Measuring The Impacts Of Environment Canada's R&D: A Case Study of Stratospheric Ozone Depletion Research

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MEASURING THE IMPACTS OF ENVIRONMENT CANADA'S R&D

CASE STUDY: STRATOSPHERIC OZONE DEPLETION RESEARCH

– Final Report –

Submitted to:

Environment Canada

Submitted by:

Marbek Resource Consultants

In Association with:

Wintergreen Consulting

May, 1998

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EXECUTIVE SUMMARY

Background and Objectives

Environment Canada retained the services of Marbek Resource Consultants and Wintergreen Consulting to help identify, describe and measure the impacts of Environment Canada (EC)'s Research and Development (R&D).

The project is one of eight projects included in the *Business Plan for Managing R&D at Environment Canada, 1996 to 1997* and responds, in part, to the 1994 *Auditor General's Report* and the 1996 *Federal Strategy for Science and Technology*, which suggested a need for increased accountability for R&D results. The project is directed by a Steering Committee composed of members of each of the Department's Services.

The objectives of the project are to provide a documented evaluation of the impacts of two programs and to validate an approach to the evaluation of such impacts. The two chosen programs are: pulp and paper effluent R&D and stratospheric ozone depletion R&D.

In choosing two different projects, the Steering Committee sought to examine research activities with different characteristics. In the case of pulp and paper, research was focused on the content of imminent regulations whereas, in the case of ozone, the research contributed to an international effort leading to global action. The case studies also represent efforts of two different research groups within the department and different aspects of the environment. By selecting case studies with these different characteristics, it was hoped to learn more about the feasibility and approaches to measuring the impact of R&D.

This report documents the impacts of the stratospheric ozone depletion R&D conducted by the Atmospheric Environment Service (AES) of Environment Canada.

Approach

The heart of the approach taken by the Project Team was the development of an "Impact Map", which is a graphical representation of the linkages between the outputs of the R&D and the various policy and behavioural changes leading to ultimate impacts and socio-economic implications. The aim was to provide an explicit and transparent description of the chains (or threads) by which the impacts of the R&D are realized. In the process of developing the Impact Map, certain impact threads were identified as priorities for analysis, because of the likelihood of significant impact or the likelihood that those impacts could be credibly identified.

The significant impact threads were explored through interviews of key individuals who where involved in the application of the R&D results and through the review of reference documents.

The analysis focused on developing the following:

- A best estimate of the contribution of AES to various research results, including contributions to Canadian positions and effectiveness in international negotiations (together with reasonable high impact and low impact scenarios).

- A best estimate of the incremental impact of the various results in terms of regulations, emissions of ozone depleting substances, behavioural change, exposure to UV radiation, markets and costs (for each scenario).

- An assessment of the health, environmental and socio-economic implications of those incremental impacts.

Although there is significant uncertainty associated with the results, it is believed that, at a minimum, they provide a good indication of the value for money of the R&D and can be used, albeit with caution, in science policy and planning.

Description of the Stratospheric Ozone Depletion Research Program

The goals of AES' Stratospheric Ozone research are:

- *To contribute to global understanding of stratospheric ozone science in order to reduce uncertainties.*

- *To provide scientific advice to the Minister and Department of Environment concerning potential domestic and international policies and programs.*

- *To provide information to Canadians so they can adapt to changing levels of ultraviolet radiation.*

The Canadian R&D on stratospheric ozone depletion emerged from more general climate-related work on conditions in the stratosphere. Canada began total ozone measurements at five stations in the early 1960s.

In concert with other countries, Canada responded to the evidence of the danger of CFCs by significantly expanding the research and monitoring program in the mid 1970s. From the mid 1970s and continuing into the 80s and 90s, the goals of the program became more focussed on providing the scientific knowledge necessary to understand and respond to the problem. In particular, Canadian efforts were directed towards monitoring trends in Canada and sharing their results with the world community, in order to gain the information needed to advise the government on the international negotiations towards a control protocol.

Beginning in the late 1980s and early 1990s, AES responded to public concerns by directing efforts to the dissemination of information (including forecasts) on ozone depletion and UV radiation for public consumption.
The results achieved include:

- Measurement technology.
- Ozone and UV measurements.
- Operation of the World Ozone and UV Radiation Data Centre.
- Identification of UV and ozone trends.
- Knowledge of ozone chemistry and transport.
- Ozone and UV forecasts.

In addition to the direct outputs of the research, the R&D activities produced an additional output:

- AES understanding of the worldwide knowledge base.

The cost of AES' research averaged $3.8 million per year, for a total of approximately $108 million (in 1997 dollars).

Identification of Impacts

The Impact Map (Figure E-1) identifies the potential impacts of the research that were considered.

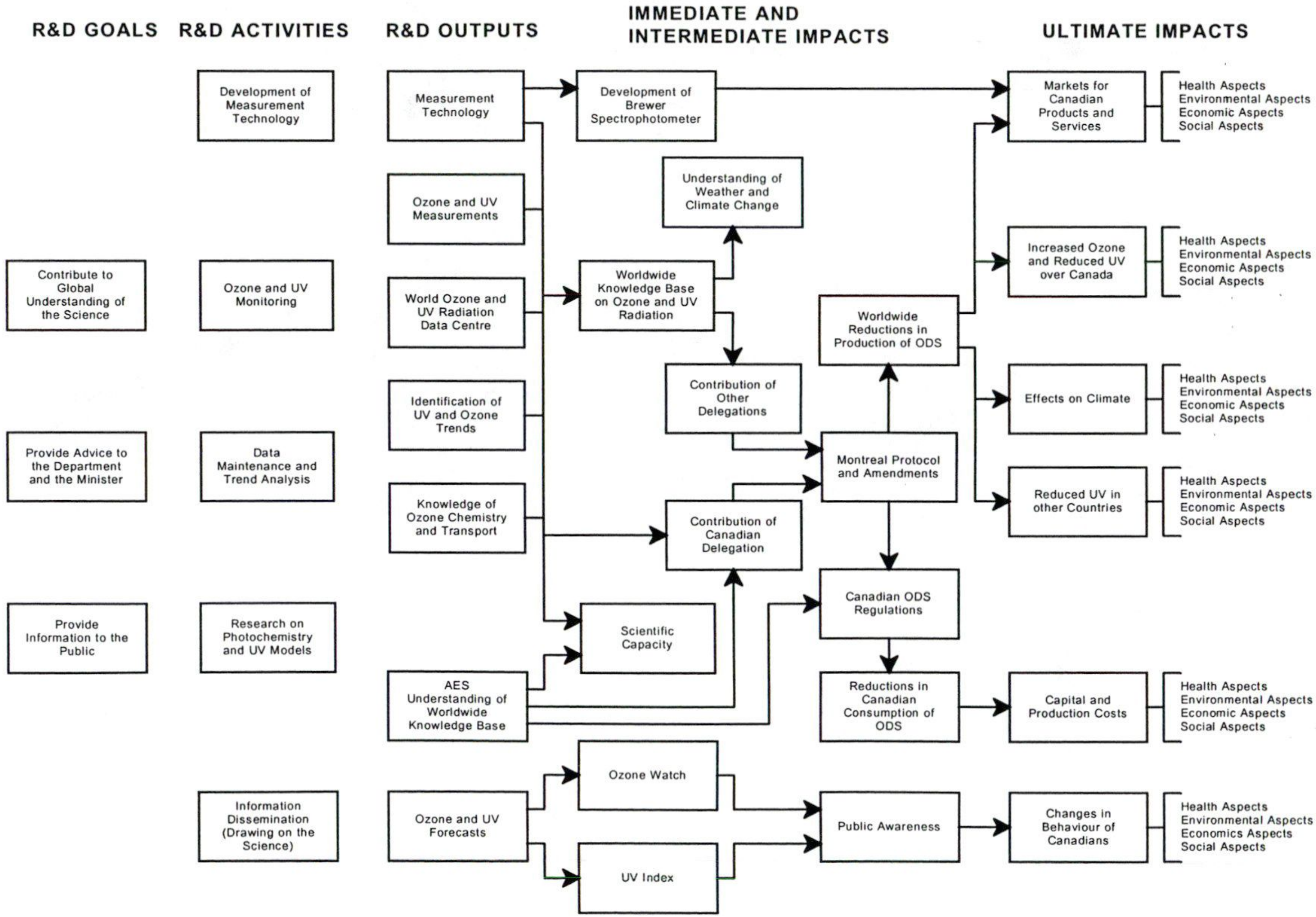
The Map distinguishes between "immediate and intermediate" impacts and "ultimate" impacts, which include health, environmental, social and economic aspects. The immediate and intermediate impacts include the results of the research and their influence on international agreements, regulations, and public behaviour.

The Map identifies thirteen immediate and intermediate impacts and six ultimate impacts, each of which has a number of socio-economic implications (including, potentially: economic, environmental, health and social aspects).

Based on the initial interviews and document reviews, a preliminary screening of the potential impacts was conducted to focus the study on the impact threads that were most significant and/or most likely to allow credible description and attribution. On the basis of these criteria, three main threads were identified:

- **Thread 1.** The impact on the ozone layer over Canada, surface UV exposure in Canada and costs to Canadians resulting from implementation of the Montreal Protocol, due, in part, to the contribution of Canadian negotiators, whose position and effectiveness were influenced by the work and the knowledge provided by AES.
- **Thread 2.** Changes in behaviour of Canadians regarding exposure to the sun resulting from awareness of the risks promoted by AES' UV Index.
- **Thread 3.** New markets for a Canadian firm resulting from the invention of the Brewer spectrophotometer.

Figure E.1 - Impact Map for Stratospheric Ozone Depletion Research



As a result of this screening, a number of significant impacts, many of which are likely to be positive, were not considered in detail. They include:

- Increased scientific capacity.
- Understanding of weather and climate change.
- Contribution of delegations from other countries to the Montreal Protocol -- resulting from AES contributions to the worldwide knowledge base.
- Increased public awareness of ozone depletion and risks of UV exposure -- resulting from the *Ozone Watch* program.
- Canadian ODS regulations -- incremental to the Montreal Protocol -- resulting from AES understanding of the worldwide knowledge base.
- Reduced UV radiation in other countries.
- Effects on Climate.
- Markets for Canadian Products and Services (ODS and substitutes) -- resulting from worldwide reductions in the use of ODS.

It should be noted that the impacts not analysed are, for the most part, real and not just hypothetical. Although they are difficult if not impossible to describe and quantify, some may be significant. Because most are positive, the analysis is considered to provide a conservative view of the benefits of the AES R&D.

Thread 1 -- Impacts of Montreal Protocol on UV Radiation and Costs to Canadian Industry

The analysis indicates that:

- AES was an important contributor to the worldwide knowledge base on ozone depletion and UV radiation.

- This contribution allowed AES to access and understand the worldwide knowledge base, and to influence the Canadian position and the effectiveness of the Canadian delegation.

- Partly (though not primarily) as a result of AES' influence, Canada was able to play a significant role in the development of the Montreal Protocol and its amendments. Ongoing AES work may also influence future amendments to the Protocol.

- The Montreal Protocol led to worldwide reductions in the consumption of ODS, which will total approximately 300 Megatonnes over the period 1987 to 2060. This will slow and eventually reverse the depletion of the ozone layer.

- Improvements to the ozone layer will reduce the levels of UV radiation in Canada. Peak reductions will be between 42% to 48%.

- Based on the analytical approach taken, the portion of these reductions attributable to AES' research was between 1.0% and 9.0%. The best guess is 4.0%.

- The Montreal Protocol led to the adoption of regulations in Canada that will cost industry approximately $4.3 billion in 1997 dollars.

- Based on the analytical approach taken, the portion of these costs attributable to AES' research was between $43 million and $387 million. The best guess is $172 million.

Thread 2 -- Impacts of UV Index on Behaviour

The analysis indicates that:

- AES was the main contributor to the development of the *UV Index*.

- The *UV Index* is raising awareness of the risks of exposure to UV radiation.

- This awareness is leading Canadians to take additional precautions to protect themselves from the sun.

- Based on the analytical approach taken, the proportion of people who protect themselves from UV radiation, through changes in behaviour attributable to AES, is between 5.2% and 31%. The best guess is 15%.

Thread 3 -- Impacts of Development of Brewer Spectrophotometer

The analysis indicates that:

- AES was virtually entirely responsible for the invention of the Brewer Spectrophotometer.

- Development of the Brewer will result in additional sales of $27 to $41 million for SCI-TEC Instruments Inc.

- Based on the analytical approach taken, the portion of sales attributable to AES' research was between $24 million and $41 million. The best guess is $32 million.

Health Aspects

The best guess scenario indicates that, in Canada, during the period to 2060, the Montreal Protocol will prevent approximately 310,000 cases of non-melanoma cancer; 19,000 cases of melanoma cancer; 760,000 cases of cataracts; and 4,550 deaths.

The *UV Index* is expected to prevent approximately 57,000 cases of non-melanoma cancer, 1,840 cases of melanoma cancer; and 590 deaths.

The overall number of health cases averted attributable to AES for the Best Guess Scenario are shown in figures E.2 and E.3.[1] The totals are:

- 13,430 to 142,900 cases of non-melanoma cancer (best guess 55,150)
- 502 to 5,620 cases of melanoma cancer (best guess 2,140)
- 5,700 to 85,500 cases of cataracts (best guess 30,400)
- 85 to 2,041 deaths (best guess 625).

Figure E.2
Health Effects Attributable to AES under Best Guess Scenario

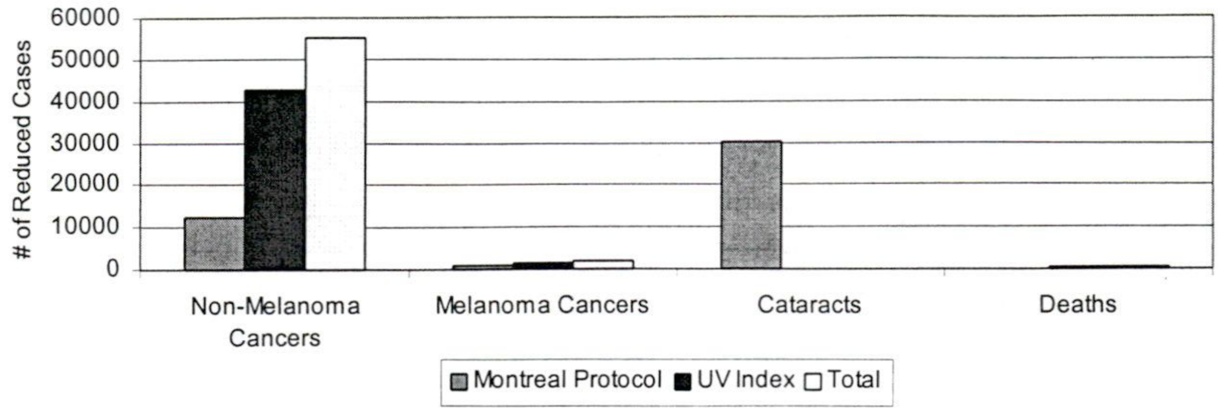
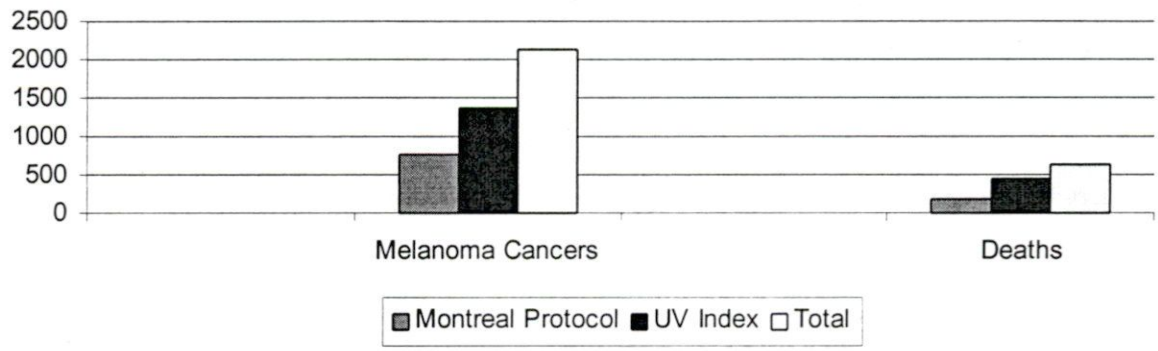


Figure E.3
Health Effects Attributable to AES under Best Guess Scenario -- Melanoma Cancers and Deaths

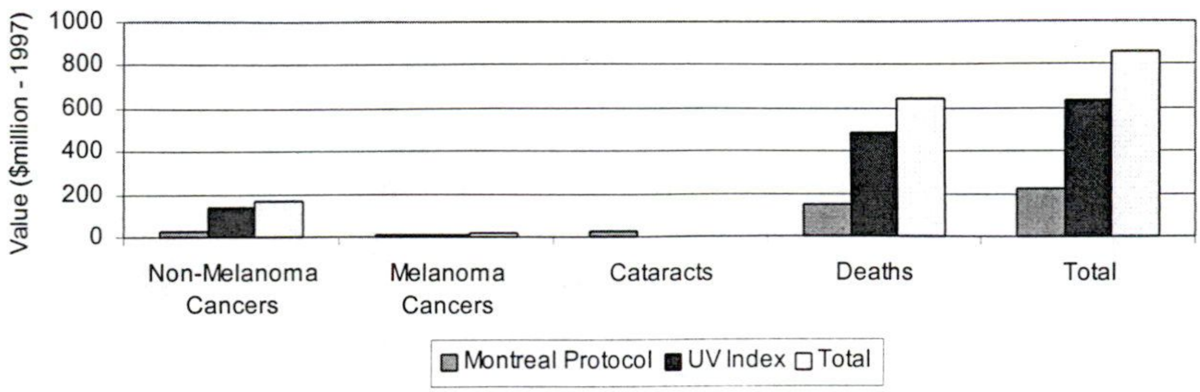


[1] To provide for better visibility, Figure E.3 shows melanoma cancers and deaths only.

In addition, the Montreal Protocol and UV Index are expected to reduce the incidence of a number of other health impacts of UV radiation, including impacts on the immunosuppression system, other eye diseases and other cancers.

The value of these benefits for the Best Guess Scenario is shown in Figure E.4. Based on the valuation approach taken, the health benefits (attributable to AES) are valued at between $139 million and $2,643 million (best guess $856 million).

Figure E.4
Value of Health Effects Attributable to AES under Best Guess Scenario

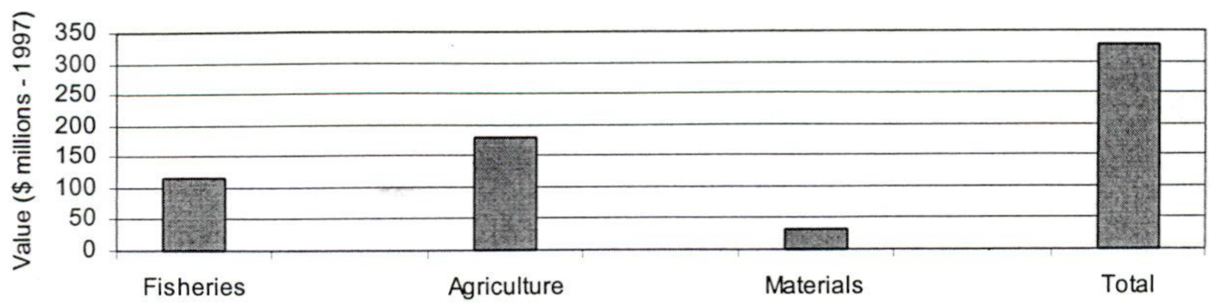


Environmental Aspects

The best guess scenario indicates that the Montreal Protocol will prevent the following environmental damages of commercial value to Canada: $2,900 million in damages to fisheries; $4,500 million in damages to agriculture; and $800 million in damages to materials. In addition, the Montreal Protocol is expected to reduce impacts on a number of other elements of the ecosystem, including animals and forests.

The environmental benefits attributable to AES for the Best Guess Scenario are shown in Figure E.5. These benefits are valued at between $40 million and $1,450 million (best guess $328 million).

Figure E.5
Value of Environmental Effects Attributable to AES under Best Guess Scenario



Economic and Social Aspects

GDP and employment impacts attributable to AES for the Best Guess Scenario are shown in figures E.6 and E.7. The analysis indicates that the Montreal Protocol, UV Index and Brewer Spectrophotometer will result in a net contribution to GDP of between $30.8 million and $1,030 million; the best guess is $210 million. This will create (preserve) between 550 and 18,580 person-years of employment; the best guess is 3,780 person-years.

Figure E.6
GDP Effects Attributable to AES under Best Guess Scenario

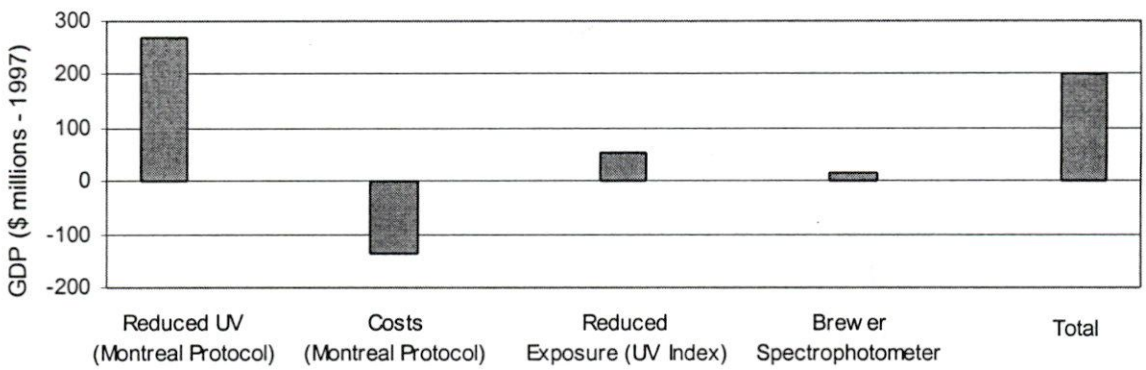
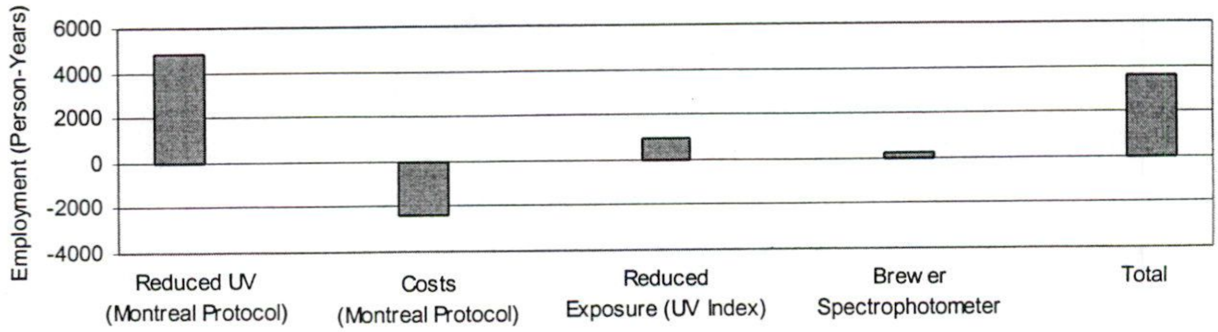


Figure E.7
Employment Effects Attributable to AES under Best Guess Scenario



Conclusions

The analysis indicates that the R&D on stratospheric ozone depletion conducted by AES during the period of 1975 to 1997 will result in the avoidance of over 57,000 cancers, 30,000 cases of cataracts, and 625 deaths (all based on the best guess scenario).

Other costs and benefits that can be attributed to the AES R&D include: $172 million of additional costs to industry, environmental benefits valued at over $300 million, and commercial benefits of $32 million (also based on the best guess scenario).

The overall effect on the economy will be a $210 million contribution to GDP and 3,780 person-years of employment (also based on the best guess scenario).

Given R&D program costs of approximately $108 million (in 1997 dollars), this means that for each dollar of research, Canadians received the following quantifiable benefits:

- $7.90 in health benefits
- $3.03 in environmental benefits
- $1.94 in economic benefits.

In addition, there were a large number of non-quantified impacts (overwhelmingly positive) including scientific capacity, benefits in other countries, effects on climate, and others.

1. INTRODUCTION

1.1 BACKGROUND AND OBJECTIVES

Environment Canada retained the services of Marbek Resource Consultants and Wintergreen Consulting to help identify, describe and measure the impacts of Environment Canada (EC)'s Research and Development (R&D).

The project is one of eight projects included in the *Business Plan for Managing R&D at Environment Canada, 1996 to 1997* and responds, in part, to the 1994 *Auditor General's Report* and the 1996 *Federal Strategy for Science and Technology*, which suggested a need for increased accountability for R&D results. The project is directed by a Steering Committee composed of members of each of the Department's Services (see Appendix A).

The objectives of the project are to provide a rigorous documented evaluation of the impacts of two programs and to validate an approach to the evaluation of such impacts. The two chosen programs are: pulp and paper effluent R&D and stratospheric ozone depletion R&D.

In choosing two different projects, the Steering Committee sought to examine research activities with different characteristics. In the case of pulp and paper, research was focussed on the content of imminent regulations whereas, in the case of ozone, the research contributed to an international effort leading to global action. The case studies also represent efforts of two different research groups within the department and different aspects of the environment. By selecting case studies with these different characteristics, it was hoped to learn more about the feasibility and approaches to measuring the impact of R&D.

1.2 THIS REPORT

This report deals with the second of those case studies: stratospheric ozone depletion R&D. It seeks to document the impacts of the research (including the ultimate economic, environmental, social and health implications). It does not attempt to assess the quality of the research nor does it seek to determine the effect of the research on subsequent R&D. It does, however, deal with all the impacts of the R&D that are considered significant, whether intended or not.

Section 2 describes the approach used.

Section 3 provides a summary of the science and describes the stratospheric ozone depletion R&D program being assessed in terms of its objectives, activities, outputs and costs. Section 3 also establishes the boundaries of the research, in terms of time, location and activities to be included.

Section 4 introduces the Impact Map for the research; describes the various immediate and ultimate impacts in general terms; and establishes the priority impact threads for more detailed analysis.

Section 5 reviews each of the impacts included in the priority impact threads. Each impact is described and attributed to the R&D (or the preceding impacts, as the case may be). Scenarios are developed to evaluate the impacts.

Section 6 integrates the results of Section 5 and assesses the overall economic, environmental, health and social implications of the ultimate impacts of the R&D. Where possible, these implications are valued in monetary terms. Otherwise, they are described in terms of biophysical or social effects (either quantitative or qualitative). Based on this overall assessment and the costs of the R&D, general conclusions concerning value for money are presented.

Section 7 identifies some general conclusions about the impacts of the R&D and the lessons learned in the process of the evaluation.

2. APPROACH

2.1 GENERAL

The challenges in evaluating the socio-economic impacts of public sector R&D include the usual methodological problems in identifying, describing and evaluating results. In addition, the evaluation of public sector R&D has to contend with the fact that the research is often directed towards producing common property benefits (which can be difficult to identify and assess). Moreover, these impacts are often at the end of a long chain of complex intermediate impacts involving government policies and changes in the behaviour of firms and individuals. The impacts of R&D which is part of a broad international effort leading to an international agreement (such as the Montreal Protocol) are particularly difficult to evaluate, because of the difficulties involved in attributing impacts to many parties whose contributions are primarily synergistic rather than additive.

The current state of the art in R&D impact measurement has been described by Williams.[2] It involves the use of methods such as benefit-cost analysis, econometric analysis, modified peer review, bibliometric analysis, case histories, user and client surveys. The view described by Williams is that there have been sufficient advances in methodologies to conduct credible "partial" assessments of R&D impacts provided that certain criteria are met. He suggests that the extent to which the research results would have been available without the specific R&D, and the extent to which the impacts are attributable to the existence of these results, are two key factors in deciding whether an assessment should be attempted. Williams also favours research that is directed towards industry and whose results are applied within a fairly short time period.

The nature of the stratospheric ozone depletion R&D (and the pulp and paper effluent R&D) is such that the applications are primarily in policy realms and they are applied over an extended period of time. Furthermore, the attribution of the research results to the R&D, and of the impacts to the research results, is not necessarily high in all cases. Given these realities, the challenge has been to develop new approaches that can provide credible measures of impacts, while recognizing the inherent limitations of the exercise.

Given the project's dual objectives of evaluating the impacts and validating the approach, it is appropriate to provide some detail on the approach that was used.[3]

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[2] Williams, D. (ARA Consulting Group Inc.). *Measuring the Impacts of Public Investment in Research & Development.* Paper presented at the Natural Sciences and Engineering Research Council of Canada, Ottawa, December 2, 1996.

[3] The approach is described in more detail in the Project Plan. Marbek Resource Consultants and Secor Inc. *Measuring the Environmental and Socio-Economic Impacts of Environment Canada's Research and Development -- Project Plan.* March 27, 1997.

2.2 IMPACT MAPPING

The heart of the approach is the development of an "Impact Map", which is a graphical representation of the linkages between the outputs of the R&D and the various policy and behavioural changes leading to ultimate impacts and socio-economic implications (see Figure 2.1). The aim is to provide an explicit and transparent description of the chains (or threads) by which the impacts of the R&D are realized.

A significant amount of effort was expended in producing and improving the Impact Map to provide the most accurate and useful representation possible. This evolved into an iterative process which began with a Map proposed by the project team and concluded with an amended Map that took into account the information gained through interviews and document reviews. In the process, certain impact threads were identified as priorities for analysis, because of the likelihood of significant impact or the likelihood that those impacts could be credibly identified.

2.3 ATTRIBUTION

Each impact shown in the Impact Map arises from various preceding influences. In analysing the Map, it is necessary to decide to what degree each impact is attributable to the preceding influence(s) shown on the map.

To do this, two different approaches have been used. In most cases, an *incremental attribution* was conducted by estimating the difference between the actual impacts that occurred and the hypothetical impacts that would have occurred under a base case (where the preceding influence was assumed not to exist). For example, impacts of the Montreal Protocol were attributed by comparing actual impacts with a base case of what would have happened in the absence of the Montreal Protocol.

In other cases, where it was difficult to speculate on a hypothetical base case, or where there were many synergistic contributions to an impact, a *proportional attribution* was conducted by estimating the percent contribution of each influence to an impact. For example, impacts of the Canadian delegation on the Montreal Protocol were attributed by estimating the percent contribution of that delegation to the Protocol (the sum of all contributions being equal to 100%).

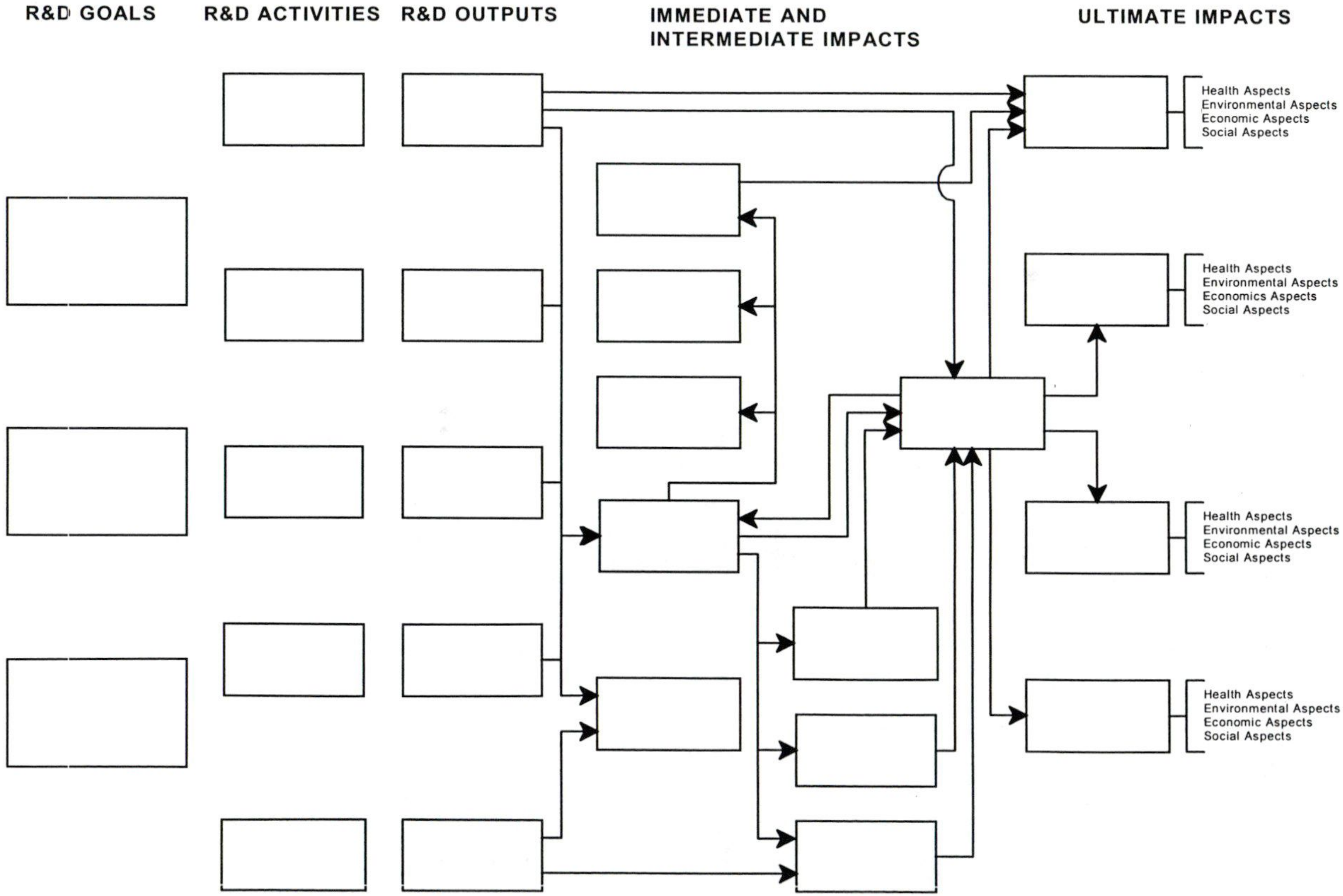
2.4 SEQUENCE OF STEPS

The analysis involved the following steps:

- **Step 1 -- Develop Initial Impact Map**

The first step was to develop a working draft of the impact map based on the initial information provided by the Steering Committee and the Atmospheric Environment Service. This also involved a preliminary selection of priority impact threads (based on criteria of significance, relevance and practicality).

Figure 2.1 - Impact Map



- **Step 2 -- Develop Questions**

Based on the Impact Map and the priority threads, a series of questions was developed. The questions were intended to establish the nature of the impacts (immediate, intermediate, and ultimate) and the attribution of those impacts to the R&D. The questions were incorporated into an Interview Guide designed to be used in a series of interviews. During the course of the project, this Guide was amended several times to respond to a number of competing needs, including:

- Keeping the interview short, simple and straightforward
- Providing an opportunity for interview subjects to tell the story
- Focussing interview subjects on the questions of interest
- Eliciting specific views on attribution of impacts
- Eliciting speculation on "what if" scenarios.

A copy of the Guide is provided in Appendix B.

- **Step 3 -- Conduct Interviews**

To answer the questions, a series of interviews was conducted. The interview subjects were identified by the Steering Committee, by the Project Team, and by some of the interview subjects themselves.

Approximately 20 interviews were conducted for the stratospheric ozone depletion case (see Appendix C). Unsurprisingly, the result of those interviews was a large amount of subjective information, some of it contradictory.[4] The interviews were very useful in understanding the full story of the impacts (and completing the Impact Map) and getting a general idea of the impacts and their attribution; however, many of the questions were left without explicit answers. This was due to a reluctance on the part of interview subjects to assign credit in anything more than general terms, and a further reluctance to speculate on what might have happened in the absence of the R&D (or what might happen in the future).

[4] The Pulp and Paper Effluent Case Study Interim Report provides additional detail on the challenges faced in obtaining reliable and useful information. Marbek Resource Consultants and Secor Inc. *Measuring the Impact of Environment Canada's R&D, Pulp and Paper Effluent Case Study -- Interim Report.* May 2, 1997.

- **Step 4 -- Review Reference Documents**

Approximately 25 documents were reviewed for the ozone case (see Appendix D). These documents provided the information necessary to identify the key knowledge elements involved and some indication of the sources of the knowledge for purposes of assigning credit. The documents also provided a basis for estimating the incremental effects of intermediate impacts attributed to the R&D. In particular we relied extensively on ARC's *Report on Benefits and Costs of Canadian Participation in the Montreal Protocol on Substances that Deplete the Ozone Layer* to identify the incremental costs and benefits to Canada of the Montreal Protocol.[5]

- **Step 5 -- Analysis**

Given the gaps in the data available for analysis, it was not possible to generate the accurate and absolute answers needed to establish the impacts and their attribution. Consequently, the approach evolved to the development of credible scenarios. Using summaries of the interviews and the reference documents, the Project Team developed the following elements of analysis:

- A best estimate of the relative contribution of AES to the R&D results (based on an overall assessment of the interview results), together with reasonable high impact and low impact scenarios.
- A best estimate of the relative contribution of AES to a series of intermediate impacts (including the contribution of Canada to the Montreal Protocol, the UV Index, and the Brewer spectrophotometer).
- A series of scenarios of what might have happened in the absence of those impacts.
- A qualitative assessment of what might happen in the future as a result of emerging impacts.

Using these estimates, the Project Team was able to describe and in some cases quantify the impacts of the R&D under various scenarios. Although there is significant uncertainty associated with the results, it is believed that, at a minimum, they provide a good indication of the value for money of the R&D and can be used, albeit with caution, in science policy and planning.

[5] ARC Applied Research Consultants. October 1997. *Benefits and Costs of Canadian Participation in the Montreal Protocol on Substances that Deplete the Ozone Layer.* For Environment Canada.

3. DESCRIPTION OF THE R&D PROGRAM

This section summarizes the science and history of the issue, and describes the goals, activities, outputs and costs of the stratospheric ozone R&D performed by Environment Canada's Atmospheric Environment Service (AES).

3.1 SUMMARY OF THE SCIENCE ON STRATOSPHERIC OZONE DEPLETION[6]

Stratospheric ozone is found in a layer concentrated between 15 and 35 kilometres above the surface of the earth. It forms a natural protective layer that helps to shield the earth from the harmful effects of the sun's ultraviolet (UV) radiation. Since 1980, the total ozone observed in the stratosphere has been declining, allowing more solar UV radiation to reach the earth's surface. "Ozone depletion" is the term commonly used to describe a reduction of stratospheric ozone as a result of human activity. The leading causes of ozone depletion are emissions of human-made chemicals. The most common of these are chlorofluorocarbons (CFCs) and halons, which, until recently, were widely used in air conditioners, refrigerators, foams, solvents, aerosols, and fire extinguishers. A single CFC or halon molecule can destroy thousands of molecules of ozone. Some CFC molecules have lifespans of up to 400 years. As a result, almost all of the CFCs and halons ever released are still in the atmosphere.

Since 1980, scientists have observed a global thinning of the ozone layer, with the maximum depletion occurring near poles. In the Antarctic during spring, a dramatic thinning of the ozone layer has occurred, with up to 70% depletion in recent years. In the Arctic, dramatic ozone loss occurred in the spring of 1997, when ozone values were 45% below normal, and in 1996, when ozone was reduced by 30%. These are the lowest springtime values ever recorded in the Arctic. In both years, conditions in the upper atmosphere were unusual for the Arctic, and similar to those found in the Antarctic. The ozone layer over southern Canada has thinned by an average of about 6% since the 1980s.

Stratospheric ozone depletion will result in increased UV radiation levels. For instance, as a result of ozone layer thinning, sunburning UV-B rays are about 7% stronger than normal over southern Canada. Increased exposure to UV radiation has been linked to increased numbers of skin cancer cases, depression of the immune system, and an increased risk of cataracts developing in humans. Higher levels of UV radiation will also cause damages to materials (buildings and equipment), reduce crop yields, damage forests, affect freshwater and marine ecosystems (thus disrupting marine food chains), and have a negative effect on wildlife. Even with the full elimination of ozone-depleting substances, UV levels are expected to remain higher than normal for 30 to 40 years, while stratospheric ozone levels recover.

[6] Source: Environment Canada. *Ozone Depletion*. In Science and the Environment Issues. October 1997

3.2 HISTORY OF THE INTERNATIONAL SCIENCE AND RESPONSE[7]

The main features of the climatology of total ozone where discovered by G.M.B. Dobson by 1930. These were the dependence on latitude and season and the day-to-day changes that are associated with meteorological conditions.

In 1974, an article in *Nature* by University of California researchers Mario Molina and Sherwood Roland suggested for the first time that widely-used industrial CFCs had the potential to migrate to the stratosphere, where they would break down and release significant quantities of ozone-destroying chlorine. University, government, and industry scientists in various centres around the world responded by intensifying their research activities. At the same time, the United Nations Environment Programme (UNEP) called for an international conference to discuss an international response to the issue.

In 1982, 24 countries met in Stockholm and agreed to launch an "Ad Hoc Working Group of Legal and Technical Experts for the Preparation of a Global Framework Convention for the Protection of the Ozone Layer". These efforts came to fruition with the signing, in March 1985, of the Vienna Convention for the Protection of the Ozone Layer. The participating countries agreed to take measures to protect the ozone layer (although these were not spelled out), and made arrangements for international cooperation in the areas of research, monitoring, and exchange of data on the state of the ozone layer and emissions of Ozone Depleting Substances (ODS).

Recognizing the need for an effective control protocol, UNEP also began negotiations on a legally binding agreement that would be ready in 1987. Consensus on the need for such a protocol was made easier by the discovery of the Antarctic ozone hole in 1985. Although the ozone hole did not confirm existing theories about the destruction of the ozone layer; it created a greater awareness among opinion leaders and the public that something serious was happening to the atmosphere and that precautionary action was necessary. An agreement also became more likely after 1986, when the American chemical industry abandoned its opposition to controls.

These developments, as well as the imagination, flexibility and determination of the negotiators, led to agreement on the Montreal Protocol on September 16, 1987.

Since then, a number of advances have been made in our understanding of the issue. These include the unravelling of the mystery of the Antarctic ozone hole and the role of polar stratospheric clouds; important evidence about ozone trends in other parts of the world (including the Arctic); generally improved understanding of transport and chemical processes; and improved modelling and measurement techniques.

The improved understanding has precipitated a significant tightening and extension of the Protocol's regulatory regime (see Table 3.1).

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[7] Source: Environment Canada, 1997. *Ozone Science: A Canadian Perspective on the Changing Ozone Layer.*

Table 3.1
Principal Provisions of the Montreal Protocol and Amendments[8]

Year	Agreement	Provisions (Developed Countries)	Provisions (Developing Countries)
1987	Montreal Protocol	· Freeze on CFCs by 1989 (based on 1986 levels)50% cut to CFCs by 1998 (based on 1986 levels)Freeze on halons by 1992 (based on 1986 levels)	· Freeze on CFCs by 1999 (based on 1986 levels)50% cut to CFCs by 2008 (based on 1986 levels)Freeze on halons by 2002 (based on 1986 levels)
1990	Amendments and Adjustments at the Second Meeting of the Parties (London)	· Phase-out CFCs, halons and carbon tetrachloride by 2000Phase-out methyl chloroform by 2005	· Phase-out CFCs, halons and carbon tetrachloride by 2010Phase-out methyl chloroform by 2015
1992	Amendments and Adjustments at the Fourth Meeting of the Parties (Copenhagen)	· Phase-out halons by 1994Phase-out CFCs, methyl chloroform and carbon tetrachloride by 1996Freeze on methyl bromide by 1995 (based on 1991 levels)Phase-out HCFCs by 2030	· Phase-out CFCs, halons and carbon tetrachloride by 2010Phase-out methyl chloroform by 2015Freeze on methyl bromide by 2005 (based on 1991 levels)Phase-out HCFCs by 2040
1995	Adjustments at the Seventh Meeting of the Parties (Vienna)	· Phase-out methyl bromide by 2010	· Freeze on methyl bromide by 2002 (based on 1995-98 levels)
1997	Adjustments at the Ninth Meeting of the Parties (Montreal)	· Phase-out methyl bromide by 2005	· Phase-out methyl bromide by 2015

3.3 R&D GOALS

The goals of AES' Stratospheric Ozone research are:

- ***To contribute to global understanding of stratospheric ozone science in order to reduce uncertainties.***
- ***To provide scientific advice to the Minister and Department of Environment concerning potential domestic and international policies and programs.***
- ***To provide information to Canadians so they can adapt to changing levels of ultraviolet radiation.***

The Canadian R&D on stratospheric ozone depletion emerged from more general climate-related work on conditions in the stratosphere. Canada began total ozone measurements at five stations in the early 1960s.

In concert with other countries, Canada responded to the evidence of the danger of CFCs by

[8] UNEP, Ozone Secretariat. (1996). Handbook for the International Treaties for the Protection of the Ozone Layer, Fourth Edition. Nairobi, Kenya.

significantly expanding the research and monitoring program in the mid 1970s. From the mid 1970s and continuing into the 80s and 90s, the goals of the program became more focused on providing the scientific knowledge necessary to understand and respond to the problem. In particular, Canadian efforts were directed towards monitoring trends in Canada and sharing their results with the world community, in order to gain the information needed to advise the government on the international negotiations towards a control protocol.

Beginning in the late 1980s and early 1990s, AES responded to public concerns by directing efforts to the dissemination of information (including forecasts) on ozone depletion and UV radiation for public consumption.

3.4 R&D ACTIVITIES

In assessing the impacts of the stratospheric ozone depletion R&D, it is essential that the boundaries of the R&D activities be clearly defined. In selecting boundaries, we have included only those activities which are central to the research effort and cannot be disassociated from it. We have selected a start date that corresponds to a significant milestone in the character of the research program. Finally, since the R&D is ongoing, we have selected an end date for the research that is as current as possible, while respecting the limitations of data collection and analysis.[9]

Thus, the body of research assessed consists of atmospheric research on stratospheric ozone depletion and UV radiation conducted by the Atmospheric Environment Service (AES) of Environment Canada, between April 1975 and March 1997.

The development of ODS substitutes and alternative technology by industry and others, research on human health effects, and research on environmental effects are not included.

The start date was chosen to correspond with a period of increased activity in this area in response to international research and concern about the effect of CFCs on the ozone layer. Later start dates were rejected in order to capture the most significant activities associated with the program and those that were reported to have had a significant influence on key intermediate impacts, particularly the Montreal Protocol.

[9] The boundaries refer to the R&D per se, not to the impacts associated with the R&D. Thus, for instance, although R&D on health effects of increased UV radiation will not be analyzed, the health impacts arising from the AES stratospheric ozone R&D will be examined. Similarly, the end date refers to the R&D per se, not to the impacts associated with the R&D. Thus, for instance, R&D carried out after the end date will not be analysed. On the other hand, impacts associated with R&D carried out before the end date will be analysed, even if the impacts occurred after the end date.

The research included the following components:

- **Development of measurement technology.** This included R&D on new instruments, development of instrument methods, maintenance of standards and the conduct of calibrations.
  - Development of Brewer spectrophotometer, field Brewer instruments, associated software, and calibration equipment
  - Calibration of Brewer instruments (domestic and international)
  - Development of technology based on infrared and visible spectroscopy to be used from balloons, aircraft and space-based vehicles
  - Operation of the National Atmospheric Radiation Centre (NARC) charged with maintaining standard instruments and calibrating client instruments
  - Hosting of international instrument intercomparisons.

- **Ozone and UV monitoring.** This included the operation of networks of Brewer spectrophotometers and ozonesondes to measure surface and column ozone and UV (see Table 3.2).
  - Establishment and operation of ground-based monitoring network using Brewer spectrophotometers
  - Establishment and operation of ozonesonde monitoring network
  - Conduct of UV-B spectral measurement program
  - Establishment and operation of an arctic observatory at Eureka.

Table 3.2
Canadian Ozone Measurement Sites

Station	Date	Instrumentation
Alert	1989	Brewer, ozonesondes
Churchill	1964	Brewer, ozonesondes
Edmonton	1957	Brewer, ozonesondes
Eureka	1993	Brewer, ozonesondes, lidars, FTIR spectrometers, Fably-Perot spectrometers, radiometers
Goose Bay	1962	Brewer, ozonesondes
Halifax	1992	Brewer
Montreal	1993	Brewer
Resolute Bay	1957	Brewer, ozonesondes
Saskatoon	1988	Brewer
Saturna	1990	Brewer
Toronto	1960	Brewer
Winnipeg	1992	Brewer

- **Data maintenance and trend analysis.** This included the maintenance of world ozone and UV data and Canadian analysis of trends.

    - Operation of the World Ozone and UV Radiation Data Centre including quality control, data management and dissemination
    - Analysis of data to detect trends.

- **Research on photochemistry and UV models.** This included the development and use of models and the provision of measurements for calibration.

    - Application of diagnostic models to interpret new measurements
    - Application of long-term ozone predictive models
    - Development work on 1,2 and 3-dimensional models
    - Contribution to the Middle Atmosphere Modelling (MAM) initiative
    - Conduct of aircraft and space-based measurement projects to measure trace stratospheric constituents
    - Development of methods for long-term UV-B prediction.

- **Information dissemination (drawing on the science).**

    - Provision of short-term forecasts of ozone
    - Provision of short-term forecasts of UV-B for public dissemination
    - Provision of summertime forecasts of ozone and UV-B radiation each spring
    - Development and implementation of information communication and dissemination strategies.

3.5 R&D OUTPUTS

The research outputs of interest are the results of the work described above. They include the methods and techniques developed, the publication of results, and application of the research through forecasts. The knowledge elements contained in these outputs can be summarized as contributions to the following research results:

- **Measurement technology.** The design and development of instruments and methods.

- **Ozone and UV measurements.** The recording of time series data on ozone and UV at key Canadian locations.

- **World Ozone and UV Radiation Data Centre.** The ongoing custody and dissemination of global ozone and UV data to scientists around the world.

- **Identification of UV and ozone trends.** The documentation of a series of trends in ozone and UV over Canada during the period from 1960 to the mid 1990s.

- **Knowledge of ozone chemistry and transport.** Contributions to the development, use and calibration of a variety of predictive models.

- **Ozone and UV forecasts.** The development and implementation of ozone and UV forecasting and dissemination products.

In addition to the direct outputs of the research, the R&D activities produced an additional output:

- **AES understanding of the worldwide knowledge base.** Environment Canada acquired an in-house understanding and expertise which could be used to understand and interpret the work of others as well as to integrate the knowledge for policy analysis and international negotiations.

A list of key results is provided in Table 3.3

Table 3.3
Key Results Achieved by AES Research on Stratospheric Ozone Depletion

Year	Result	Reference(s)
1958-Present	Ozone measurements for Canadian Stations: 12 station ozone network operated automatically since 1995; Network for Detection of Stratospheric Change (NDSC) Arctic Observatory at Eureka	Tarasick, David W. 1995. *Ozone Climatology and Trends at Canadian Stations*. AES Internal Report, CARD-95-004. Atmospheric Environment Service, Environment Canada, Downsview, Ontario.
1979-1982	Invention of Brewer Spectrophotometer	Kerr, James B., C. Thomas McElroy and David I. Wardle. *The Brewer Instrument Calibration Center 1984-1996.* Atmospheric Environment Service, Environment Canada,, Downsview, Ontario.
1986	Start of UV spectral monitoring	Evans, W.F.J., H. Fast, A.J. Forester, G.S. Henderson, J.B. Kerr, R.K.R. Vupputuri, D.I. Wardle. 1987. *Stratospheric Ozone Science in Canada: An Agenda for Research and Monitoring.* Atmospheric Environment Service, Environment Canada, Downsview, Ontario
1987	Recognition and quantification of significance of ozone depletion by chloroform	Henderson, G.S., W.F.J. Evans, J.C. McConnell, E.M. Templeton. 1987. "A numerical model for simulation of stratospheric chemistry." *Atmosphere-Ocean*, 25:427-459.
1987-1990	Identification of large mid-latitude negative ozone trend	Evans, W.F.J., H. Fast, A.J. Forester, G.S. Henderson, J.B. Kerr, R.K.R. Vupputuri, D.I. Wardle. 1987. *Stratospheric Ozone Science in Canada: An Agenda*

Year	Result	Reference(s)
		for Research and Monitoring. Atmospheric Environment Service, Environment Canada, Downsview, Ontario Kerr, J.B. 1991. "Trends in Total Ozone at Toronto Between 1990 and 1991". *Journal of Geophysical Research,* Vol. 96, No. D11, Pg. 20,703-20,709. Atmospheric Environment Service, Environment Canada, Downsview, Ontario
1985-1997	Contributions to UNEP Ozone Science Assessments[10]	*Atmospheric Ozone 1985: Assessment of our Understanding of the Processes Controlling its Present Distribution and Change,* 3 Volumes, WMO Nol 16. *Report to the International Ozone Trends Panel: 1988,* 2 Volumes, WMO No. 18. *Scientific Assessment of Stratospheric Ozone.* 1989. 2 volumes. WMO No. 20. *Scientific Assessment of Ozone Depletion.* 1991. WMO No. 25 *cientific Assessment of Ozone Depletion.* 1994. WMO No. 37
1991	International intercomparison of ozonesondes (calibration)	Kerr, J.B., H Fast, C.T. McElroy, S.J. Oltmans, J.A. Lathrop, E. Kyro, A. Paukkunen, H. Claude, U. K_hler, C.R. Sreedharan, T. Takao, Y. Tsukagoshi. "The 1991 WMO International Ozonesonde Intercomparison at Vanscoy, Canada". *Atmospheric Ocean*, Vol. XXXII, No. 4, pp. 685-716, December 1994.
1992	Observations of high-altitude ozone using Sun PhotoSpectrometer on US Space Shuttle Challenger	McElroy, C.T. et. al. 1991. *SPEAM-I (sunphotometer Earth atmosphere measurement) observations of high-altitude ozone from STS 41-G*
1992	Development of Ozone Watch and UV Index	Kerr. J.B., C.T. McElroy, D.W. Tarasic, D.I. Wardle. *The Canadian Ozone Watch and UV-B Advisory Programs.* Atmospheric Environment Service, Downsview, Canada. Burrows, William R., Marcel Vallée, David I. Wardle, James B. Kerr, Laurence J. Wilson, David Tarasick. *The Canadian operational procedure for forecasting total ozone and UV radiation.* Vol. 28, Met Apps.1,

[10] Note that the next Scientific Assessment is due to be released in 1998.

Year	Result	Reference(s)
		pgs. 247-265 (1994).
1992	Development of Ozone Watch and UV Index (continued)	Kerr. James B. 1994. "Decreasing Ozone Causes Health Concern: How Canada Forecasts Ultraviolet-B Radiation." *Environmental Science & Technology*, pgs 514A-518A.
1992-1997	Measurement of solar irradiance on-board NASA ER-2 high-altitude research aircraft	McElroy, C.T. "A spectoradiometer for the measurement of direct and scattered solar irradiance from on-board the NASA ER-2 high-altitude research aircraft." *Geophysical Research Letters*, Vol 22, No. 11, pgs. 1361-1364, June 1995.
1993	Demonstration of UV increase linked to ozone depletion	Kerr, J.B., McElroy, C.D. "Evidence for Large Upward Trends of Ultraviolet-B Radiation Linked to Ozone Depletion". *Science*, Reprint Series, 12 November 1993, Volume 262, pp. 1032-1034.
1993	Extension of World Ozone Data Centre to include UV (the Centre has been operated by Canada since 1957-58)	Wardle, David I., Edward W. Hare, David V. Barton, C. Thomas McElroy. "The World Ozone and Ultraviolet Radiation Data Centre -- Content and Submission." *Proceedings of the Quadrennial Ozone Symposium*, l'Aquila, Italy, September 1996. Environment Canada, Downsview, Ontario.
1993	Identification of record low ozone values over Canada in early 1993	Kerr. J.B., D.I. Wardle, D.W. Tarasick. "Record Low Ozone Values Over Canada in Early 1993." *Geophysical Research Letters*, Vol 20, No. 19, pgs. 1979-1982, September 15, 1993.
1995	Identification of downward trend of free tropospheric ozone over Canada	Tarasick, D.W., D.I. Wardle, J.B. Kerr, J.J. Bellefleur, J. Davies. "Tropospheric ozone trends over Canada: 1980-1993". *Geophysical Research Letters*, Vol 22, No. 4, pgs. 409-412, February 15, 1995.
1996	Designation by WMO of the Toronto Brewer Triad as the standard of ozone measurement	Kerr, James B., C. Thomas McElroy and David I. Wardle. *The Brewer Instrument Calibration Center 1984-1996.* Atmospheric Environment Service, Environment Canada,, Downsview, Ontario.
1997	First attribution of global warming as a significant contribution to Arctic ozone depletion	Wardle, D.I.,, J.B. Kerr, C.T. McElroy and D.R. Frandcis Eds. Ozone Science: *A Canadian Perspective on the Changing Ozone Layer.* Environment Canada Report CARD 97-3, 1997. Fioletov, V.E., J.B. Kerr, D.I. Wardle, J. Davies, E.W. Hare, C.T. McElroy, and D.W. Tarasick. *Long-term ozone decline over the Canadian Arctic to early 1997 from ground-based and balloon observations.* Geophysical Research Letters, Vol. 24, pgs 2705-2708,

Year	Result	Reference(s)
		1997. Donovan, D.P., H. Fast, Y. Makino, J.C. Bird, A.I. Carswell, J. Davies, T.J. Tuck, J.W. Kaminski, C.T. McElroy, R.L. Mittermeier, S.R. Pal, V. Savastiouk, D. Velkov, and J.A. Whiteway. *Ozone, column C10, and PSC measurements made at the NDSC Eureka Observatory (80N 86W) during the spring of 1997.* Geophysical Research Letters, Vol. 24, pgs 2709-2712, 1997.

3.6 COSTS

AES has estimated the costs associated with the research activities, including external components. A summary of these costs is presented in Table 3.4. More detail is provided in Appendix E.

Table 3.4
Summary of Costs of R&D on Stratospheric Ozone Depletion
($ million)[11]

Year	Total	Total in $1997
75/76	1.23	3.57
76/77	1.31	3.51
77/78	1.41	3.48
78/79[12]	1.61	3.64
79/80[11]	1.47	3.01
80/81[11]	1.60	2.92
81/82	1.97	3.25
82/83[11]	2.53	3.94
83/84	3.08	4.59
84/85	3.40	4.88
85/86	3.27	4.51
86/87	5.00	6.60
87/88	5.09	6.46
88/89	5.27	6.37
89/90	4.78	5.51
90/91	4.47	4.89
91/92	4.88	5.25
92/93	7.76	8.20
93/94	6.35	6.70
94/95	5.82	6.01
95/96	5.90	6.00
96/97	5.07	5.07
Total	**83.3**	**108.4**

[11] Estimates accurate to within 15%.
[12] Cost information not available - estimated on the basis of previous forecasts.

4. IDENTIFICATION OF IMPACTS AND LINKAGES

4.1 THE IMPACT MAP

As expected, the Impact Map for the stratospheric ozone depletion R&D evolved considerably as knowledge and insights were accumulated from the interviews, the document reviews and the analysis. The final version of the Map is shown in Figure 4.1.

The left hand side of the Map presents the goals, activities and outputs described in the previous section. The balance of the Map distinguishes between "immediate and intermediate" impacts and "ultimate" impacts. The former include the results of the research and their influence on policy, international agreements and behaviour; while the later are tangible impacts that have implications for the economy, the environment, society and/or human health.

The Map identifies thirteen potential immediate and intermediate impacts arising from the R&D outputs and six ultimate impacts, each of which has a number of socio-economic implications (including, potentially, health, environmental, economic and social aspects). Of the nineteen impacts identified, ten are directly related to the program objectives (shown in bold in Figure 4.1), while the rest, though important, were not necessarily deliberate.[13] Eighteen of the impacts are direct applications of the research and one (scientific capacity) is an indirect impact which recognizes that scientific discovery is not a linear process and that the knowledge and skills acquired in the process of conducting this R&D may have other applications.

A summary of the potential impacts follows:

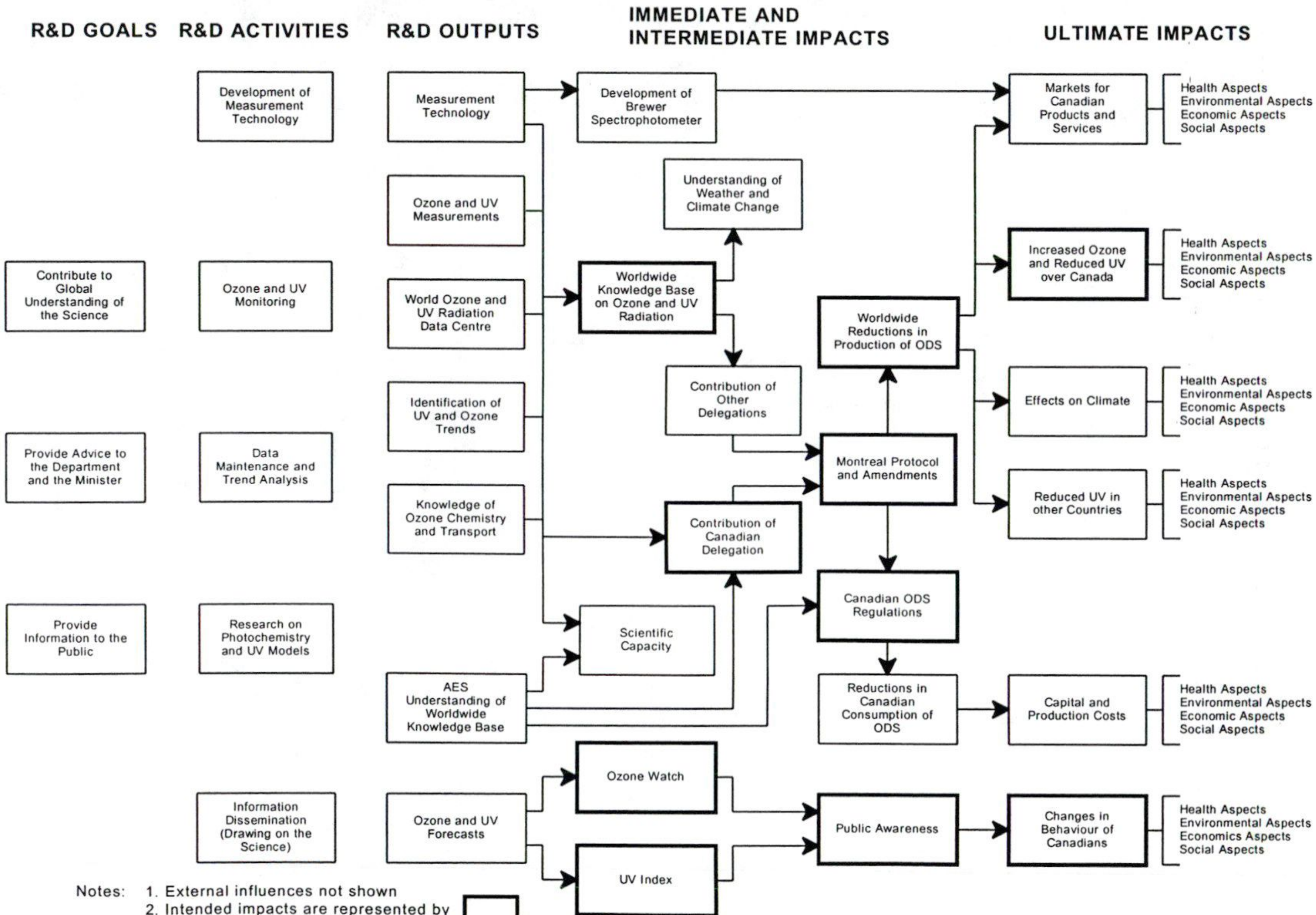
4.1.1 Immediate and Intermediate Impacts

- **Worldwide knowledge base on ozone and UV radiation**. The principal immediate impact of the R&D would have been a contribution to the worldwide knowledge base concerning various aspects of ozone depletion and UV radiation (as described in Section 3). In addition, the development, by AES, of measurement technology may lead to additional knowledge through the application of those technologies in research, or in the monitoring of the effectiveness of the Montreal Protocol.

- **Scientific capacity**. The R&D may also have contributed to building a technical infrastructure, including people, equipment and know-how. This infrastructure can create socio-economic impacts in several ways: it may lead to further productive R&D and it may provide economic and social benefits by maintaining Canadian jobs and expertise, which, in part, can be used to assimilate the R&D of others.

[13] It is arguable that some of these impacts are legitimate policy objectives and therefore intended R&D impacts, by association with the objective of supporting good policy.

Figure 4.1 - Impact Map for Stratospheric Ozone Depletion Research



Notes: 1. External influences not shown
2. Intended impacts are represented by ☐

- **Understanding of weather and climate change**. In the process of investigating the atmospheric processes and trends related to ozone depletion, information and knowledge was obtained which may also contribute to the investigation and understanding of weather and climate change.
- **Contribution of the Canadian delegation**. The results of the Canadian R&D provided information and knowledge which, in combination with other factors, may have contributed to the elaboration of the Canadian position in the negotiations for the Montreal Protocol (and its amendments) and to the effectiveness of the Canadian negotiators. This may have occurred directly, based on Canadian research results, and indirectly, through access and understanding of the worldwide knowledge base. Furthermore, ongoing results and use of Canadian technology may lead to increased knowledge of the effectiveness of the Montreal Protocol and enable future Canadian negotiators to contribute to further amendments, if necessary.
- **Contribution of other delegations**. Similarly, the worldwide knowledge base (including the Canadian portion thereof) would have provided the basis for the contribution of the other delegations in the negotiations.
- **Montreal Protocol and amendments**. The efforts of the negotiators (Canadians and others) led to the adoption of the 1987 Montreal Protocol and its amendments (described in Table 3.1). As knowledge increases, other amendments may occur.
- **Worldwide reductions in the use of ODS**. The principal effect of the Montreal Protocol is to reduce the production and consumption of ODS and, ultimately emissions of ODS. These reductions began in accordance with the provisions of the protocol and will continue indefinitely.
- **Canadian ODS regulations**. As a consequence of having adopted the Montreal Protocol, Canada put in place regulations to implement its provisions. These included a variety of regulations which took the form of quotas on consumption defined as production plus imports minus exports. Canada also implemented a small number of regulations that went beyond the requirements of the Montreal Protocol.
- **Reductions in Canadian production and use of ODS**. The result of the regulations would have been to reduce or eliminate the supply of ODS to the Canadian market. This would have had an effect on Canadian suppliers (producers and importers) and consumers of ODS. Producers would have had to reduce their ODS production (possibly switching to substitutes). Consumers would have had the choice of paying higher costs for the remaining ODS on the market, switching to substitutes, or undertaking more fundamental process or product changes.
- **Development of Brewer Spectrophotometer**. AES work on measurement technology led to the invention and development of the Brewer spectrophotometer.
- **Ozone Watch**. AES work on ozone measurement led to the development and implementation of the *Ozone Watch* program. *Ozone Watch* is a weekly bulletin describing the state of the ozone layer over Canada.
- **UV Index**. AES work on ozone measurement and UV forecasting led to the development

and implementation of the *UV Index* program. The *UV Index* is an advisory program which produces daily forecasts of UV-B radiation. The Canadian UV Index is recognized as the international standard by WMO and WHO and is now used by several other countries.

- **Public Awareness**. The *Ozone Watch* and *UV Index* programs may have contributed to building public awareness of the health risks of ozone depletion (specifically) and the risks of exposure to the sun (more generally).

4.1.2 Ultimate Impacts

- **Markets for Canadian Products and Services**. The development of the Brewer spectrophotometer may have created a new business opportunity for a Canadian company, involving significant export potential. A market effect of a different sort may have resulted from the regulations limiting the production and importation of ODS. In this case, the effect would have been to reduce or eliminate the market for certain substances (ODS), and to create or increase the market opportunities for other substances (substitutes) or for services associated with the adaptation process.

- **Increased ozone and reduced UV over Canada.** As a result of the worldwide reduction in ODS emissions, the ozone layer is expected to stabilize and begin a slow recovery, which should result in decreased incidence of UV in Canada.

- **Reduced UV in other countries.** Similarly, the recovery of the ozone layer should result in decreased incidence of UV worldwide.

- **Effects on climate**. Since many ODS are also greenhouse gases, their emission reduction should also have an effect on climate change impacts. This may be somewhat offset by the recovery of the ozone layer, which is also a greenhouse gas. The reduced emission of ODS may also affect the mechanism for climate change in more complex ways which are not presently well understood.

- **Capital and production costs**. As stated previously, the dwindling supply of ODS may have impacted consumers (mainly businesses) through higher costs for the remaining ODS on the market. This increased price would leave consumers with three choices: paying the higher costs, switching to substitutes or making more fundamental process or product changes. In all of these cases, there may be additional costs (either capital, production, or both).

- **Changes in the behaviour of Canadians**. As stated previously, the development and dissemination of ozone and UV forecasts may be helping to build public awareness of the health risks of ozone depletion (specifically) and the risks of exposure to the sun (more generally). As a result, Canadians may be taking additional precautions to protect themselves from UV radiation, through avoidance, protective clothing, etc.

  Although an attempt has been made to identify all potential impacts (even those whose nature is unclear), it is possible, and perhaps likely, that there are other impacts (past, present and future) that have not been identified.

4.2 SIGNIFICANT IMPACT THREADS

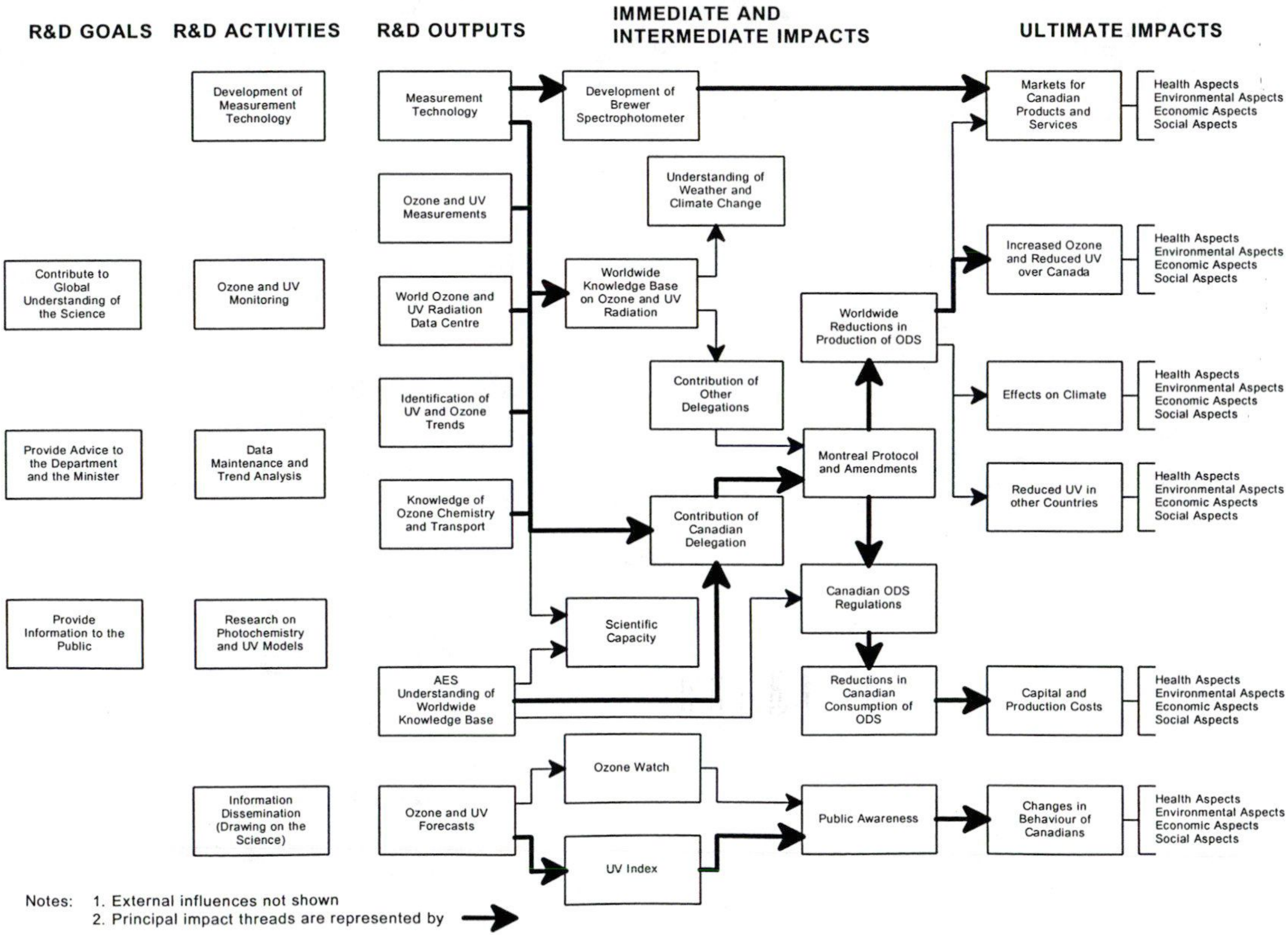
Based on the initial interviews and document reviews, a preliminary screening of the potential impacts was conducted to focus the study on the impact threads that were most significant and/or most likely to allow credible description and attribution. On the basis of these criteria, three main threads were identified (see Figure 4.2 and the individual representations in Section 5):

- **Thread 1.** The impact on the ozone layer over Canada, surface UV exposure in Canada and costs to Canadians resulting from implementation of the Montreal Protocol, due, in part, to the contribution of Canadian negotiators, whose position and effectiveness were influenced by the work and the knowledge provided by AES.
- **Thread 2.** Changes in behaviour of Canadians regarding exposure to the sun resulting from awareness of the risks promoted by AES' UV Index.
- **Thread 3.** New markets for a Canadian firm resulting from the invention of the Brewer spectrophotometer.

The impacts that are **not** a part of one of the significant impact threads have been eliminated from further consideration for the following reasons:

- **Scientific capacity**. This impact includes the technical infrastructure that is developed, including people, equipment and know-how (e.g., methodologies). It also includes access to the work of others and the development of absorptive capacity for such research. The infrastructure also creates other socio-economic impacts: it may lead to further productive R&D, it provides economic and social benefits by creating and maintaining Canadian jobs and expertise (e.g., training of graduates, keeping leading scientists in Canada), and it fosters a science based approach to problem solving and decision-making. Because such impacts are extremely difficult to define and attribute, they are not considered further, although they are anticipated to be positive.

Figure 4.2 - Principal Impact Threads for Stratospheric Ozone Depletion Research



- **Understanding of weather and climate change**. Although some knowledge has emerged, the incremental impact of this knowledge on worldwide understanding of the complex mechanisms of climate and weather, and the ultimate impacts of emerging greenhouse gas mitigation efforts, are extremely difficult to assess. For this reason the impacts are not considered further, although they are anticipated to be positive.

- **Contribution of delegations from other countries to the Montreal Protocol -- resulting from AES contributions to the worldwide knowledge base**. The dissemination of AES results in various fora (e.g., international Scientific Assessments and international symposia) means that delegations from other countries in negotiations for the Montreal Protocol would have, in part, based their contributions on those results. Although it is possible to estimate the AES contribution to the worldwide knowledge base (see Section 5), it is not practical to examine the other factors that influenced the contribution of the various foreign delegations. For this reason, these impacts are not considered further, although they are anticipated to be positive.

- **Increased public awareness of ozone depletion and risks of UV exposure -- resulting from the *Ozone Watch* program**. Based on the views of AES staff, the impact of *Ozone Watch* on the general public would have been much less significant than that of the *UV Index*. In order to concentrate our efforts, this impact is not considered further, although it is anticipated to be positive.

- **Canadian ODS regulations -- incremental to the Montreal Protocol -- resulting from AES understanding of the worldwide knowledge base**. Although many provinces and the Federal government implemented some measures that went beyond the Montreal Protocol, the incremental impact of these measures (in comparison with the impacts of the Protocol) are small and the link between them and the knowledge provided by AES is uncertain. For this reason these impacts are not considered further, although they are anticipated to be positive.

- **Reduced UV radiation in other countries**. The impacts are tangible and measurable, and may have significant direct implications for Canadians who spend significant time in other countries. However, because the main focus of the study was on the value of the R&D in Canada, it was decided not to pursue these impacts, although they are anticipated to be positive.

- **Effects on Climate**. Although the Montreal Protocol is having an effect on greenhouse gas emissions and hence on climate change, there are many uncertainties about the nature and scale of those effects. For this reason these impacts are not considered further, although they are anticipated to be positive.

- **Markets for Canadian Products and Services (ODS and substitutes) -- resulting from worldwide reductions in the use of ODS**. Preliminary indications are that the overall effect has been small. Canadian markets for ODS were lost but new markets for

ODS substitutes were created. The Montreal Protocol coincided with measures, by the large chemical manufacturers, to rationalize international production of various substances. As a result, Canada now manufactures a larger proportion of some ODS substitutes but imports a larger share of its total needs. Overall, the net loss of markets is not considered to be significant and the link to the Montreal Protocol is somewhat weak. For these reasons these impacts are not considered further, although they are anticipated to be negative.

It should be noted that the impacts not analysed are, for the most part, real and not just hypothetical. Although they are difficult if not impossible to describe and quantify, some may be significant. Because most are positive, the following analysis is considered to provide a conservative view of the benefits of the AES R&D.

5. DESCRIPTION OF IMPACTS AND INDIVIDUAL ATTRIBUTION

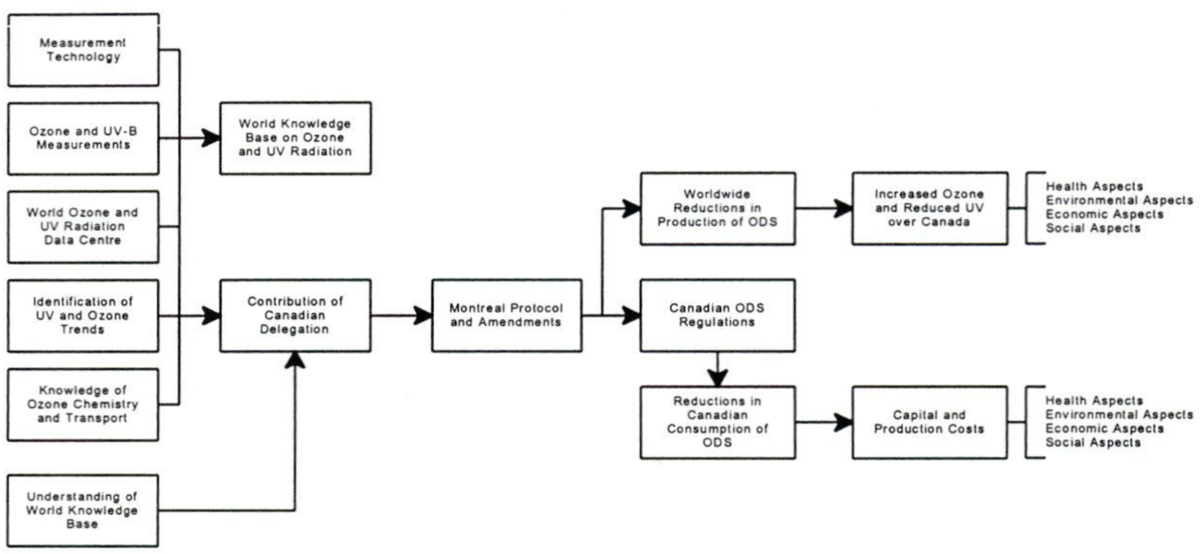
This section documents the result of efforts to characterize and attribute the impacts associated with the principal impact threads:

- **Thread 1.** The impact on the ozone layer over Canada, surface UV exposure in Canada and costs to Canadians resulting from implementation of the Montreal Protocol, due, in part, to the contribution of Canadian negotiators, whose position and effectiveness were influenced by the work and the knowledge provided by AES.
- **Thread 2.** Changes in behaviour of Canadians regarding exposure to the sun resulting from awareness of the risks promoted by AES' UV Index.
- **Thread 3.** New markets for a Canadian firm resulting from the invention of the Brewer spectrophotometer.

5.1 THREAD 1 -- MONTREAL PROTOCOL

Thread 1 is illustrated in Figure 5.1. It postulates that AES research contributed to the worldwide knowledge base on ozone and UV radiation and that, as a result, Canada gained scientific credibility and an improved understanding of the knowledge base. This contributed to Canada's position and the effectiveness of the Canadian negotiators developing the Montreal Protocol. The Canadian delegation, in turn, contributed to the Protocol and its amendments and will continue to contribute to possible future amendments. The Protocol is leading to worldwide reductions in the use of ODS which will control and eventually reverse the depletion of the ozone layer and reduce the incidence of UV radiation in Canada. Canadian ratification of the Protocol also led to Canadian ODS regulations which resulted in additional capital and production costs in Canada.

Figure 5.1 Thread 1 -- Impacts of Montreal Protocol



The linkages are:

- Contribution of AES research outputs to worldwide knowledge of ozone depletion and UV radiation
- Contribution of AES research and knowledge to the position and effectiveness of the Canadian delegation
- Contribution of the Canadian delegation to the Montreal Protocol
- Impact of the Montreal Protocol on reductions in worldwide use of ODS
- Impact of reductions in worldwide use of ODS on the ozone layer and UV radiation in Canada
- Impact of the Montreal Protocol on Canadian ODS regulations
- Impact of Canadian ODS regulations on reductions in Canadian use of ODS
- Impact of reductions in Canadian use of ODS on capital and production costs.

These linkages are considered, in turn, in the following subsections.

5.1.1 Immediate and Intermediate Impact: *Contribution of AES Research Outputs to Worldwide Knowledge of Ozone Depletion and UV Radiation*

There are three principal categories of knowledge at issue:[14]

- Knowledge of stratospheric ozone chemistry and transport mechanisms
- Knowledge of trends in stratospheric ozone
- Knowledge of the influence of ozone on surface radiation.

Although not linked directly to other impacts, the contributions of AES to each of these categories would have played a role in AES' ability to contribute to the position and effectiveness of the Canadian delegation and the delegation's contribution to the Montreal protocol.

Each contribution is examined in detail in Appendix F. Our conclusion is that the most significant AES contributions were to knowledge of trends in stratospheric ozone and knowledge of the influence of ozone on surface radiation.

Our overall proposed attribution is as follows:

Contribution of AES research outputs to the worldwide knowledge of ozone depletion and UV radiation:

- Low impact scenario: 4.0%
- Best guess scenario: 9.5%
- High impact scenario: 15.0%.

[14] Note that only atmospheric science is considered here. It is acknowledged that other elements of science and technology (e.g., health impacts, replacement technology) were also important.

5.1.2 Immediate and Intermediate Impact: *Contribution of AES Research and Knowledge to the Position and Effectiveness of the Canadian Delegation*

As described previously, Thread 1 postulates that, as a result of AES' contribution to the worldwide knowledge base, Canada gained scientific credibility and an improved understanding of this knowledge base, which in turn positively influenced the contribution of the Canadian negotiators developing the Montreal Protocol.

This influence would have been exerted in two ways: first, in shaping the Canadian positions entering into negotiations, and second, by contributing to the effectiveness of the negotiators (by arming them with solid scientific information and by giving them the credibility to speak on behalf of a country with good scientific credentials).

In order to address the impact of the R&D on the Canadian contribution, we need to consider four issues:

- The extent of the science-policy linkage on ozone issues.
- The extent of access to international science procured by the R&D.
- The AES contribution to the Canadian position.
- The AES contribution to the effectiveness of the Canadian negotiators.

- **The Extent of the Science-Policy Linkage on Ozone Issues**

The extent of the linkage between AES science and Canadian policy with respect to the international negotiations has not been extensively documented. However, there are a few references that are relevant:

The 1997 paper entitled *Learning from the Ozone Experience* makes the following points:[15]

- Since its beginning, the ozone experience has been characterized by a pathbreaking partnership between scientists and policymakers.

- Following the first wave of interest from policymakers in the mid-seventies, governments set in motion a World Plan of Action on the Ozone Layer, which led to the creation of a Coordinating Committee on the Ozone Layer to evaluate the science.

- Delegates negotiating the Vienna Convention in 1985 failed to reach agreement on controls, mainly because of the lack of clear scientific evidence. This led to a framework document that formalized scientific cooperation.

[15] French, Hillary. F. 1997. *Learning from the Ozone Experience.* In "State-of-the-World 1997" (pp. 151-171). Worldwatch Institute, Washington.

- At the signing of the Montreal Protocol in 1987, delegates noted that many gaps remained in scientific understanding, including the lack of comprehensive estimates of measured ozone loss or detectable increases in the UV radiation reaching the earth.

The recent report on ozone layer protection by the Auditor General of Canada also commented on the importance of the linkage between science and policy:[16]

- The Montreal Protocol broke new ground. Many factors have contributed to its success, including a strong scientific basis, supported by major scientific assessments on ozone depletion at the UNEP level.

- Many factors were critical to Canada's successes in influencing and implementing the controls under the Montreal Protocol. Such factors included ongoing measurement of results achieved, scientific, technical and cost-benefit justification, and effective stakeholder consultation.

A recent address, at the Ninth Meeting of the Parties to the Montreal Protocol (in Montreal, September 1997), by a prominent member of the Ozone Science Assessment Panel captured the relationship as follows:

- If one continues to add chlorine to the atmosphere it is very likely that significant ozone depletion lies ahead and the reversibility will be very slow. Based on that, the effects of such depletion, and the possible options of substitutes for CFCs, nations put their signatures to the Protocol on the 16th of September, 1987. But then a process began which asked the expert communities in science to periodically come back to them and give them their best updated statement of the understanding to see whether adjustments or amendments are warranted.

Although the above observations are directed primarily to the linkages that occurred at the international level, they indicate the extent to which the policy dialogue was being driven (at least in the early stages) by scientific considerations. Given that Canada participated actively in these initiatives and was involved in dealing with the key information gaps, it suggests that AES scientists would have had an important role. In fact, the evidence (see below) indicates that, prior to the negotiations for the Montreal Protocol, Canadian negotiations were led by scientists from AES.

[16] Auditor General of Canada. *Ozone Layer Protection: The Unfinished Journey*. Report of the Auditor General, Chapter 17, December 1997.

Leading while Keeping in Step: Management of Global Atmospheric Issues in Canada makes the following observations[17]:

- At both federal and provincial levels in Canada, the atmospheric science and policy communities are small, so relations between scientists and policymakers are close.

- In the early seventies the federal government established the AES Advisory Committee on Stratospheric Pollution, a group of senior scientists who advised on priorities for research, reviewed current research, and summarized the state of world research and its policy implications. When the Committee issued a report in 1976 saying it was time to control ODS', within one week, the Minister announced the government's intention to regulate CFCs in aerosol sprays.

- When the Coordinating Committee on the Ozone Layer was established, AES scientists acted as technical consultants to the chair and wrote the Committee's reports for several years. When international negotiations to control ozone depletion began in 1982, a small group of AES and Environment Canada officials pursued the negotiations full-time.

- The prominence of AES at the intersection between the atmospheric science and policy communities affects both how science is done and how policy is made. This system facilitates a particular mechanism for bringing scientific knowledge to bear on policy: the senior advisory committee of scientists and officials (AES Advisory Committee on Stratospheric Pollution), charged with both reviewing and prioritizing research effort, and drawing implications for policy.

The same paper also makes the following important statements:

- By the 1980s, all Canadian policy was reactive to, and derivative from, international scientific assessments and negotiations, even though these international processes had been substantially driven by Canadians. The decline in significance of the AES Advisory Committee marked the increasing subordination of Canadian policy to international policy and science.

- Still, the reactive character of Canadian responses to international policy and scientific processes is not total, for it is not acceptable merely to import assessments from abroad without at least "putting a Canadian slant on them." Domestic scientific expertise is always used to evaluate and validate international assessments, even when the international assessments have been strongly shaped by Canadians.

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[17] Parson, E.A., Dobell, A.R., Fenech, A., Munton, D. and Smith, H. (Version 4.1, Draft 1996). *Leading while Keeping in Step: Management of Global Atmospheric Issues in Canada.* John F. Kennedy School of Government, Harvard University.

The picture that emerges from these references is one of a tight science-policy linkage in the early stages of international discussions followed by a more indirect linkage, through the international science assessment process, beginning in the mid-1980s. Thus the influence of Canadian R&D on Canadian negotiators, which would have been almost direct in the 1970s, was felt more indirectly after that.

The Extent of Access to International Science Procured by the R&D

An important part of the influence of Canadian R&D was providing access to, and understanding of, the international knowledge base. This issue was addressed by nine interview subjects. Their views are summarized as follows:

- AES provided easy access to the knowledge. It might not have been so easy otherwise. The ability to draw Canadian conclusions was important in providing assurance that what we were advocating was right.

- Without the R&D, Canada could have had access to the Scientific Assessments but would not have been present at key meetings where the issues were debated. In practice, unless you are involved in the R&D, you cannot get a good sense of the underlying issues. You cannot get an in-depth understanding just by reading the reports (even if you have a scientific background). This requires involvement in the R&D. Familiarity with both the literature and the informal scientific consensus are essential to providing good scientific advice to policy-makers.

- To some extent, the R&D was not necessary because the Science Assessments would have been available anyway. However, Canada needed to be doing some work to gain access to the science, understand it, and interpret the implications for Canada. Canada also needed information on the Canadian situation. Workshops and Compendiums (some of which were organized by AES) were also valuable in gaining access and understanding the international work. Overall, the fact that R&D was being done was less important for gaining access to the science than it was in being able to assimilate international research results.

- The R&D work of AES was essential for assimilating the world knowledge base. Leadership came from a small number of AES people who drove the policy positions based on their appreciation of the science.

- The R&D work was not that important but the expertise of the science advisors was. Canada also had direct access to the expertise of US scientists. Overall, only 50% of the scientific knowledge used by the Canadian delegation passed through Canadian scientists.

- AES R&D was necessary to gain access to meetings where the issues were being discussed. Although Canada could have relied on the Science Assessments, they were too late to be incorporated into the thinking for the negotiations. AES R&D

was also necessary to preserve an independent source of advice. The R&D also allowed the scientists to be able to interpret the science for the negotiators.

- The AES contribution got Canada invited to the meetings and made it somewhat easier to gain access to the international science. The R&D was most important in assimilating the science, though we might have achieved most of the benefits by employing a scientist to monitor the emerging international science.

- Having valuable results from Canadian R&D was important because it allowed Canada to obtain the most recent results from other countries. Without the R&D, it would have been difficult to assimilate the knowledge. 60% to 70% of the available knowledge for policy formulation was attributable to being involved in the R&D. Canada could not have been a player in the negotiations otherwise.

- Without the R&D done in Canada, Canada would have had difficulties in gaining access to the science. Both the amount of information and the timing would have been affected. R&D is also very important in being able to assimilate the knowledge. Without it, Canadian scientists would not have been able to interpret the science for policy-makers.

Despite some differences in degree, there seems to be a consensus that the AES R&D was important in obtaining and understanding the international scientific knowledge.

AES Contribution to the Canadian Position

The question of AES influence on the Canadian position was addressed by six interview subjects. Their views are summarized as follows:

- The Canadian position was due in equal measure to input from AES (25%), other scientific input (25%) and economic and policy considerations (25%). Knowledge of the positions of other countries (15%) and other considerations (10%) also played a role.

- Overall, the atmospheric science contribution to the Canadian position was about 30%, of which 10% was due to AES R&D, and the rest coming from interpretation of the world science. Knowledge of effects, technology, economics, and other policy considerations contributed the remaining 70%.

- AES contributed only 5% to the Canadian position (not counting the knowledge of former AES scientists on the negotiating team). Knowledge of effects, economic and policy considerations, and knowledge of the position of others was far more important.

- The science provided by AES, the knowledge of effects, economic and policy considerations and the positions of other countries were each essential elements in forming the Canadian position.

- The Canadian position was primarily due to knowledge of the effects of ozone depletion and available technology. Economic and policy implications and knowledge of the position of other countries were also important. Atmospheric science probably contributed only about 10%, 2% to 3% of which was due to AES R&D.

- The Canadian position was shaped to a large extent by AES knowledge of the impacts on ozone and UV in Canada. Overall, this was probably about 30% of the input. Knowledge of technology options provided by industry, economic and other policy considerations, and knowledge of the positions of other countries made up the remaining 70%.

- The Canadian position was principally a result of knowledge of the positions of others (55%). AES science (15%), other science and technology (15%), and other policy considerations (15%) also played a role.

Despite some differences of opinion, the overall view seems to be that AES scientific knowledge (internally or externally generated) was an important input to the Canadian position (one of four principal inputs).

AES Contribution to the Effectiveness of the Canadian Negotiators

The question of AES influence on the effectiveness of the Canadian negotiators was addressed by eight interview subjects. Their views are summarized as follows:

- Canadian effectiveness in the negotiations was influenced by AES knowledge (25%), diplomatic credibility (25%), inherent skills of the Team (35%) and other factors (15%).

- The important factors were Canada's reputation and the expertise and skills of the participants. The fact that they understood the issues and were able to call on scientific knowledge when necessary was also a factor, but Canada's scientific credibility was not.

- Scientific reputation was not a major factor in the effectiveness of the negotiators. The main factors were diplomatic credibility and the skills and credibility of the Team. 5% of the effectiveness could be attributed to AES.

- The effectiveness of the negotiators was due primarily to diplomatic credibility (50%), scientific credibility (25%) and personal skills and credibility (25%).

- The main factors were the inherent skills of the Team (80%) and Canada's diplomatic credibility (18%). Knowledge provided by AES contributed 2%.

- The effectiveness was mainly due to diplomatic credibility and the team members themselves. AES credibility and knowledge added to this and all factors were essential.

- The skills of the team (50%) and Canada's diplomatic credibility (40%) were the prime factors. The influence of AES was about 10%.

- The effectiveness of the team was based on a good mix of factors. People listened because they knew Canada had the scientific knowledge. Overall, AES science contributed 30%, diplomatic credibility -- 30%, and the inherent skills of the team -- 40%.

- The effectiveness of the team was due primarily to Canada's diplomatic credibility (50%). Scientific knowledge and credibility (25%) and the skills of the Team (25%) were also important.

Overall, the influence of AES scientific knowledge and credibility appears to have been secondary to Canada's diplomatic credibility and the inherent skills of team members.

Overall Assessment of the Contribution of AES Research and Knowledge to the Position and Effectiveness of the Canadian Delegation

The views above indicate that the AES contribution, though secondary, was still an important influence on both the position and effectiveness of the Canadian delegation. This is also supported by the documentation which indicates a strong science-policy linkage on this issue. Considering the access to international science that AES provided and the preponderance of views on the AES role, the following attribution estimate is suggested.

Contribution of AES research and knowledge to the position and effectiveness of the Canadian delegation:

- Low impact scenario: 10%
- Best guess scenario: 20%
- High impact scenario: 30%.

5.1.3 Immediate and Intermediate Impact: *Contribution of the Canadian Delegation to the Montreal Protocol*

By most accounts (see below), Canada played a leadership role in the development of the Montreal Protocol and it was this leadership, in part, which led to the selection of Montreal as the site of the final negotiations.

The development of the Montreal Protocol was the culmination of many years of international efforts, including the activities of the CCOL and the negotiation of the Vienna Convention. Throughout this period, the international dynamic was conditioned by the position of the two main participants: the US and the EU.

One US negotiator described the evolution as follows. In the early years (before the US had an official position), Canada led the negotiations and coordinated the activities of "like-minded countries" in pressuring the EU to accept limits on production of CFCs. After the US announced its intention to ban aerosol use of CFCs as a first step in 1983, Canada took on the role of attempting to convince EU countries to do the same. Although no firm commitments were obtained through the Vienna Convention, Canada was instrumental in obtaining a commitment on a timetable for a binding protocol. Ultimately, this ended up going further than a ban on aerosols. During the Protocol negotiations, the US was responsible for drafting text but was highly influenced by Canadian ideas. Canada also played a large role in convincing other countries of the merits of these proposals. In doing so, Canada was able to take advantage of its "honest broker" status to push positions that the US would have had difficulty advocating directly. Canada's ideas and behind-the-scenes work on achieving consensus were critical to the achievement of the Protocol.

This account appears to be supported by the available documentation.

The report on ozone layer protection by the Auditor General of Canada includes the statement[18]:

- Foreign government officials and experts see Canada as a pivotal player in the early development and ongoing evolution of the global response to ozone layer depletion. Some hold the view that the Montreal Protocol would not exist in its current form had it not been for the leadership and intervention of Canadians.

Leading while Keeping in Step: Management of Global Atmospheric Issues in Canada makes the following observations[19]:

- A country like Canada that is rich and scientifically advanced but only of medium size can more readily make leading contributions on environmental or scientific issues, where the requisite resources are primarily scientific and diplomatic expertise, than on security or economic policy.

- Canadian individuals and institutions exercise a striking degree of leadership, and of constructive contribution generally, to international science, policy, and management on these issues (ozone, climate change and acid rain).

- On all three issues, Canadians were the first, or among the first, to advocate

[18] Auditor General of Canada. *Ozone Layer Protection: The Unfinished Journey*. Report of the Auditor General, Chapter 17, December 1997.

[19] Parson, E.A., Dobell, A.R., Fenech, A., Munton, D. and Smith, H. (Version 4.1, Draft 1996). *Leading while Keeping in Step: Management of Global Atmospheric Issues in Canada*. John F. Kennedy School of Government, Harvard University.

international management. Once international processes were underway, Canadians were conspicuous in their support, both operationally and substantively.

- The decision to hold the September 1987 Ministerial conference in Montreal, at which the Protocol was signed, acknowledged the contributions to the negotiations of key Canadians.

The question of Canada's contribution to the Montreal Protocol was addressed by eight interview subjects. Their views are summarized as follows:

- Canada was a key player in formulating the structure of the Protocol, including the focus on consumption defined as production plus imports minus exports. Others may have had the same ideas so there is some overlap, but overall the credit to Canada for the Protocol should be between 25% and 35%.

- The countries that influenced the Protocol were the US, the EU, Canada, Australia, the Nordic countries, Egypt (on behalf of developing countries) and Russia. Canada played a leadership role. Because of the ideas generated and the behind-the-scenes work on achieving consensus, the contribution of Canada exceeded the air time it received during the discussions. Overall, a minimum of 20% could be attributed to the Canadian delegation.

- The key players were the US, the UK, Germany, France, Russia and Canada. Canada's role was very important, particularly because US positions were always considered suspect by other countries (countries like Canada, Switzerland and the Netherlands often have a disproportionate influence in such circumstances). The Canadian negotiators were thought to be very effective and trustworthy. Canada's work leading to the Vienna Convention paved the way for a more comprehensive and effective Montreal Protocol. Canada was very instrumental in finding ways to harmonize the holistic (but ineffective) approach suggested by the EU with the effective (but narrow) approach suggested by the US. Canada was always willing to try new ideas (some better than others) and this helped move the process forward. Canada was particularly effective because it was perceived to be an honest broker. Other countries putting forth the same suggestions would not have been as effective. This played a role in the selection of Montreal for the site of the Protocol signing. Canada's role carried forward to the negotiations of amendments in London and Copenhagen. If Canada had not participated, the structure of the Protocol would probably still be the same but the magnitude of the cuts might not have been as significant (at least initially) because Canada helped convince the EU that more stringent targets were necessary (both in magnitude and timing). Overall, the Canadian contribution was in the 10% to 20% range.

- Canada helped keep the initiative alive after Vienna by calling together a group of "like-minded countries" in Toronto to keep the pressure on others. Canada was part of a small group that brokered the final deal. In particular, Canada played a role in promoting the EU position on the scope and the US position on controls. Canada's role in Copenhagen was also important. Overall the Canadian contribution was about 20%.

- Canada played the honest broker role and was very important in resolving disputes between the US and other parts of the world. In particular, there was a meeting in Toronto (after the Vienna Convention) which brokered a solution to the impasse that then existed. Later on, in dealing with important commercial interests (US and UK), Canada brought a labour negotiations approach to resolve issues and forge a compromise (this was analogous to Canada's role in negotiating the recent Land Mines Treaty). If Canada had not participated, the process would have taken longer (maybe only a few months) and the Protocol would have been somewhat weaker. Overall, Canada contributed 25% to 35% to the Protocol.

- Canada played a major role in the negotiations. This included developing the control mechanism (which ultimately allowed the effort to be expanded from the initial 26 countries to a global one) and the use of the ozone depletion potential parameter. Canada played the role of honest broker which was crucial in overcoming commercial concerns (in the US and UK). Without Canada, the Protocol would have been like the Vienna Convention (no controls, no mechanism for continuous improvement and longer delays). Overall, Canada contributed 40%, the US -- 30%, the EU -- 20%, and the Nordic countries -- 10%.

- The US and the EU were the leaders but Canada's contribution was significant. The negotiators were very active and participated in key meetings that involved only a few countries. Without Canada, a few clauses would definitely been different. Overall, Canada contributed about 10%.

- Canada played a key role in the negotiations, especially up to 1990. Without Canada, the Protocol would have taken much longer to negotiate and developing countries would not have been inclined to participate. Canada played the honest broker, bringing others into the agreement. Overall, the Canadian contribution was 30% to 40%.

- The US and EU were the dominant players but Canada also played a major role. In particular, the formation of the "Toronto Group" was a key development. Without Canada, the Protocol might not have been completed in 1987 but would have been soon after. Canada also contributed some key design features. Overall, the Canadian contribution was about 30%.

- Canada's contribution to the Protocol was important. The Canadian team was well-balanced, knew the science and technological issues, and was able to identify the problems and find creative solutions to them. If Canada had not participated, there would have been fewer creative ideas and this would have been a problem because creative ideas were essential in this new type of international law. A delay was unlikely but the design would have been less effective and the phase-out schedule would have been less ambitious. Overall, the Canadian contribution was 30%, the US -- 30%, Nordic countries -- 20%, the rest of Europe -- 15%, and New Zealand -- 5%.

- Canada played an important role, brokering deals between the US and others. Overall, the contribution was about 10%.

Given the documentation and interview results, there appears to be a reasonable consensus that Canada, though probably not the most important contributor to the Protocol, played a very important role. Based on all the available information, the following attribution estimated is suggested:

Contribution of the Canadian Delegation to the Montreal Protocol:

- Low impact scenario: 10%
- Best guess scenario: 20%
- High impact scenario: 30%.

5.1.4 Immediate and Intermediate Impact: *Impact of the Montreal Protocol on Reductions in Worldwide Use of ODS*

The global impacts (costs and benefits) of the Montreal Protocol were the subject of a recent report prepared by ARC Applied Research Consultants for the 10th Anniversary Meeting of the Parties, held in Montreal in September, 1997.[20] Following publication of that report, ARC prepared a second report for Environment Canada on the benefits and costs to Canada (drawing on the results and methodology used in the global study). The analysis presented below draws extensively from the second ARC report.

For simplicity and for consistency with the ARC Report, this analysis assumes that all measures contained in the Montreal Protocol are attributable to it. [21]

The Montreal Protocol and later amendments commit signatories to a schedule of reductions in the consumption of ODS (defined as production plus imports minus exports). ARC used data provided by UNEP, ICF Kaiser Inc. and Ausimont Inc. to

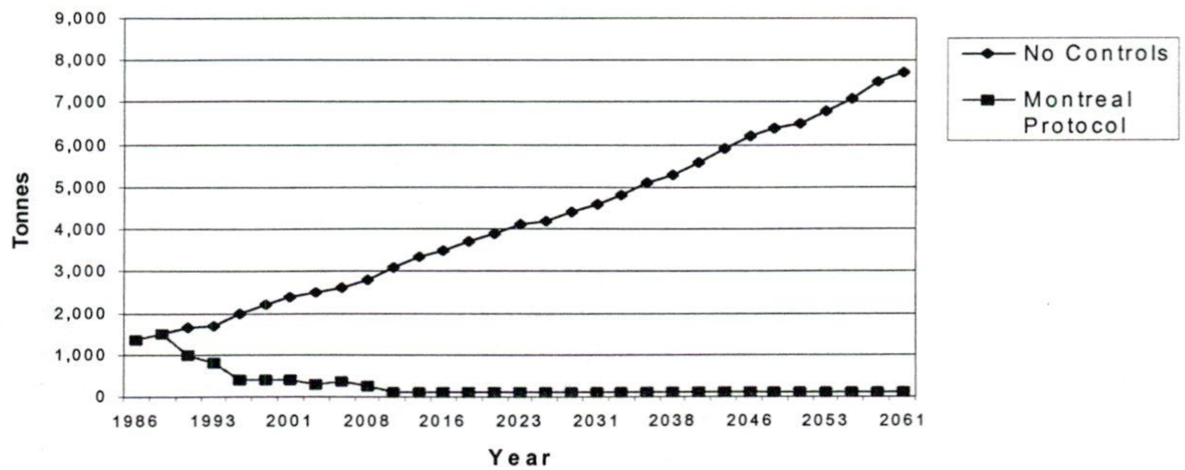
[20] ARC Applied Research Consultants. September 1997. *Global Benefits and Costs of the Montreal Protocol on Substances that Deplete the Ozone Layer.* For Environment Canada.

[21] Some countries might have implemented some measures in the absence of the Protocol. In principle, such measures could be excluded from this step in the analysis (i.e., not attributed to the Protocol). The degree of attribution of such measures to AES research would then need to be separately determined. However, there is no practical basis for doing so, because the nature and extent of such hypothetical measures is unknown, as is their attribution to AES R&D. Thus, attribution of all measures contained in the Montreal Protocol to the protocol is a reasonable simplification that makes use of available data.

estimate the global consumption of ODS under the Protocol and in a no controls scenario for the period 1986 to 2060. The date 2060 is the approximate date at which scientists expect that the ozone layer will have recovered and corresponds to the lifespan of persons who were born at the time the Montreal Protocol was signed.

Figure 5.2 presents ODS consumption by year (for both developed and developing countries). It should be noted that Figure 5.2 reflects the current provisions of the Protocol, which will continue to evolve, in part as a result of ongoing measurements of ozone and UV radiation and resulting decisions on adjustments or amendments to the Protocol.

Figure 5.2
Global Consumption of ODS, 1986-2060[22]



[22] Weighted by Ozone Depleting Potential

Impact of the Montreal Protocol on Reductions in Worldwide Use of ODS

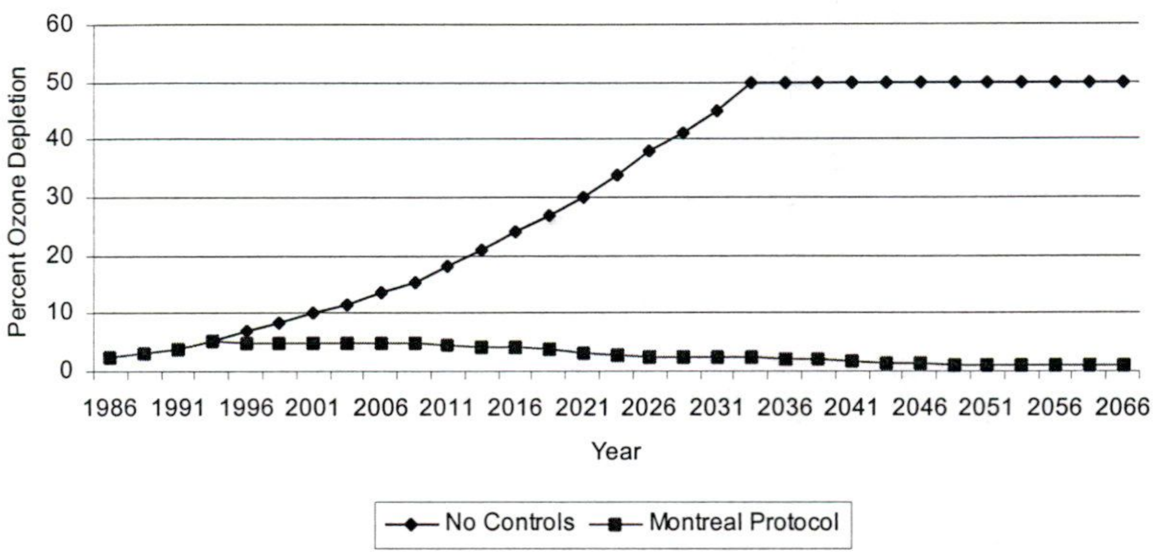
Based on the data presented in Figure 5.2, the Montreal Protocol will yield a reduction, over the 1986 to 2060 period, of approximately 300 megatonnes of ozone depleting substances (weighted by Ozone Depleting Potential).

5.1.5 Ultimate Impact: *Impact of Reductions in Worldwide Use of ODS on the Ozone Layer and UV Radiation in Canada*

ARC relied on an existing model developed for the US Environmental Protection Agency (US EPA) to estimate the atmospheric effects of the Protocol, and of a no controls scenario.[23] The model uses detailed information on ODS use patterns to estimate emissions, and uses these emissions to estimate global ozone depletion.

Results are shown in Figure 5.3. The model limits ozone depletion to a maximum of 50% in the no controls scenario. This restricts the size of the annual benefits associated with the Protocol, in recognition of the limitations of existing knowledge about atmospheric dynamics at such severe depletion levels.

Figure 5.3
Ozone Depletion, 1986-2060



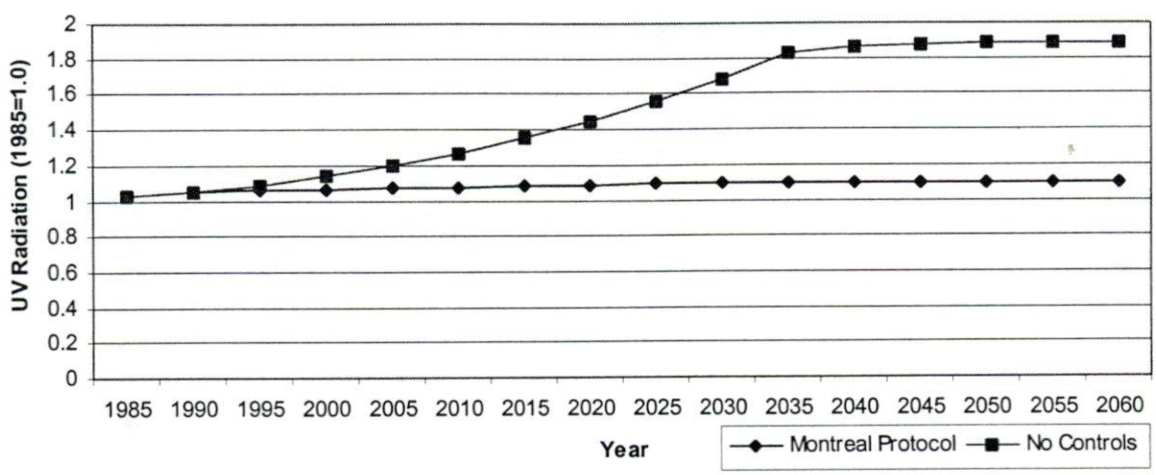
[23] US Environmental Protection Agency. (1992). *Regulatory Impact Analysis: Protection of Stratospheric Ozone Vol. I Regulatory Impact Analysis Document.* Prepared for US Environmental Protection Agency. July 1992.

In the case of full compliance with the Montreal Protocol, the ozone layer is expected to reach its maximum depletion before the year 2000. Thereafter, the ozone layer will re-establish itself, a process that is expected to take more than fifty years.

ARC used the annual change in global ozone to estimate the percentage change in UV. The analysis first examined relevant action spectra for the Middle Region of the US (approximately 35°N) based on a formula used in the Regulatory Impact Assessment conducted for the US EPA.[24] The result was a set of estimated UV changes, weighted for various UV spectra, for the latitude band 30°N to 40°N, by year. Values were then estimated for other latitude bands, based on stratospheric ozone measurements between 1979 and 1993, taken from the Science Assessment.[25]

For Canada, three latitude bands were used (40°N to 50°N, 50°N to 60°N, and 60°N to 70°N). For each band, the percentage change in UV radiation from 1985 levels was calculated, by year, for the Protocol and the no controls scenario, weighted for the relevant UV spectra (depending on the effect being estimated). Figure 5.4 presents results for the 40°N to 50°N band, for the spectra weighted for non-melanoma cancer.

Figure 5.4
UV Radiation Level Relative to 1985 (1985 = 1.0)
(Spectra Weighted for Non-Melanoma Cancer)



[24] US Environmental Protection Agency. (1992). *Regulatory Impact Analysis: Protection of Stratospheric Ozone Vol. I Regulatory Impact Analysis Document.* Prepared for US Environmental Protection Agency. July 1992.
[25] *Scientific Assessment of Ozone Depletion: 1994.* WMO Report no. 37.

Impact of Reductions in Worldwide Use of ODS on UV Radiation in Canada

Based on these estimates, UV radiation for this latitude band in 2060 will be approximately 42% lower than what it would have been in the absence of the Protocol. Peak reductions for other spectra and other latitude bands range from 42% to 48%.

5.1.6 Immediate and Intermediate Impact: *Impact of the Montreal Protocol on Canadian ODS Regulations*

Prior to the Montreal Protocol, Canada had implemented, in 1981, regulations dealing with the use of CFCs as propellants for personal care products. Following the Protocol, and the proclamation of the Canadian Environmental Protection Act (CEPA) in 1988, Canada issued new regulations and consolidated the existing ones. As amendments and adjustments were made to the Protocol, Canadian regulations were also amended and consolidated. The history of Canadian regulations is detailed in Table 5.1.

Table 5.1
History of Canadian ODS Regulations[26]
(* Indicates Regulations that Go Beyond the Protocol)

Year	Regulation	Description
1989	Chrlorofluorocarbon regulations	These regulations integrated the original 1981 regulations dealing with the uses of CFCs as a propellant in personal care products to include them under the Canadian Environmental Protection Act (CEPA).
1989	Ozone-depleting Substance Regulations, No. 1	These regulations dealt with CFCs and established a reduction schedule consistent with the Montreal Protocol schedule.
1990	Ozone-depleting Substances Regulations, No. 2	The bromofluorocarbon regulations established Canada's reduction schedule for halons.
1990	Ozone-depleting Substances Regulations, No. 3* (Products)	These regulations prohibited the use of CFCs in products for specified non-essential uses or where substitutes were available (in aerosols, plastic foam packaging and in small refrigerant refill containers).
1993	Ozone-depleting Substances Regulations, No. 4	These regulations established Canada's control schedule for carbon tetrachloride and methyl chloroform.
1994 (Amendment)	Ozone-depleting Substances Regulation, No. 3* (Products)	This amendment prohibited the import of specified products from non-Parties to the Montreal Protocol
1994	Ozone-depleting Substances Regulations	These regulations consolidated the previous regulations, No. 1, 2 and 4, added hydrochlorofluorocarbons (HCFCs) to the list of

[26] Source: ARC Applied Research Consultants. October 1997. *Benefits and Costs of Canadian Participation in the Montreal Protocol on Substances that Deplete the Ozone Layer*. For Environment Canada.

Year	Regulation	Description
		controlled substances and incorporated the accelerated reduction schedules for CFCs and halons from the Copenhagen amendments to the Protocol.
1994 (Amendment)	Ozone-depleting Substances Regulations	This regulation implemented Canada's control schedule for methyl bromide.
1995 (Amendment)	Ozone-depleting Substances Regulation	These regulations established a control schedule for HCFCs to meet Protocol requirements.
1996 (Amendment)	Ozone-depleting Substances Products Regulations*(Products)	This regulations allowed the import and sale of small pressurized containers for laboratory use, clarified product definitions and provided an exemption for CFCs sold to be recycled or reclaimed for use as a refrigerant.

At present, all substance regulations required by the Montreal Protocol (e.g., CFCs, halons, carbon tetrachloride, methyl chloroform, HCFCs, methyl bromide) have been consolidated in the Ozone-depleting Substances Regulations. With minor exceptions (involving more stringent criteria or accelerated schedules), the regulations match the requirements of the Protocol.

As a leader in the worldwide effort to control ODS, Canada may have adopted some ODS regulations even without the Protocol (e.g., the pre-existing CFC regulations). However, as Canada's policies on ODS were intrinsically linked to the international negotiations, we assume for the purposes of this analysis that the regulations that conform with the Protocol are entirely the result of the Protocol (this mirrors our assumption concerning the attribution of worldwide ODS reductions to the Protocol).

5.1.7 Immediate and Intermediate Impact: *Impact of Canadian ODS Regulations on Reductions in Canadian use of ODS*

The ARC report on Canadian costs and benefits examined Canadian use of ODS.[27]

ARC used estimates provided by Environment Canada to determine a benchmark of ODS consumption for 1986. This consumption is shown in Table 5.2.

[27] ARC Applied Research Consultants. October 1997. *Benefits and Costs of Canadian Participation in the Montreal Protocol on Substances that Deplete the Ozone Layer.* For Environment Canada.

Table 5.2
Estimated Canadian Consumption of ODS (1986)

ODS	Consumption (tonnes/year)
CFCs	19,450
HCFCs	2,500
Halons: 1201	220
1301	250
Methyl Chloroform	15,600
Carbon Tetrachloride	100
Methyl Bromide	179
Total	**38,299**

For the period 1987-2060, Table 5.3 shows total estimated reductions in Canadian ODS use due to the Canadian regulations. The data in this table is based on the difference between the Canadian ODS regulations and a no controls scenario. Consumption under the Canadian regulations is based on Environment Canada estimates for the period 1987 to 1995, with reductions beyond 1995 as mandated by the regulations. The forecast use for the no controls scenario is based on the observed and expected growth in each affected application.

Table 5.3
Estimated Reductions in Canadian ODS Use (1987-2060)
due to Canadian ODS Regulations

ODS	Application	Total Reduction (Tonnes)
CFCs	Aerosols	108,000
	Flexible Foam	14,000
	Rigid Foam	340,000
	Refrigeration and Air Conditioning	237,000
	Solvents	94,000
	Sterilants	22,000
HCFCs	All (same as for CFCs)	195,000
Halons: 1201	Fire Control	42,000
1301		26,000
Methyl Chloroform	Solvents	81,000
Carbon Tetrachloride (Non Feedstock)	Various	2,000
Methyl Bromide	Fumigation	1,000
Total		1,162,000

Impact of Canadian ODS Regulations on Reductions in Canadian Use of ODS

Table 5.3 shows total reductions in Canadian ODS use of 1.16 million tonnes during the period 1987 to 2060, as a result of the Canadian ODS regulations.

5.1.8 Ultimate Impact: *Impact of Reductions in Canadian Use of ODS on Capital and Production Costs*

In their report on global costs and benefits, ARC examined the measures and approaches used in converting from ODS use in a variety industries.[28] These adaptations are described in Table 5.4.

Table 5.4
Adaptations to ODS Controls in Selected Industries

ODS	Application	Adaptation
CFCs	Aerosols	Replace with hydrocarbons
	Flexible Foam	Replace with water and HCFCs
	Rigid Foam	Replace with HCFCs
	Refrigeration and Air Conditioning	Replace with HCFCs
	Solvents	Improved practices, replace with other solvents or HCFCs
	Sterilants	Conservation or replace with HCFCs
HCFCs	All (same as for CFCs)	Replace with CO_2 systems or HFCs
Halons 1201 1301	Fire Control	Replace with CO_2 or dry chemical, replace with sprinklers and increased detection, replace with clean agent systems (FM 200, inert gases) or HCFCs
Methyl Chloroform	Solvents	Replace with alternative solvents
Carbon Tetrachloride (Non Feedstock)	Various	Various methods
Methyl Bromide	Fumigation	Various methods

Based on the unit cost (capital and production) for each adaptation and the total amount of ODS to be replaced in each year, ARC calculated the total capital and operating costs associated with the implementation of the Canadian regulations.[29] The calculation

[28] ARC Applied Research Consultants. September 1997. *Global Benefits and Costs of the Montreal Protocol on Substances that Deplete the Ozone Layer.* For Environment Canada.

[29] This calculation involved the use of complex models to account for different replacement technologies; forecasts of usage and equipment installation and retrofit; forecast of the price for CFCs and HCFCs; the timing of intermediate replacement by HCFCs; and the implication of forecasts on year-to-year changes in requirements for ODS and/or substitutes.

included equipment costs, cost of substances, maintenance costs, energy costs and substance recycling costs. The present (1997) value of the capital costs and ongoing production costs was calculated, using a discount rate of 5%. Results are shown in Table 5.5.

Table 5.5
Summary of Total Costs to Canadian Industry for Montreal Protocol Controls (1987-2060)

ODS	Application	Unit Cost ($1997 per Kg)[30]	Total Cost ($1997 Millions)
CFCs	Aerosols	($1.19)	($128.40)
	Flexible Foam	$0.12	$1.70
	Rigid Foam	$2.43	$826.50
	Refrigeration and Air Conditioning	$6.24	$1,477.00
	Solvents	$1.52	$143.30
	Sterilants	$1.93	$42.40
Halons	Fire Control		
1201		($2.03)	($85.40)
1301		$40.50	$1,062.00
HCFCs	All (same as for CFCs)	$3.90	$760.00
Methyl Chloroform	Solvents	$2.03	$165.30
Carbon Tetrachloride (Non Feedstock)	Various	$1.24	$2.50
Methyl Bromide	Fumigation	$5.94	$5.70
Total			**$4,272.60**

[30] Negative numbers indicate net cost savings.

Impact of Reductions in Canadian Use of ODS on Capital and Production Costs

Table 5.5 shows total costs to Canadian industry of $4.3 billion (in 1997 dollars) during the period 1987 to 2060, as a result of the Canadian ODS regulations.

5.1.9 Summary

AES research contributed 5% to 15% of the worldwide knowledge base on ozone depletion and UV radiation. As a result, Canada gained scientific credibility and an understanding of this knowledge base which influenced the contribution of the Canadian negotiators developing the Montreal Protocol.

Recent and ongoing work by AES to measure trends will continue to have an effect on the worldwide knowledge base and will influence future changes to the Protocol.

AES research and knowledge was responsible for 10% to 30% of the position and effectiveness of the Canadian delegation in the negotiation of the Montreal Protocol. The Canadian delegation in turn contributed between 10% and 30% to the negotiation of the Protocol and Amendments.

The Montreal Protocol will lead to reductions in ozone depletion and reduced UV over Canada. Based on the analysis completed by ARC, peak reductions in UV (occurring around 2060) will range from 42% to 48% of the estimated non-Protocol levels.

Based on the analysis completed by ARC, the capital and production cost to Canadian industry of implementing the Canadian regulations arising from the Montreal Protocol will total approximately $4.3 billion, in 1997 dollars.

5.2 THREAD 2 -- UV INDEX

Thread 2 is illustrated in Figure 5.5. It postulates that AES work on UV forecasts led to the development and implementation of the *UV Index* which increased public awareness of the risks of UV radiation and led Canadians to take measures to protect themselves.

Figure 5.5

Thread 2 -- Impacts of UV Index

The linkages are:

- Contribution of AES ozone and UV forecasts to the development and implementation of the *UV Index*
- Impact of the *UV Index* on public awareness of the risks of exposure to UV radiation
- Impact of awareness of the risks on behaviour of Canadians (involving protective measures)

These linkages are considered, in turn, in the following subsections.

5.2.1 Immediate and Intermediate Impact: *Contribution of AES Ozone and UV Forecasts to the Development and Implementation of the UV Index*

The development of the *UV Index* is described in several publications, including:

- *The Canadian Ozone Watch and UV-B Advisory Programs*[31]
- *The Canadian Operational Procedure for Forecasting Total Ozone and UV Radiation*[32]
- *Decreasing Ozone Causes Health Concern -- How Canada Forecasts Ultraviolet-B Radiation*[33]
- *The Canadian UV Index Program: 1992-1997*[34]

The *UV Index* program was launched in May 1992, one year ahead of schedule, fulfilling a 1991 Green Plan commitment to provide Canadians with daily information on the

[31] Kerr, J.B., McElroy, C.T., Tarasick, D.W. and Wardle, D.I. (1994). *Canadian Ozone Watch and UV-B Advisory Programs*. In Proc. Quad. Ozone Symp. Charlottesville, VA. June, 1992, 794-797.
[32] Burrows, W., Vallee, M., Wardle, D., Kerr, J., Wilson, L and Tarasick, D. (1994). *The Canadian Operational Procedure for Forecasting Total Ozone and UV Radiation.* Met Apps., 1:247-265.
[33] Kerr, J.B. (1994). *Decreasing Ozone Causes Health Concern -- How Canada Forecasts Ultraviolet-B Radiation.* Environ. Sci. Technol., Vol. 28, No. 12.
[34] Broadhurst, D. (1997). *The Canadian UV Index Program: 1992-1997.* Draft for publication in the Report of the WMO-WHO Meeting of Experts on Standardization of UV Indices and Their Dissemination to the Public, Les Diablerets, Switzerland, July, 1997.

intensity of incident UV-B radiation by 1993. The heart of the program is the provision of daily maximum UV Index forecast values for communities across the country. The UV scale has been subdivided into four descriptive categories to provide context to the forecast: low (0-3.9), moderate (4-6.9), high (7-8.9), and extreme (9.0 or more). Forecasts are issued in the early morning valid for that day, and in the afternoon for the following day.

The *UV Index* was a departure from traditional AES programs in that it directly addresses a public health issue. As such, AES worked closely with health organizations and professionals to design the UV program and craft the sun protection messages associated with the index.

The forecast technique involves a four step process:

- Step One. Forecast of total ozone across North America based on weather prediction model
- Step Two. Correction to forecast based on ozone observations from twelve stations in Canada
- Step Three. Calculation of clear sky UV-B irradiance and the UV Index for each location based on the ozone forecast, along with variables dependant on latitude and time of year
- Step Four. Adjustment of the forecast to account for cloud conditions.

The forecasts are currently produced for 48 sites and distributed in a national bulletin. For each site, the bulletin predicts the maximum UV Index and associated category, the predominant sky condition and the hours of the day for which the Index is expected to be moderate or higher.

As noted above, although the *UV Index* is an AES program, AES staff acknowledge the contribution of various sources to its development and implementation. The extent of external contribution was explored in five interviews. The views expressed are summarized as follows:

- AES was principally responsible for the Index, but Health Canada played a role.

- There were seven important contributions. Four were essential, including advanced knowledge of numerical weather prediction (the knowledge is worldwide, AES is 100% responsible for applying it); knowledge of the effects of ozone on UV (15% due to AES -- see Section 5.1); development of the index design (100% due to AES); and real time measurements of ozone (100% due to AES). Three were important but not essential, including definition of measures to minimize exposure (25% due to AES, mainly done by health organizations); provision of the dissemination system (100% AES); and development of the communications strategy (50% AES, the rest coming from a wide range of stakeholders). Note that prior to the Index, Australia and New Zealand made public qualitative information on a regular basis, but AES invented the Index.

- There were four main factors: the measurements (AES was 90% responsible); the method (AES was 80% responsible, the rest came from Health Canada); the definition of measures to reduce exposure (AES was possibly 50% responsible, the rest came from health organizations); and the communication and dissemination strategy (AES- 90%). All four factors were relatively equal in importance, though the communications strategy was key and the measures to reduce exposure less so.

- There were four main factors: the measurements (AES -- 100%); the method (AES -- 100%); the definition of measures to reduce exposure (50% to AES, the rest to health organizations); and the communications strategy (AES -- 75%).

- There were four main factors: the measurements (AES -- 100%); the method (AES -- 80%, the rest was policy input); the definition of measures to reduce exposure (maybe 50% due to AES); and the communications strategy (50% to 60% AES). The definition of measures and the communications strategy were most important.

There is a clear consensus that AES was the principal source of the Index design and implementation. Based on the views collected, the following attribution estimate is proposed:

Contribution of AES Ozone and UV Forecasts to the Development and Implementation of the UV Index:

- Low impact scenario: 65%
- Best guess: 75%
- High impact scenario: 85%.

5.2.2 Immediate and Intermediate Impact: *Impact of the UV Index on Public Awareness of the Risks of Exposure to UV Radiation*

A number of publications have reported that the *UV Index* has increased public awareness of UV radiation and the risks of exposure.

- *The Canadian UV Index Program: 1992-1997* reports that Health Agencies have indicated that the UV Index has increased public understanding of UV radiation and served to keep the sun protection message before the public.[35]

- A December, 1992 Decima Research survey of 1200 Canadians found that 91% of respondents were aware of the relationship between UV rays and health and 73%

[35] Broadhurst, D. (1997). *The Canadian UV Index Program: 1992-1997*. Draft for publication in the Report of the WMO-WHO Meeting of Experts on Standardization of UV Indices and Their Dissemination to the Public, Les Diablerets, Switzerland, July, 1997.

were aware of the *UV Index*.[36]

- A March 1996 study by Goldfarb Consultants for Health Canada reported on a series of focus groups with parents and teens in Montreal, Toronto and Calgary. The focus groups dealt with opinions and behaviours concerning ozone depletion, UV radiation and risk.[37] Parents identified the main sources of information about UV as their own children, the Weather Chanel's UV Index and sunscreen advertisement. Teenagers reported receiving information from a variety of sources. In Montreal, older teens reported having a good awareness of the UV Index which is broadcasted regularly on the Cable Weather Chanel.

- The most comprehensive survey on sun protection ever undertaken in Canada was the Fall 1996 survey by investigators from the University of British Columbia.[38] The *National Survey on Sun Protection and Protective Behaviours* asked 4,023 Canadians a series of 55 questions about their habits and attitudes concerning sun protection. Four of these questions dealt specifically with the *UV Index*. Results indicate that approximately 75% of respondents heard or saw information on the *UV Index* at least sometime between June and August 1996. Of those, approximately half appeared to understand the numbers used in the UV rating system.

These studies indicate that there is relatively high awareness of the *UV Index*. Unfortunately, it is not clear to what degree this awareness is responsible for broader awareness of the risks of exposure to UV radiation nor is it clear that those who are aware of the *UV Index* necessarily understand it (witness the 50% in the UBC survey who did not).

Given the available information, we can only provide a gross estimate of the impact of the UV Index on awareness. Given the inherent uncertainty, conservative estimates are proposed.

Impact of the UV Index on public awareness of the risks of exposure to UV radiation[39]*:*

- Low impact scenario: 20% of people are aware
- Best guess: 40% of people are aware
- High impact scenario: 60% of people are aware.

[36] Decima Research (1993). *An Investigation of Canadian Attitudes Related to Environment Canada's UV Index.* 6pp.

[37] Goldfarb Consultants. (1996). *A Research Project on Opinions and Behaviours Concerning Ozone Depletion, UV Radiation and Risk.* For Health Canada, March 1996.

[38] Lovato C., Shoveller J., Rivers, J., (Eds.), 1997, *"National Survey on Sun Exposure and Protective Behaviours: Final Report"*. Vancouver: Institute of Health Promotion Research, University of British Columbia.

[39] These estimates reflect the portion of the entire population who are aware of the risks, primarily as a result of the UV Index.

5.2.3 Ultimate Impact: *Impact of Awareness of the Risks on Behaviour of Canadians (Involving Protective Measures)*

Both the Decima and UBC surveys reported that those who were aware of the UV Index, were taking precautions:

- The Decima Survey indicated that, of those who were aware of the Index, 59% (43% of the full sample) indicated that it had influenced their sun exposure habits (81% of these used more sunscreen, 68% stayed out of the direct sun, 65% wore protective clothing and 58% wore sunglasses more often).[40]

- The UBC survey indicated that, of those who were aware of the Index, 57% (51% of the full sample) took extra precautions when the UV Index was rated as high.[41] The survey also reported that during leisure hours the proportion of people who take stated precautions at least sometimes was: seek shade (72%), avoid sun (66%), wear hat (59%), wear protective clothes (67%), sunscreen face (53%), sunscreen body (52%) and wear sunglasses (70%).

- Another study by the Canadian Environmental Monitor reports that 81% of Canadians are taking action to reduce their exposure.[42] This study reports the following actions: using sunscreen (67%), reducing exposure (65%), wearing protective clothing (38%), wearing sunglasses (13%).

Given this information (and noting the tendency of respondents to over-report desirable behaviour), we propose the following estimate:

Impact of Awareness of the Risks on Behaviour of Canadians:

- Low impact scenario: 40% of those who are aware protect themselves
- Best guess: 50% of those who are aware protect themselves
- High impact scenario: 60% of those who are aware protect themselves.

Combining these estimates with the estimates of the impact of the UV Index on awareness (Section 5.2.2) yields the following estimate:

Impact of UV Index on Behaviour of Canadians:

- Low impact scenario: 8% of people protect themselves
- Best guess: 20% of people protect themselves
- High impact scenario: 36% of people protect themselves.

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[40] Decima Research (1993). *An Investigation of Canadian Attitudes Related to Environment Canada's UV Index.* 6pp.

[41] Lovato, C., Shoveller, J., Peters, L. and Rivers, J. (October, 1997, in progress). *National Survey on Sun Protection and Protective Behaviours.* Technical Report.

[42] Canadian Environmental Monitor (1994). *Reducing Exposure to UV Rays.*

Of those who take action, we note that at least two-thirds avoid the sun or wear protective clothing.[43]

5.2.4 Summary

AES contributed 65% to 85% of the knowledge and work that produced the *UV Index*.

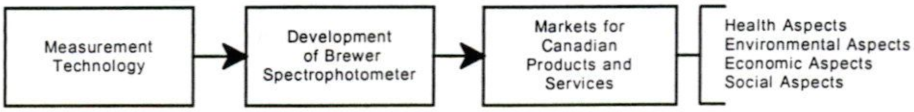
The UV Index is responsible for 20% to 60% of the population being aware of the risks of exposure to the sun. An estimated 40% to 60% of those who are aware of the risks, take protective measures. Taken together, these figures indicate that the UV Index is responsible for 8% to 36% of the population protecting themselves from UV radiation. At least two-thirds avoid the sun or wear protective clothing.

[43] Note that we do not know how much overlap there is between those who practice one of the set of behaviours. Consequently, we cannot determine the proportion of the affected population that practices one or the other.

5.3 THREAD 3 -- BREWER SPECTROPHOTOMETER

Thread 3 is illustrated in Figure 5.6. It postulates that AES work on measurement technology led to the invention and development of the Brewer Spectrophotometer. This led to sales and exports for a Canadian firm.

Figure 5.6
Thread 3 -- Impacts of Development of Brewer Spectrophotometer



The linkages are:

- Contribution of AES measurement technology to the invention and development of the Brewer Spectrophotometer
- Impact of the Brewer Spectrophotometer on sales and exports by Canadian firm(s).

These linkages are considered, in turn, in the following subsections.

5.3.1 Immediate and Intermediate Impact: *Contribution of AES Measurement Technology to the Invention and Development of the Brewer Spectrophotometer*

The Brewer Spectrophotometer was developed by AES scientists in the early 1980s to supplement the Dobson instrument which had been used in the Global Ozone Observing System for nearly 40 years.[44] As of 1996, there were more than 120 Brewers operating in about 35 countries.

The instrument has been licensed for manufacture and sale exclusively to SCI-TEC Instruments Inc. of Saskatoon. According to SCI-TEC, their contribution was to adapt the design for manufacturing and marketing, but the entire R&D work was done by AES.

Based on this information, we propose the following attribution estimate:

Contribution of AES measurement technology to the invention and development of the Brewer Spectrophotometer:

- Low impact scenario: 90%
- Best guess: 95%
- High impact scenario: 100%.

[44] Kerr, J.B., McElroy, T., Wardle, D.I. (1996). *The Brewer Instrument Calibration Center 1984-1996.* Environment Canada Technical Paper.

5.3.2 Ultimate Impact: *Impact of the Brewer Spectrophotometer on Sales and Exports by Canadian Firm(s)*

As noted above, the Brewer is licensed exclusively to SCI-TEC Instruments Inc. The company reports that as of 1997, it had sold 155 instruments (average of 12 per year) at an average price of $100 to $125 thousand. The company also reports that all but 20 of the units were sold outside Canada.

Because the market is relatively stable and there are no other instruments that compare to the Brewer, the Company expects sales to continue at the same pace for the foreseeable future.

Assuming 12 units per year (and exports of 85% of those -- in keeping with current proportions), this represents annual sales of $1.2 to $1.5 million and exports of $1.0 to $1.3 million. Assuming future sales of 12 units per year for 20 years, discounted at a rate of 5%, the 1997 present value of all sales would add up to $34 million.[45] Exports would total $29 million.

Assuming a range of plus or minus 20%, we propose the following estimate:

Impact of Brewer Spectrophotometer on Sales by SCI-TEC (net present value of all sales in 1997 dollars):

- Low impact scenario: $27 million
- Best guess: $34 million
- High impact scenario: $41 million.

5.3.3 Summary

AES is 90% to 100% responsible for the invention and development of the Brewer Spectrophotometer.

The Brewer Spectrophotometer will result in additional sales of $27 to $41 million for SCI-TEC Instruments Inc. About 85% of sales will be for export.

[45] This amount includes past sales with an estimated present value of approximately $18 million. Precise figures are unavailable

6. EVALUATION OF IMPACTS

6.1 GLOBAL ATTRIBUTION

In Section 5, we provided estimates of the degree to which a number of immediate impacts could be attributed to the AES R&D activities. We also provided estimates for the ultimate impacts that flow from these immediate impacts (in some cases via a series of intermediate impacts).

In order to calculate the overall impact of AES R&D, we need to combine these estimates. The results of this exercise are summarized in Tables 6.1 to 6.3. Three scenarios are presented:

- A low impact scenario that combines a low attribution of the immediate impacts to AES with low estimates for the ultimate impacts[46]

- A best guess scenario that combines a best guess attribution of the immediate impacts to AES with best guess estimates for the ultimate impacts

- A high impact scenario that combines a high attribution of the immediate impacts to AES with high estimates for the ultimate impacts.

In the case of the low and high impact scenarios, we are combining two or more estimates of low probability, resulting in an outcome that is even more unlikely. This should provide a reasonable degree of confidence that the actual impact is bounded by the low and high impact scenarios.

[46] For Thread 1 (Montreal Protocol) only a single estimate is provided for the ultimate impacts, based on available data. This estimate is used in all three scenarios.

Table 6.1
Global Attribution of Impacts (Low Impact Scenario)

Thread	Attribution of Immediate Impacts to AES R&D	Estimated Ultimate Impact (Total)	Ultimate Impact Attributable to AES R&D[47]
Thread 1 -- Montreal Protocol	5% of world knowledge base		
	AES is responsible for 10% of the position and effectiveness of the Canadian delegation; Canadian delegation contributed 10% to the negotiation of the Protocol. Thus, AES is responsible for 1% of Montreal Protocol	Reductions in UV radiation (peak reductions between 42-48%) $4.3 billion in additional costs to industry	1.0% of benefits of reductions in UV $43 million in additional costs to industry
Thread 2 -- UV Index	65% of UV Index	8% of people protect themselves from UV radiation	5.2% of people protect themselves from UV radiation
Thread 3 -- Brewer Spectrophotometer	90% of Brewer Spectrophotometer	$27 million in sales	$24 million in sales

Table 6.2
Global Attribution of Impacts (Best Guess Scenario)

Thread	Attribution of Immediate Impacts to AES R&D	Estimated Ultimate Impact (Total)	Ultimate Impact Attributable to AES R&D[44]
Thread 1 -- Montreal Protocol	10% of world knowledge base		
	AES is responsible for 20% of the position and effectiveness of the Canadian delegation; Canadian delegation contributed 20% to the negotiation of the Protocol.Thus, AES is responsible for 4% of Montreal Protocol	Reductions in UV radiation (peak reductions between 42-48%) $4.3 billion in additional costs to industry	4.0% of benefits of reductions in UV $172 million in additional costs to industry
Thread 2 -- UV Index	75% of UV Index	20% of people protect themselves from UV radiation	15% of people protect themselves from UV radiation
Thread 3 – Brewer Spectrophotometer	95% of Brewer Spectrophotometer	$34 million in sales	$32 million in sales

[47] Caution must be exercised in the interpretation of the impacts attributable to AES, particularly the additional costs to industry. These are costs incurred to achieve the benefit of reduced UV exposure, and as such must be considered in this analysis. These costs should not, however, be considered in isolation from the associated benefits (and vice versa).

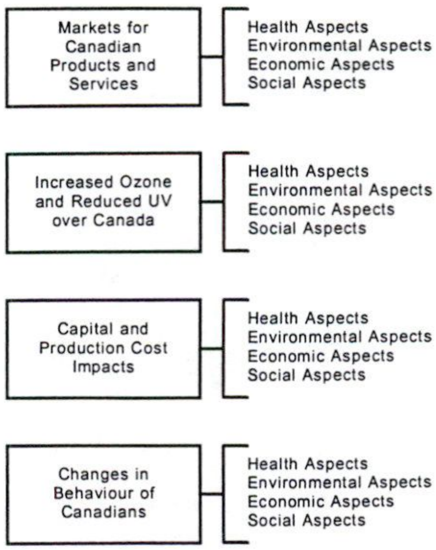
Table 6.3
Global Attribution of Impacts (High Impact Scenario)

Thread	Attribution of Immediate Impacts to AES R&D	Estimated Ultimate Impact (Total)	Ultimate Impact Attributable to AES R&D[44]
Thread 1 -- Montreal Protocol	15% of world knowledge base		
	AES is responsible for 30% of the position and effectiveness of the Canadian delegation; Canadian delegation contributed 30% to the negotiation of the Protocol. Thus, AES is responsible for 9% of Montreal Protocol	Reductions in UV radiation (peak reductions between 42-48%)	9.0% of benefits of reductions in UV
		$4.3 billion in additional costs to industry	$387 million in additional costs to industry
Thread 2 -- UV Index	85% of UV Index	36% of people protect themselves from UV radiation	31% of people protect themselves from UV radiation
Thread 3 -- Brewer Spectrophotometer	100% of Brewer Spectrophotometer	$41 million in sales	$41 million in sales

6.2 HEALTH, ENVIRONMENTAL, ECONOMIC AND SOCIAL ASPECTS

In this section, we examine the health, environmental, economic and social implications of the impacts described in Section 6.1. These impacts are, in fact, the ultimate impacts on the right-hand side of our Impact Map. The relevant portion of the Map is reproduced here as Figure 6.1.

Figure 6.1
Ultimate Impacts



More specifically, the ultimate impacts that we have analysed are:

- Markets for the Brewer spectrophotometer
- Reduced UV radiation in Canada as a result of the Montreal Protocol
- Increased costs to industry as a result of the Montreal Protocol
- Changes in behaviour as a result of the UV Index.

6.2.1 Health Aspects

In this sub-section, we address the health aspects of the ultimate impacts. We assume that there are no significant health implications associated with markets for the Brewer Spectrophotometer and the increased costs to industry. We concentrate, therefore, on the health implications of reduced UV radiation (due to the Montreal Protocol) and changes in behaviour (due to the UV Index).

Health Impacts Due to Montreal Protocol

Section 5.1.5 described the changes in UV radiation expected as a result of the implementation of the Montreal Protocol. ARC used these estimates to calculate the resulting change in expected rates of five health effects:[48]

- Non-melanoma cancer (squamous cell)
- Non-melanoma cancer (basal cell)
- Melanoma cancer
- Deaths from skin cancer
- Cataracts.

Percentage increases in incidence of these health effects were calculated under the two scenarios (no controls and Montreal Protocol) by latitude band, for various population groups.

The equation that was used is as follows:

$$I = (E+1)^b - 1$$

where:

I = fractional change in incidence of the health effect;

E = fractional change in UV exposure (average lifetime); and

b = dose-response coefficient or biological amplification factor (BAF)

Biological amplification factors used in the analysis were obtained from the Regulatory Impact Assessments conducted in the U.S. These factors are listed in Table 6.4.

Table 6.4
Biological Amplification Factors[49]

Health Effect	Male	Female
Squamous	2.5	2.5
Basal	1.4	1.4
Melanoma	0.42	0.51
Cataracts	0.225	0.225

[48] ARC Applied Research Consultants. October 1997. *Benefits and Costs of Canadian Participation in the Montreal Protocol on Substances that Deplete the Ozone Layer.* For Environment Canada.
[49] US Environmental Protection Agency. (1992). *Regulatory Impact Analysis: Protection of Stratospheric Ozone Vol. I Regulatory Impact Analysis Document.* Prepared for US Environmental Protection Agency. July 1992.

Using this equation, and the fractional change in UV exposure, ARC estimated the fractional change in incidence of the various health effects. Population and base incidence rates (for 1985) were then used to calculate the estimated number of cases for each scenario. The difference between the two was then calculated to establish the incremental impact of the Montreal Protocol.

ARC also developed estimates of the value of health effects averted using a "willingness to pay" approach. This approach measures the amount of goods and services a person is willing to give up for a small reduction in risk of disease or death. Based on literature reviews and consideration of various factors relating to "willingness to pay", ARC developed the following values:

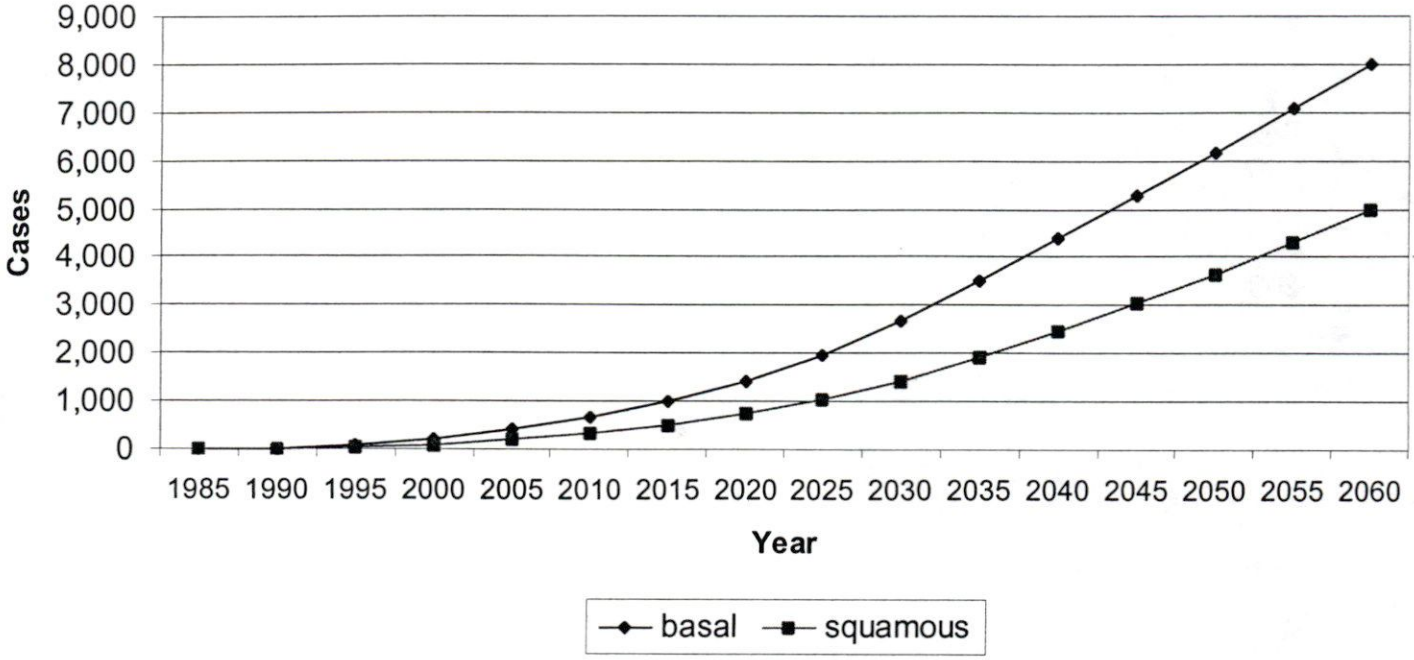
- Death - $6.75 million per case
- Basal cell carcinoma - $13,500 per case
- Squamous cell carcinoma - $23,760 per case
- Melanoma skin cancer - $51,030 per case
- Cataracts - $6,750 per case.

ARC used these values and the estimates of incremental cases to value the health benefits of the Montreal Protocol. Because the cases occur over a number of years, a 5% social discount rate was used to establish the present value in 1997 Canadian dollars.

Non-Melanoma Cancer

The number of non-melanoma cases averted due to the Montreal Protocol is shown in Figure 6.2. Approximately 310,000 fewer cases are anticipated over the interval from 1987 to 2060. By the year 2000, there will have been 1,500 fewer cases. By the year 2030, there will have been 56,000 fewer cases. The model predicts that about 60% of the cases avoided would have been basal cell and about 40% would have been squamous cell carcinomas. The present value of the non-melanoma cancer cases averted was calculated to be $734 million.

Figure 6.2
Annual Non-Melanoma Cases Averted in Canada Due to Montreal Protocol

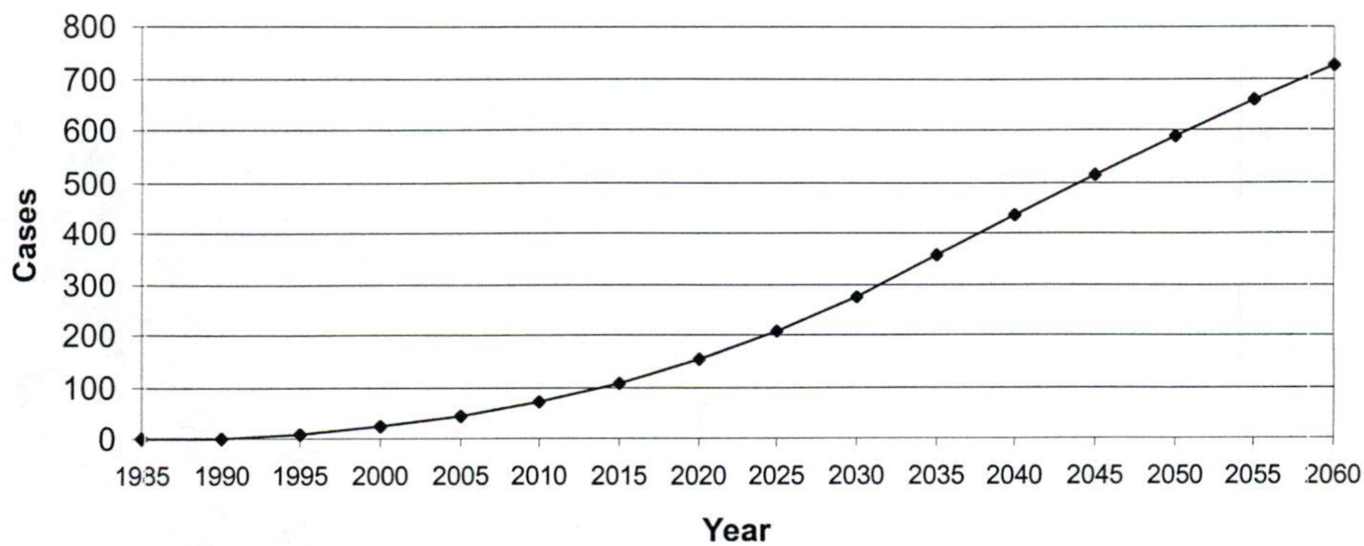


Melanoma Cancer

The number of melanoma skin cancer cases averted due to the Montreal Protocol is shown in Figure 6.3. Approximately 19,000 fewer cases are anticipated over the interval from 1987 to 2060.

The present value of the melanoma cancer cases averted was calculated to be $144 million.

Figure 6.3
Annual Melanoma Cases Averted in Canada Due to Montreal Protocol



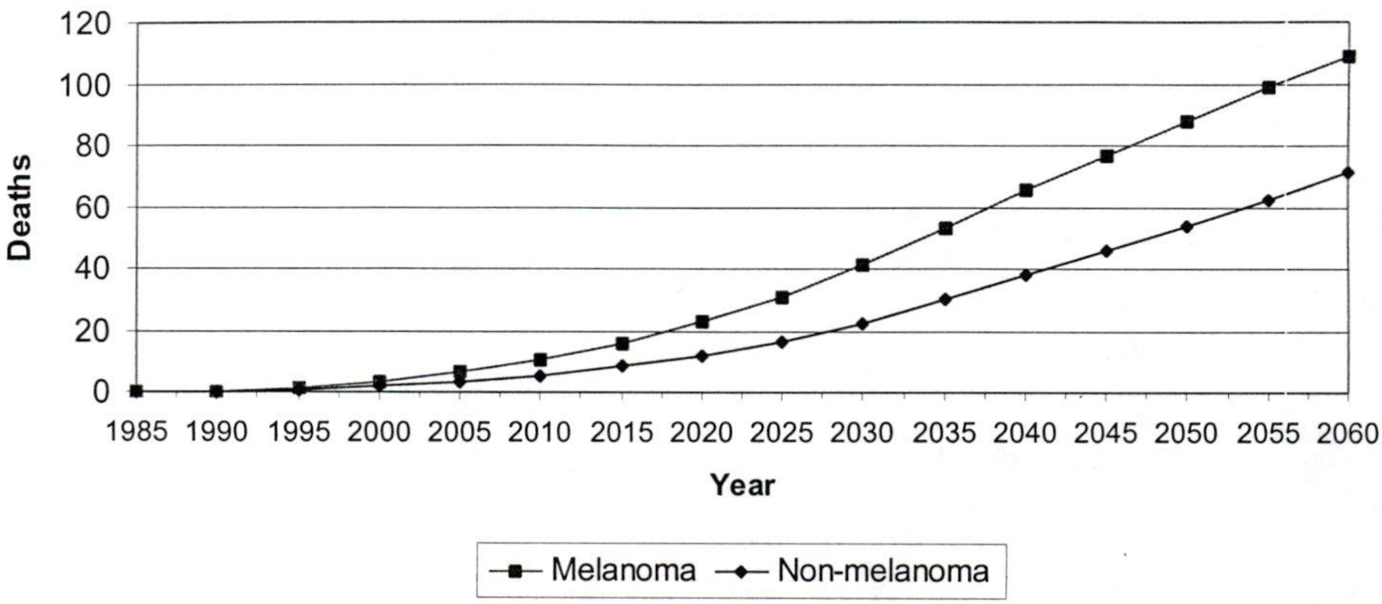
Deaths from Skin Cancer

Based on the range of estimates found in the literature, ARC estimated deaths from skin cancer to fall in the range from 0.1% to 1.0% of non-melanoma skin cancers and from 10% to 20% of melanoma skin cancers.

A best guess estimate (halfway between the upper and lower bounds) of the number of deaths is shown in Figure 6.4. Approximately 2,200 to 6,900 (best guess 4,550) fewer deaths are anticipated over the interval from 1987 to 2060.

The present value of the deaths averted (based on the best guess estimate) is calculated to be approximately $3,840 million. The low impact scenario is $1,770 million and the high impact scenario is $5,900 million.

Figure 6.4
Annual Deaths from Skin Cancer Averted in Canada Due to Montreal Protocol

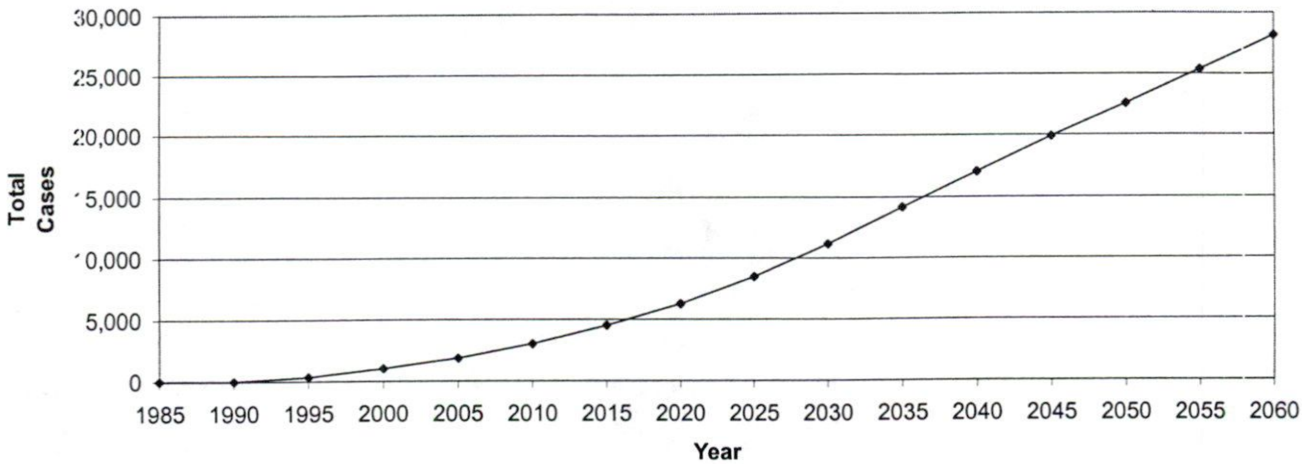


Cataracts

The number of cataracts cases averted due to the Montreal Protocol are shown in Figure 6.5. Approximately 760,000 fewer cases are anticipated over the interval from 1987 to 2060.

The present value of the cataracts cases averted was calculated to be $771 million.

Figure 6.5
Annual Cataracts Cases Averted in Canada Due to Montreal Protocol



Other Health Effects

According to ARC, a number of other health effects of increased UV-B are suspected but could not be quantified. These include impacts on the immunosuppression system, other eye diseases and other cancers.

Attribution of Montreal Protocol Health Benefits to AES

Based on estimates of the health benefits of the Montreal Protocol, we can calculate the portion attributable to AES, using the attribution scenarios of Tables 6.1 to 6.3.

Although the ARC report did not provide a range for their estimates (except for deaths averted), we introduce a range of plus or minus 25% to account for uncertainties in the various assumptions. This leads to three scenarios, which we combine with the attribution scenarios of Tables 6.1 to 6.3 to obtain the result, shown in Table 6.5.

Table 6.5
Health Impacts of AES Research (Montreal Protocol)

Health Effects		Low Impact		Best Guess		High Impact	
		Total	Attributable to AES R&D (1.0%)	Total	Attributable to AES R&D (4.0%)	Total	Attributable to AES R&D (9.0%)
Non-Melanoma	Cases avoided	233,000	2,330	310,000	12,400	388,000	34,900
	Value (1997 millions)	$551	$6	$734	$29	$918	$83
Melanoma	Cases avoided	14,300	143	19,000	760	23,800	2,140
	Value ($1997 millions)	$108	$1	$144	$6	$180	$16
Deaths	Cases avoided	2,200	22	4,550	182	6,900	621
	Value ($1997 millions)	$1,770	$18	$3,840	$154	$5,900	$531
Cataracts	Cases avoided	570,000	5,700	760,000	30,400	950,000	85,500
	Value ($1997 millions)	$578	$6	$771	$31	$964	$87
Total	Value ($1997 millions)	$3,007	$30	$5,489	$220	$7,962	$717

Health Impacts Due to UV Index

The health benefit of changes in behaviour resulting from the *UV Index* depends largely on the nature of the behavioural change and the frequency and duration of the change. Avoidance behaviour can be expected to have the largest benefits since exposure is largely eliminated. Other behaviours (e.g., sunblock, sunglasses) will also have benefits but these have not been quantified. As documented in Section 5.2, a majority of survey respondents indicated that some sort of avoidance was practised. Unfortunately we have no data on the extent or duration of this avoidance.

Given the variety of behaviours reported, the unknown degree to which they are practised, and their varying effectiveness, we are required to make some assumptions. For the purposes of this analysis, we assume that, over their lifetimes, those who report taking precautions, do so one-third of the time, and that those precautions are one-third effective in reducing UV exposure. The result is that, for those who report taking precautions, UV exposure would be reduced by a factor of 1/3 X 1/3, or approximately 10%. Although little more than a guess, this value of 10%, combined with previous estimates of the effectiveness of the *UV Index,* allows us to develop a working estimate of the impact of AES in this area.

Given this estimate of the fractional change in exposure, we can calculate the fractional change in incidence of health effects using the biological amplification factors provided in Table 6.4 (for simplicity, we use an average factor for incidence of male and female melanoma).

Using these factors, we estimate that, for any segment of the population that adopts protective behaviour as described above (i.e., behaviour that reduces exposure by 10%), the fractional change in incidence of health effects would be:[50]

- Squamous – 26.9% reduction
- Basal – 14.3% reduction
- Melanoma – 4.5% reduction.

These figures assume the reduced exposure occurs over the *full* lifetime of all individuals in the population segment. The analysis must reflect reduced exposure over only the *remaining* lifetime of the individuals. To do this, we used figures for the Canadian population (by age group) to calculate the cumulative reduction in exposure for each age group.

We then used the base incidence rate (1985) to calculate the number of cases that could have been averted through protective behaviour, if the entire population adopted such behaviour.[51] To obtain the number of cases averted as a result of the UV Index we

[50] Note that cataracts cases averted were not calculated for the UV Index.

[51] Note that by using 1985 base incidence rates (which predate most ozone depletion), we isolate the effect of the UV Index from the effect on this Montreal Protocol, and so avoid double counting. These cases are therefore incremental to any cases averted as a result of the Montreal Protocol.

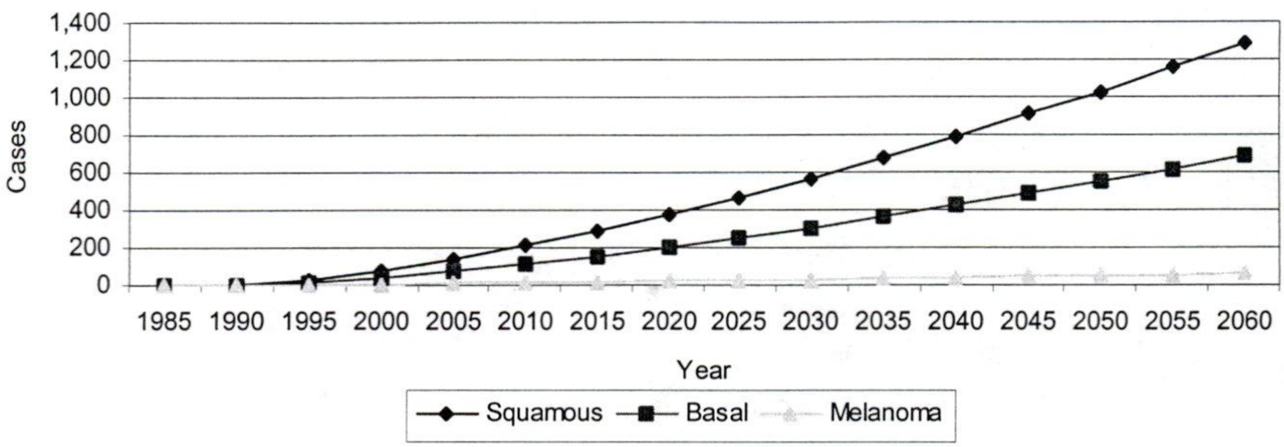
multiplied the result by the percentage that take protective action, as shown in Tables 6.1 to 6.3. Noting that the UV Index was implemented in 1992, we began counting potential cases averted in 1993.

Non-melanoma and Melanoma Cancer

Best guess results for squamous and basal cell carcinoma and melanoma are shown in Figure 6.6. Approximately 57,000 cases of non-melanoma cancer and 1,840 cases of melanoma would be averted over the period as a result of the UV Index.

Using ARC's valuation, the present value of the non-melanoma cancer cases averted was calculated to be $183 million. The present value of the melanoma cases was calculated to be $16 million.

Figure 6.6
Annual Cancer Cases Averted Due to UV Index



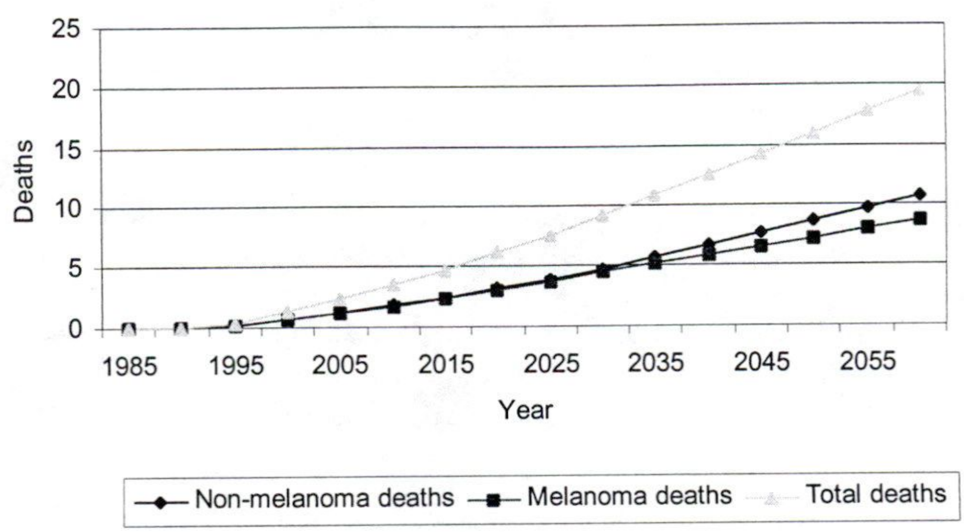
Deaths

To determine reduction in incidence of death, we used the ARC estimates for rates of death for each type of cancer (0.1% to 1% for non-melanoma skin cancers, and from 10% to 20% for melanoma skin cancers). Using these estimates, we calculated the resulting deaths that would be averted as a result of the UV Index. Results (using the average estimates) are shown in Figure 6.7.

A best guess estimate (halfway between the upper and lower bounds) of the number of deaths is shown in Figure 6.7. Approximately 97 to 1,670 (best guess 590) fewer deaths are anticipated over the interval from 1993 to 2060, as a result of the UV Index.

The present value of the deaths averted (based on the best guess estimate) is calculated to be approximately $649 million. The low impact scenario is $107 million and the high impact scenario is $1,830 million.

Figure 6.7
Annual Cancer Deaths Averted due to UV Index



Attribution of UV Index Health Benefits to AES

As in the case of health impacts of the Montreal Protocol, we introduce a range of plus or minus 25% to account for uncertainties in the various assumptions. When coupled with the impact estimates and AES attribution presented in Tables 6.1 and 6.3, this leads to three scenarios, shown in Table 6.6.

Table 6.6
Health Impacts of AES Research (*UV Index*)

Health Effects		Low Impact		Best Guess		High Impact	
		Total	**Attributable to AES (65%)**	**Total**	**Attributable to AES (75%)**	**Total**	**Attributable to AES (85%)**
Non-Melanoma	Cases	17,100	11,100	57,000	42,750	127,000	108,000
	Value (1997 millions)	$54	$35	$183	$137	$407	$346
Melanoma	Cases	553	359	1840	1380	4090	3480
	Value ($1997 millions)	$4.7	$3.1	$16	$12	$36	$30
Deaths	Cases	97	63	590	443	1,670	1,420
	Value ($1997 millions)	$107	$70	$649	$487	$1,830	$1,550
Total	Value ($1997 millions)	$166	$108	$848	$636	$2,273	$1,926

These results indicate that the health benefits (attributable to AES) as a result of the UV Index far outweigh the benefits (attributable to AES) of the Montreal Protocol. This is due to two factors: first, the earlier impact of the UV Index, and second, the higher level of attribution to AES. This result also demonstrates the important opportunity to reduce health risks by influencing behaviour related to sun exposure.

Total Health Benefits

From the results presented in Tables 6.5 and 6.6, we can calculate the total health benefits (Montreal Protocol and *UV Index*). Results are shown in Table 6.7.

Table 6.7
Health Impacts of AES Research (Montreal Protocol and *UV Index*)

Health Effects		Low Impact	Best Guess	High Impact
Non-Melanoma	Cases	13,430	55,150	142,900
	Value (1997 millions)	$41	$166	$429
Melanoma	Cases	502	2140	5620
	Value ($1997 millions)	$4	$18	$46
Cataracts	Cases	5,700	30,400	85,500
	Value ($1997 millions)	$6	$31	$87
Deaths	Cases	85	625	2,041
	Value ($1997 millions)	$88	$641	$2,081
Total	Value ($1997 millions)	$139	$856	$2,643

6.2.2 Environmental Aspects

In this sub-section, we address the environmental aspects of the ultimate impacts. We assume that there are no significant environmental implications associated with markets for the Brewer Spectrophotometer, the increased costs to industry, and the *UV Index*. We concentrate, therefore, on the environmental implications of reduced UV radiation (due to the Montreal Protocol).

Section 5.1.5 described the changes in UV radiation expected as a result of the implementation of the Montreal Protocol. ARC examined the effect of increased UV radiation on four components of the ecosystem:[52]

- ***Animals.*** Terrestrial animals will be subject to many of the same effects as human populations. Impacts can be expected to vary depending on whether the animal is wild or domesticated.
- ***Terrestrial Plants.*** Research has shown that UV-B radiation can have several negative effects, including inhibition of photosynthesis, DNA damage, changes in plant morphology, changes in the relationship between climate and plant functions, and changes in productivity. There is some information to estimate impacts on agriculture. Effects on forests are less well understood.
- ***Aquatic Ecosystems.*** There is conclusive evidence that increased UV-B radiation damages aquatic ecosystems in several ways. Most notably, UV-B decreases the survival rates of phytoplankton, a food source for most commercial species. UV-B also affects commercial fish, crustaceans and mollusks directly by impairing development of larvae and juveniles. There is some information available to estimate impacts on the fishing industry.
- ***Manufactured materials.*** Synthetic polymers and some naturally occurring materials are adversely affected by UV radiation. These materials (especially plastics) degrade in sunlight, thereby limiting their useful life. To limit the effects, more light stabilizers and UV-resistant materials will likely be used; however, this could result in significant costs. There is some information available to estimate the impacts on polymer production.

ARC noted that most of the environmental effects of increased UV-B could not be quantified. However, rough estimates of the economic impacts of those effects on agriculture, fisheries and PVC production were available from the US Regulatory Impact Assessment.[53]

ARC extrapolated from these estimates to generate estimates of the potential magnitude of these impacts in Canada. Although these estimates reflect only a small portion of the environmental impacts and are essentially commercial impacts, they may be indicative of the scale of other environmental impacts.

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[52] ARC Applied Research Consultants. October 1997. *Benefits and Costs of Canadian Participation in the Montreal Protocol on Substances that Deplete the Ozone Layer.* For Environment Canada.

[53] ICF Kaiser Inc. (1992). *Regulatory Impact Analysis: Compliance with Section 604 of the Clean Air Act for the Phaseout of Ozone Depleting Chemicals*. Prepared for the US EPA, July 1992.

Table 6.8 presents the results based on the ARC report, together with their proposed attribution to AES.[54]

Table 6.8
Present Value of Environmental Effects of AES Research (Montreal Protocol)
$1997 millions

Environ-mental Effects	Indicator	Low Impact		Best Guess		High Impact	
		Total	Attributable to AES R&D (1.0%)	Total	Attributable to AES R&D (4.0%)	Total	Attributable to AES R&D (9.0%)
Fisheries	Catch (reduced catch avoided)	$1,400	$14	$2,900	$116	$5,700	$513
Agriculture	Cereals Production (lost production avoided)	$2,200	$22	$4,500	$180	$8,900	$801
Materials	PVC Production (increased costs avoided)	$400	$4	$800	$32	$1,500	$135
Total		$4,000	$40	$8,200	$328	$16,100	$1,450

[54] Some sources have suggested that these estimates may be high. However, given the narrow focus of the analysis and the fact that other environmental impacts are not quantified, there is reasonable certainty that the overall estimate of environmental impacts is conservative.

6.2.3 Economic and Social Aspects

- **Introduction**

In this sub-section, we address the economic and social implications of the ultimate impacts identified in Section 5.

Three types of **economic impacts** can be described:

- ***Direct impacts*** are attributable to the activity that would be generated directly by the ultimate impacts. These include the salaries and wages paid to workers, and the revenues earned by companies.

- ***Indirect impacts*** are the economic impact of purchases of goods and services from other agents. For example, the value of the demand for ODS substitutes and the reduced demand for medical services are indirect effects of the Montreal Protocol.

- ***Induced impacts*** are the multiplied effects of the direct and indirect incomes earned through an economic activity. For example, with the wages earned, individuals can purchase goods and services which become revenues for another economic agent. These revenues generate cycles of economic impacts which when added together form the induced effect.

Induced impacts are sometimes calculated to promote an industry or activity. However, because of the promotional, rather than economic-analytical nature of these impacts, they are not accepted by the Government of Canada as a basis for policy or decision analysis.[55] Consequently, they are not included in this analysis.

The two most relevant ways to express **direct and indirect** economic impacts are:

- ***Dollar value of the change in GDP***. The value of all goods and services produced in an economic region over a period of time by the residents of that region. Often, "GDP" and "value added" will be used as interchangeable terms.[56]
- ***Number of full-time equivalent (FTE) person-years of employment created (or lost)***. A unit that measures the normal amount of work performed by one

[55] The principal reason for this view is that the unspecified nature of the economic activity leads to speculative conclusions that add very little information to an analysis (since such effects are always present).

[56] GDP can be measured in one of three ways:

- Income Based. The value of all the incomes in the economy including labour income, interest income, and revenues received by governments as indirect taxes (less subsidies).
- Expenditure Based. The value of all things purchased in the economy, including consumer purchases of goods and services, investments in equipment and additions to inventories, government purchases of goods and services, and purchases made by foreigners (less the value of what we buy as imports).
- Value Added. The sum of the value of all the products produced in the economy less the cost of making those products.

By accounting definition all three methods will arrive at the same value for GDP.

employee in an industry sector over one year. It does not necessarily correspond to the number of employees in a sector. For example, two people working half time for one year would yield one FTE.

Social impacts are, for the most part, difficult to identify and even more difficult to quantify. Examples include standard of living, justice, etc. For the purposes of this analysis, we consider GDP and employment levels as indicators of social impacts. In addition, health impacts (already discussed in Section 6.2.1) are themselves an important social impact.

As noted above, in this sub-section we address the economic and social implications of each of the ultimate impacts identified in Section 5:

1. Reduced UV radiation in Canada as a result of the Montreal Protocol
2. Increased costs to industry as a result of the Montreal Protocol
3. Changes in behaviour as a result of the UV Index
4. Markets for the Brewer spectrophotometer.

Each of these impacts is addressed, in turn, below. Costs and benefits have been discounted to 1997, with further details provided in the relevant sections below.

1. Reduced UV Radiation in Canada as a Result of the Montreal Protocol

The economic and social implications of reduced UV radiation in Canada, arising from the Montreal Protocol, have been assessed by considering the following indicators:

- Economic and social impacts of deaths avoided [57]
- Economic and social impacts of non-fatal health effects avoided
- Economic and social impacts of the environmental costs avoided.

These indicators are discussed below.

Deaths Avoided

In Table 6.5, the number of deaths avoided (attributable to AES) was estimated as follows:

Low impact scenario: 22 deaths avoided
Best guess scenario: 182 deaths avoided
High impact scenario: 621 deaths avoided

For a conservative estimate of the economic impact of deaths avoided, we consider only

[57] In Section 6.2.1, the value of health effects avoided was estimated using a "willingness to pay" approach (deaths avoided, non-melanoma cancer avoided, etc.). These values are separate and distinct from the economic implications presented in this section.

the direct impact of lost wages. We also note that deaths from cancer usually occur late in the working life of individuals, and therefore, calculate the avoided lost wages on the basis of 10 years of the average salary of a typical Canadian in 1997 (we assume $28,000 per year).[58] Over a 10 year period, the present value of wages earned would be $226,000 (at a 5% discount rate[59]).

Using this value, and further discounting to account for the year in which the deaths would have occurred,[60] we calculate the total contribution to GDP (attributable to AES) of deaths averted as a result of the Montreal Protocol to be between $0.7 million and $19 million (best guess $5.7 million).

Non-fatal Health Effects Avoided

In Table 6.5, the number of non-fatal health effects avoided (attributable to AES) was estimated for non-melanoma cancers, melanoma, and cataracts. The total number of cases was estimated as follows:

Low impact scenario: 8,173 cases avoided
Best guess scenario: 43,560 cases avoided
High impact scenario: 122,540 cases avoided

For a conservative estimate of the economic impact of avoiding these non-fatal health effects, we have estimated the "cost of injury" associated with these cases. To do this, we used an approach based on the calculated value of non-fatal health effects. These values are presented in Table 6.5, and range from $13 million to $186 million (best guess $66 million). We have converted these values to "cost of injury" using a factor of 0.5.[61]

"Cost of injury" includes both out-of-pocket expenses (such as health care costs) and lost work income. We assume that health care costs have no net effect on GDP.[62] Therefore, we consider only lost work income. We have no data that allows us to determine the portion of "cost of injury" that arises from lost work income; it has been necessary therefore to make a somewhat arbitrary assumption that lost income represents 50% of the "cost of injury".

Based on this approach, we calculate the total contribution to GDP (attributable to AES)

[58] This is an estimate based on 1996 Statistics Canada data.
[59] This discount rate was chosen for consistency with the analysis presented in Section 5, which utilized data from the ARC report. The data was derived using a 5% discount rate.
[60] Further discounting is required, because lost wages associated with a death in the year 2050 have a different present value than a death in the year 2000.
[61] The conversion factor is based on Lauraine Chestnut, Hagler Bailly Consulting, Inc., *Environmental and Health Benefits of Cleaner Vehicles and Fuels: Supplemental Report 3: Selected Economic Evidence of Monetary Valuation of Human Health Effects*, Canadian Council of Ministers of the Environment Task Force on Cleaner Vehicles and Fuels, 1995.
[62] In fact, the net effect of this health care spending on GDP would be negative, if capital is diverted from more productive investment. Since we are concerned here with avoided health care costs, our assumption that health care costs have no impact on GDP is a conservative assumption.

of non-fatal health effects averted to be between $3 million and $46.5 million (best guess $16.5 million).

Environmental Costs Avoided

In Table 6.8, the environmental costs avoided (attributable to AES) were estimated as follows:

Low impact scenario: $40 million of environmental costs avoided
Best guess scenario: $328 million of environmental costs avoided
High impact scenario: $1,450 million of environmental costs avoided

For an accurate assessment of the effects on GDP of these avoided environmental costs, it would be necessary to have a better description of the nature of the avoided costs (lost production avoided vs increased costs avoided). This data would then be analyzed using an input-output model of the Canadian economy.

However, given the uncertainties associated with our environmental cost data, we can estimate the effects on GDP using simplifying assumptions. First, for the purposes of this analysis, we assume that the benefits are entirely composed of lost production avoided (this is almost certainly the case for fisheries and agricultural impacts, which constitute the majority of the benefits). Second, we assume that each dollar of lost production equals 75 cents of lost GDP.[63]

Based on these assumptions, the total contribution to GDP associated with environmental costs avoided (attributable to AES) would be between $30 million and $1,090 million (best guess $246 million).

Total Economic and Social Implications of Reduced UV Radiation in Canada

The total effect on GDP of the avoided health and environmental costs outlined above (attributable to AES) is presented in Table 6.9. This table also presents the equivalent employment impact of this contribution to GDP. The employment impact is presented as full-time equivalent (FTE) person-years of employment created, based on the average employment impact for the Canadian economy (18 FTE person-years per $million of GDP).

[63] This is a working estimate based on our recent use of the input-output model to quantify the effect on GDP of increased pulp & paper production. In that case, each dollar of production raised GDP by approximately 74 cents. We believe that the estimate in this case is conservative since the level of foreign input to fisheries and agriculture is likely lower than for pulp and paper.

Table 6.9
Summary of Effects on GDP and Employment of Reduced UV Radiation in Canada arising from the Montreal Protocol (attributable to AES)

Impact		Low Impact	Best Guess	High Impact
Deaths avoided	GDP ($million 1997)	$0.7	$5.7	$19.0
	Employment (FTE)	13	103	340
Non-fatal health effects avoided	GDP ($ million 1997)	$3.0	$16.5	$46.5
	Employment (FTE)	54	297	840
Environmental costs avoided	GDP ($ million 1997)	$30	$246	$1,090
	Employment (FTE)	540	4,430	19,620
Total	GDP ($ million 1997)	$34	$268	$1,155
	Employment (FTE)	607	4,830	20,800

2. Increased Costs to Industry as a Result of the Montreal Protocol

Tables 6.1 to 6.3 list the increased costs to Canadian industry as a result of implementation of the Montreal Protocol. The portion of these costs that is indirectly attributable to AES was estimated as follows:

Low impact scenario: $43 million
Best guess scenario: $172 million
High impact scenario: $387 million

In order to calculate the impact of these costs on GDP, we need to compare the effect of this non-productive investment in ODS substitutes, with an alternative investment, which we assume would have been productive.[64]

To make this comparison, we make a number of assumptions:

- First, that both investments would have generated an equal amount of indirect economic activity.
- Second, that the present capitalized value of the additional costs, if invested productively, could have earned a return (after inflation) of 10%.[65]
- Third, that the present value of the revenue stream can be calculated by projecting the revenues for twenty years and using a discount rate of 5%.
- Finally, that 40% of the return would go to foreign claims, and therefore would

[64] Note that "non-productive" in this context refers to economic return only. This is justified since the health and environmental benefits have been considered separately.

[65] In the pulp and paper case study, we used a lower figure for rate of return on alternative investments. In both cases studies, the goal was to select a rate of return that provided for a conservative analysis. The use of different rates in the two cases is therefore justified, because the analysis focusses on costs avoided in one case (pulp and paper) and costs incurred in the other (ozone).

not contribute to GDP in Canada.[66]

Based on these assumptions, we calculate the reduction in GDP arising from increased costs to industry as a result of the Montreal Protocol (attributable to AES) to be between $33 million and $300 million (best guess $135 million).

The corresponding effect on employment is a loss of between 594 FTE person-years and 5,400 FTE person-years (best guess 2,430 FTE person-years). The impact is presented as full-time equivalent (FTE) person-years of employment created, based on the average employment impact for the Canadian economy (18 FTE person-years per $million of GDP).

3. Changes in Behaviour as a Result of the UV Index

The economic and social implications of changes in behaviour as a result of the UV Index have been assessed by considering the following indicators:

- Economic and social impacts of deaths avoided
- Economic and social impacts of non-fatal health effects avoided.

Other indicators could in principle have been examined. For instance, changes in behaviour would have led to increased sales of sunscreen, protective clothing, and sunglasses. However, because of a lack of data, these economic impacts have not been assessed. It is, however, anticipated that such impacts would be positive.

Deaths Avoided

In Table 6.6 the number of deaths avoided due to the *UV Index* (attributable to AES) was estimated as follows:

Low impact scenario: 63 deaths avoided
Best guess scenario: 443 deaths avoided
High impact scenario: 1,420 deaths avoided

Using the same approach as for the Montreal Protocol, we calculate the total contribution to GDP (attributable to AES) of deaths averted as a result of the *UV Index* to be between $2.3 million and $52 million (best guess $16 million).

Non-fatal Health Effects Avoided

In Table 6.6, the number of non-fatal health effects avoided due to the *UV Index* (attributable to AES) was estimated for non-melanoma cancers and melanoma. The total

[66] This is based on the Bank of Canada Review (Summer 1997), which reports a figure of 40%.

number of cases was estimated as follows:

Low impact scenario: 11,459 cases avoided
Best guess scenario: 44,130 cases avoided
High impact scenario: 111,480 cases avoided

Using the same approach as for the Montreal Protocol, we calculate the total contribution to GDP (attributable to AES) of non-fatal health effects averted as a result of the *UV Index* to be between $9.5 million and $94 million (best guess $37 million).

Total Economic and Social Implications of Changes in Behaviour Arising from the UV Index

The total effect on GDP of the avoided health costs outlined above (attributable to AES) is presented in Table 6.10. This table also presents the equivalent employment impact of this contribution to GDP. The employment impact is presented as full-time equivalent (FTE) person-years of employment created, based on the average employment impact for the Canadian economy (18 FTE person-years per $million of GDP).

Table 6.10
Summary of Effects on GDP and Employment of Changes in Behaviour Arising from the *UV Index* (attributable to AES)

Impact		Low Impact	Best Guess	High Impact
Deaths avoided	GDP ($million 1997)	$2.3	$16.0	$52.0
	Employment (FTE)	41	288	936
Non-fatal health effects avoided	GDP ($ million 1997)	$9.5	$37.0	$94.0
	Employment (FTE)	171	666	1,692
Total	GDP ($ million 1997)	$11.8	$53.0	$146.0
	Employment (FTE)	212	954	2,628

4. Markets for the Brewer Spectrophotometer

In Tables 6.1 to 6.3, we estimate the sales of the Brewer Spectrophotometer (attributable to AES) to be:

Low impact scenario: $24 million
Best guess scenario: $32 million
High impact scenario: $41 million

To calculate the impact on GDP of the sales of the Brewer spectrophotometer, we assume once again that each dollar of sales equals 75 cents of GDP.

Thus, the total contribution to GDP of sales of the Brewer spectrophotometer (attributable to AES) would be between $18 million and $31 million (best guess $24 million). Using the same factor as above, the corresponding effect on employment is between 324 FTE person-years and 558 FTE person-years (best guess 432 FTE person-years).

Summary: Total Effect on GDP and Employment

The effects of the various impacts on GDP and employment, as well as the total are summarized in Table 6.11.

Table 6.11
Summary of Effects on GDP and Employment of AES Research

Impact		Low Impact	Best Guess	High Impact
Reduced UV Radiation in Canada as a result of the Montreal Protocol	GDP ($million 1997)	$34.0	$268.0	$1,155.0
	Employment (FTE)	607	4,830	20,800
Increased Costs to Industry as a Result of the Montreal Protocol	GDP ($ million 1997)	$33.0	$135.0	$300.0
	Employment (FTE)	594	2,430	5,400
Changes in behaviour as a result of the *UV Index*	GDP ($ million 1997)	$11.8	$53.0	$146.0
	Employment (FTE)	212	954	2,628
Markets for the Brewer Spectrophotometer	GDP ($ million 1997)	$18.0	$24.0	$31.0
	Employment (FTE)	324	432	558
Total	GDP ($ million 1997)	$30.8	$210.0	$1,030.0
	Employment (FTE)	550	3,780	18,580

These totals represent the one time (1997) equivalent of the aggregate changes in GDP and employment (which vary over time). The impact on GDP is expected to grow as the benefits of the Montreal Protocol rise through the period to 2060.

6.3 SENSITIVITY ANALYSIS

Section 6.2 provides rough estimates of the health, environmental and socio-economic implications of the three impact scenarios developed in section 5. These estimates rely on a number of simplifying assumptions whose accuracy and reliability has not been established (though they have been chosen with a bias towards a conservative estimate of the impacts).

Although further study to improve the accuracy and reliability of these assumptions is beyond the scope of this report, sensitivity analysis provides a means to assess the potential effect of changes in the assumptions. Four assumptions are examined (using the best guess scenario):

1. The assumption that taking precautions against UV radiation results in a 10% reduction in exposure
2. The assumption that a cancer death reduces GDP by $226,000
3. The assumption that a non-fatal cancer reduces GDP by 25% of the willingness to pay to avoid such cancers
4. The assumption that each dollar of lost production reduces GDP by 75 cents.

1. Reduction in Exposure from Precautions against UV Radiation

In Section 6.2.1, we assumed that precautions would reduce UV exposure by 10%. Since this value is highly speculative, we examine the effect of a wide range of alternative assumptions, from 1 to 25%:

- ***1% Reduction in Exposure***

A 1% reduction instead of a 10% reduction would mean 4,050 cases of non-melanoma cancer avoided (instead of 42,750) and 154 cases of melanoma avoided (instead of 1,380). This would mean 55 deaths averted (instead of 443).

- ***25% Reduction in Exposure***

A 25% reduction instead of a 10% reduction would mean 116,000 cases of non-melanoma cancer avoided (instead of 42,750) and 3,370 cases of melanoma avoided (instead of 1,380). This would mean 1,145 deaths averted (instead of 443).

Within these ranges, the effect of different assumptions is almost (but not exactly) linear.

2. GDP Impact of Cancer Deaths

In Section 6.2.3, we assumed that each cancer death resulted in a loss to GDP of $226,000 (in 1997 dollars). This was based on 10 years of lost wages and did not account for the contribution to GDP of retired persons (through their demand for goods and services). We examine the effect of a range of alternative assumptions from $100,000 to $500,000:

- ***$100,000 Impact on GDP***

Assuming each death has a $100,000 impact instead of $226,000 would mean that the contribution to GDP would be $9.6 million (instead of $21.7 million). This would mean 173 FTE (instead of 391 FTE).

- ***$500,000 Impact on GDP***

Assuming each death has a $500,000 impact instead of $226,000 would mean that the contribution to GDP would be $48 million (instead of $21.7 million). This would mean 864 FTE (instead of 391 FTE).

The effect of different assumptions is linear.

3. GDP Impact of Non-Fatal Cancers

In Section 6.2.3, we assumed for convenience that "cost of injury" was equal to 50% of "willingness to pay" and that the impact on GDP was 50% of "cost of injury" (i.e. 25% of "willingness to pay"). This was based on the assumption that the remaining 50% of the "cost of injury" was related to health care costs whose impact was conservatively estimated to be zero. We examine the effect of a range of alternative assumptions from 10% to 50% of "willingness to pay":

- ***GDP Impact Equal to 10% of "Willingness to Pay"***

Assuming that the Impact is equal to 10% of "willingness to pay" instead of 25% would mean the contribution to GDP would be $21.4 million (instead of $53.5 million). This would mean 385 FTE (instead of 963 FTE).

- ***GDP Impact Equal to 50% of "Willingness to Pay"***

Assuming that the Impact is equal to 50% of "willingness to pay" instead of 25% would mean the contribution to GDP would be $107 million (instead of $53.5 million). This would mean 1,926 FTE (instead of 963 FTE).

The effect of different assumptions is linear.

4. GDP Impact of Production

In Section 6.2.3, we assumed that for every dollar of production, 75 cents was added to GDP. This was based on the assumption that for the impacts described (lost production due to environmental impacts and new production of Brewer spectrophotometers), there is a significant element of foreign content which offsets the direct and indirect effects. We examine the effect of a range of alternative assumptions from 50 cents to $1.25:

- ***GDP Impact Equal to 50 Cents per Dollar of Production***

Assuming that the Impact is equal to 50 cents per dollar of production instead of 75 cents would mean the contribution to GDP would be $180 million (instead of $270 million). This would mean 3,240 FTE (instead of 4,860 FTE).

- ***GDP Impact Equal to $1.25 per Dollar of Production***

Assuming that the Impact is equal to $1.25 per dollar of production instead of 75 cents would mean the contribution to GDP would be $450 million (instead of $270 million). This would mean 8,100 FTE (instead of 4,860 FTE).

The effect of different assumptions is linear.

6.4 VALUE FOR MONEY ASSESSMENT

The cost of AES' research was summarized in Table 3.4. The total in $ 1997 is $108 million. The average annual expenditure of $3.8 million (in current year dollars) represents approximately 5% of global expenditures on stratospheric ozone research, estimated at approximately $70 million per year.[67]

For this expenditure, Canadians gained knowledge of stratospheric ozone trends and processes which contributed to development of worldwide knowledge, the Montreal Protocol, the UV Index and the Brewer spectrophotometer.

Based on the analysis of Appendix F, the best guess is that AES contributed approximately 9.5% of world knowledge. The resulting quantifiable costs and benefits are listed in Table 6.12 (based on the best guess scenario).

Table 6.12
Assessment of Costs and Benefits of AES R&D on Stratospheric Ozone Depletion

Type of Benefit		Number of Cases	Number per $million of research	Value ($million)	Value/Dollar of research
Health cases avoided	Non-melanoma	55150	511	166	1.53
	Melanoma	2140	20	18	0.17
	Cataracts	30400	281	31	0.29
	Deaths	625	6	641	5.91
	Total Health			856	7.9
Environmental losses avoided	Fisheries	n/a	n/a	116	1.07
	Agriculture	n/a	n/a	180	1.66
	Materials	n/a	n/a	32	0.3
	Total Environmental	n/a	n/a	328	3.03
Socio-Economic Impacts	Employment (FTE)	3,780	35	n/a	n/a
	GDP	n/a	n/a	210	1.94

[67] Source: Bob Watson, World Bank. Rough estimate based on personal communication.

Based on Table 6.12, the analysis indicates that for each dollar of research, Canadians received the following quantifiable benefits from the selected impact threads:

- $7.90 in health benefits
- $3.03 in environmental benefits
- $1.94 in economic benefits.

In addition, there were a number of non-quantifiable benefits from these impact threads (e.g., other environmental benefits) and benefits attributable to the impacts that were not considered (see Section 4.2).

7. CONCLUSIONS

7.1 OBSERVATIONS ON THE EVALUATION METHODOLOGY

Our experience in conducting this evaluation suggests a number of observations:

- It is possible to conduct a credible, if somewhat imprecise, evaluation of the impacts of public good R&D even if the research is relatively recent and the impacts are spread out over many years.
- Such an analysis must be based in part on assumptions, the nature of which can have a significant impact on the findings. It is therefore essential to make the assumptions explicit.
- The evaluation of health and environmental impacts is particularly dependent on the use of various methodological assumptions and crude estimates. As a result, the range of estimates for quantified impacts is exceptionally large.
- Impact maps provide a useful tool for visualizing the threads that link the research to ultimate impacts. Impact maps also provide a mechanism for explicitly considering assumptions concerning the priority impacts and linkages.
- Attribution of immediate impacts to R&D activities can most effectively be handled through a proportionate attribution of credit for the results. Attribution of some intermediate impacts (such as contribution to the development of the Montreal Protocol) which involve the synergistic influence of many contributors is also best handled in this manner. Incremental attribution is possible for most impacts and is the preferred approach.
- Interviews are important for gathering the information and data necessary to identify, describe and quantify impacts. However, it is necessary to balance the need for information with the need to keep the interviews focussed, clear and short. Consideration must be given to dealing with information that may be contradictory, or of varying relevance.
- Because of the nature of the analysis required, detailed knowledge of events surrounding the research is essential. Thus, the analysis must engage the key players who were involved in the application of the R&D results; this involvement must be significant and recurring, at strategic points throughout the duration of the analysis. While such a contribution is essential, it raises the possibility of bias of the results; therefore, verification of key inputs, transparency of assumptions, and other aspects of the methodology must be utilized to reduce this possibility.
- An early focus of the research should be to identify and obtain key reference documents. Once again, the assistance of the key players who were involved in the application of the R&D results is essential.

- The construction of scenarios is a useful way to deal with uncertain information, particularly when speculation is required to establish hypothetical past or future situations.
- When dealing with imprecise estimates of impacts, it is cost-effective to make simplifying assumptions to evaluate their effects (e.g., economic, health, etc.).
- The nature of this case is quite different from the previous case (pulp and paper toxicity R&D). In contrast to that case, the attribution to AES R&D was relatively low in the case of one key impact thread (the Montreal Protocol). This case was also complicated by the need to develop methods of estimating health and environmental benefits (which was greatly aided by the use of the ARC report). Although these characteristics posed interesting challenges, they were not incompatible with the methodology.

7.2 R&D IMPACTS

This evaluation has identified three main impact threads for the R&D on stratospheric ozone depletion undertaken by AES:

- ***Thread 1.*** The impact on the ozone layer over Canada, surface UV exposure in Canada and costs to Canadians resulting from implementation of the Montreal Protocol, due, in part, to the contribution of Canadian negotiators, whose position and effectiveness were influenced by the work and the knowledge provided by AES.

- ***Thread 2.*** Changes in behaviour of Canadians regarding exposure to the sun resulting from awareness of the risks promoted by AES' UV Index.

- ***Thread 3.*** New markets for a Canadian firm resulting from the invention of the Brewer spectrophotometer.

Thread 1 -- Impacts of Montreal Protocol on UV Radiation and Costs to Canadian Industry

Our conclusions are as follows:

- AES was an important contributor to the worldwide knowledge base on ozone depletion and UV radiation.
- This contribution allowed AES to access and understand the worldwide knowledge base, and to influence the Canadian position and the effectiveness of the Canadian delegation.
- Partly (though not primarily) as a result of AES' influence, Canada was able to play a significant role in the development of the Montreal Protocol and its amendments. Ongoing AES work may also influence future amendments to the Protocol.
- The Montreal Protocol led to worldwide reductions in the consumption of ODS, which

will total approximately 300 Megatonnes over the period 1987 to 2060. This will slow and eventually reverse the depletion of the ozone layer.

- Improvements to the ozone layer will reduce the levels of UV radiation in Canada. Peak reductions will be between 42% to 48%.
- Based on the analytical approach taken, the portion of these reductions attributable to AES' research was between 1.0% and 9.0%. The best guess is 4.0%.
- The Montreal Protocol led to the adoption of regulations in Canada that will cost industry approximately $4.3 billion in 1997 dollars.
- Based on the analytical approach taken, the portion of these costs attributable to AES' research was between $43 million and $387 million. The best guess is $172 million.

Thread 2 -- Impacts of UV Index on Behaviour

Our conclusions are as follows:

- AES was the main contributor to the development of the *UV Index*.
- The *UV Index* is raising awareness of the risks of exposure to UV radiation.
- This awareness is leading Canadians to take additional precautions to protect themselves from the sun.
- Based on the analytical approach taken, the proportion of people who protect themselves from UV radiation, through changes in behaviour attributable to AES, is between 5.2% and 31%. The best guess is 15%.

Thread 3 -- Impacts of Development of Brewer Spectrophotometer

Our conclusions are as follows:

- AES was virtually entirely responsible for the invention of the Brewer Spectrophotometer.
- Development of the Brewer will result in additional sales of $27 to $41 million for SCI-TEC Instruments Inc.
- Based on the analytical approach taken, the portion of sales attributable to AES' research was between $24 million and $41 million. The best guess is $32 million.

Health Aspects

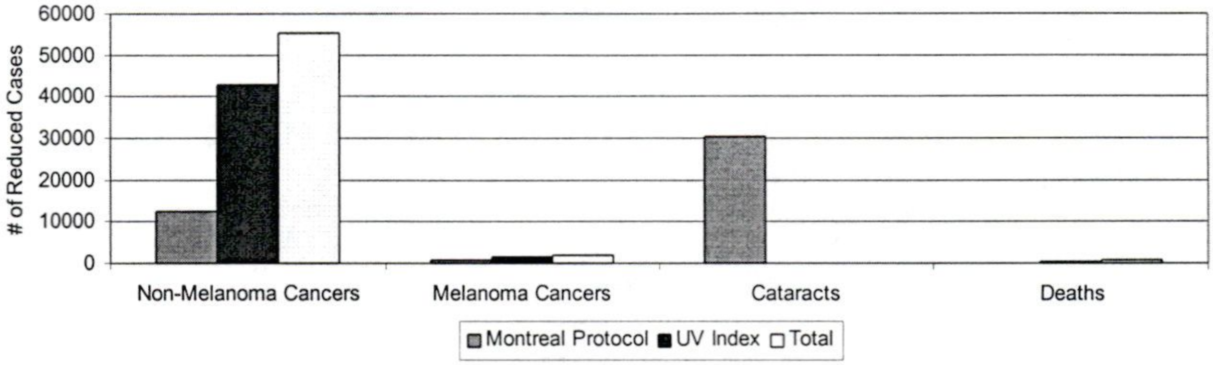
The best guess scenario indicates that, in Canada, during the period to 2060, the Montreal Protocol will prevent approximately 310,000 cases of non-melanoma cancer; 19,000 cases of melanoma cancer; 760,000 cases of cataracts; and 4,550 deaths.

The *UV Index* is expected to prevent approximately 57,000 cases of non-melanoma cancer, 1,840 cases of melanoma cancer; and 590 deaths.

The overall number of health cases averted attributable to AES for the Best Guess Scenario are shown in Figures 7.1 and 7.2.[68] The totals are:

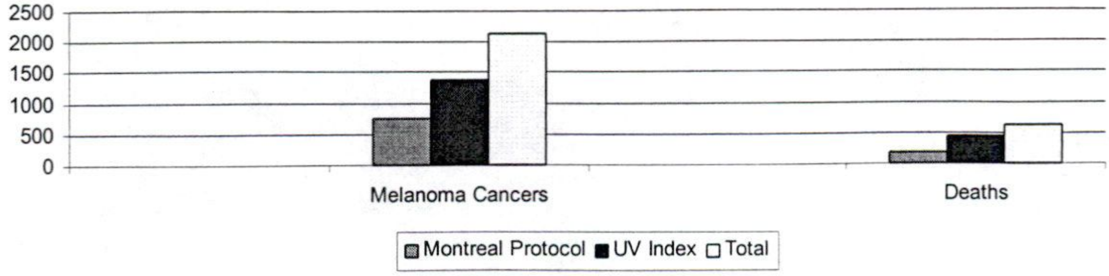
- 13,430 to 142,900 cases of non-melanoma cancer (best guess 55,150)
- 502 to 5,620 cases of melanoma cancer (best guess 2,140)
- 5,700 to 85,500 cases of cataracts (best guess 30,400)
- 85 to 2,041 deaths (best guess 625).

Figure 7.1
Heath Effects Attributable to AES under Best Guess Scenario



[68] To provide for better visibility at an appropriate scale, Figure 7.2 shows melanoma cancers and deaths only.

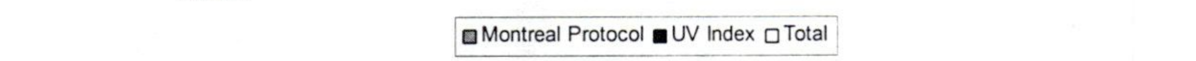
Figure 7.2
Heath Effects Attributable to AES under Best Guess Scenario - Melanoma Cancers and Deaths



In addition, the Montreal Protocol and UV Index are expected to reduce the incidence of a number of other health impacts of UV radiation, including impacts on the immunosuppression system, other eye diseases and other cancers.

The value of these benefits for the Best Guess Scenario is shown in Figure 7.3. Based on the valuation approach taken, the health benefits (attributable to AES) are valued at between \$139 million and \$2,643 million (best guess \$856 million).

Figure 7.3
Value of Health Effects Attributable to AES under Best Guess Scenario

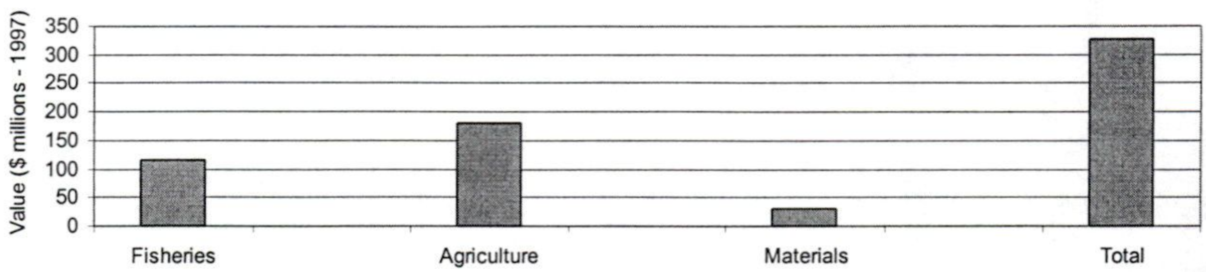


Environmental Aspects

The best guess scenario indicates that the Montreal Protocol will prevent the following environmental damages of commercial value to Canada: $2,900 million in damages to fisheries; $4,500 million in damages to agriculture; and $800 million in damages to materials. In addition, the Montreal Protocol is expected to reduce impacts on a number of other elements of the ecosystem, including animals and forests.

The environmental benefits attributable to AES for the Best Guess Scenario are shown in Figure 7.4. These benefits are valued at between $40 million and $1,450 million (best guess $328 million).

Figure 7.4
Value of Environmental Effects Attributable to AES under Best Guess Scenario



Economic and Social Aspects

GDP and employment impacts attributable to AES for the Best Guess Scenario are shown in Figures 7.5 and 7.6. The analysis indicates that the Montreal Protocol, UV Index and Brewer Spectrophotometer will result in a net contribution to GDP of between $30.8 million and $1,030 million; the best guess is $210 million. This will create (preserve) between 550 and 18,580 person-years of employment; the best guess is 3,780 person-years.

Figure 7.5
GDP Effects Attributable to AES under Best Guess Scenario

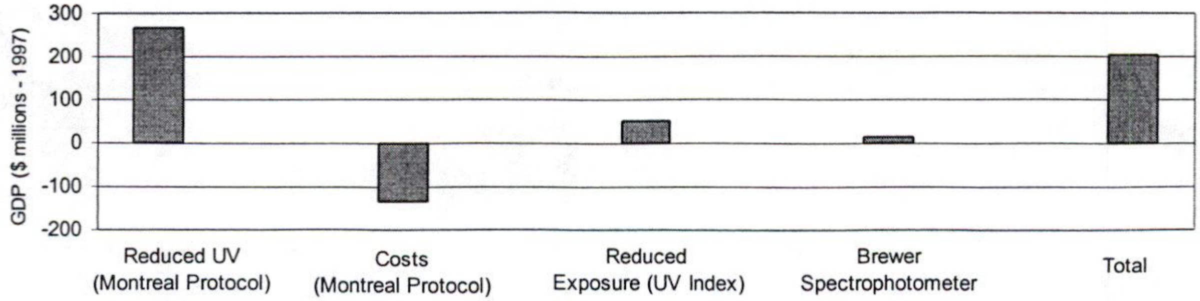
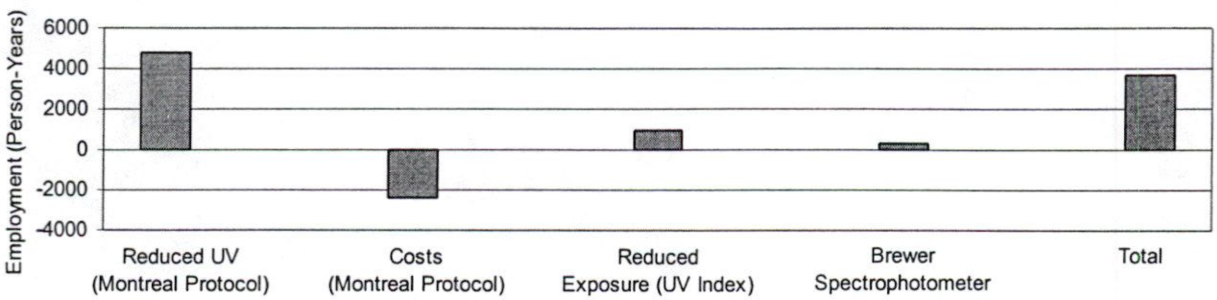


Figure 7.6
Employment Effects Attributable to AES under Best Guess Scenario



Summary

The analysis conducted indicates that the R&D on stratospheric ozone depletion conducted by AES during the period of 1975 to 1997 will result in the avoidance of over 57,000 cancers, 30,000 cases of cataracts, and 625 deaths (all based on the best guess scenario).

Other costs and benefits that can be attributed to the AES R&D include: $172 million of additional costs to industry, environmental benefits valued at over $300 million, and commercial benefits of $32 million (also based on the best guess scenario).

The overall effect on the economy will be a $210 million contribution to GDP and 3,780 FTE person-years of employment (also based on the best guess scenario).

The sensitivity of these results to changes in the principal assumptions is essentially linear.

Given R&D program costs of approximately $108 million (in 1997 dollars), this means that for each dollar of research, Canadians received the following quantifiable benefits:

- $7.90 in health benefits
- $3.03 in environmental benefits
- $1.94 in economic benefits.

In addition, there were a large number of non-quantified impacts (overwhelmingly positive) including scientific capacity, benefits in other countries, effects on climate, and others.

APPENDIX A

- **List of Steering Committee Members**

APPENDIX A
List of Steering Committee Members

Name	Position/Address	Phone/Fax/E-mail	Status
Cynthia Wright	DG Corporate Management and Review Environment Canada Terraces de la Chaudiere 10 Wellington Street, 26th Floor Hull, PQ K1A 0H3	T: (819) 953-2091 F: (819) 953-3388	Chair
Jean Leclerc	Evaluation Manager, Review Branch Environment Canada Terraces de la Chaudiere 10 Wellington Street, 26th Floor Hull, PQ K1A 0H3	T: (819) 997-3948 F: (819) 994-7321	Secretary
Mike Beale	Director, Economic Issues Branch Environment Canada Terraces de la Chaudiere 10 Wellington Street, 22nd Floor Hull, PQ K1A 0H3	T: (819) 953-9459 F: (819) 997-0709	Member
Dave Black	Economist, Policy Directorate Corporate Policy Group Environment Canada Terraces de la Chaudiere 10 Wellington Street, 22nd Floor Hull, PQ K1A 0H3	T: (819) 997-1158 F: (819) 997-0709	Alternate
John Carey	Executive Director National Water Research Institute Canada Centre for Inland Waters 867 Lakeshore Road, P.O. Box 5050 Burlington, ON L7R 4A6	T: (905) 336-4625 F: (905) 336-6444	Member
Jennifer Moore	DG, Regulatory Affairs and Program Integration Environmental Protection Service Environment Canada 351 St. Joseph Blvd., 16th Floor, PVM Hull, PQ K1A 0H3	T: (819) 997-5674 F: (819) 953-5916	Member
Lynda Urquhart	Economist, Regulatory and Economic Assessment Branch, Environmental Protection Service Environment Canada 351 St. Joseph Blvd., 16th Floor, PVM Hull, PQ K1A 0H3	T: (819) 953-6697 F: (819) 997-2769	Alternate
Roger Street	Director, Environmental Adaptation Research Group Atmospheric Environment Service Environment Canada	T: (416) 739-4271 F: (416) 739-4297	Member

Name	Position/Address	Phone/Fax/E-mail	Status
	4905 Dufferin Street, Room 3S208 Downsview, ON M3H 5T4		
Richard Turle	Chief, Analysis and Air Quality Division Environmental Technology Centre Environment Canada K1A 0H3	T: (613) 990-8559 F: (613) 990-8568	Member
Stephen McLellan	DG, Ecosystems & Environmental Resources Directorate Environment Canada 351 St. Joseph Blvd., 6th Floor, PVM Hull, PQ K1A 0H3	T: (819) 953-4736 F: (819) 994-2541	Member
André Jacquemot	Resource Economist Environmental Systems Branch Environment Canada 351 St. Joseph Blvd., 7th Floor, PVM Hull, PQ K1A 0H3	T: (819) 953-1427 F: (819) 994-6787	Alternate

APPENDIX B

➢ Interview Guide and Questions

APPENDIX B
Interview Guide and Questions

As discussed in the Environment Canada letter soliciting your involvement, our evaluation will focus on the key channels through which AES ozone-related R&D has had a significant impact. In your case, we are interested in the contribution of AES to the signing of the Montreal Protocol on Substances that Deplete the Ozone Layer and changes in the behaviour of Canadians associated with the UV-Index program.

Regarding the Montreal Protocol, our hypothesis is that the AES ozone program gave AES scientists the credibility and capability to access the international knowledge base, and to understand and interpret this knowledge base for Canadian policy-makers and negotiators. It also gave Canada some credibility in the negotiations and enabled the Canadian delegation to influence the final form of the Montreal Protocol. Hence, the effectiveness of the Canadian negotiators in influencing the development and signing of the Protocol relied to a much greater extent on AES research than the simple proportionate contribution of the R&D outputs to world science would indicate. This hypothesis is illustrated in the diagram overleaf.

Regarding the impacts of the UV-Index, our expectation is that AES was primarily responsible for its development, that it had an effect on the behaviour of Canadians (e.g. stay out of sunlight, protective clothing, sunscreen, etc.), and that the changes in behaviour had an impact on health and other socio-economic factors.

AES R&D
Activities and Outputs

proportionate contribution of AES to the effectiveness of Canadian negotiators for the Montreal Protocol (x%)[69]

Canadian participation in the negotiations leading up to the signing of the Protocol

proportionate Canadian influence on the Protocol (y%)

The Montreal Protocol[70]

Costs and benefits to Canada

We would like to begin the interview by soliciting your views on these interpretations, before leading into the questions themselves.

[69] This relates to the relative importance of science (versus, for example, negotiating skills per se) – and in particular, atmospheric science -- in establishing the influence of the Canadian negotiating team. Given our working hypothesis, taking the proportionate direct contribution of AES to the international knowledge base as a proxy would greatly undervalue the impacts of AES R&D on the Montreal Protocol. Nonetheless, we would like to estimate this contribution, since it might, for example, offer insights about the level of effort and achievement necessary in order to gain access to and influence within a global research community.

[70] Unless otherwise noted, "Montreal Protocol" refers to the sum total of the 1987 Protocol and subsequent amendments to accelerate reduction schedules and expand the list of substances. For the moment, however, the focus is on defining the AES role in relation to the original protocol. The assumption is that the original Protocol is by far the most significant step; with subsequent amendments coming as logical extensions. Note also that the impacts and associated costs and benefits of complying with the Protocol are the subject of a recently completed in-depth study. This source obviates the need to pursue this line of inquiry in the questionnaire.

EVALUATION OF IMPACTS OF AES R&D ON STRATOSPHERIC OZONE DEPLETION

INTERVIEW GUIDE

1. AES contributions to the global knowledge base on trends and relationships in stratospheric ozone depletion and UV radiation levels

1.1 Please verify, and if necessary expand on or add to, the following broad-based list of contributions of AES's R&D work to world knowledge on stratospheric ozone depletion and related physical/chemical conditions. Where possible, please estimate the proportionate contributions (in percentage terms, to total 100 across the rows) of AES versus other contributors:

Category of Knowledge/Capability	AES	Other Canadian Entities	U.S.	Other Countries
Knowledge of global trends in stratospheric ozone (and ability to monitor those trends)				
Knowledge of relationship between trends in stratospheric ozone and releases of ozone-depleting substances (and ability to predict future trends)				
Knowledge of effects of stratospheric ozone depletion on UV levels (i.e., increased UVB radiation at the ground)				
Information on the biological/ecological/health impacts of increased UVB				
Other:				

1.2 What was the relative importance of these categories of knowledge in developing the Protocol (in terms of incentive and content)?

1.3 Without AES's contribution, would worldwide knowledge/capability in any of the above areas have been significantly affected? Please specify.

1.4 In addition to AES's direct contribution, were there other ways in which AES scientists significantly affected the development of the world knowledge base (e.g., via influence over international research initiatives)? Please specify.

2. AES access to, and use of, international scientific knowledge

2.1 How important was AES's ozone-related R&D in ensuring access to ongoing advances in the subject area in the international scientific community?

2.2 How important was AES's ozone-related R&D in establishing the capability to assimilate these advances in international knowledge (i.e., to develop a well-rounded scientific understanding of the issues), and to assess their significance in terms of Canadian policy?

3. Canada's Negotiating Position and Role in the Montreal Protocol

3.1 Relative to all other players, in percentage terms, what would you estimate Canada's influence to be in shaping the Montreal Protocol?

3.2 If Canada had not participated, speculate on the differences in the Protocol that would have emerged.

3.3 Please estimate the proportionate influence of the following factors in shaping the Canadian negotiating team's positions.

	Influence (to total 100)
AES information/analysis/recommendations -- i.e., the physical/chemical science	
Other sources of science-based information -- e.g., ozone depletion effects and technology alternatives	
Analysis of economic, policy and other implications	
Knowledge of the perspectives and positions of other key players in the negotiations	
Other (please specify):	

3.4 Please estimate the proportionate contribution of the following to Canada's effectiveness in the negotiations:

	Influence (to total 100)
Canada's perceived scientific credibility in the subject area, based on AES's work/reputation	
Canada's diplomatic credibility (reputation as "honest broker" etc.)	
The negotiating team's inherent skills and credibility	
Other (please specify):	

3.5 Considering the above, what would you estimate to be the proportionate overall contribution of AES to Canada's influence in the negotiations?

4. Development of the Ozone Watch and UV Index

4.1 Please verify, and if necessary expand on or add to, the following building blocks for the development of Canada's Ozone Watch and UV Index. In the first column, indicate AES's proportionate contribution to each of the building blocks (i.e., its contribution relative to all other players combined). In the second column, indicate the relative importance of each of the building blocks in terms of the development/success of these tools. (This column should add to 100.)

	AES's contribution	**Relative importance (to total 100)**
Direct real-time measurement of UV-B at the Brewer Spectrophotometer sites		
Development of the Index method (taking into account both the science that established the relationships on which the Index is based, and the Index method itself)		
Definition of measures to minimize exposure		
The communication strategy (please elaborate)		
Other (please specify):		

5. Impact of the Ozone Watch and UV Index

5.1 How well do Canadians understand the relationships between ozone depletion, increased UV-B, and risks to health and the environment? How much of the current state of knowledge can be attributed to Ozone Watch and the UV Index? Please provide a percentage estimate

5.2 What adaptations have Canadians made in response to the health risks associated with increased UV-B? To what extent was the Ozone Watch Program and the UV Index responsible for bringing about these adaptations? Please provide a percentage estimate.

5.3 What are the health implications of these changes?

5.4 What other factors were key?

6. Role of AES in the development of the Brewer spectrophotometer

6.1 Of the total R&D necessary to develop the instrument, for what proportion can AES claim responsibility?

APPENDIX C

➢ List of Interview Subjects

APPENDIX C
List of Interview Subjects

Glenn Allard
Director General, Special Projects
(formerly Director of Commercial Chemicals Branch of EPS (86-89), Associate DG of EPS (89-91), Head of the Delegation at 1990 London meeting)
Environment Canada

Jim Armstrong
Chief, Chemicals Control Division
Environment Canada

Per Bakken
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APPENDIX D

- **List of Reference Documents**

APPENDIX D
List of Reference Documents

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APPENDIX E

- **Estimate of Costs of R&D on Stratospheric Ozone Depletion**

APPENDIX E

Estimate of Costs of R&D on Stratospheric Ozone Depletion ($million)[71]

Year	Salaries[72]	O&M[2]	Capital[2]	Employee Benefits[73]	Share of Overhead[74]	Total	Total in $1997
75/76	0.31	0.31	0.31	0.06	0.25	1.23	3.57
76/77	0.33	0.33	0.33	0.07	0.26	1.31	3.51
77/78	0.35	0.35	0.35	0.07	0.28	1.41	3.48
78/79[75]	0.40	0.40	0.40	0.08	0.32	1.61	3.64
79/80[5]	0.37	0.37	0.37	0.07	0.29	1.47	3.01
80/81[5]	0.40	0.40	0.40	0.08	0.32	1.60	2.92
81/82	0.49	0.49	0.49	0.10	0.39	1.97	3.25
82/83[5]	0.63	0.63	0.63	0.13	0.51	2.53	3.94
83/84	0.77	0.77	0.77	0.15	0.62	3.08	4.59
84/85	0.85	0.85	0.85	0.17	0.68	3.40	4.88
85/86	0.82	0.82	0.82	0.16	0.65	3.27	4.51
86/87	1.25	1.25	1.25	0.25	1.00	5.00	6.60
87/88	1.27	1.27	1.27	0.25	1.02	5.09	6.46
88/89	1.32	1.32	1.32	0.26	1.05	5.27	6.37
89/90	1.19	1.19	1.19	0.24	0.96	4.78	5.51
90/91	1.12	1.12	1.12	0.22	0.89	4.47	4.89
91/92	1.22	1.22	1.22	0.24	0.98	4.88	5.25
92/93	1.94	1.94	1.94	0.39	1.55	7.76	8.20
93/94	1.59	1.59	1.59	0.32	1.27	6.35	6.70
94/95	1.45	1.45	1.45	0.29	1.16	5.82	6.01
95/96	1.48	1.48	1.48	0.30	1.18	5.90	6.00
96/97	1.27	1.27	1.27	0.25	1.01	5.07	5.07
Total	20.8	20.8	20.8	4.2	16.7	83.3	108.4

[71] Estimates considered accurate to within 15%.

[72] Direct costs are estimated to be 1/3 salary, 1/3 O&M, 1/3 capital.

[73] Calculated on the basis of 20% of salary costs.

[74] Calculated on the basis of 40% of salary and O&M costs.

[75] Cost information not available - estimated on the basis of previous forecasts.

APPENDIX F

- **Evaluation of the AES Contribution to Worldwide Knowledge of Ozone Depletion and UV Radiation**

APPENDIX F
Evaluation of the AES Contribution to Worldwide Knowledge of Ozone Depletion and UV Radiation

There are three principal categories of knowledge at issue:[76]

- Knowledge of stratospheric ozone chemistry and transport mechanisms
- Knowledge of trends in stratospheric ozone
- Knowledge of the influence of ozone on surface radiation.

Knowledge of Stratospheric Ozone Chemistry and Transport Mechanisms

The principal contributions of AES in this area include:

- Contributions to the Middle Atmosphere Modelling initiative, including the Canadian Middle Atmosphere Model.

- Contributions to various other modelling initiatives, including measurements used for calibration and validation of these models (through balloons, aircraft, and space-based experiments).

- Recognition and quantification of the significance of ozone depletion by chloroform.

A review of the reference documentation (including the Science Assessments) indicates that these contributions, while important, have provided only a small part of the worldwide knowledge base in this area.

The extent to which knowledge in this area should be attributed to AES was addressed by eight interview subjects. Their views are summarized as follows:

- AES had little involvement in modelling of atmospheric chemistry.

- AES contributed little to the modelling aspects.

- In the early years, AES did some significant work on atmospheric mechanics, which although not related to ozone, helped create a foundation. AES had some impact in this area. The work on space and high-altitude monitoring was useful.

- AES contributed little to the knowledge of atmospheric mechanisms on ozone.

[76] Note that only atmospheric science is considered here. It is acknowledged that other elements of science and technology (e.g., health impacts, replacement technology) were also important.

- AES probably contributed some modelling work. Overall, probably about 5% of the knowledge in this area.

- AES probably contributed about 5% of the knowledge in this area. The US was the leader at 75% to 80%.

- AES' contribution in this area was not as significant but there was some modelling work. Overall probably about 5%. Canadian universities contributes another 5%, while the US was responsible for 60% and the rest of the world 30%.

- Not aware of any significant contribution by AES in this area.

The information is relatively consistent in concluding that the AES contribution in this area is small but not negligible. Based on all the available information, the following attribution estimate is proposed:

Contribution of AES to worldwide knowledge of stratospheric ozone chemistry and transport mechanisms:

- Low impact scenario: 2%
- Best guess: 4%
- High impact scenario: 6%.

Knowledge of Trends in Stratospheric Ozone

The principal contributions of AES in this area include:

- The invention of the Brewer spectrophotometer which is steadily becoming the instrument of choice for surface-based ozone measurements.

- Calibration and standard maintenance for the worldwide network of Brewers and for ozonesondes.

- Operation of the World Ozone and UV Radiation Data Centre providing reliable data for worldwide trend analysis.

- Four decades of ozone measurements from the Canadian ozone network which represents a significant portion of the worldwide network for surface-based measurements (12 of 160) and an even more significant portion of the stations with important long-term records (4/16).[77]

- Regular measurements of the vertical ozone profile using ozonesonde at six stations.

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77 Environment Canada. 1997. Ozone Science: A Canadian Perspective on the Changing Ozone Layer.

- Operation of the Arctic observatory at Eureka, as part of the Network for Detection of Stratospheric Change (NDSC) whose aims are to (1) provide high-quality, ground-based, remote-sounding stations for observations of a variety of parameters, (2) provide an independent calibration of satellite sensors, and (3) obtain data for testing models.
- Participation in space-based and high-altitude monitoring.
- Identification of a large mid-latitude negative ozone trend since 1960 and record low ozone values in 1993 (linked to volcanic debris from the eruption of Mount Pinatubo).
- Identification of a downward trend of free tropospheric ozone over Canada since 1980.

Based on direct arithmetic, the contribution of AES stations to worldwide ground-based observations amounts to between 8% and 25% (depending on the weight given to long-term records). According to one interview subject (see below), such worldwide ground-based observations would make-up half of the record necessary for trend analysis, with most of the rest accounted for by satellite observations. On this basis, the AES contribution to the record would amount to between 4% and 12.5%. In addition, there is the additional contribution of AES to ozone profiles, high-altitude measurements and detailed arctic observations (which are of particular importance).

Furthermore, the ever increasing number of stations using Brewer spectrophotometers (over 50) and the improved quality of data provided by those stations, together with AES work on standards and calibration, and the maintenance of the World Ozone and UV Radiation Data Centre, suggest that the AES contribution could be significantly more important.

Finally, AES' detection and quantification of ozone trends over Canada has been an important component of the overall assessment of mid-latitude and arctic trends in the Northern Hemisphere.

A review of the reference documentation indicates that these contributions of AES are having a significant impact on the global ability to monitor the ozone layer and detect trends and form a large part of the worldwide record on ozone depletion.[78] This record has played an important role in increasing overall understanding of ozone trends which was important in motivating changes to the Montreal Protocol and will continue to be important in assessing the Protocol's effectiveness.

A review of the relevant chapters in the 1994 and 1998 (draft) Science Assessments indicates the following:

- Chapter 1 of the 1994 Assessment: "Ozone Measurements" contains 139 citations, 18 of which include authors funded by AES (13%).

[78] Scientific Assessment of Ozone Depletion: 1994. WMO Report no. 37.

- Chapter 4 of the draft 1998 Assessment: "Ozone Variability and Trends" contains 159 citations, 23 of which include authors funded by AES (14%).

The extent to which knowledge in this area should be attributed to AES was addressed by eight interview subjects. Their views are summarized as follows:

- AES' contribution to the knowledge of trends was huge (between 25% and 75%). They have been at it for a long time and the work in the Arctic is crucial.
- AES' contribution to the knowledge of trends was not unimportant, particularly providing coverage at northern latitudes and for calibration and validation of the satellite data -- estimates around 3% to 5% of the data. The Brewer instruments are far superior but their contribution is only beginning to be felt. Operation of the Data Centre (though a fairly mechanical process) has been crucial -- the integrity of the data requires constant supervision by senior and knowledgeable people. Without AES, there would have been holes in the trend data and less certainty. However, the rest was probably compelling enough. On the other hand, it would have meant even more reliance on US data which would not necessarily have been accepted by all parties.

- AES work was key to providing knowledge on trends. The development of the Brewer and the operation of the Data Centre may have made a significant incremental contribution. The work on space and high-altitude monitoring was also important.

- AES contributed measurements, documenting conditions in the Arctic and the repository for the data (World Ozone and UV Radiation Data Centre). They also helped interpret the satellite measurements and what they meant for Canada. The contribution was probably about 5%. 70% came from the US.

- The AES contribution was the third most significant (after the US and UK). This was due to geography and the number of stations in Canada, the operation of the World Data Centre (including quality assurance and quality control), invention of the Brewer and analysis of Canadian trends. Overall the contribution was more than 10%, less than 50%, probably around 20%. Without AES, the trends in the northern latitudes would not be as well understood.

- The AES contribution was significant (15% to 20%). The US contributed 60% (mainly NASA), the EU 20%. Without AES, there would have been some gaps in the record and the Brewer would not be available.

- In the 1980s, the AES contribution consisted primarily of measurements from the Dobson instrument network (AES had approximately 1/4 of the operating stations). AES also added measurements from ozonesondes and operated the Data Centre. Overall the contribution was 20% (US was 60%). With the invention of the Brewer, this contribution increased to 30%. Without AES, it might have taken longer (12 to 18 months) to prove the statistically significant decrease in ozone. The ground-based monitoring and ozonesondes were particularly important because of the drift in measurements experienced by satellite instruments. As a result, it would have taken a few more years to calibrate the models.

- The AES contribution to the measurement of trends was probably around 10% to 15% initially, rising to 20% to 25% after the invention of the Brewer. The US was 30% to 40%, the Europeans 20% to 30%. Without AES, there would have been important gaps in the record (particularly circumpolar measurements). The Brewer was also very important.

Despite some inconsistencies, the information from the references and the interviews is relatively conclusive that the AES contribution was important. Based on all the available information, the following attribution estimate is proposed:

Contribution of AES to worldwide knowledge of trends in stratospheric ozone:

- Low impact scenario: 5%
- Best guess: 15%
- High impact scenario: 25%.

Knowledge of the Influence of Ozone on Surface Radiation

The principal contributions of AES in this area include:

- Conduct of a UV-B spectral measurement program beginning in 1981.

- Demonstration of UV increase linked to ozone depletion.

This contribution to global understanding of the link between ozone depletion and UV radiation was recognized through the 1995 award of the World Meteorological Organization (WMO) Norbert Gerbier-Mumm International Award to AES scientists for their paper entitled *Evidence of Large Upward Trends in UV-B Radiation Linked to Ozone Depletion.*[79]

This 1993 study was the first to show the effects of ozone depletions on integrated daily UV-B at mid-latitudes, including cloudy conditions.[80]

A review of the reference documentation indicates that these contributions of AES had an important impact. For example, helping justify one of the fourteen major scientific findings of the 1994 Science Assessment.[81]

[79] Kerr, J.B. and McElroy, C.T. 1993. *Evidence of Large Upward Trends in UV-B Radiation Linked to Ozone Depletion.* In Science, Vol. 262, pp. 1032-1034.

[80] *Scientific Assessment of Ozone Depletion: 1994.* WMO Report no. 37.

[81] Scientific Assessment of Ozone Depletion: 1994. WMO Report no. 37.

A review of the relevant chapters in the 1994 and 1998 (draft) Science Assessments indicates the following:

- Chapter 9 of the 1994 Assessment: "Surface Ultraviolet Radiation" contains 70 citations, 3 of which include authors funded by AES (4%)

- Chapter 11 of the 1998 Assessment: "Ultraviolet Radiation at the Earth's Surface" contains 171 citations, 19 of which include authors funded by AES (11%).

The work was also recognized as a significant discovery in a speech given by one of the Co-chairs of the Science Assessment Panel, at the ninth meeting of the Parties to the Montreal Protocol, in 1997: "In 1994, the Science Assessment pointed out, among other things, that, as we saw earlier from the excellent data reported from the Canadian networks, increases in UV radiation, the next to last step in the cause-effect chain to human impacts, had been observed. This was reported in Vienna where Parties chose to place caps on other ozone depletors like methyl bromide that were not covered at that time."

The extent to which knowledge in this area should be attributed to AES was addressed by eight interview subjects. Their views are summarized as follows:

- Strong involvement in this area (between 25% to 75%).

- Early on, there was little work by anyone in this area. AES has made some recent contributions.

- The work of AES in this area was important.

- The AES contribution in this area was about 15% (though this may be somewhat generous).

- AES' contribution was strong. This was recognized by the Scientific Assessment Panel. The only reliable system for measuring UV was in Canada. Overall, the AES contribution was about 50%.

- The AES contribution was 15% to 20%. The US was 50%, other countries were 25%.

- The AES contribution in this area was about 10% early on but increased to 20% with the use of the Brewer spectrophotometer and the work by Kerr and McElroy.

- The AES contribution was 5% to 10%. There was not a lot of work going on generally, but AES worked with the US early on and later produced the work of Kerr and McElroy.

The information is relatively consistent in concluding that the AES contribution in this area was significant. Based on all the available information, the following attribution estimate is proposed:

Contribution of AES to worldwide knowledge of the influence of ozone on surface radiation:

- Low impact scenario: 10%
- Best guess: 15%
- High impact scenario: 20%.

Relative Importance of Elements to Worldwide Knowledge of Ozone Depletion and UV Radiation

The relative importance of the various knowledge elements was addressed by eight interview subjects. Their views are summarized as follows:

- The relative importance changed in the period from the Vienna Convention to the London Amendment. At first, chemistry and transport mechanisms were most important (80%), followed by trends (15%) and effects on UV (5%). Later, trends became more important (60%), followed by chemistry and transport (35%) and effects on UV (5%).

- The knowledge of trends and effects on UV were equally important, however, the knowledge of the chemistry and transport was most important.

- The work proceeded somewhat sequentially: first came knowledge of the chemistry and transport, second the trends for ozone and UV.

- Knowledge of the chemistry and transport and the trends was equally important (40% each). Effects on UV somewhat less so (20%).

- The relative importance of the elements shifted over time. Before 1987, chemistry and transport was most important, trends less so and effects on UV hardly important at all. By the time of the London Amendment, trends was most important. After Copenhagen, effects on UV became more important and will remain so as ongoing monitoring of the effectiveness of the Protocol proceeds.

- The relative importance shifted over time. Until 1990, chemistry and trends were relatively equal in importance. Since then, trends have become more important.

- The relative importance shifted slightly after the signing of the Protocol. Before, it was chemistry and transport (55%), followed by trends in ozone (30%) and effects on UV (15%). After, chemistry and transport (55%) stayed important, trends in ozone was less so (20%) and effects on UV more so (25%).

- The relative importance shifted over time. Before the Protocol, it was chemistry and transport (50%), trends (45%) and effects on UV (5%). Later, it was trends (55%), chemistry and transport (40%) and effects on UV (5%).

The views are relatively consistent in concluding that the importance of the elements shifted over time but that, overall, transport and chemistry was most important, followed by trends and, finally, effects on UV. For simplicity, we propose to average out the shifts in importance and propose the following relative weighting:

Relative weight of knowledge elements in worldwide knowledge of ozone depletion and UV radiation:

- Knowledge of stratospheric ozone chemistry and transport mechanisms: 50%
- Knowledge of trends in stratospheric ozone: 40%
- Knowledge of the influence of ozone on surface radiation: 10%.

Overall Assessment of the Contribution of AES Research Outputs to Worldwide Knowledge of Ozone Depletion and UV Radiation

Given our assessments of the AES contributions to each of the knowledge elements and our assessment of the weight of these elements in the overall knowledge base, we can calculate the overall contribution of AES. The results for three scenarios (low impact, best guess, high impact) are shown in Table F.1.

The conservative aspect of these estimates is reinforced by a number of statements in a paper entitled *Leading while Keeping in Step: Management of Global Atmospheric Issues in Canada*. This paper suggests the following:[82]

- Canadian individuals and institutions exercise a striking degree of leadership, and of constructive contribution generally, to international science on these issues (ozone, climate change and acid rain).

- The dominance of AES in Canadian atmospheric science provides secure support for the kind of careful, long-term, unglamorous monitoring and observational work that is essential for the development of baselines and the identification of long-term trends. It can also provide resources to support international public goods, through extended participation in international research and coordination activities. The remarkable involvement of Canadians in activities of UNEP, WMO and other international bodies in part reflects the value placed on such activity.

- AES expertise was particularly strong and long-standing on ozone, giving exceptional confidence and commonality of view to their recommendations.

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[82] Parson, E.A., Dobell, A.R., Fenech, A., Munton, D. and Smith, H. (Version 4.1, Draft 1996). *Leading while Keeping in Step: Management of Global Atmospheric Issues in Canada.* John F. Kennedy School of Government, Harvard University.

Table F.1
Overall Contribution of AES to Worldwide Knowledge Base

Knowledge Element	Relative Weight (%)	AES Contribution (%)	Weighted AES Contribution (%)
Stratospheric Ozone Chemistry and Transport Mechanisms	50	Low Impact: 2 Best Guess: 4 High Impact: 6	Low Impact: 1.0 Best Guess: 2.0 High Impact: 3.0
Trends in Stratospheric Ozone	40	Low Impact: 5 Best Guess: 15 High Impact: 25	Low Impact: 2.0 Best Guess: 6.0 High Impact: 10.0
Influence of Ozone on Surface Radiation	10	Low Impact: 10 Best Guess: 15 High Impact: 20	Low Impact: 1.0 Best Guess: 1.5 High Impact: 2.0
Total			Low Impact: 4.0 Best Guess: 9.5 High Impact: 15.0

Based on these scenarios, the following attribution is suggested:

Contribution of AES to the worldwide knowledge base on ozone depletion and UV radiation:

- Low impact scenario: 4.0%
- Best guess scenario: 9.5%
- High impact scenario: 15.0%.