Annualized Costs for All Industry

					Annualized Costs ($)
Capital Cost	155,000,000	x	0.062 a/	=	9,610,000
Non-Recurring Cost	57,500,000	x	0.062 a/	=	3,565,500
Annual Operating Cost				=	21,000,000

*Note: This control is used here to illustrate the method used to estimate costs. It is not anticipated that this control is likely to be undertaken in response to regulations on CFCs.

a/ Annualization factor used to spread capital costs. Calculated as:

$$0.02/(1-(1/(1+0.02)^{20})) = 0.062.$$

EXHIBIT I-15 (continued)

EXAMPLE SOCIAL COST ESTIMATE FOR AN ADD-ON ENGINEERING CONTROL OPTION

			Annualized Costs ($)
Salvage of Capital			
	10 %	Salvageable Capital	
x	155,000,000	Capital Cost	
x	0.673 b/		
x	0.062 c/	=	-647,000 d/
Annual Offsetting Savings			-8,000,000
		TOTAL	25,528,000

3. Cost Adjustment to Industry-Wide Values

	$25,528,000	Annualized Costs
x	2%	Market Penetration
		= $ 510,560

4. Annualized Cost per Kilogram of CFC Use Reduction

$ 510,560	Adjusted Annualized Costs
138,000	Use Reduction for Application (Kilograms)

Social Annualized cost per kilogram = $3.70

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b/ Present value factor calculated as: $1/(1+0.02)^{20} = 0.673$

c/ See footnote a/

d/ Negative cost.

- capital and non-recurring costs occur in year 0;
- capital salvage occurs at end of the capital's operating life;
- depreciation expense occurs over seven years; operating costs and offsetting savings are incurred during the technical substitute's operating life.

2. Total pre-tax costs were calculated for each year over the control's operating life.

3. Taxes were applied to costs incurred after year 0 by multiplying the costs by (1-tax rate). Annual offsetting savings were also multiplied by (1-tax rate).

4. Depreciation was "added back" to net after-tax costs to account for the tax savings attributable to this non-cash expense.

5. The stream of after-tax cash flows was discounted using the private cost of capital to compute a net present value of the costs of the control over its entire life.

6. The present value of the after-tax costs was annualized using the private cost of capital as the discount rate. This present value is then divided by the total reduction in CFC use that can be achieved by the control to produce an annualized private cost per kilogram of use avoided.

Taxes were calculated using a marginal total tax rate of 44 percent. This rate includes a federal corporate income rate of 34 percent and an assumed average state tax rate of 10 percent. Investment Tax Credits (ITCs) were assumed not to be available. After-tax cash flows arising from capital salvage were calculated by multiplying pre-tax salvage by (1-tax rate). A tax loss was included on undepreciated capital whenever the depreciable life exceeded the operating life of capital.

Annual depreciation expense was calculated using the straight line method over seven years. This assumption is conservative because depreciation expenses occur uniformly over the depreciation period, whereas accelerated depreciation methods produce tax benefits in earlier years. Because depreciation is based on initial acquisition costs, annual depreciation expense was deflated by an inflation index to calculate real depreciation. An inflation rate of 4 percent was used.

To select the appropriate rate of private discount, the available literature was surveyed.[23] As was the case for the social rate of discount (see Appendix H), little consensus existed among the experts who have studied this problem. The range of estimated values for the real rate of return on private investments was from 4 to 9 percent. Accordingly, 6 percent was selected as a median estimate.

This range of estimates agrees well with the cited range for the rate of social discount. One would expect the private rate to be from 2 to 5 percentage points higher than the social rate because of (a) the taxation of private income and (b) the need for society to subsidize capital formation to provide for future generations.

The costs of energy losses due to reduced insulating abilities of product substitutes may not be incurred by firms. Instead, these costs (or a portion of these costs) may be incurred by consumers if the reduced insulating value of the product substitutes is not capitalized into their market price. The analysis assumes that the reduced insulating value of the substitutes is capitalized into the price of the substitutes, meaning that consumers are left unaffected, and the firms making the substitutes "incur" these costs. The importance of this baseline assumption may be explored through sensitivity analysis by varying the portion of these costs incurred by firms, and the portion incurred by consumers.[24]

3.5 Construct Derived Demand Schedules for Each Application

Based on estimates of social and private annualized costs and reduction potentials for control possibilities, two derived demand schedules for CFCs (social and private) were constructed for each application. The demand schedules reflect the amounts of reduction that the controls can achieve and the annualized cost per kilogram of achieving them.

Of particular importance in developing these demand schedules is that the individual control possibilities be aggregated in a proper manner, so that compatible controls are adopted over time. To specify the set of compatible

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[23] Studies surveyed included Jacob Stockfish, "The Interest Rate Applicable to Government Investment Projects," in Program, Budgeting and Benefit Cost Analysis, Hinrichs and Taylor (eds.); Daniel Holland and Stewart Myers, "Profitability and Capital Costs for Manufacturing Corporations and All Nonfinancial Corporations," American Economic Review, May 1980; Barbara Fraumeni and Dale Jorgenson, "Rates of Return by Industrial Sector in the United States, 1948-1976," American Economic Review, May 1980; William Brainard, John Shoven and Laurence Weiss, "The Financial Valuation of the Return to Capital," Brookings Papers on Economic Activity, 1980; Robert Lind, "A Primer on the Major Issues Relating to the Discount Rate for Evaluating National Energy Options," in Discounting for Time and Risk in Energy Policy, Resources for the Future, 1982.

[24] This issue does not arise in the computation of social costs because the distribution of the costs (i.e., between manufacturers and consumers) is not considered.

controls, the full list of control possibilities for each application was examined, and a subset of likely controls was identified. This subset is referred to as a control plan.

The choice of options to include in the control plan is uncertain and somewhat subjective. The key factors considered in developing the control plans were: technical feasibility and expected availability; cost; potential impacts on product quality; and internal consistency both within each year (i.e., substitutes may be mutually exclusive) and across time (i.e., firms may decide not to undertake controls available today in anticipation of other, preferred controls becoming available later). For example:

- although several potential chemical substitutes may be feasible, only one chemical substitute is likely to be used, particularly if different process modifications are required to use each of the substitutes;

- some controls are likely to be used in tandem, requiring the analysis to ensure equal adoptions of each; and

- two (or more) controls may be mutually exclusive, meaning that only one is likely to be undertaken.

In general, the development of the control plan reduced the menu of likely controls from the total of about 550, to about 350. The number of control possibilities per application generally ranges from about three to ten. These three to ten control possibilities were used to construct the derived demand schedule for each of the applications.

The control possibilities in the control plan for each application were then ordered from least to most costly based on the private annualized cost, representing the assumption that the available least costly controls would be undertaken first. Then the use reduction potential over time for each of the controls was modified to reflect the impacts of the controls being taken in a group. (The use reduction estimates described above in section 3.3 were estimated based on the assumption that the controls were taken individually.)

For controls that are independent, the least expensive control was assumed to achieve its full use reduction potential. More costly controls are modeled to result in less reductions, because the cheaper controls have already reduced the total use in the application. In general, the more expensive controls are assumed to apply only to the portion of the application not affected by the cheaper controls.[25]

Because the various controls are estimated to become available over time, and because each control requires time to penetrate the market and become implemented, the potential reductions that can be achieved increase over time.

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[25] Several exceptions to this procedure were implemented in cases where the control plans specified that the separate controls applied to different segments of the application in a manner that results in the full reduction potential of each being achievable.

Based on these estimates, the private and social derived demand schedules for each application can be drawn. The private derived demand schedule is drawn first because the private costs determine the order of the controls in the curve. As shown in Exhibit I-16, the horizontal steps in the demand schedule represent the reduction in annual CFC use associated with the controls. The vertical steps are the annualized costs per kilogram of undertaking the controls. The private derived demand schedule slopes downward because the controls are ordered from least to most costly.

Also shown in Exhibit I-16 is the fact that the derived demand schedule shifts over time. As additional controls become available and may be implemented, the level of reduction that can be achieved increases. Therefore, the curve appears to shift downward over time.

Exhibit I-17 displays a social derived demand schedule. The format for the curve is the same, but it need not be downward sloped because the order of the controls is defined by the private costs.

3.6 Aggregate Derived Demand for CFCs

The social and private aggregate derived demand schedules for all the CFCs being controlled as a group were estimated by: (1) summing the derived demand schedules from all the applications within each compound to create aggregate compound derived demand schedules; and (2) aggregating across compounds by scaling according to the ozone depletion potential of each. The results are social and private aggregate derived demand schedules that relate total demand for all the ozone depleting compounds to their price (expressed in ozone depleting potential units as well).

These aggregate derived demand schedules are analogous to the individual application schedules and have the same general shape. The primary difference is that the aggregate schedule is expressed in terms of ozone depleting potential, and there are many more steps.

3.7 Estimate Social and Private Costs

The social and private costs of restricting the use of CFCs is estimated by identifying the appropriate area under the derived demand schedule as described in Section 1. For each year of the analysis, the appropriate aggregate derived demand curve is first identified. Then the level of reduction required by the policy in that year is identified. The level of reduction is equal to the percentage change from the baseline level of CFC use (that would occur in the absence of the controls) that is required. Because the level of CFC use is generally expected to increase in the absence of regulatory requirements, even a freeze in the amount of allowable CFC use at, say, 1986 levels will require a reduction in use over time. Because baseline CFC use is expected to grow, the required amount of reduction will also grow.

The level of reduction required is used to identify which controls in the aggregate derived demand schedule must be undertaken. For example, Exhibit I-18 displays the requirements of a 20 percent reduction. All the controls that fall to the right of the line marked "quota" are simulated to be needed to reach the

EXHIBIT I-16

EXAMPLE OF A PRIVATE DERIVED DEMAND SCHEDULE

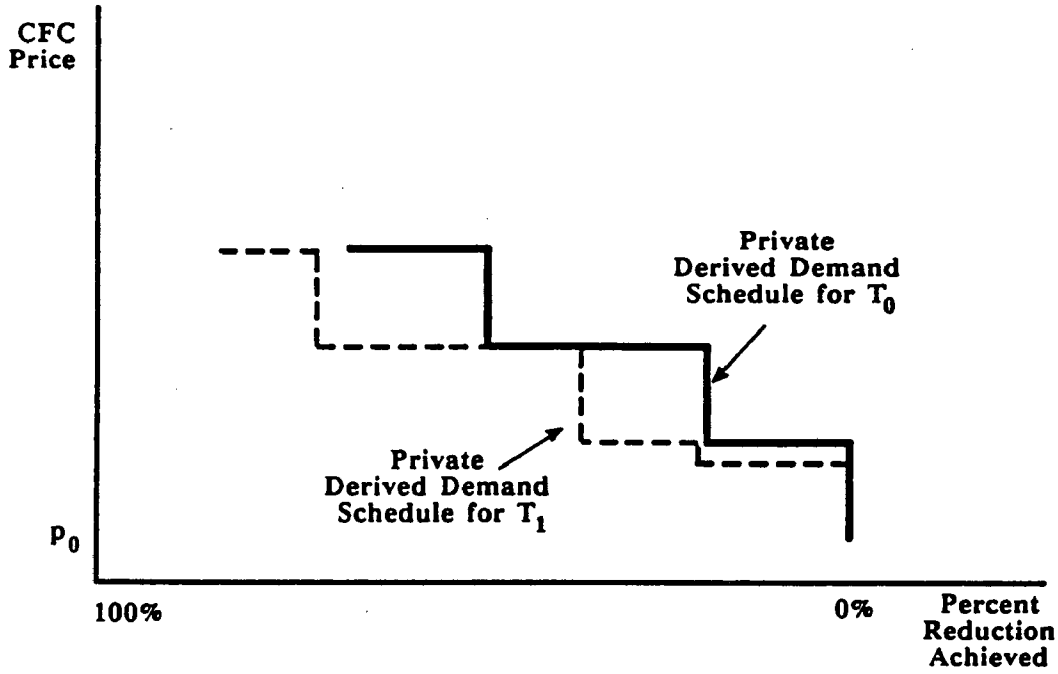
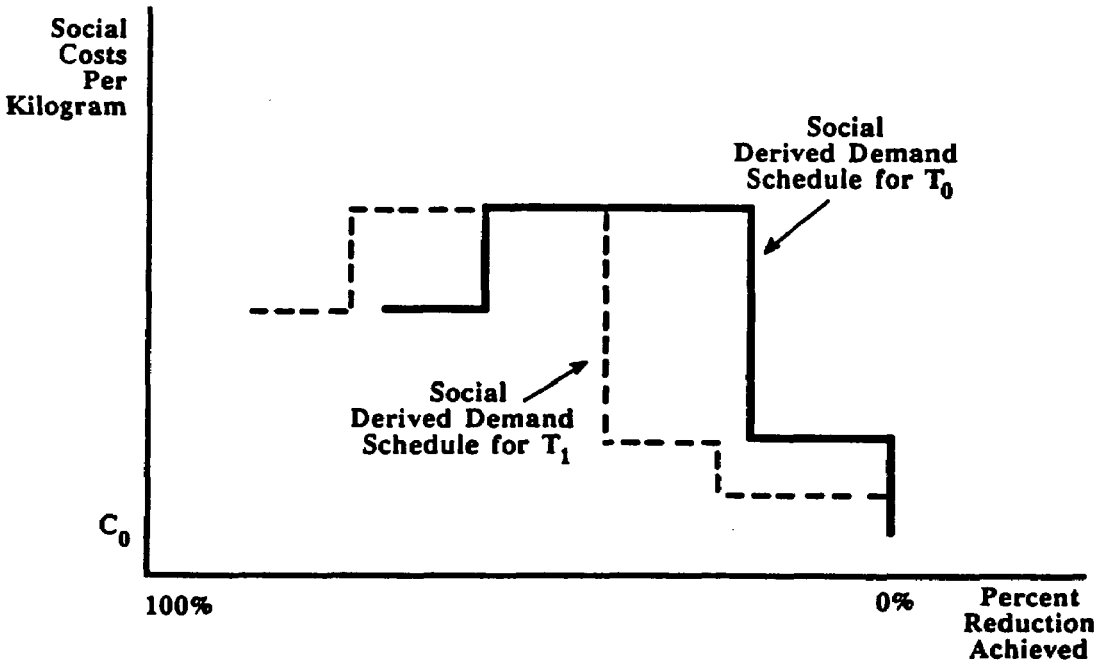


EXHIBIT I-17

EXAMPLE OF A SOCIAL DERIVED DEMAND SCHEDULE



desired 20 percent reduction. These controls may fall in any number of applications, and some applications may be simulated to undertake no controls at all (at this level of reduction).

As shown in the exhibit, the quota may fall in the middle of a horizontal step. For purposes of analysis, it is assumed that the entire control represented by that step will be undertaken. In this case, the actual reduction achieved will exceed the desired reduction. The "over reduction" is expected to be small, however, because the reductions achievable with individual controls are small relative to the total use of the compounds.

The area labeled C in Exhibit I-18 is used to estimate the private cost of achieving the 20 percent reduction (an analogous area exists on the social derived demand schedule for purposes of estimating social costs).[26] An analogous calculation is made using the social derived demand curve for purposes of estimating the total social costs.

Exhibit I-18 also identifies the transfer payments made by firms as the result of the restriction in CFC production. The increased cost per kilogram that results is given by P(1), the simulated resulting price, minus P(0), the original price. This cost is equal to the incremental cost of the most costly control simulated to be taken in that year. This value times the remaining CFC use (in this example, 80 percent of the baseline use) gives the estimate of the transfer payments.[27]

The implications for each application can also be evaluated by breaking the aggregate derived demand curve back into its individual components. The costs of the controls that are simulated to be taken within each application can be estimated, along with the level of reduction achieved and the transfer payment. To compute the transfer payment for an application, the most costly control simulated to be taken in the aggregate derived demand schedule is used, and not the most costly control simulated in the application derived demand schedule. As noted above, the level of reduction may vary across the applications.

By breaking the aggregate derived demand curve into its individual components, the level of chemical substitute use can also be estimated. This level is of interest because it depends upon the simulated availability of potentially new compounds that are currently under development.

This method of analyzing a reduction in use can also be applied to the evaluation of a fee or a command and control policy. The fee is evaluated by identifying the intersection of the fee level with the derived demand curve. In Exhibit I-18 the fee level would be equal to P(1) minus P(0), and the cost of the reductions associated with the fee would be the same as the cost of the quota.

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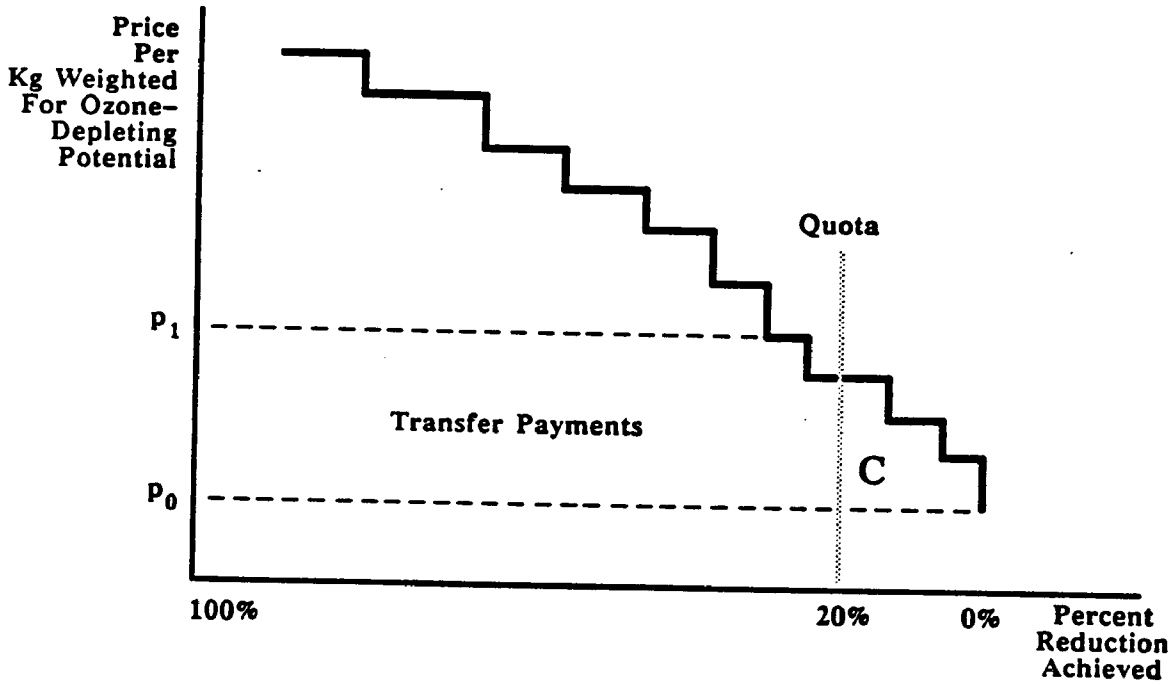
[26] Note that the calculation is made on an aggregate basis. The cost of the reduction is multiplied by the number of kilograms reduced. This method assumes implicitly that the mix of uses in the baseline remains unchanged.

[27] Transfer payments are only estimated using the private derived demand schedule. The transfers are not considered to be social costs.

EXHIBIT I-18

EXAMPLE OF A PRIVATE COST ESTIMATE USING THE PRIVATE DERIVED DEMAND CURVE



To evaluate a command and control option, the controls required are arranged into a derived demand schedule, and the area beneath it is used to estimate social and private costs. Because the controls are not simulated to be undertaken in response to increased prices for CFCs, there is no transfer payment in the command and control evaluation.

4. LIMITATIONS

The methods used to assess the social private costs of proposed restrictions on CFC use are limited in terms of the data available and the manner in which the method is applied. The primary limitations of the data include:

- Identification of Control Possibilities. By definition, only those control possibilities that are currently known are included in the analysis. It is likely that as the prices of CFCs rise in response to the constriction of supply that additional control possibilities will be identified. The inability to incorporate unknown control possibilities biases the estimates of costs upward, although the extent of the bias is not known.

- Aggregation of Control Possibilities. The aggregation of the control possibilities to reflect the impacts of taking groups of controls is subjective. Alternative views of aggregation could lead to alternative estimates of control costs and achievable reductions.

- Uncertainty Surrounding New Chemical Substitutes. Many of the data estimates are very uncertain, and consequently ranges of values are used, and sensitivity analysis is performed. Nevertheless, the uncertainty surrounding the data describing the new chemical substitutes has a large influence on the cost estimates produced. The areas of uncertainty primarily include the timing of availability of the new chemical substitutes (which has a large influence on the level of reductions that can be achieved), the cost of the new chemical substitutes, and the extent to which the new chemical substitutes can be used in existing products.

- Unallocated Use. A significant portion of current CFC use cannot be allocated to specific applications. Therefore, there are no specific methods identified for controlling these uses. The analysis addresses this problem by assuming that the costs of controlling this unallocated use are similar to the costs of controlling the allocated use. As a sensitivity, the unallocated use may be assumed to be uncontrollable. Because the unallocated use must be controllable at some cost, the sensitivity analysis must be biased upward. The potential bias of the base assumption is not known, although the fact that the use is not easily identifiable may imply that it is more difficult to control than the identified use. If this is the case, then the base assumption is biased downward.

Another set of limitations of the method used relates primarily to the aggregate manner in which the control data are applied. The aggregate derived demand curve indicates the levels of reductions that can be achieved at various levels of costs. The costs are expressed on a per kilogram basis, and are estimated based on 1985 values. The method implicitly assumes that the controls are divisible (i.e., there are no major economies of scale) and that they can be phased in over time. Further, because the estimates are based on 1985 data, the potential changing mix of uses (in the absence of controls) is not reflected. Because the implementation of individual pieces of equipment are not tracked over time, the implications of this aggregate approach cannot be assessed.

The method also assumes that the primary mechanism driving the allocation of CFCs across competing uses is price. Although this is a standard assumption for analyses of this type, other factors (such as the relationship between producers and their customers) may influence the allocation of CFCs. To the extent that CFCs are not allocated based on price, the estimates of costs will be biased downward. A related assumption is that manufacturers implement the least costly control options. If more costly controls are undertaken, the cost estimates are also biased downward. The implications of the least costly controls not being taken is evaluated by "omitting" sets of inexpensive controls from the menu of control possibilities. (See Chapter 9 of Volume I.)

Two types of costs not considered are transition costs and risks. Transition costs (e.g., temporary unemployment or premature retirement of capital equipment) are generally small over the long-term, but may be important when reductions are initially required. Because significant phase-in times are contemplated, transition costs are likely to be small. Also many of the control options are compatible with existing equipment (thereby avoiding the premature retirement of capital).

The additional risks posed by the control options have not been evaluated. Numerous options were deleted from consideration due to risks, so that the options used in the analysis may not result in significant risks. However, some examples of risks are evident, and additional analysis to assess these risks may be warranted.[28]

A key assumption is that the demand for the services provided by the CFC-related products is sufficiently inelastic and the portion of the products' costs accounted for by CFCs is sufficiently small that the reductions in end useproduct demand that result from increased prices of CFCs can be ignored. This is probably a reasonable assumption in most cases. The implications of the assumption are that more controls are simulated to be taken than would otherwise be the case, and social costs are biased upward.

Finally, the analysis assumes that the CFC supply curve is horizontal and CFC prices equal their marginal costs. This assumption results in no estimates of lost producer surplus in the CFC market. If the price of CFCs exceeds

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[28] For example, pentane is listed as an alternative blowing agent. Although the costs of equipment to address its potential fire hazard are included in the cost estimates, the potential impact of pentane emissions on smog conditions has not been evaluated, except as it adds costs to that option.

marginal cost, and if the supply curve for CFCs is not horizontal in the relevant range, then the social cost estimates are biased downward.