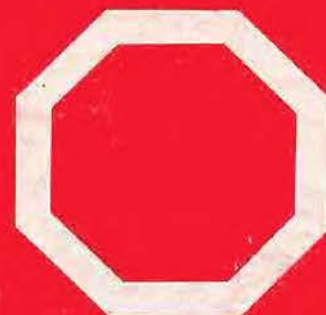


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MARC REPORT NUMBER 1



General Report

**THE OZONE DEPLETION
PROBLEM
(AN EXAMPLE OF HARM
COMMITMENT)**

Prepared by:
MONITORING AND ASSESSMENT RESEARCH CENTRE of the
SCIENTIFIC COMMITTEE ON PROBLEMS OF THE ENVIRONMENT,
INTERNATIONAL COUNCIL OF SCIENTIFIC UNIONS

With the support of
UNITED NATIONS ENVIRONMENT PROGRAMME and
THE ROCKEFELLER FOUNDATION

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The Centre's work in this regard is funded by the United Nations Environment Programme and The Rockefeller Foundation.

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**The Ozone Depletion
Problem
(An Example of Harm
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by Lester Machta

A General Report (1976)



Prepared by:
Monitoring and Assessment Research Centre of the
Scientific Committee on Problems of the Environment,
International Council of Scientific Unions
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PREFACE

The problem of ozone depletion is so interdisciplinary and complex that it is difficult for the non-expert to evaluate its urgency and severity. As a result, this potential threat cannot readily be compared with the myriad of others without committing scarce resources to comprehensive monitoring and assessment programmes.

This Report attempts, in non-technical language, to provide a summary of current predictions of ozone depletion and its possible effects and, as an annex, an economic analysis of the consequences of restrictions of one set of the chemicals involved, the chlorofluorocarbons.

The Report shows how the problem of ozone depletion fits the dose and harm commitment concepts. When given quantities of certain chemicals enter the environment, theory predicts that an extra dose of ultraviolet radiation from the sun and additional skin cancers will almost inevitably follow even if delayed by years.

Finally, the Report concludes with suggestions for the actions required to resolve many of the uncertainties still plaguing the theoretical predictions of ozone depletion and its effects. It also indicates the steps needed to evaluate the economic consequences of restrictions of chlorofluorocarbon releases to the atmosphere.

Gordon T. Goodman
Director

1.0 Introduction

The chemicals potentially depleting the ozone layer generally do not produce other environmental hazards. Ozone depletion, if it does occur, takes place long after the chemicals enter the environment. The reduced ozone shield permits more solar ultraviolet radiation to reach the ground. The ozone depletion and its enhanced ground level ultraviolet radiation can persist for many years even after cessation or reduction of the offending chemicals. Thus, once in the environment, the future dose of increased solar ultraviolet radiation is committed.

This report examines the quantitative increase in human skin cancers which, from our present understanding, would be expected to result from enhanced solar ultraviolet radiation. Other damage as well as some benefits may ensue from this greater ground level ultraviolet radiation. But these cannot either be quantified or foreseen at present. Further, this small man-induced increment of solar ultraviolet radiation should be placed in perspective by comparing it with natural space and time variability of the radiation.

The several steps leading to and resulting from man-induced ozone depletion appear in Table 1 and are discussed in greater depth below.

Table 1, The ozone depletion problem

1. Certain chemicals, such as oxides of nitrogen and chlorofluorocarbons, are released to the atmosphere by human activities.
2. These chemicals are transported by air motions to altitudes within the stratosphere at which photochemical reactions occur.
3. The chemicals or their products catalytically destroy ozone.
4. The chemicals or their products also form stable molecules which can be transported downward by air motions to the lower atmosphere where they are removed from the air mainly by rain scavenging.
5. The reduced ozone shield allows more ultraviolet radiation from the sun to reach the lower atmosphere.
6. The enhanced ground level ultraviolet radiation can increase skin cancer and produce other harmful or beneficial effects on people and other living things.
7. The altered ozone distribution in the stratosphere and certain of the added man-made chemicals can modify the radiative balance of the atmosphere and possibly create climatic changes.

2.0 The Chain of Events from Chemicals to Skin Cancers

2.1 Theory of Ozone Depletion

Ozone (O_3) is formed and destroyed naturally in the stratosphere by photochemical reactions. These, together with transport processes, determine the natural steady state or observed concentrations.

A number of chemicals have been identified as potentially altering the amount of stratospheric ozone. At present, they mainly comprise gases yielding two products: chlorine oxides (ClO_x) and nitrogen oxides (NO_x). The sources of ClO_x are primarily chlorofluorocarbons (F-11; CCl_3F and F-12; CCl_2F_2) used as propellants in aerosol spray cans and as refrigerants, carbon tetrachloride (CCl_4) of uncertain origin, and other natural gases such as methyl chloride (CH_3Cl). All of these gases enter the atmosphere near the earth's surface but in contrast to more abundant hydrogen chloride (HCl) or sea salt ($NaCl$) survive tropospheric removal mechanisms and are transported by natural air motions into the stratosphere. The NO_x derives mainly from nitrous oxide (N_2O), virtually all of natural origin at the earth's surface (e.g., denitrification) and in the troposphere (e.g., lightning). N_2O can also survive tropospheric removal. A secondary much smaller source of NO_x is nitric oxide (NO) injected directly into the stratosphere and upper troposphere by high flying aircraft and rockets. There are other sources of ClO_x and NO_x which are thought to be less important. Other halogens, especially certain brominated gases, can also, in theory, reduce stratospheric ozone.

2.2 Ozone and Ultraviolet Radiation

Ozone absorbs sunlight significantly in the near ultraviolet portion of the solar spectrum (280 to 320 nanometers, called UV-B). It is this portion of the solar spectrum which produces sunburning, skin cancers in animals and cellular and sub-cellular damage. Changes in ground level UV-B are strongly but negatively correlated with changes in total ozone. Total ozone is the amount of ozone in a vertical column between sea level and the top of the atmosphere. The reduction in total ozone due to man-released chemicals takes place almost entirely in the stratosphere.

The amount of UV-B received at ground level from the sun depends on other factors in addition to the amount of intervening ozone. In particular, clouds, haze, fog, and dust attenuate sunlight in the UV-B as well as the visible portions of the solar spectrum. Ground cover

which controls reflected sunlight plays a less important role in determining the amount of UV-B striking people. The UV-B is greater in elevated regions because of lesser atmospheric attenuation.

2.3 Ultraviolet Radiation and Skin Cancers

The final step linking chemicals to skin cancer in people is the UV-B skin cancer relationship found from epidemiological studies at locations with varying amounts of UV-B. Unfortunately, most of the epidemiological studies are unsatisfactory although they uniformly display higher incidence (new occurrences of cancer in a given year) nearer to the equator. Total ozone increases towards the poles from the equator.

Quantitative relationships between UV-B and skin cancer incidence or mortality are complicated by geographical differences in dress, outdoor exposure, and skin pigmentation of local populations. Light skinned people constitute the susceptible population.

The relationship between UV-B and skin cancer in people is normally obtained from the latitudinal gradients of the two variables. But an infinitude of parameters vary with latitude. The association between UV-B and the production of skin cancers depends mainly on laboratory studies of UV-B production of skin cancers in animals and on the predominance of non-melanoma skin cancer on those parts of the human body most exposed to sunlight. Skin cancers occur either in pigmented or dark spots, called melanoma skin cancer, or elsewhere on the body, non-melanoma skin cancers.

Melanoma skin cancer incidence and mortality as well as non-melanoma skin cancer incidence increase equatorwards. But the distribution of melanoma cancers are poorly related to parts of the body exposed to sunlight. In recent years, there has been a marked increase in melanoma death rates in North America and elsewhere. The areas of the body of these increased numbers of cancers appear to correspond to newer body areas being exposed to the sun by modern dress styles. While most investigators agree that melanoma skin cancers are UV-B related, they admit that the case is much poorer than for a UV-B non-melanoma skin cancer association.

Mortality from non-melanoma skin cancers is very small when treated. Its incidence in North America is about 40 times as large as for melanoma skin cancers. But since there is a 40% mortality from melanoma skin cancers despite the best treatment, the death rates from the two types of skin cancers in North America are about equal

to the first approximation. The death statistics for non-melanoma skin cancers are notoriously unreliable, however.

3.0 Ultraviolet Radiation and other Living Organisms

While there is evidence for UV-B damage to many living organisms other than man, the relationship between UV-B and damage to plants and animals cannot be quantified at this time.

4.0 Climate Effects

Reducing or redistributing ozone in the stratosphere by man-made chemicals may alter the climate. F-11, F-12 and CCl₄ directly produce a "greenhouse" warming of the lower atmosphere similar to that attributed to increasing carbon dioxide. These potential climatic effects are not known with sufficient certainty.

5.0 Ozone Depletion

The predictions of ozone depletion by ClO_x and NO_x are obtained entirely by calculation using model simulations of chemical reactions and atmospheric transport. The only known validation of such a model is the high altitude decrease in ozone at high geomagnetic latitudes from the natural production of NO_x by ionizing radiation during a polar cap event in early August 1972. Total ozone trends and variations during recent decades when man may have disturbed stratospheric ozone by ClO_x from chlorofluorocarbons or by NO_x from large nuclear tests, high flying aircraft, or large scale fertilizer usage do not appear to be detectably different from limited data in earlier periods.

5.1 Calculating ozone depletion

The calculations of ozone depletion require three ingredients each with significant uncertainties:

- (i) atmospheric transport and dispersion;
- (ii) rate constants, including temperature dependence, for relevant chemical and photochemical reactions;
- (iii) quantitative information about certain stratospheric constituents (including solar radiation).

A discussion of information gaps and uncertainties of the predictive models could occupy many pages of this report. Ongoing research and monitoring make it likely that new data acquired between the writing and reading of the report could markedly alter some of the

dose commitment calculations. No uncertainty is attached to the estimates of ozone depletion below but it is very likely that none of the estimates are at present better than a factor of two.

5.1.1 Oxides of Nitrogen from Aircraft

NO_x (mainly as NO) originates in the upper atmosphere as one of the emissions from aircraft. Both the altitude of the source as well as the amount determine the magnitude of the ozone depletion. Table 2 lists a few of many calculations of ozone reduction due to aircraft.

Table 2, Estimates of percentage ozone depletion due to the injection of 10¹¹ grams of NO_x per year at 16-18 kilometers (100 Concorde/TU-144 flying 7 hours per day)*

CALCULATED BY	GLOBAL AVERAGE OZONE DEPLETION**
U.S. Climatic Impact Assessment Program	0.34%
U.S. National Academy of Sciences	0.57%
U.K. COMESA	0.11%

* There are differences in the assumed aircraft NO_x emission rates among the three reports. The injection rate of 11¹¹g NO_x/year corresponds to different numbers of flying hours. The table heading uses the COMESA estimates.

** The largest ozone depletion is likely in the 30-60°N band and might be about 1.8-2.0 times as great as these global average values.

The percentage ozone depletion in Table 2 and later tables are based on steady state conditions; that is, the new lower level of ozone. The emissions are assumed to be constant and continuous into the indefinite future at the indicated annual rate.

In addition to the calculations of Table 2, the U.S. Climatic Impact Assessment Programme has provided some additional estimates of ozone depletion due to other types of aircraft than the Concorde/TU-144:

- i. 400 wide bodied subsonic aircraft flying at 10.5 kilometers altitude produce a steady state ozone reduction of 0.082% and
- ii. 100 "proposed" large U.S.-type supersonic transports flying at an

altitude of 19.5 kilometers yield a steady state ozone reduction of 3.27%.

5.1.2 Oxides of Nitrogen from Fertilizer Denitrification

N₂O can be carried by air motions into the stratosphere from the denitrification of fixed nitrogen spread as agricultural fertilizers or from other man-made sources. Two of several estimates of the steady state ozone reduction are given in Table 3. Note that the delay between fixed nitrogen application to the soil and denitrification releasing N₂O may be very long.

Table 3, Estimates of percentage ozone depletion due to the use of 200 × 10¹² grams of nitrogen per year as fertilizer*

Calculated by	Global Average Ozone Depletion	Remarks
CAST (3)	3%; 23%	Two analyses yield the two values of ozone; both numbers assume N ₂ O/N ₂ =0.07 during denitrification.
Crutzen (4)	less than 1.8%	Upper limit since factors favorable to ozone depletion were optimized; N ₂ O/N ₂ =0.07 during denitrification.
Liu <i>et al</i> (5)		Argues that the response time for ozone depletion following fertilizer application is hundreds to thousands of years.

*This annual level of application may occur in 2000 AD if the growth rate in usage is maintained at 6%/year to that date.

5.1.3 Chlorofluorocarbons

Calculations of steady state emissions of F-11 and F-12 based on projections of current releases are used to obtain a steady state estimate of ozone depletion. Several of these estimates are listed in Table 4.

Table 4, Estimates of percentage ozone depletion due to the release of 2×10^{11} grams of F-11 per year and 3×10^{11} grams of F-12 per year (6)*

CALCULATED BY	GLOBAL AVERAGE OZONE DEPLETION
Crutzen	6.5-7%
Rowland & Molina; Wofsy, McElroy & Sze	13-18%
Turco & Whitten	10-18%
IMOS	7%
Derwent, Eggleton & Curtis	8%

*The releases correspond to those actually occurring in 1973.

5.2 Ozone to Ultraviolet Radiation

Theoretical computations for clear sky conditions (or in some cases for highly idealized cloudy conditions) suggest a magnification factor of about 2 between UV-B and ozone changes. A magnification factor is here defined as the percentage change in UV-B from a unit percentage change in total ozone. Observed magnification factors based on naturally occurring sky conditions are slightly lower than 2, perhaps 1.5, and this latter value is recommended. The uncertainty is less than 50% in the recommended value.

5.3 Ultraviolet Radiation to Skin Cancer

The magnification factor converting percentage changes of UV-B to percentage changes in non-melanoma skin cancer incidence is usually taken as 1.0 but with an uncertainty ranging from 0.5 to 7.5. The same magnification factors for melanoma skin cancer are: 0.8 for incidence and 0.4 for mortality.

Assignment of uncertainty to the melanoma magnification factors may be misleading since there is doubt whether UV-B even produces human melanoma skin cancers.

6.0 Summary — The Harm Commitment

Based on the preceding sections, Table 5 summarizes the estimates of skin cancer incidence and mortality. The estimates apply when the amount of UV-B due to ozone depletion has reached a steady state. In some instances, as for example denitrification producing N_2O from increased fertilizer usage, the time to achieve a steady state reduction of ozone may lag behind the chemical release by tens to thousands of years.

Table 5, Estimated incidence of and mortality from, skin cancers from steady state release of selected chemicals*

Chemical	Input (g/yr)	Altitude of Input (Km)	Source	Dose Commitment		Harm Commitment		
				% Ozone Depletion	% Increase UV-B	Additional Incidence	Mortality	
NO _x	156 × 10 ¹¹	10.5	400 wide-bodied subsonic aircraft	0.082	0.12	Non-melanoma skin cancers 2000	Melanoma skin cancers 40	Melanoma skin cancers 10
NO _x	1 × 10 ¹¹	16-18	100 Concorde TU-144 aircraft	0.11-0.57	0.17-0.86	2500-15 000	50-250	10-50
NO _x	164 × 10 ¹¹	19.5	100 large supersonic aircraft	3.27	4.91	75 000	1500	300
N ₂ O	2 × 10 ¹⁴ (N ₂)	0	Fertilizers in 2000 AD and constant thereafter	<1.8-23	<2.7-35	<40 000-500 000	<900-10 000	<150-2000
F-11 F-12	{ 2 × 10 ¹¹ } { 3 × 10 ¹¹ }	0	Aerosols, refrigerants, etc. at 1973 rate	6.5-18	9.8-27	150 000 400 000	30 000	600-1500

* Estimates assume a constant world light-skinned population of 10⁹ persons.

** Based on current non-melanoma skin cancer incidence of 150/100 000 light-skinned persons per year; melanoma incidence of 4/100 000; melanoma mortality of 1.5/100 000.

The estimates of skin cancer incidence and mortality in this report are not intended for any national or international regulatory decisions.

7.0 Ozone Depletion as an Example of Dose and Harm Commitment

The dose commitment concept assigns a numerical value to the damage from a given chemical input into the environment regardless of how small or how long after the release the damage occurs. Normally, concern ceases after concentrations or effects fall below an accepted standard or if there were no immediate effects. But the harm commitment concept follows the damage to its vanishingly low values; damage is assumed proportional to dose for susceptible populations even at very low doses.

Realistically, however, extremely low doses are excluded since their probability of producing damage possesses no practical significance in everyday life. The threshold below which one ignores small doses is a matter of personal or societal judgement and undoubtedly depends on the penalty paid to avoid the dose and the benefits accrued from the offending chemicals and their products. Where one segment of society benefits from the products while another is penalized by the chemical, the problem of disregarding low doses becomes particularly knotty.

The ozone depletion-skin cancer problem appears to fulfill the criteria for application of the dose and harm commitment concept. Numerical values can be assigned to the incidence and mortality from a specified rate of input of ClO_x or NO_x as illustrated in Table 5. As far as now known, increases of skin cancer incidence and mortality vary approximately linearly with man-caused increases in UV-B. Barring catastrophic errors in this theory, the approximate linearity to small doses will hold even with modifications in various links of this theory.

The ozone depletion problem contains several other features common to or at variance with other examples of the dose commitment concept as noted below.

7.1 Benefits

While the penalties from a dose of toxic chemicals or enhanced UV-B are the focus of attention, in many cases there are real or imagined benefits beyond the reason for their initial use. Two benefits from enhanced UV-B have been suggested: production of Vitamin D and, less often, germicidal effects. In a review of benefit and harm from

enhanced Vitamin D production, Daniels(8) concludes "that any hope that an increase in UV might be beneficial should be tempered with caution." There is a suggestion in many areas of the world of a slight increase in cloudiness having the effect of reducing UV-B. Thus, a man-made reduction of ozone might help maintain a more stable flow of UV-B to the ground.

7.2 Incomplete Assessment

The ozone depletion problem also highlights the omission of other ways in which the chemicals in question may offend or benefit man or his environment. This neglect usually results from too little information upon which to determine a quantitative insult or benefit. Two types of omissions may be noted:

- (i) known effects which cannot be quantified
- (ii) those whose existence is currently unknown.

An example of the latter arose in the ozone depletion problem. The "greenhouse" warming of the lower atmosphere by F-11, and F-12 and CCl₄ was recognized only after a few years following intense scientific scrutiny of these chemicals by environmentalists.

7.3 Uncertainties

At this time, the predictions of ozone depletion and the subsequent cancer production by enhanced UV-B are replete with major uncertainties. This is typical of practically all, if not all, other examples of dose commitment.

7.4 Comparison of Dose with Natural Variability

Very many examples of dose and harm commitment, including the present one, involve types of damage to man and his environment which also occur naturally. Ever since man has been on the earth, the sun has continued to irradiate him with UV-B. Ozone depletion by man-made chemicals, according to theory, merely increases the existing UV-B. An often quoted comparison between natural and man-made UV-B changes follows. In North America, the UV-B doubles roughly every ten degrees of latitude. The upper limit of most current man-made chemical threats to the stratospheric ozone layer is of the order of 10%. An increase of 10% corresponds to the amount of UV-B a person will receive if he moves only several hundred kilometers to the south. Further, at one location, the natural variation in ozone and UV-B over the period of years will be of the order of 10% or less.

These types of comparisons have been used to put the consequences of chemical emissions into perspective. However, it should be noted that the man-made increase in UV-B will add to any natural amount, no matter how variable or small might be the case naturally.

7.5 Unique Feature

In most examples of dose commitment, the offending chemical itself affects man or his environment. The ozone depletion problem is an exception. It is the enhancement of UV-B produced indirectly by the chemicals that is of concern.

8.0 The Role of Dose Commitment in Policy Formulation

The dose commitment is but one of several factors to be balanced in coming to a policy decision on environmental protection. Even without the grave uncertainties in almost all of the current dose commitment examples including the present one, the decision maker faces many other considerations in formulating his policy. Some penalty almost always must be paid for restrictions on chemical emissions, land uses, etc. Examples may be taken from the ozone depletion problem. The two main uses of F-11 and F-12 are as aerosol-spray-can propellants and refrigerants. Most of society would more willingly accept substitutes for or even the elimination of aerosol cans as opposed to the loss of refrigeration and/or air-cooling. Indeed, if refrigeration were solely dependent on F-11 and F-12, society might readily accept the penalty of extra skin cancers. Fortunately, there are other choices although at present the alternatives possess economic and energy efficiency penalties.

The economic impact of restrictions on the release of F-11 and F-12 is given in the Annex below. It illustrates the complexities and choices in any policy decision.

The decision maker may also wish to compare the dose commitment with other risks which occur naturally or which, like inevitable motor vehicle accidents, society accepts. The comparison may suggest other protective tactics. For example, skin cancer due to natural UV-B can be greatly reduced simply by avoiding sunlight between about 10:00 am and 2:00 pm. An effort to educate people to avoid the sun during these hours would probably reduce skin cancer by many tens of percent in contrast to the possible man-induced increase of perhaps no more than 10%. Such judgements by society through their decision makers would be sounder when quantitative, if albeit

uncertain estimates of risks and benefits are available for comparison.

The subjective judgements by decision makers are further complicated by admitted uncertainties and the divergent views of "experts". The lay person might appreciate some of the uncertainties; for example, the uncertainty in substituting animals for humans in medical experiments. But what is the layman to make of the fact that aircraft have been flying and aerosol cans have been used for tens of years yet no anthropogenic ozone depletion has been identified?

Another important consideration for decision makers involves the time required for the atmosphere to return to its natural ozone content if the offending chemical source is cut-off. In some instances, like NO_x emissions from aircraft, this time is only a few years. But for others, such as F-11 and F-12, the response time is measured in tens of years or longer.

The goal of environmental research, monitoring, and assessment is the protection of man and his environment. To achieve this goal, the decision maker should use the dose and harm commitment, where applicable, as an important but not exclusive consideration.

9.0 Conclusions

The harm commitment to higher skin cancer incidence, resulting from increased UV-B, which, in turn is caused by ozone depletion from chemical releases, is based upon a series of theoretical but plausible links and therefore deserves further validation. Waiting for proof of the theory by observing a decrease in ozone, an increase in UV-B or an increase in skin cancers is unacceptable on at least three grounds. First, insofar as possible, the harm should be anticipated and avoided: this is a prime objective of environmental protection. Second, it may be impossible to determine the relative contributions made to ozone depletion (and hence to UV-B and skin cancer increase), by each of the chemical processes involved. Finally, theory predicts that the recovery from the chemical attack on the ozone layer may last many years; delayed action can be too late to prevent extensive harm.

Rather, the individual links in the ozone depletion chain must be further assessed. Laboratory chemical reaction rates should be established or confirmed. The UV-B-skin cancer relationship must be refined and placed on a firmer footing. Transport processes in the stratosphere must be better understood. But monitoring is also called for in several areas to:

- (i) determine time trends for the ozone depleting chemicals such as

- NO_x, F-11, F-12 and CCl₄ in the lower and upper atmosphere;
- (ii) determine time trends of the reaction products of the above chemicals;
 - (iii) determine the atmospheric content of naturally occurring ozone depleting chemicals and others which play a role in ozone formation and destruction;
 - (iv) document changes in ozone, UV-B, and skin cancers which may take place either naturally or due to human activities.

A laboratory research effort and an atmospheric monitoring programme will improve predictions and assessment of the ozone depletion problem. The WMO already has an active programme to co-ordinate existing national activities along these lines.

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ANNEX

ECONOMIC IMPACT OF RESTRICTIONS ON THE ATMOSPHERIC RELEASE OF CHLOROFLUOROCARBONS F-11 AND F-12

1.0 Introduction

Decisions related to environmental protection require an understanding of the penalties paid for the decision. If no action is chosen, then an environmental risk is possible; if a restriction is imposed in order to reduce the risk, an economic or social penalty is often paid. The main body of this report tabulates estimated increases in skin cancer which, from our present understanding, would be expected to follow the release of certain chemicals to the environment. This is an example of the consequence of inaction in the ozone depletion problem. The economic impact of possible restrictions of some of the chemicals will be summarized below based on available reports, in particular that of the A. D. Little, Inc. to the U.S. Environmental Protection Agency.

Chlorofluorocarbons F-11 and F-12 (often called FREONS after their Du Pont trade name) and carbon tetrachloride are currently suspected of depleting the ozone layer. It is not at present known for certain whether carbon tetrachloride originates solely from industrial sources. The present annex treats F-11 and F-12 almost exclusively.

2.0 Production, Atmospheric Release and Uses

Industrial statistics on F-11 and F-12 (two gases in a family of fluorocarbons) are often combined with those for other halogens, particularly other fluorocarbons. Where statistics are available only for the U.S.A., the world values are probably about twice those for the U.S.A. except for air-conditioning and refrigeration where the factor is less than two.

2.1 Production and Release

The estimated world production and atmospheric release of F-11 and F-12 are given in Table 1. The difference between the amount made in a year and that released to the air mainly depends on storage in products such as refrigeration units although some are used as intermediate products in manufacturing another substance. Thus, in 1974, although aerosol cans accounted for 49 per cent of F-11 and F-12 production in the U.S.A., they accounted for 62 per cent of the

releases to the air. With present controls almost all F-11 and F-12 ultimately becomes airborne. The cessation of growth in production and release from 1974 to 1975 probably results from the economic recession in certain countries and from adverse publicity to the use of F-11 and F-12 in aerosol cans. One spokesman for industry feels that left unrestrained, the natural world demand would grow about 10 per cent per year for several tens of years; a report of the Organization for Economic Co-operation and Development (OECD) suggests a 4 per cent rate over the next 10 years and the A. D. Little Inc. report 5 per cent per year over 20 years.

The raw materials for the production of fluorocarbons are carbon tetrachloride, hydrofluoric acid and chloroform. In the U.S.A. (1974), 80 per cent, 40 per cent and 56 per cent respectively of those materials produced ended up as fluorocarbons.

2.2 Production and Trade

Table 2 illustrates the current estimates of the world production by country. Over 40 companies (considering the same company name in two countries as distinct since the degree of international management is unknown) make chlorofluorocarbons in about 23 countries. Virtually every country in the world uses F-11 and F-12 in some product; the U.S.A. alone shipped over 50 million pounds to over 70 countries in 1974.

2.3 Monetary Value and Employment by Use — U.S.A., 1974

The uses of F-11 and F-12 are shown in Table 3. The table also provides the U.S.A. chlorofluorocarbon dependent employment and U.S. dollar value of products. The use of F-11 and F-12 in aerosol spray cans and in air-conditioning and refrigeration are well known. By foaming is meant the blowing of F-11 in the manufacture of rigid and flexible polyurethane and F-12 in the manufacture of polyurethane and polystyrene. The employment and dollar value figures for the refrigeration and air conditioning industry are the largest. In the U.S.A. (1973) about 5 per cent of refrigerant gas was F-11 and 65 per cent F-12. The remaining 30 per cent was primarily F-22 which is not presently under suspicion as a cause of ozone depletion.

3.0 Alternatives or Substitutes

3.1 Aerosols

Over 75 per cent of the aerosol cans in the U.S.A. (and possibly for the

1953	38.1	32.4	128.9	104.5	24.4	102.5	78.3	701.6	499.6	202.0	4.8	9	14.0	2.3	11.0
1954	46.1	40.2	175.0	144.8	30.2	108.3	88.8	809.9	588.5	221.4	6.4	1.3	20.4	3.6	16.0
1955	58.0	49.9	233.0	194.7	38.3	128.0	100.5	937.9	688.9	249.0	8.2	1.8	28.6	5.4	23.0
1956	71.7	62.3	304.7	257.0	47.7	151.9	116.4	1089.8	805.3	284.5	13.4	2.7	42.0	8.1	33.0
1957	74.9	69.8	379.6	326.8	52.8	164.2	132.5	1254.0	937.8	316.2	13.9	2.5	55.9	10.6	45.0
1958	65.4	65.7	445.0	392.5	52.5	162.8	138.7	1416.8	1076.5	340.3	16.7	3.1	72.6	13.7	58.0
1959	78.8	67.2	523.8	459.7	64.1	194.6	154.8	1611.4	1231.3	380.1	24.8	5.9	97.4	19.6	77.0
1960	110.1	88.1	633.9	547.7	86.2	221.4	185.4	1832.8	1416.7	416.1	26.8	7.4	124.2	27.0	97.0
1961	133.8	113.2	767.7	660.9	106.8	242.4	208.4	2075.2	1625.1	450.1	26.8	8.0	151.0	35.0	116.0
1962	173.2	142.2	940.9	803.2	137.7	287.4	240.4	2362.6	1865.5	497.1	34.0	10.0	185.0	45.1	139.0
1963	207.2	174.4	1148.1	977.6	170.5	329.8	283.5	2692.4	2149.1	543.3	38.7	12.4	223.7	57.5	166.0
1964	246.4	206.8	1394.5	1184.4	210.1	385.0	331.8	3077.4	2480.9	596.5	49.3	15.0	273.0	72.4	200.0
1965	273.8	237.0	1668.3	1421.3	247.0	432.0	376.5	3509.4	2857.3	652.1	55.3	17.8	328.3	90.3	238.0
1966	312.2	263.5	1980.5	1684.8	295.7	499.6	426.3	4009.0	3283.6	725.4	69.5	21.6	337.8	111.8	286.0
1967	359.9	304.4	2340.4	1989.2	351.2	567.2	486.9	4576.2	3770.5	805.7	82.3	27.0	480.1	138.9	341.0
1968	411.7	346.0	2752.1	2335.3	416.8	609.7	532.4	5185.9	4302.9	883.0	100.5	36.0	580.6	174.8	405.0
1969	491.0	403.6	3243.1	2738.8	504.3	685.4	599.4	5871.3	4902.3	969.0	123.3	44.7	703.9	219.5	484.0
1970	541.0	460.7	3784.1	3199.6	584.5	737.9	652.6	6609.2	5554.9	1054.3	129.3	51.0	833.2	270.6	562.0
1971	604.2	511.5	4388.3	3711.1	677.2	783.0	698.1	7392.2	6253.0	1139.2	142.2	57.9	975.4	328.5	646.0
1972	698.4	575.8	5086.7	4286.9	799.8	877.0	770.0	8269.2	7023.0	1246.2	154.3	68.2	1129.7	396.6	733.0
1973	809.1	665.8	5895.8	4952.6	943.1	970.2	843.5	9239.4	7866.5	1372.9	168.6	78.7	1298.3	475.3	823.0
1974	880.5	751.4	6776.3	5704.1	1072.2	1041.9	934.0	10281.3	8800.5	1480.8	193.4	92.1	1491.7	567.4	924.0
1975	786.0	750.8	7562.3	6454.9	1107.4	915.9	910.6	11197.2	9711.1	1486.1	162.2	103.8	1653.9	671.2	982.0

Note: *Source - Manufacturing Chemists Association, March 1, 1976.

Annex Table 2. Worldwide production¹ of F-11, F-12 and total fluorocarbons, 1970-74*

	Production of all types of fluorocarbons (metric tons)				
	1970	1971	1972	1973	1974
WORLD, TOTAL	719,194	767,361	889,191	975,274	1,048,391
NORTH AMERICA, TOTAL	360,084	363,721	415,571	452,434	489,491
Canada	14,378	16,057	18,869	21,772	25,310
Mexico	NA ⁵	NA	NA	NA	NA
United States	342,404	344,671	393,651	426,304	461,451
WESTERN EUROPE, TOTAL	215,500	240,500	290,400	314,500	338,300
England	NA	NA	NA	NA	NA
France	NA	NA	NA	NA	NA
West Germany	NA	NA	NA	NA	NA
Italy	NA	NA	NA	NA	NA
Netherlands ²	NA	NA	NA	NA	40,000
Spain ³	5,300	6,000	7,000	7,500	10,500
Greece	NA	NA	NA	NA	NA
SOUTH AMERICA, TOTAL	4,810	6,350	7,840	8,750	11,200
Argentina	NA	NA	NA	NA	NA
Brazil	NA	NA	NA	NA	NA
Venezuela ⁴	NA	NA	NA	NA	NA
EASTERN EUROPE, TOTAL	81,000	89,000	98,000	107,000	118,000
Czechoslovakia	NA	NA	NA	NA	NA
East Germany	NA	NA	NA	NA	NA
Rumania	NA	NA	NA	NA	NA

U.S.S.R.	NA	NA	NA	NA	NA	NA
SOUTH ASIA AND MIDDLE EAST, TOTAL	1,200	1,290	1,380	1,490	1,600	1,600
India	NA	NA	NA	NA	NA	NA
Israel	NA	NA	NA	NA	NA	NA
AFRICA, TOTAL	6,000	6,500	7,000	7,500	8,000	8,000
South Africa	NA	NA	NA	NA	NA	NA
SOUTH-EAST ASIA AND PACIFIC, TOTAL	50,600	60,000	69,000	83,600	81,800	81,800
Australia	9,235	10,082	11,337	13,036	15,706	15,706
China	NA	NA	NA	NA	NA	NA
Japan	35,765	42,964	49,816	58,779	59,246	59,246

Notes:

*Sources: Data based on the OECD Report which contains figures from E. I. du Pont and Co.; country responses to U.S. & Canada. Unpublished data from the UNEP survey are also included. (See also Notes 1-5 below).

¹ Production figures for the World and the geographical regions (in bold type) are estimates prepared by E. I. du Pont de Nemours and Co.; figures for individual countries are those reported in survey conducted by the U.S., Canada, and the United Nations Environment Programme.

² Netherlands 1974 figure represents production capacity, not necessarily actual production.

³ Figures for Spain represent mixtures of all fluorinated and chlorinated hydrocarbon derivatives. Fluorocarbon production was therefore probably less.

⁴ Start up in 1976.

⁵ Not available.

Annex Table 3, U.S.A. dollar value and employment in 1974 for uses of fluorocarbons*

Use	U.S.\$ Millions	Employment 1000's
Aerosol propellants	1,873	27.5
Refrigeration and Air-conditioning	22,769	495.5
Foaming	840	57.0
	PLUS	
Chemical Manufacturers		
Basic Chemicals**	339	1.3
Fluorocarbons**	551	2.7

Notes:

*Source — U.S. Department of Commerce "Economic Significance of Fluorocarbons", December 1975.

**Include production of some fluorocarbons besides F-11 and F-12.

whole world) which use F-11 and F-12 as propellants in 1973 were for hair care, antiperspirants and deodorants.

Substitute fluorocarbons to replace F-11 and F-12 in aerosols suffer from several disadvantages and problems, as noted in Table 4. Hydrocarbons, now used extensively as paint spray propellants, are cheaper than F-11 and F-12 but are highly inflammable (Table 4). Compressed gases, particularly carbon dioxide, suffer mainly from an inferior delivery spray (Table 4). Finally, chlorocarbons are also cheaper than F-11 and F-12 but have other disadvantages (see Table 4).

Mechanical or other (roll-on) delivery systems are currently being sold but public preference for aerosol dispensers in many countries is evident. Typical pump costs for mechanical delivery systems are about \$0.10-\$0.15, but a cap to minimize leakage adds slightly to the cost. For comparison, aerosol can valves for F-11 and F-12 usage cost \$0.03-\$0.04 and filling about \$0.40-\$0.45 per pound including filling losses. The fluorocarbon propellant costs are estimated to be about 30 per cent of the direct production cost. The cost of mechanical substitutes are less expensive than aerosol cans using F-11 and F-12.

Technological developments may overcome the drawbacks of certain delivery systems, especially compressed carbon dioxide and

Annex Table 4, Alternative aerosol propellants and their characteristics (Adapted from A. D. Little, Inc. Report)

Propellant Types	Price U.S.\$ per pound	Relevant Characteristics
Fluorocarbons		
F-11	.35	Highly favourable as a propellant; non-inflammable, non-toxic, favourable boiling points and vapour pressures.
F-12	.41	
F-114	.49	Safety must be assured (they also contain chlorine which may destroy ozone in stratosphere). Higher cost. Some are inflammable, irritate the skin, or have undesirable boiling points or vapour pressures, or are poor solvents.
F-115	1.50	
Others (such as perfluorocarbons)	some 2.00-6.00	
Hydrocarbons		
Propane	.14	Highly inflammable but other properties favourable as a propellant; cheap.
Isobutane	.12	
-Butane	.12	
Compressed Gases		
Carbon dioxide	.05	Failure to deliver fine spray with 1975 technology. Nitrogen has poor stability. Nitrous oxide presents a personal hazard because of the strong oxidizing power. They are cheap. Carbon dioxide and nitrogen offer no environmental problems and even nitrous oxide may have negligible environmental hazard.
Nitrous oxide	.19	
Nitrogen	.03	
Chlorocarbon		
Methylene chloride	.17	May also threaten stratospheric ozone. Problems of inflammability, toxicity and skin irritation require mixtures with other propellants. Cost is less than for F-11 and F-12.

mechanical ones. This development may be accelerated by threats, in some countries, of restrictions in F-11 and F-12 usage. The delivery system must, of course, be treated as a whole and in some cases the product may have to be redesigned for alternative delivery.

3.2 Refrigerants

The 1972 ASHRAE Handbook on Fundamentals lists 79 refrigerants categorized as follows: Halocarbons, Cyclic Organic Compounds, Hydrocarbons, Oxygen Compounds, Nitrogen Compounds, Inorganic Compounds, and Unsaturated Organic Compounds. But F-11, F-12 and F-22 have largely displaced all others despite their higher prices. Their advantages are non-toxicity, chemical inertness, and good performance. For example, ammonia can be explosive if it leaks while sulphur dioxide, although non-inflammable, is highly toxic.

F-12 appears to have very few, if any, substitutes as the working gas in common household refrigeration for thermodynamic reasons. F-22 can replace many refrigeration and air-conditioning products but only after major redesign of equipment.

Other types of cooling devices such as thermoelectric, absorption, or vapour pressure are either in an experimental stage or much more expensive than using fluorocarbons in either their capital and/or operating costs.

The present pessimistic outlook for substitute working fluids for cooling devices may be balanced by the likelihood that relatively simple procedures and modifications can reduce the emissions from devices now using F-11 and F-12. It appears that more than 60 per cent of all refrigerant emissions could be eliminated with improved service procedures and with relatively minor design changes. Another 25 per cent could be recovered at the point of product disposal.

3.3 Foam Blowing

The blowing agents form the cellular structure in the manufacture of foams made from polyurethane, polystyrene, and polyolefins (very small amounts used for this latter purpose).

Table 5 lists some suggested substitutes for F-11 and F-12 in plastic foam manufacture. These substitutes each have some minor or major disadvantage over the currently used halocarbons. For example, substitution of water/CO₂ blowing agent systems for halocarbons in rigid polyurethane foams would result in their economic advantage over other insulating systems being lost due to higher heat conduction.

Annex Table 5, Halocarbon usage and substitutes in plastic foam manufacture*

Halocarbon typically used	Type of plastic foam	Quantity of halocarbon used U.S.A. 1973 (millions of pounds)	Typical product application	Alternative blowing agent
F-11,-12,-113	Low density rigid polyurethane	44.8	Insulation	Water/CO ₂
F-11	High density rigid polyurethane		Furniture parts	Water/CO ₂
F-11 Methylene Chloride	Flexible polyurethane	35.4	Cushioning, bonded foam fabrics	Water/CO ₂
F-12 Methyl Chloride	Extruded polystyrene	8.4	Food trays	Pentane
F-11, -12	Expanded polystyrene	0.5	Packaging, insulation	Pentane
F-114, -12	Polyolefin	1.1	Packaging, insulation	Azodicarbamide aliphatic hydrocarbons, nitrogen

Note: *Adapted from A. D. Little, Inc. Report

In some cases, the large percentage losses of halocarbons to the air can be reduced by halocarbon recovery or destruction during manufacture or fabrication.

3.4 Some Unique Applications

Fluorocarbons are used in very small amounts for aerosol products with special benefits to medicine. In hospitals they are used as propel-

lants to sterilize and sanitize operating rooms, etc. For example, ethylene oxide is valuable in the sterilization of surgical instruments, bandages, etc. However, it is a highly inflammable and explosive gas. When mixed with fluorocarbons, its inflammability and explosiveness is controlled but sterilization is not inhibited. In pharmaceutical applications, inhalation units to relieve asthma and spray applied bandages employ fluorocarbons.

4.0 Time to Implement Alternatives

Although predicting the time needed to introduce substitutes for F-11 and F-12 is highly uncertain, industrial technologists in the U.S.A. have offered their judgments.

4.1 Aerosols

Table 6 provides estimates for the time required to introduce substitutes for the present spray cans using F-11 and F-12. Up to five more years should be added to the time in the table if a new chemical propellant must be identified and developed.

Annex Table 6, Time required for introducing products to personal care market*

Expand production of existing non-aerosol products	1-3 years
Introduce compressed gas aerosol products	1-3 years
Introduce liquefied gas aerosol products	2-4 years after new propellant identified

Note: *Source — Arthur D. Little, Inc., estimates based on aerosol product industry sources.

4.2 Refrigeration

Table 7 suggests very uncertain estimates for the time to improve existing cooling equipment or to substitute new refrigerants.

Annex Table 7, Time to improve existing air-cooling equipment or introducing products with new refrigerants or cooling methods

Product categories	Reduce or eliminate losses in products using F-11 & F-12	Convert to new refrigerant** or new cooling method
Appliances (e.g. home refrigerators)	2-3 years	3-6 years
Mobile air-conditioners	3-4 years	3-5 years
Room (home) air-conditioners	2-3 years	3-5 years
Commercial refrigeration	2-3 years	3-6 years
Commercial air-conditioners (chillers)	2-3 years	1-5 years

Notes:

*Adapted from A. D. Little, Inc. Report.

**After a new refrigerant is identified and assuming it is available in sufficient quantities. This time may be another five years.

4.3 Foam Blowing

Table 8 shows the estimated times to develop and install emission control equipment and to substitute a new blowing agent. If new substitute chemicals must be identified and developed, up to six more years should be added to the appropriate line.

5.0 Consequences of Various Strategies of F-11 and F-12 Restrictions

Because the current uses of F-11 and F-12 exist in a price- and performance-competitive situation in most countries, one can generally contend that for a given product performance, the current uses of F-11 and F-12 are the least costly way of satisfying the need as perceived by the consumer. Restrictions would shift the consumption to

Annex Table 8, Time to install control equipment and substitute other blowing agents*

Develop and install vapour recovery equipment	2-3 years
Substitute blowing agent in rigid foam applications	3 years
Substitute blowing agent in flexible foam applications	6 months

Note: *A. D. Little, Inc., estimates based on industry sources.

the next best alternatives which would either be more expensive or perform less satisfactorily. However, as already noted, the alternative need not be more expensive.

Net employment changes resulting from restrictions may be either upward or downward although an adverse job impact on some employees is almost certain.

The two sets of studies of possible restrictions in the U.S.A. given below, intended to reduce the emissions of F-11 and F-12 must be considered preliminary as neither was treated in the depth deemed necessary.

5.1 Options of the Department of Commerce

The following three options were chosen for the varying perspectives they provide by an agency of the Department of Commerce, although the Department of Commerce has not necessarily officially endorsed the analysis.

5.1.1 Option 1

Effective Date: January 1, 1978

Conditions: No further use of F-11, F-12 and F-22 except:

- a. For replacement in existing refrigeration and air-conditioning equipment, where it is impossible to use substitute products.
- b. For other selected uses under extreme conditions, and on a case-by-case approval basis.

5.1.2 Option II

Effective Date: January 1, 1980

Conditions: No further use of F-11, F-12 and F-22 except:

- a. For replacement in existing refrigeration and air-conditioning equipment, where it is impossible to use substitute products.
- b. For other selected uses under extreme conditions, and on a case-by-case approval basis.

5.1.3 Option III

Effective Date: January 1, 1978

Conditions:

- a. No further use of F-11, F-12, and F-22 for any aerosol application.
- b. Other uses continue as permissible.

5.2 Economic Impacts of Each Option of the Department of Commerce

The impacts of the three options on the U.S. economy are:

5.2.1 Option I

5.2.1.1 Refrigeration Restriction of the use of fluorocarbon refrigerants would have widespread adverse economic implications. Such a time frame would be insufficient to develop and test new refrigerants and the equipment necessary to utilize new compounds in an efficient and safe manner.

More than 466 000 employees in the U.S.A. could be directly affected either by layoffs or curtailed employment. A larger employment sector in dependent industries such as food processing, data processing, drugs, electronics, etc., could also be adversely affected.

Restriction to use the fluorocarbons for replacement in existing equipment would mean termination of manufacture and installation of all new equipment after January 1, 1978.

5.2.1.2 Aerosols A discussion of the situation as it affects the aerosol can industry is presented under Option III.

5.2.1.3 Foamed Plastics No great impact; some changes are required in manufacturing processes, e.g. for thermal insulation foams, up to 50 per cent reduction in insulation efficiency.

5.2.1.4 Other Fluorocarbon Uses Numerous other applications

accounting for 10 to 15 per cent of the total consumption include several of small volume but of critical importance to military and industrial requirements. There would be no alternative to fluorocarbons for these applications; however, case-by-case approval could cover the essential requirements.

5.2.1.5. Chemical Manufacturing Manufacture of one billion (thousand million) pounds per year of fluorocarbons represents sales revenue of \$400 million to \$450 million and requires chemical raw materials valued at about \$400 million. Option I restrictions would reduce by more than 50 per cent the revenues from fluorocarbons and raw materials supplied with some reduction in employment.

5.2.2 Option II

The economic impacts of Option II would be essentially the same as under Option I. The additional time period of two years would be insufficient to develop acceptable substitutes for the fluorocarbons or to complete the redesign of refrigeration equipment.

There is some conceivable prospect that within five years existing refrigeration equipment designs could be modified to provide tight systems that would not leak; that is, losses of fluorocarbons to the atmosphere could be minimized.

5.2.3 Option III

The economic impacts of Option III would affect directly only the aerosol industry, leaving refrigeration, foamed polyurethanes and other uses free of restrictions.

5.2.3.1 Aerosol Cans Fluorocarbons are used in approximately 50 to 60 per cent of the aerosol units sold, with fluorocarbons-11 and -12 accounting for over 90 per cent of the fluorocarbons used. There appears to be no efficient alternative propellant for hair sprays, antiperspirants, and other personal products because of problems of inflammability and other technological considerations.

Although aerosol cans constitute only three to four per cent of all metal cans produced, they account for about 99 per cent of all aerosol containers, which package about 600 products valued at roughly \$3 million annually. About 25 companies produce aerosol containers, including the four largest can manufacturers in the United States. A ban on fluorocarbon propellants would undoubtedly adversely affect

the industry, which is already faced with excessive manufacturing capacity.

The extent of the economic impact on the metal-can industry cannot be readily measured, as most aerosol cans are produced in the same plants making other types of metal cans, and separate data are not available.

5.2.3.2 Refrigeration The industry could continue operations without interruption, in both maintenance of existing equipment and manufacture of new units. However, refrigerant costs might increase because of loss of aerosol production volume.

5.2.3.3 Fluorocarbon Manufacture and Chemical Raw Material Suppliers Because aerosols represent about 50 per cent of the total fluorocarbon consumption, the fluorocarbon manufacturers and their raw material suppliers would be substantially affected, as noted for Option I. Reduced production volume might increase the unit cost of manufacture, with attendant higher sales prices to other uses.

5.3 Other Major Considerations

Any actions that affect the choice of refrigerant used in existing air-conditioning and refrigeration equipment should recognize that such equipment in operable condition has an estimated replacement value exceeding \$50 billion. Such units would be rendered inoperable if replacement fluorocarbons were not available to the industry.

5.4 Analysis by the A. D. Little, Inc.

This assessment analysis included nine possible regulatory options given in Table 9. The Impact Code tabulated in the lower right of the table is explained below:

1. *Severe Impact*

A severe impact implies that most companies in the sector will be affected, at least to a moderate degree (some seriously), and more than 40 per cent of the directly related business activity of which the chemical production or chemical consuming production is a part will be ended or significantly disrupted.

2. *Substantial Impact*

A substantial impact implies that some firms in the sector will experience at least a moderate and in some cases a serious impact,

Annex Table 9. Summary of emission reductions and the economic impacts on different industries from various regulatory options proposed on the U.S. use of F-11, F-12 and carbon tetrachloride*

Regulatory option†	Percent emission reduction††	Economic Impacts						
		Basic chemical producers†††	Independent fillers	Can manufacturers	Valve manufacturers	Aerosol marketers	Air-conditioning refrigeration manufacturers	Plastic foam producers
1.	92	2-3***	1	3	1	2	1	2
2.	82	3	1	3	1	2	4	3
3.	70	3	1	3	1	2	5	4
4.	80	3	1	3	1	2	4	3-4
5.	83	3	2-3	5	2-3	3	1-2	3
6.	74	3	2-3	5	2-3	3	4	3
7.	63	3	2-3	5	2-3	3	5	4
8.	69	3	2-3	5	2-3	3	5	4
9.	54	5	3-5	5	3-5	5	5	4
Approximate (1972-3) production value (\$million)**		\$360	\$130	\$300	\$60	\$1,000	\$7,000	\$600
Employment (thousands)**		3	7	2.5	2	7.5	150	35

Notes:

*Source: Arthur D. Little, Inc., estimates.

**These lines differ from those in Table 3 (U.S. D.C. study) because each analysis group uses its own definitions of the fraction of industry related to fluorocarbon use.

***IMPACT CODE

- 1 — severe
- 2 — substantial
- 3 — moderate
- 4 — limited
- 5 — essentially none

See Section 5.4 of report for definition of terms.

†REGULATORY OPTIONS

- 1. Ban all but replacement uses of controlled chemicals after six months.
 - 2. Regulation of non-propellant uses and ban of propellant uses after six months.
 - 3. No regulation of non-propellant uses and ban of propellant uses after six months.
 - 4. Government control of total chemical production after six months.
 - 5. Ban all but replacement uses of controlled chemicals after three years.
 - 6. Regulation of non-propellant uses and ban of propellant uses after three years.
 - 7. No regulation of non-propellant uses and a ban of propellant uses after three years.
 - 8. Government control of total chemical production after three years.
 - 9. No regulation of non-propellant applications and ban of propellant uses after six years.
- ††Percent reduction in U.S. F-11, F-12, and carbon tetrachloride emissions to the atmosphere over a 20-year period beginning in 1976. A 5 percent demand growth is assumed in the absence of controls; no restriction on critical propellant uses (5 percent of total), a 5-year half-life for refrigerants and 50 percent control of emissions from plastic foams are assumed.

and a significant portion (greater than 10 per cent but less than 40 per cent) of the directly related business activity of which the chemical production or chemical consuming production is a part will be ended or significantly disrupted.

3. Moderate Impact

A moderate impact occurs when a few firms in a sector will experience a moderate impact on sales or profits, and no more than a small portion (less than 10 per cent) of the directly related business activity of which the chemical production or chemical consuming production is a part will be ended or significantly disrupted.

4. Limited Impact

The limited impact category includes those situations in which the regulations would affect firms in a sector or the production in the sector related to the controlled chemicals only through increases in product prices. If a reduction in production of a chemical or the imposition of a tax results in a large increase in the price of the chemical, the resulting product price increase in sectors continuing to use the chemical may result in some unit sales fall-off. Equipment upgrading to reduce emissions to the atmosphere would also raise produce prices and fall in this category if the regulation imposed no other limitations on continued production. While the magnitudes of these price and sales changes have not been defined, the instances when they may occur have been identified as Limited Impacts.

5. No Impact

The no impact category covers instances when the proposed regulations would have essentially no impact on the firms or production of a particular sector related to the controlled chemicals. Very small price increases are possible under this category.

6.0 Outstanding Needs

6.1 Predictions of Environmental Damage

The urgency of regulatory action, if any, depends upon the risks resulting from delays. The greater these risks can be shown to be, the greater the need for expedient action.

6.2 Up-to-date Status on F-11 and F-12 Substitutes

Although industrial confidentiality is likely to inhibit frank revelations, this item obviously plays a dominant role in any impact assessment from regulatory actions.

6.3 Impact Assessments

Comprehensive assessments of economic, social, and environmental damage or benefits from regulatory actions should precede the decision to restrict emissions of F-11 and F-12.

6.4 Other Chemicals

The environmental risk from the release of certain nitrogen compounds and other halogens should be undertaken in depth.

7.0 Acknowledgement

This summary is based largely on an A. D. Little, Inc. report by R. E. Shamel, J. K. O'Neill and R. Williams "Preliminary Economic Impact of Possible Regulatory Action to Control Atmospheric Emissions of Selected Halocarbons", U.S. Environmental Protection Agency, EPA-450/3-75-073, September 1975. The condensation of about 300 pages of text and tables involves the author's bias, although except for Section 6.0 every effort to preserve the original ideas has been made.

8.0 References

In addition to the above A. D. Little, Inc. report, four others merit notice:

- (1) U.S. Department of Commerce (1975), Bureau of Domestic Commerce Staff Study "Economic Significance of Fluorocarbons".
- (2) U.S. Government (1975), "*Fluorocarbons and the Environment*" including an attachment "*Preliminary Analysis of Economic Impacts of Fluorocarbon Restrictions on Industry*" (IMOS Report).
- (3) OECD Environmental Committee (1975), "*Fluorocarbons: An Assessment of Worldwide Production, Use and Environmental Issues*", Paris.
- (4) U.K. Department of the Environment (1976), "*Chlorofluorocarbons and their Effect on Stratospheric Ozone*", Pollution Paper No. 5, H.M.S.O., London.

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