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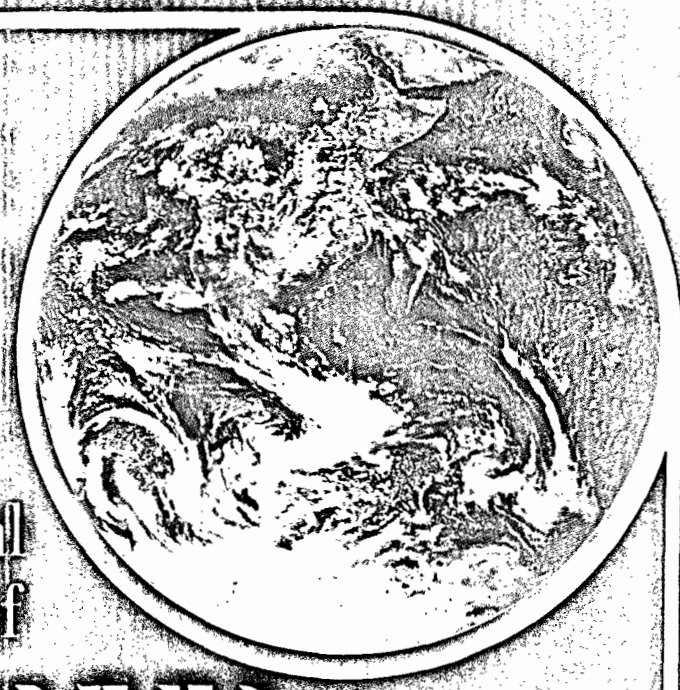

Environmental Assessment of OZONE LAYER

Depletion and its Impact

as of November 1979

Bulletin No. 5 - January 1980

A yearly bulletin on ongoing and planned research activities

UNEP

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CONTENTS

INTRODUCTION

The third session of the UNEP Co-ordinating Committee on the Ozone Layer was held, at the kind invitation of the Government of France, in Paris from 20 to 23 November 1979. It was attended by representatives of Australia, Canada, France, Germany, Federal Republic of, Italy, Japan, the Netherlands, Norway, the Union of Soviet Socialist Republics, the United Kingdom of Great Britain and Northern Ireland, the United States of America, the United Nations Environment Programme, the World Health Organization, the World Meteorological Organization, the International Council of Scientific Unions and the Chemical Manufacturers Association.

The Committee examined reports presented by members on ongoing and planned research programmes relevant to the World Plan of Action on the Ozone Layer, and recent research results. On the basis of these, the Committee updated its previous assessment - December 1978 - of ozone depletion and its impacts. In reviewing the implementation of the World Plan of Action on the Ozone Layer, the Committee made a total of fifteen recommendations for further work. An Executive Summary of the assessment of ozone depletion and its impacts and the recommendations for further work agreed to by the Committee can be found under Section I in this issue of the Bulletin. The full text appears under Section II.

Section III gives the recent research results and ongoing and planned research programmes relevant to the World Plan of Action on the Ozone Layer on which the assessment of ozone depletion and the recommendations by the Committee were based.

In response to a recommendation by the International Conference on Chlorofluoromethanes, held at Munich in the Federal Republic of Germany from 6-8 December 1978, the United Nations Environment Programme requested all Governments to provide information on annual production figures for the chlorofluorocarbons F–11 and F–12 and their major uses, in order to assess total global emissions. The results of the survey as of 1 November 1979, are tabulated under Section IV.

Section V consists of figures on the world production and release of chlorofluorocarbons 11 and 12 through 1978, provided by the Chemical Manufacturers Association.

The Committee also considered the periodicity of the UNEP Ozone Layer Bulletin and recommended that it be published once a year, rather than twice as hitherto.

ABBREVIATIONS

AERE	–	Atomic Energy Research Establishment
BrOx	–	Oxides of bromine
BUV	–	backscattered ultra-violet radiation
CFMs	–	chlorofluoromethanes
CFM 11	–	freon 11 ($CFCl_3$)
CFM 12	–	freon 12 (CF_2Cl_2)
CFM 21	–	freon 21 ($CCHCl_2F$)
CFM 22	–	freon 22 ($CHClF_2$)
C10x	–	oxides of chlorine
CMA	–	Chemical Manufacturers Association
CMEA	–	Council for Mutual Economic Assistance
CNRS	–	National Scientific Research Centre (Paris, France)
COSPAR	–	Scientific Committee on Space Research
EEC	–	European Economic Community
EERM	–	Etablissement d'Etudes et de Recherche Météorologique
ev	–	electron volt
HALOE	–	Halogen Occultation Experiment
HAPP	–	High Altitude Pollution Programme
HMSO	–	Her Majesty's Stationery Office
NAS	–	National Academy of Sciences
NASA	–	National Aeronautics and Space Administration (USA)
NBS	–	National Bureau of Standards
nm	–	10^{-9} metre
NOx	–	oxides of nitrogen
ONERA	–	Office National d'Etudes et de Recherche Aérospatiale
ppb	–	parts per billion
ppmv	–	parts per million by volume
SAGE	–	Stratospheric Aerosol and Gas Experiment
SME	–	Solar Mesosphere Explorer
SIBEX	–	Joint experiment between National Physical Laboratory and the University of Florence
SO_2	–	sulphur dioxide
STRATOZ	–	An experiment in radiometric monitoring of the stratosphere
Tm	–	metric tonnes

UNEP	–	United Nations Environment Programme	WMO	–	World Meteorological Organization
UV-A	–	ultraviolet radiation between 400 and 320 nm	1-D	–	one-dimensional
UV-B	–	ultraviolet radiation between 290 and 320 nm	2-D	–	two-dimensional
WHO	–	World Health Organization	3-D	–	three-dimensional

Section I

EXECUTIVE SUMMARY OF THE ASSESSMENT OF OZONE LAYER DEPLETION AND ITS IMPACTS–NOVEMBER 1979

1. The UNEP Committee on the Ozone Layer met in Paris from 20-23 November for its third session. The Committee examined the substantial contributions presented to it by various countries, and the research efforts in measuring and modelling necessary for the study of the stratosphere. Having considered the new information available including comprehensive new reports of the National Academy of Sciences of the USA and of the Department of the Environment of the UK, the Committee's present assessment remains broadly similar to that made by the UNEP Committee in November 1978.

2. The Committee concluded that a risk to the ozone layer is still most likely due to chlorofluoromethane releases, although in future other components, such as methyl chloroform, which can reach the stratosphere, require increased consideration.

3. Present model calculations are estimated to result in an ultimate ozone depletion of about 15 per cent, if chlorofluoromethane releases continue at the present rate. According to these models an ozone depletion of about 2 per cent should already have occurred. Such an amount cannot be detected directly with present technology, and no change attributable to human activity has been observed.

4. The influence of NO_x (from supersonic aircraft) and of N_2O (from fertilizers) seems to be of minor importance.

5. For many species, there is an acceptable agreement within the range of uncertainties between model calculations and atmospheric measurements. In some cases, however, discrepancies occur that cannot yet be explained.

6. There is increasing, but still inadequate knowledge of possible effects of increased UV-radiation on ecosystems and plants, which may be the most serious impact. There is a high degree of correlation for the relationship between UV-B radiation and non-melanoma skin cancer in man, and there is some indication that there may be a connexion for melanoma.

7. The Committee welcomed the decision of Governments at the International Conference on Chlorofluoromethanes in Munich 6-8 December 1978, to reduce chlorofluoromethane emissions significantly.

8. The Committee made a number of recommendations concerning further research and monitoring to reduce the existing uncertainties.

9. The WMO and WHO, with the support of UNEP, are continuing internationally co-ordinated studies of measurements of atmospheric constituents and health evaluation.

Section II

AN ASSESSMENT OF OZONE DEPLETION AND ITS IMPACTS, NOVEMBER 1979

1. Introduction

The threat to the stratospheric ozone layer by human activity is of continuing concern. Since the Second Session of the UNEP Co-ordinating Committee on the Ozone Layer in November 1978, a number of scientific studies relevant to this problem have been published. New comprehensive reports of the National Academy of Sciences of the USA (1979), and of the Department of the Environment of the UK (1979).

The Committee met in Paris from 20-23 November 1979 for its third meeting with the intention of reassessing the risk to the ozone layer and the resulting change of the biologically active UV-radiation after consideration of the information available. The Committee feels that the conclusion reached in its "Assessment of the Ozone Depletion and its Impacts"–1978, that predicted ozone depletion of 15 per cent, which would ultimately result from the continued release of chlorofluoromethanes at its present level, is still valied and is supported by the present state of scientific knowledge. There are some areas (e.g. kinetics, effects, etc.) where some of the uncertainties have been reduced. The effects of CFMs on climate is predicted to be less significant than their effect on stratospheric ozone resulting in increased UV-B.

In the following sections, the present state of knowledge for the most important areas involved will be reviewed as well as the main deficiencies still existing. Since CFMs currently are believed to have a major effect on the ozone layer, most work has been carried out on this aspect. It should be mentioned, however, that other chlorinated hydrocarbons such as $CH_3\,CCl_3$, can reach the stratosphere. Rising production values of these compounds merit increasing concern. The Committee's previous assessment, that increased N_2O and NO_x releases alone is likely to have little effect on stratospheric ozone has been strengthened by the newly available information. Releases of these and other substances such as CO, CO_2 may modify to some extent the impact of CFM releases.

PRESENT ASSESSMENT OF THE PROBLEM

Sources and tropospheric sinks

World production of CFMs 11 and 12 as measured by CMA has fallen by 17 per cent between 1974 and 1978 from 851.2 to 709.1 thousand Tm p.a. These figures are estimated to be accurate within x 5 per cent, and include an estimated 8 per cent contribution from countries not reporting via the Chemical Manufacturers' Association. The corresponding estimated release of these CFMs have fallen from 741.2 to 624.5 thousand Tm p.a. over the same period. The bulk of this reduction has been in the usage in aerosols, but at the same time, there has been a growth in other uses, especially foams.

These data are essential for any modelling exercises, and to detect experimentally whether or not there are any significant tropospheric sinks for CFMs 11 and 12. Whilst an instantaneous global balance rules out a large sink, this method is not sensitive enough to detect a small but significant sink. The trend analysis approach may detect small sinks and answers should appear in a further few years, depending on the size of the sink. Accurate estimates of actual release data are vital to this exercise particularly in view of the changing patterns of use. Methods for better estimating the rate of release, particularly from foams are currently being investigated.

Direct evidence for specific tropospheric sinks continues to

be sought. The significance of the demonstrated destruction on dry sand surfaces is still not quantified. The possibilities that the small amount of CFM 21 and 22 in the atmosphere reported by some workers are indicative of the breakdown of CFMs 11 and 12, is also being investigated.

Attention is being directed to other chloro-compounds such as methyl chloroform (CH_3CCl_3) and CFM 22, whose use has increased significantly in recent years, as well as other halocarbons which possess sufficient tropospheric stability to act as carriers for chlorine or bromine to the stratosphere.

Current status of model predictions

Recent improved modelling efforts have supported the predicted ozone depletion due to releases of CFM 11 and 12 given at the meeting of the UNEP Co-ordinating Committee held in November 1978. Most predictions of ozone depletion continue to rely on 1-D models which currently yield most probable values of about 15 per cent depletion at steady-state for continuing release of CFM 11 and 12 at 1977 rates. These models also show that the predicted steady state depletion is linearly related to release rates up to rates equal to or somewhat larger than current levels, and that the present ozone depletion should be about 2 per cent. Improvements have been made in rate constant data for reactions currently included in models though there is still a need for further information on pressure dependence and product analysis in some cases. There has also been an improvement in deriving transport parameters and 1-D models now include improved schemes for radiative transfer, diurnal averaging and temperature feed-back. Refinement of 1-D model structure is rapidly approaching its useful limit. 1-D models have inherent limitations in their averaging procedures and this in turn makes difficult, comparisons with atmospheric measurements at particular places and times. Inherently, 1-D models can provide no information on seasonal and latitudinal dependence. 2-D models which overcome some of these difficulties are now actively being developed. These have already provided information on dynamic feedbacks. Other 2-D results show that both the predicted ozone depletion and its seasonal dependence increase with latitude, though the mean global value remains close to the 1-D model predictions. As a consequence, the ratio between UV-B increase and ozone variation is also latitude dependent. This ratio is about two to one in mid-latitudes, decreasing towards the equator and increasing towards the poles. 3-D models have so far been used mainly to explore dynamic coupling between radiation and transport terms.

While some errors in present model predictions can be quantified, others cannot. Attempts to identify new reactions, tropospheric sinks, or gross errors in rate constants which would seriously challenge the present predictions have so far been unsuccessful and the probability of their being discovered decreases with time. However, any ozone changes due to halocarbons will be affected by changes in the amounts of other substances released to the atmosphere such as nitrogen oxides, carbon dioxide and carbon monoxide.

Comparison of model predictions and measurements of atmospheric constituents

Validity of 1-D models can be checked by comparing calculated concentration against measurements of minor constituents, for example the way these concentrations vary with height. Of course, the 1-D models can only provide globally averaged values of these concentration profiles for trace species. Although the number of measurements and their geographic coverage have increased considerably, they are still far from providing true global averages. For most substances, the agreement between models and measurements is acceptable within the stated limitations and uncertainties. However, there are exceptions, disturbing to some, such as one of the ten measurements of ClO. The concentrations of total HF and OH are also of concern. The shapes of the vertical profiles of ClO, HCl, and HF also show certain inconsistencies which may be the result of the parameterization adopted in the 1-D models and appear to be more consistent with 2-D models. These questions should benefit from further development of 2-D models. On balance, it is concluded that 1-D models provide results which are accurate in describing the present atmosphere within the uncertainties of both the measurements and the models, but their use for pre-

dictions of perturbations must be treated with some care.

Trends in ozone concentration

Recent developments in statistical methods show that a trend attributable to anthropogenic sources in the total ozone of the order of 3-6 per cent is the smallest that could be detected by the present monitoring network. The magnitude of the various contributions to error in ozone trend estimates have been quantified, including the minimum white noise, Dobson instrument errors, aerosols, meteorological observing conditions and transport variations, geographical distribution of stations, solar variation, chemistry and boundary condition uncertainties.

The introduction of a suitably validated global satellite vertical ozone observing system may provide a measurement accuracy sufficient to detect a trend of the order of 1.5 to 3 per cent. However, it is recognized that a quality-controlled satellite data set of at least 10 years must be developed for such trend detection. Therefore, the Committee recognizes that the satellite and ground monitoring efforts including short-Umkehr measurements of the participating countries are of the utmost importance for early detection of ozone trends.

Health effects

Considerable progress in understanding the human health effects of increased ultra-violet radiation has been achieved. These effects include sun-burn, eye diseases, skin diseases and skin cancer, including non-melanoma and the more serious melanoma. The severity of health and other biological effects of radiation depend on its spectral distribution irradiance, and exposure time; biological factors and other environmental conditions may also modify the response. UV-B radiation has been demonstrated to be more biologically effective than UV-A radiation. The present state of our understanding can be summarized as follows:

- Epidemiological studies have revealed that exposure to sunlight correlates with incidence of non-melanoma skin cancers, based on present available and still limited epidemiological data particularly related to light-skinned people and high-risk populations. Specifically, skin cancer incidence surveys were conducted in various locations within the United States to provide more reliable estimates of the dose-response relation of UV-B and skin cancer development among light-skinned people. Results from these investigations are consistent with the evidence that increased amounts of UV-B radiation lead to increased incidence of non-melanoma. Epidemiological studies of these dose-response relationships for locations in the United States indicate that a one per cent increase in UV-B correlates with an approximate two per cent increase in non-melanoma skin cancer incidence.

- There is an increasing indication that there is a relationship between UV-B and melanoma.

- UV radiation has been shown in some studies in the United States of America on animals to alter the response of the immunological system to prevent or impede recognition of a tumor as a foreign body.

- UV dose response data are indispensable for relating wavelength irradiance and duration of exposure to health effect response.

UV-B Biological Effects

Recent activities include studies of plant species under simulated, natural and enhanced UV-B levels, experiments with aquatic ecosystems, and effects on food production. Some important effects observed are:

- All plants tested revealed sensitivity to UV-B at some exposure level; some plants experience yield reductions, others suffer bleached or discoloured leaves;

- UV-B damages larvae of shrimp, crab, mackerel and an-

chovy;

- Photorepair and adaptation mechanisms are suggested as a potential mitigation of UV-B effects in plants.

Instrumentation

Medium resolution, field type spectroradiometers and calibration standards for UV-B measurements for biological effects studies, have been developed.

Intergrated Assessment

A model, including parameter uncertainties, has been developed for integrated assessment of costs/benefits of regulation versus non-regulation.

CONCLUSIONS

The considerations leading to the prediction of an ozone depletion due to anthropogenic emissions of halocarbons like CFMs are plausible and largely consistent. To a large extent the models are consistent with measurements of atmospheric constituents, although discrepancies and uncertainties still exist. There is some difference of opinion between the delegates concerning the degree of confidence, which can be attached to the predicted ozone depletion, given the highly complex and partly understood processes occurring in the real atmosphere. Recent developments in statistical methods shows that a trend attributable to anthropogenic sources in total ozone of the order of three to six per cent is the smallest that could be detected by the present monitoring network. Within these limits, the present data do not show any significant trend in the total ozone amount. Model calculations supported by measurements remain the only tool for predicting future impacts of such activities.

Current models concur in a range of evaluations of ultimate ozone depletion with a most probable value of 15 per cent at a steady state for continuing release at present levels. These models predict that about a 2 per cent depletion has already occurred which is below the detection limit of present technology. There is greater accuracy in the chemical kinetics involved, and additional C10 measurements have been made which are more consistent with the model. However, as a result of the increase in knowledge of the complexity of the atmosphere, the problems now under consideration are even more complicated and sophisticated than those initially dealt with.

There have been improvements in the models and in the measurements used as inputs to, and checks for, the models.

There is increasing, but still inadequate knowledge on possible effects of increased UV-radiation on ecosystems and plants, which may be the most serious impact. There is a high degree of evidence for the relationship between UV-B radiation and non-melanoma skin cancer in man, and there is some indication that there is a connection for melanoma.

RECOMMENDATIONS

On the basis of last year's assessment findings, the Committee had recommended: Policy makers should consider these findings and take such action as may be deemed appropriate at this time. A comprehensive environmental assessment of the impact of ozone depletion including the economic aspects of corrective and alternative actions should be considered.

Considering the present state of scientific knowledge, the Committee maintains and reinforces this recommendation. Following the second session of this Committee, the Governments of major CFM producing countries at the International Conference on Chlorofluoromethanes in Munich, 6-9 December 1978, agreed inter alia, to a significant reduction of CFM emissions. The Committee welcomes this responsible step of the Governments and proposes prompt implementation. Governments are encouraged to undertake all efforts to reach as large a reduction as seems possible. Provision of annual production figures of CFMs 11 and 12 and their major uses to UNEP were also agreed to at the Munich con-

ference. It is proposed to continue this procedure and to include other relevant components e.g. CH_3CCl_3. The producing companies are requested to provide this data to the national Governments.

RECOMMENDATIONS FOR FURTHER WORK

1. Develop higher dimensional models and compare the results.

2. Extend the measurements of rate constant over the pressure and temperature ranges found in the stratosphere, and identify the reaction products.

3. Search for and investigate any additional reactions which may effect stratospheric chemistry.

4. Continue efforts to increase understanding of tropospheric chemistry.

5. Undertake simultaneous in situ measurement of the relative concentrations of photochemically-related compounds of the various families.

6. Maintain efforts to increase total chlorine and total fluorine measurements.

7. Undertake measurements of hydroxyl concentrations in the troposphere and stratosphere.

8. Continue to develop tropospheric monitoring to assess the lifetimes of stable species.

9. Significant further effort is needed to:

   (a) Extend UV and ozone monitoring and assess over a significant period of time, current dose-response relationships of skin cancer to UV radiation over as wide a latitude range as possible;

   (b) Develop the information to the point where reasonably reliable extrapolations can be made of the potential hazard to man from a UV radiation increase.

   (c) Increase research studies on the biological effects of UV-B on plants, animals, other organisms and ecosystems.

10. To initiate an international epidemiological study of the incidence of skin cancer, a expert panel be assembled by WHO to propose details of unified-protocols and analysis of data, and to be available as an advisory body to the various countries and international organizations when data will be collected and analyzed.

11. To initiate a co-ordinated international programme relating to biological effects of UV-B on plants, animals and ecosystems.

12. Improve the total ozone monitoring by redetermination of ozone absorption coefficients, intercomparisons of Dobson spectrophotometers, and new stations optimally distributed, and maintain uninterrupted satellite total ozone measurements.

13. Establish and expand vertical ozone monitoring by development of automatic multi-wavelength ("short-Umkehr") observations, together with an expanded balloon-borne and rocket-borne ozone-sonde programme essential for providing ground truth for the satellite vertical ozone determinations.

14. Re-establish the co-operative meteorological rocket network essential for the continued development of 2-D and 3-D models.

15. Improve and expand the development of standardized, quality-controlled data sets for input to and validation of model predictions, particularly aimed at the reduction of sources of uncertainties in the measurement programme and model verification.

Section III

RECENT RESEARCH RESULTS AND ONGOING AND PLANNED RESEARCH PROGRAMMES RELEVANT TO THE WORLD PLAN OF ACTION ON THE OZONE LAYER

1. Canada

A co-operative balloon measurements programme with the CSIRO and FAA to make measurements of stratospheric nitrogen constituents in Australia has been successfully concluded. The Atmospheric Environment Service and York University were involved in the series of 5 balloon flights.

The development of the Tunable Diode Laser Spectrometer for balloon measurements of nitric oxide and nitrogen dioxide is continuing at York University.

Intercomparison testing of the Brewer ozone spectrophotometer with the Dobson instruments has continued at NASA Wallops and at Toronto. Initial results for direct sun measurements of total ozone indicate that the Brewer is a very promising replacement possibility for the Dobson. Total SO_2 is being monitored with the Brewer instrument concurrently with the total ozone measurements.

Recent results from the Canadian ozone monitoring network indicate the possibility of a slight downward trend in total ozone at Canadian locations.

Canada also participated in the WMO rocket ozone intercomparisons held at Wallops Island in October.

2. France

The French activities in stratospheric research are directed towards five fields: dynamics, chemical reactions, monitoring of ozone and measurement of minor constituents, statistical evaluation of ozone trends, and numerical modelling.

Dynamics

More than 25 rockets and wind and temperature soundings have been performed by EERM in the upper stratosphere (Biscarrosse, Komor), along with some temperature measurements by CNRS/SA with a Lidar (Rayleigh diffusion). Studies on gravity waves and 3-D turbulence by means of repetitive balloon ascents have been carried out (CNRS/LMD and SA).

A few other balloon flights were devoted to the study of exchanges between troposphere and stratosphere, using radioactive natural tracers (Rn 222 and the Po 210/Pb 210 concentration ratio).

Chemical reactions

By various methods, including E.P.R. (electronic paramagnetic resonance), some reaction rates have been accurately measured. Among them, one should note the $Cl + H_2CO \rightarrow HCl + H\,CO$, which proves to be effective in moderating the chlorine action on ozone (laboratory COMBOUR:EU); and the $Cl\ O + H_2CO$ reaction ($H_2CO >> C10$) which proves to be rather ineffective, as a potential sink of C10.

Monitoring of ozone

Two Dobson spectrometers (Montlouis, Biscarrosse) are being continuously operated in France; their data are sent to the Toronto Data Centre, together with the ozone profiles (Brewer ozone-sonde) which are weekly obtained at EERM Biscarrose.

Umkehr Measurements are performed at Montlouis.

The Dobson spectrometers have participated in the Arosa (1970) and Potsdam (1979) intercomparison campaigns, sponsored by WMO. Preliminary results in ozone vertical profile retrieval were obtained by Lidar (differential absorption) measurements (CNRS/SA).

The second volume of the Atlas of ozone line intensities (below 14 microns) has been edited.

Measurements of various trace species

Two ground IR spectrometers have been used for HNO_3 vertical profile retrieval. The so-called S:SAM interferential spectrometer (0.020 cm^{-1} resolution) designed by Reims University, detected and measured H_2CO (integral depth 5.10^{15} mol. cm^{-2}).

Balloon flights were performed in south France for measurements of high altitude ozone (CNRS/SA), NO_2 (CNRS/SA) and H_2O (ONERA and CNRS/SA).

Concurrent with the LIMS (NIMBUS 7 satellite) experiment, the ONERA grid spectrometer was operated onboard balloons at Palestine (Texas) for N_2O, H_2O, H NO_3 and CH_4 profile observation.

The STRATOZ experiment

This experiment was carried out on board a Caravelle aircraft, flying at stratospheric altitude along the 70th meridian (west) from Greenland to Patagonia, during the autumn of 1978.

Two sets of spectrometers installed in this aircraft were aimed at measuring the meridian profile of various species (ONERA grid spectrometer and EERM/ONERA/IASB spectrometer). The first NO_2 and HNO_3 retrievals show interesting results, to be compared to the previous latitude survey flight (1976).

Ozone trends

Besides various statistical means (modified Student test, Box and Jenkins models), a new topological "proximity analysis" has been designed and tested on classical meteorological fields, for extraction of trends in the field of the total ozone variable.

These methods, applied to the world ozone network (150 stations) data, show no significant trend in the 1958-1975 observation period (EERM).

Modelling

Along with a continuing effort in 3-D modelling, a 1-D stratospheric model has been set up (EERM). This photochemical model, which takes into account 32 species and includes diurnal variation, underwent various verifications against N_2O, CH_4, Cl, ClO profiles; it provides an evaluation of asymptotic ozone depletion (18.4% for CFM release at 1975 rate). Various sensitivity experiments will be carried out with this model.

3. Germany, Federal Republic of

It has been reported previously, that fluorocarbons can be destroyed on certain sands in the absence of sunlight. Other investigations show that fluorocarbons are broken down, not only by free electrons of low energy (0-10 ev), but also by weakly banded electrons at the surface of solids. This destruction mechanism may contribute to the phenomenon observed.

It is known that the structure of the ozone layer is dependent on solar activity. The reuslts of balloon flights indicate quite smooth ozone profiles during calm episodes, whereas after chromospheric eruption (especially in the H region) strong vertical inhomogenities with extreme values were observed.

Mixing ratios of N_2O ($\sim$320 – 370 ppb), H_2 (500 – 600 ppb), CH_4 (1.5 – 1.7 ppm), $CFCl_3$ (130 – 160 ppt) and CF_2CFl_2 (240 – 280 ppt) showed no marked altitude-dependence in the

range up to 13 km, whereas CO concentrations fell from ~200 ppb at 1.5 km to ~50 ppb at 13 km altitude.

The RO_2 and NO_2 radicals show a markedly decreasing gradient with increasing altitude, especially in the inversion layer. Relatively high RO_2 concentrations ($\sim 5.10^{10}$ molec. cm^{-3}) have been observed in the air over a petro-chemical complex. Vertical concentration-profiles have been obtained by balloon flights up to 35 km at a latitude of about 44°N for H_2, CH_4, CO, N_2O, $CFCl_3$ and CF_2Cl_2 simultaneously. The profiles of 4 different flights were quite consistent except for CO, where contamination problems arose. In general, the profiles observed (excluding CO) are in good agreement with theoretical considerations.

In addition, stratospheric measurements of C_2H_6, C_2H_2 and CH_3Cl have been carried out.

In another study, the rate of N_2O photolysis in the stratosphere is being determined.

The kinetics of different reactions of the OH radical (with OH, HO_2, N_2O, CO) have been investigated. The results are in general agreement with reaction rates now used for model calculations. This is also true for the reaction rate of the important $NO + HO_2$ reaction that has been determined. The branching ratio for the $O(^1O)$ + H_2O reaction shows that the formation of $H_2 + O_2$ is of no importance compared to that of OH radicals.

4. Italy

Since several years the Italian Government has been following with great care and interest the problem of stratospheric ozone layer. Through its scientific organizations, namely the National Research Council (C.N.R.) and the Universities, the Government is sponsoring several research activities in the field.

Also the industry is very active to this problem and sponsors research programmes.

The main research activities in which Italy is involved are the following:

1. Geophysical aspect and consequences of variation in the chemical composition of atmosphere. Emphasis is given to the application of theoretical models to assess the climatic effects of varying the ozone distribution and the ozone overburden. The importance of the ozone distribution with respect to the "greenhouse effect" is also investigated.

2. Importance of the diffuse solar field by atmospheric molecules and aerosols in the photochemistry of atmospheric active species (O_3, NO_2, HNO_3, H_2O_2).

3. In the field of stratospheric measurements, the IROE/University of Florence, in collaboration with NPL/Teddington is completing a balloon experiment aimed at the evaluation of the vertical distribution and the diurnal variability of the following stratospheric constituents: H_2O, O_3, HNO_3, NO_2, N_2O, HF, HCl, ClO. The project is based on spectroscopy in the submillimeter spectral region. Two balloon flights have been carried out in 1978 and 1979. A third flight is foreseen in 1980.

4. Qualitative and quantitative analytical methods for the determination of fluorocarbons in the troposphere–Particular care is given to the reliability and reproducibility of measurements. The project deals also with the search of possible tropospheric sinks for fluorocarbons.

In view of the global environmental aspect of the ozone problem, UNEP appears to be the appropriate forum for the co-ordination of the international research efforts.

5. Netherlands

Possible disturbances in the atmosphere, such as the depletion of the ozone layer, are recognized by the Netherlands as being potentially major threats to man and the environment.

Research relevant to the World Plan of Action on the Ozone

Layer is limited.

Two programmes can be mentioned. Firstly, an investigation is being carried out at the University of Utrecht, to establish the relationship between ozone reduction and (non-melanoma) skin-cancer increase. This involves experiments on animals and modelling. Secondly, suitability of dimethylether as an alternative propellant in aerosol spray cans is being studied. First results are promising, but toxicology studies have not yet been completed.

6. Norway

In connection with the implementation of the World Plan of Action, Norway provides total ozone observations at three stations and active ozone modelling work, both 1-D and 2-D models. From these studies it has been possible to predict that a doubling of the present concentration of the atmospheric CO_2 would cause only a 2.8 per cent increase of the total ozone.

7. Union of Soviet Socialist Republics

The article on CFM impact on the Ozone Layer and Climate prepared by Professor Borisenkov and Dr. Kozakov is devoted to some scientific aspects of the ozone problem. It also contains data on CFM production in the Soviet Union as well as other countries of CMEA. The analysis of data on world CFM production shows that the USSR share is 1.3 per cent for F–11 and 4.8 per cent for F–12. The authors concluded that there is a probable depletion of the ozone layer due to CFM release. The impact of stratospheric transport is negligable at present.

The article also pays attention to additional sources of Cl which could reach the stratosphere as a result of the use of NH_4ClO_4 for oxidant for rocket fuels. Roughly 50 per cent of this NH_4ClO_4 is released into the stratosphere during a rocket launching.

The authors also believed that continuous CFM release, at present rates, might well have an impact on climate in the range of a 1°C increase in global surface temperature in the period of 100 years.

8. United Kingdom of Great Britain and Northern Ireland

Measurements

Concentrations of a number of stratospheric trace gases have been measured from aircraft, balloons and satellites. Balloon measurements carried out by the National Physical Laboratory in collaboration with the University of Florence under the SIBEX programme have comprised two experiments at Palestine, Texas. Measurements were derived from two types of spectrometer, one of Italian and one of U.K. design. Profiles of several species including chlorine compounds have been obtained and evaluation of the results is near completion. At A.E.R.E., Harwell, profiles of methyl chloride and some fluorine compounds have been determined, and results are in course of publication. Satellite observations have been used by a group at Oxford University to determine concentrations of several species. In the Meteorological Office, an aircraft of the Meteorological Research Flight was equipped with a gas chromatograph and has recently made measurements of CFCs and of N_2O. Also grab sampling has been carried out from this aircraft, a similar technique now being developed for balloon-borne sampling.

Laboratory Studies

Reaction rate measurements and other laboratory studies have been undertaken and some results published. At Cambridge University, reactions involving CFCl and HO_2 have been measured, while HO_2 kinetics have been studied also at Harwell. At Queen Mary College, London, measurements of reaction rates involving OH radicals have been published, and calculations made of rate constants in SO and ClO reactions, while further laboratory work on UV absorption by nitrogen has been undertaken.

Other Work

1. A proposal has been put forward by the Meteorological Office for a major stratospheric investigation under the NASA, UARS programme. The investigation will involve assimilation of

satellite measurements into a three-dimensional stratospheric model, yielding continuous and consistent analyses of stratospheric parameters. The Meteorological Office is also collaborating in the HALOE project.

2. The Oxford group have been involved in the WMO intercomparison of Dobson spectrophotometers carried out at Arosa and Potsdam.

3. Several groups have played an active part in the preparation of an EEC report on ozone modelling studies.

Assessment

The U.K. Department of the Environment has recently published its second comprehensive report on the ozone depletion problem (Chlorofluorocarbons and their effects on Stratospheric Ozone (Second Report)—Pollution Paper No. 15 – HMSO). This contains inter alia the report of the Stratospheric Research Advisory Committee which assesses the present status of atmospheric chemistry, modelling, monitoring of chemical species and ozone trend analysis. A novel feature of the report is the inclusion of the results of 2-D modelling carried out at Harwell, the Meteorological Office and Oxford University. The Harwell tropospheric 2-D model is used to provide improved estimates of the input of halocarbon species to the stratosphere and the other 2-D models have been used to provide prediction of the latitudinal and seasonal dependence of both ozone depletion and UV-B increase resulting from CFM 11 and 12 releases. The predicted global mean ozone depletions in steady state for continued release of CFMs 11 and 12 at average 1973-1976 production rates were 11 per cent, 13 per cent and 16 per cent for the Meteorological Office 3 column model, the Harwell 1-D model and the Oxford University 2-D model respectively. A figure of 13 per cent is given for the overall "best estimate" of ozone depletion of which half would be reached after 50 years. Ozone depletion at the present time should be between 0.7 and 1.3 per cent. If releases of CFM 11 and 12 could be terminated in the near future then the ozone depletion would increase to about 2 per cent in the next 5-15 years and a recovery would then commence. The 2-D models show that significant variations with latitude and season are to be expected. The maximum percentage reduction occurs in late winter at high latitudes. At low latitudes the reduction is about one quarter of the maximum value. The percentage increase in the penetration of UV-B to the earth's surface resulting from the predicted ozone depletion shows an even stronger latitude dependence. This means that the simple working relationship used formerly, that a 1 per cent decrease in total ozone results in a 2 per cent increase in UV-B may no longer be appropriate. Consideration is given to the overall ozone depletion resulting from the interaction between CFM 11 and 12 emissions and other emissions such as those of nitrogen oxides, carbon dioxide and further chlorocarbons. These may result in non-additive effects. The report also includes a critical assessment of the degree to which current models are supported by atmospheric measurements. It concludes that uncertainties have widened rather than narrowed since the 1976 report of the Department of the Environment. Although for a considerable number of trace gases, a fair degree of agreement between model and observations can be claimed there are still a number of disturbing discrepancies which need to be resolved.

9. United States of America

The United States of America continues its intensive and extensive research and monitoring programs on the possibility of stratospheric ozone depletion by chlorofluoromethanes (CFMs) and the undesirable effects on living things of increasing ultraviolet-B radiation resulting from decreasing stratospheric ozone. The U.S. National Academy of Sciences (NAS) has completed a comprehensive analysis and assessment "Stratospheric Ozone Depletion by Halocarbons: Chemistry and Transport". A companion report, "Protection Against Depletion of Stratospheric Ozone by Chlorofluorocarbons", expected to be published by 1980, will discuss human, biological, climatic effects of ozone depletion, ways to control the depletion and options for impleting controls.

The principal findings are:

— continued release of halocarbons into the atmosphere will result in a decrease in stratospheric ozone;

— new values for some of the chemical rate coefficients have increased the predicted ozone reduction resulting from continued release of chlorofluoromethanes (CFMs);

— the most probable value calculated for the eventual ozone depletion due to continued release of CFMs at the 1977 level is 16.5 per cent. This value is obtained from the value of 18.6 per cent calculated from the computer model by allowing for possible tropospheric sinks for CFMs and for the effects on stratospheric chemistry of the CFM greenhouse effect;

— there have been considerable improvements in the computer models and in the laboratory and atmospheric measurements, which have reduced the uncertainty range;

— although there are a few exceptions, the comparison between the models and measurements of substances in the present stratosphere is considered to be satisfactory within the uncertainties of the measurements. We therefore believe that the projections for ozone depletion are valid within the stated uncertainty ranges;

— the uncertainties in the chemical rate coefficients, in atmospheric transport, and in the use of one dimensional models have been combined to give an overall uncertainty range of a factor of 6 within a 95 per cent confidence level;

— the uncertainty ranges means that for the case of continued release of CFMs at the 1977 level there is 1 chance in 40 that the ozone depletion will be less than 5 per cent and 1 chance in 40 that it will be greater than 28 per cent;

— even allowing for the best professional judgement of the possibility that some important chemical reaction has been overlooked or that there remain large errors in the measured chemical rate coefficients, it is believed that there is a 3 out of 4 chance that continued release of CFMs at the 1977 level will result in an ozone depletion that lies in the range of 9 to 24 per cent;

— if the rapidly increasing use of F–22 (CHF_2Cl) and methyl chloroform (CH_3CCl_3) continues unabated, the release rates and atmospheric behaviour of these compounds will require careful attention. However, since chemical reactions remove appreciable fractions of these compounds before they reach the stratosphere, substitution of F–22 for F–11 ($CFCl_3$) and F–12 (CF_2Cl_2) would be beneficial;

— it is unlikely that direct measurements of the average global ozone amount would permit detection of a decrease of less than 5 per cent attributable to human activity. Total cessation of CFM release at the time of detection would result in a decrease of ozone of about 7 per cent some 15 years later.

RESEARCH PROGRAMME SUMMARY

A selection of U.S. research and monitoring programmes significant findings of the most immediate practical import for the UNEP World Plan of Action on the Ozone Layer are presented as follows:

OZONE MONITORING

Upgrading the Global Dobson Spectrophotometer Station Network

Since 1977, the U.S. has worked with the World Meteorological Organization's (WMO) Global Ozone Research and Monitoring Programme to intercalibrate regional and primary standard Dobson spectrophotometers, and to modernize and calibrate selected spectrophotometers. During 1978/79, personnel modernized and calibrated against the world standard instrument (No. 83 at Boulder, Colorado) the spectrophotometers from Mexico City, Mexico; Natal, Brazil, Leningrad, USSR, Manila, Philippines and Boulder, USA. This international programme of Dobson instrument intercomparison and

the careful development of a set of standardized instructions for operation of the Dobson spectrophotometer can increase the achievable accuracy of the observations to + 3 per cent, with a long-term precision of + 1.5 per cent for the network global average. Maintenance of this programme is of the greatest importance, since the Dobson spectrophotometer is the standard instrument adopted by the World Meteorological Organization and continues to form the basic global ozone monitoring network.

WATER VAPOR MONITORING

New Instrument Development

Because of the influence of stratospheric water vapor on stratospheric ozone, as well as for other climatic reasons, monitoring of stratospheric water vapor is deemed important. The U.S. has developed and tested successfully in Wyoming and Brazil, a new balloon-borne instrument for measurement of stratospheric water vapor. The instrument contains a hydrogen Lyman-alpha lamp whose shortwavelength ultraviolet radiation dissociates water vapor, and an optical system that measures radiation from the OH fragment.

The results from the Brazil flight have shown that the water vapor concentration reaches a minimum of about 3 ppmv at about 20 km, substantially above the tropical tropopause, with a slight increase to about 4 ppmv at 23 km.

In 1978-79 the program of grab sample balloon measurements aimed at measuring the stratospheric concentrations of the chlorofluoromethanes ($CFCl_3$ and CF_2Cl_2) and nitrous oxide (N_2O), was extended spatially, with flights from Wyoming, Antarctica, and Brazil, for global distribution for these stratospheric constituents, including methane (CH_4) and methyl chloroform (CH_3CCl_3). Extensive N_2O measurements provided information on vertical eddy-diffusion coefficient profiles and their variability, important for verification of the ID photochemical model assumptions.

SATELLITE DATA ARCHIVING

Satellite total ozone data, based on observations of upward-emitted infrared (9.6 micrometer) radiation, became available late in 1979. Daily output from both the Tiros-N and NOAA-6 spacecraft typically amounts to 7,000 to 8,000 soundings, including data derived from the three Tiros Operational Vehicle Sounder (TOVS) sensors (Microwave Sounding Stratospheric Sounding Unit, and High Resolution Infrared Radiation Sounder), and are archived on magnetic tape on a weekly basis (7 days per tape) by the Satellite Data Services Division of the National Climatic Centre at Asheville, N.C. Each sounding contains layer mean temperatures, precipitable water, tropopause parameters, cloud cover, measured radiances, and total ozone amounts in Dobson units.

The ozone vertical profile data from Nimbus 4 Backscatter Ultraviolet (BUV) measurements is available for April 1970 to April 1972.

The High Altitude Pollution Program (HAPP) efforts include:

1. **Ozone monitoring**

— Continued the analysis and use of the 9.8 micron irradiance data from the Block 5D Meteorological Satellites in deriving total ozone.

— Initiated plans to intercompare ozone measurements by Block 5D, Nimbus 7, and Tiros N satellites over a common grid network.

— Conducted, in co-operation with WMO, the first international intercomparison of rocketborne ozone sondes at the Wallops Flight Center Facility. Australia, Canada, India, Japan and the United States are the nations participating in this effort.

2. **Stratospheric constituent measurements**

— Continue to develop instruments to measure total odd and

selected odd nitrogen (defined as NO, NO_2, HNO_3, N_2O_5, HO_2NO_2, and $ClONO_2$).

3. Laboratory

— Continue the compilation and critical evaluation of chemical and photochemical data for atmosphere modelling.

— New efforts have been initiated to reduce the uncertainties in the tropospheric and upper stratospheric NO_x-catalyzed-O_3 production mechanisms. Specifically, absolute rate coefficients for the following reactions will be determined.

$$CH_3O + O_2 \rightarrow HO_2 + CH_2O$$

$$CH_3O + O_3 \rightarrow \text{product}$$

$$CH_3O_2 + NO \rightarrow CH_3O + NO_2$$

4. Development of computational modelling

— Continue the improvement of 1D modelling of NO_x injection. In addition to a continued analysis of parameters to which the models are sensitive, a full description of NO_x injections from the subsonic fleet of aircraft has been initiated and the effects of hypersonic aircraft have been studied. More complete halogen chemistry, including ClO_x and BrO_x, has been included in order to assess the interaction with NO_x injections.

— A new effort has been initiated to assess the variabilities in atmospheric chemical and physical parameters and the consequent effects on trace species measurements and model validation.

Measurement methods and standards for ultraviolet radiation:

The program "Calibration and Measurement Technique Development for UV-Radiometry" has, as its goal, the development of the necessary instruments, calibration and measurement techniques, such that solar terrestial spectral irradiance between 290-320 nm may be determined with uncertainties not exceeding 5%. The information developed under this project will be disseminated to the UV-B radiation effects community requiring it.

Methods and standards for halocarbon concentration measurements in the atmosphere:

It is planned that the National Bureau of Standards will serve as the source of reference materials for halocarbon and N_2O collaborative measurements and will participate in measurement methodology activities. In data evaluation activities, work progressed on updating the NBS Special Publication 513 ("Reaction Rate and Photochemical Data for Atmospheric Chemistry—1977").

Laboratory studies continue to improve our knowledge of the key reaction kinetics and spectroscopy pertinent to the stratosphere. A periodic survey and evaluation of the best values for stratospheric photochemical rates has been initiated. Co-ordinated field measurements of stratospheric minor species and aerosols, with emphasis on the key photochemical radical species, are being made to test theories of photochemical processes and to determine the extent of variability within the stratosphere. Lower atmospheric measurements are being made to improve our understanding of the sources of upper atmospheric minor constituents.

Nimbus 7 satellite is measuring the global morphology of ozone and certain related species with emphasis on the nitrogen chemical family, and in coming years the Stratospheric Aerosol and Gas Experiment (SAGE), Halogen Occultation Experiment (HALOE), and Solar Mesophere Explorer (SME) satellite missions will also provide needed data on aerosols, halogen species, and mesospheric properties. Instrument definition and development for future satellite and Space Shuttle missions is continuing. In particular, definition of potential multi-user instrument systems for the Shuttle is focusing on an active laser lidar system and a cryogenic limscanning interferometer spectrometer.

Theories of stratospheric processes are increasingly stressing the inter-relation of the different chemical families and the coupling among dynamic, radiative, and chemical processes. Theoretical one, two, and three dimensional models are being developed and utilized along with empirical models of large data sets. However, one-dimensional photochemical models still form the basis for assessment of upper atmospheric perturbations. In the assessment area, predictions of the amount of ozone depletion resulting from releases of chlorofluoromethane (CFMs) have increased significantly over the past two years, and with improved accuracy.

HEALTH EFFECTS

The United States conducts basis and clinical research into the health effects of UV radiation. These effects include sunburn, eye diseases, skin diseases, and skin cancer. Health effects and their severity depend upon radiation wavelength and intensity, exposure time, and host and environmental factors.

Epidemiologic studies have revealed that exposure to sunlight correlates with increased incidence of nonmelanoma skin cancers, particularly in Caucasians and other high risk groups.

Specifically, skin cancer incidence surveys were conducted in various geographic locations within the United States to provide more reliable estimates of the dose-response relationship of UV-B and skin cancer development among American Caucasians. Results from investigations were consistent with the hypothesis that increased amounts of UV-B radiation lead to increased incidence of skin cancer. Estimates of the dose-response relationship indicated that for most locations in the U.S. a one per cent increase in UV-B would eventually result in an approximate two per cent increase in non-melanoma skin cancer incidence.

Animal models are very useful for investigating photo-carcinogenesis and the efficacy of sunscreening substances that interfere with photocarcinogenesis.

UV dose response data are indispensable for relating wavelength, intensity and duration of exposure to health effect responses.

UV-B Biological Effects Research

Activities include surveys of skin cancer incidence among population at different latitudes, measurements of solar UV-B (290–320nm) at these sites, studies of plant species under simulated and natural UV-B levels, experiments with aquatic ecosystems, and social/economic assessments. Results to date are as follows: Surveys generally support belief that skin cancer incidence is related to UV-B exposure; mortality from skin cancer is increasing among the young, probably due to changes in life style—for example, more time spent outdoors; all plants tested revealed sensitivity to UV-B at some exposure level, some plants experience yield reductions, others suffer bleached or discoloured leaves; UV-B damages larvae of shrimp, crab, mackerel and anchovy; photorepair mechanism is suggested as a potential mitigator of UV-B effects in plants. Field type, medium resolution spectroradiometers and calibration standards for UV-B measurements have been developed. A model, including parameter uncertainties, has been developed for integrated assessment of costs/benefits of control versus noncontrol; reliability of assessments increase as parameter uncertainties decrease.

10. World Health Organization

The representative of WHO described the proposed programme on ultra-violet induced skin cancer. The Plan of Action for the UNEP/WHO epidemiological study on skin cancer and ultra-violet radiation was presented. Recommendations for future development of health effects evaluations for consideration by the Committee were suggested. The WHO Environmental Health Criteria document on ultra-violet radiation will be issued shortly giving public health authorities the necessary information for the evaluation of health risks on ultra-violet radiation. The publication will be submitted to members of the Co-ordinating Committee on the Ozone Layer.

11. World Meteorological Organization

The representative of WMO informed the meeting of the pro-

gress made by WMO in the implementation of the World Plan of Action on the Ozone Layer since the second session of the Committee through work done under the WMO Global Ozone Research and Monitoring Project supported by UNEP. WMO has succeeded in stimulating the establishment of two new stations in China, one in Singapore and one in Brazil. With regard to the standardization of the total ozone observing network, WMO organized a second intercomparison of European-based Dobson spectrophotometers in June 1979. The results of these intercomparisons will be published in due course and sllow the necessity for regular intercomparisons of Dobson instruments. These intercomparisons, inspection, and upgrading of total ozone station instruments should continue in parallel with efforts for their optimal distribution. Action should be taken to present any significant deterioration of the ozone observing network in the southern hemisphere. WMO organized, with support from the United States, an international rocket-borne ozone-sonde comparison at Wallops Island in November 1979. This comparison proved the need for continuous rocket measurements mainly for use in satellite data reduction. It is desirable that stations in locations with frequent cloud-free sky conditions be encouraged to undertake "short-Umkehr" observations regularly. A careful assessment of the performance characteristics of ozone observing systems was planned for summer 1980. It seems that there is an immediate need for redetermination of ozone absorption coefficients used in data reduction as well as further studies on the role of aerosols, possible variability of solar UV flux in wavelengths important to ozone photochemistry.

A comprehensive review on ozone measurements for satellites is being made. More Umkehr and rocket-borne ozone-sonde data are needed to verify and complement forthcoming satellite measurements.

A meeting of experts on Stratospheric Circulation Analysis and Ozone was organized by the WMO in July 1979. It was recommended that further studies should be undertaken on the stratospheric circulation and that work should continue on 1-D, 2-D and 3-D models, and a review on 2-D models is scheduled for January 1980.

A summary of the current work on the assessment of trends in ozone concentrations was presented to the Committee emphasizing the need for employing sophisticated statistical analyses on carefully checked sets of ozone data and the need for the clarification of the influence of solar and aerosol effects on data reduction, before making definitive conclusions on the evidence of trends in ozone records.

12. International Council of Scientific Unions (ICSU)

(a) International Association of Meteorology and Atmospheric Physics (IAMAP)

Three sessions at the International Union of Geodesy and Geophysics (IUGG) General Assembly, Canberra, December 1979 are relevant to the World Plan of Action on the Ozone Layer. The Upper Atmosphere Commission will arrange two days of sessions on modelling, devoted primarily to concentrations of trace elements important to ozone formation and destruction and to transport factors which also play a significant role. The sessions will stress two and three dimensional models, and will include the latest results from the most recent satellites.

The Commission on Atmospheric Chemistry and Global Pollution will also arrange a 1½-day discussion on life cycles of trace constituents in the atmosphere. Many of these are of relevance to the ozone problem and have long enough lifetimes to reach the stratosphere.

A symposium on ozone is planned in late 1980 in association with other ICSU bodies such as COSPAR, and with WMO and UNEP.

(b) Scientific Committee on Problems of the Environment (SCOPE)

The SCOPE-UNEP International Nitrogen unit has been established in Stockholm at the Royal Swedish Academy of Sciences. The main objective is the critical evaluation, examination and

synthesis of the global nitrogen cycle. There is an important release of nitrogen oxides into the atmosphere resulting in the main from heavy applications of nitrogen fertilizers in intensive agriculture. SCOPE is planning to study the effects on the ozone layer of this release and agreement is being sought from UNEP to include this as part of the unit's activities.

(c) Scientific Committee on Solar Terrestrial Physics (SCOSTEP)

The plans for the Middle Atmosphere Programme (MAP) were approved by the General Assembly of ICSU in Athens in September 1978. The MAP is a plan for global study of the structure, composition, energetics and motions of the stratosphere and mesosphere over a five-six year period. Simultaneous observations of a series of variables will be made over the globe, and the goal of the programme is to improve the understanding of the middle atmosphere and its reactions to various perturbations.

(d) Committee on Data for Science and Technology (CODATA)

CODATA held one meeting (in April 1979) of its Task Group on Chemical Kinetics to draw up outlines for the preparation of data sheets on elementary reactions involving ozone in the stratosphere.

(e) International Union of Biological Sciences (IUBS)

The International Association of Photobiology (AIP) will hold a symposium on the biological effects of ozone depletion during the 7th International Congress on Photobiology, July 1980, in Strasbourg.

Of the recommendations adopted at the first meeting of CCOL, there has probably been least progress in establishing a co-ordinated programme relating to biological effects other than those on human health (nos. 10, 11, 12). Therefore, during the Strasbourg Photobiology Congress, AIP will initiate discussions of the feasibility of establishing a mechanism for co-ordinating and disseminating information on UV-B photobiology (World Plan of Action, recommendation 6) and developing an appropriate international programme.

13. Chemical Manufacturers Association

The atmospheric lifetime experiment (ALE), which aims to establish the tropospheric lifetimes of F–11 and F–12 by monitoring concentrations of these species, continues to progress satisfactorily. Performance of the four monitoring stations, which have now been in operation for 18 months, continues at a high level. Comprehensive statistical analysis of the data is in hand. A fifth station, at Oregon, USA, is to be established, to augment the data for the all-important temperate zone in the northern hemisphere where the majority of the CFMs are released. Calibration experiments, to convert the relative measurements on atmospheric concentrations to absolute values of the highest possible precision, are at an advanced stage.

Modelling of the stratosphere and its chemistry to predict the extent of ozone perturbation continues. The two dimensional (2-d) "box" model is now fully operational and has been used to study the effect on predicted ozone depletion of excited molecular oxygen, alternate reaction pathways, and the coupling of the CFM perturbation with those from fertilizers (the NO_x cycle), combustion (the $CO_2/CO/CH_4$ cycle), and the bromine cycle. In the area of comparison of measured and calculated stratospheric concentrations (and concentration ratios), attention is being focussed on those species ClO, HCl, $HF/HCl/HNO_3/NO_2$, where major discrepancies persist. Development of a full 2-d model has just begun in collaboration with the US Air Force Geophysical Laboratory.

Work on analysis of trends in measured ozone concentration under two separate contracts awarded recently to US statisticians of a very high standing is in progress. Ground-based (Dobson) data and satellite data are both being analysed. One of the major problems that has recently been highlighted is the need to identify the trends due to natural causes, and instrument drift and bias and to reduce the uncertainties in these trends, so that the threshold for the detection of a possible trend due to CFMs is reduced.

CMA's contribution to the elucidation of stratospheric continues to be largely centred upon the species Cl, ClO, higher chlorine oxides, and HO_2. Laboratory measurements are continuing with the aim of improving the quantitative chemistry of established reactions, and of investigating some of the more speculative chemistry. Particular attention is being given to these reactions which might produce, rather than destroy, odd oxygen, and those which might proceed by alternative routes or via complex formation. Accumulation of spectroscopic data from a variety of ground-based techniques is continuing. Reduction to date of the data from the successful National Physical Laboratory/University of Florence balloon flight in April has yielded profiles for O_3, HNO_3, F–11 and F–12 with the promise of further data on HCl, HF, N_2O, CH_4, O_2 and CO_2, and possibly also on ClO, NO_2 and CO. This expedition has proved to be an outstanding success in meeting the need for simultaneous measurements on a large number of species. Further simultaneous measurements, together with development of specialized experimental techniques, will be the main features of our future programme on stratospheric measurements.

Liaison with governmental and other bodies, and co-ordination of US/European activities and interests, continues.

Section IV

WORLD PRODUCTION AND MAJOR USES OF CHLOROFLUOROCARBONS F–11 AND F–12 COLLECTED BY THE UNITED NATIONS ENVIRONMENT PROGRAMME

An international conference on Chlorofluoromethanes was held at Munich in the Federal Republic of Germany, from 6 to 8 December 1978. The conference **inter alia** recommended that all Governments accept an obligation to provide to the United Nations Environment Programme, annual production figures for the chlorofluorocarbons F–11 and F–12 and their major uses, in order that an assessment of total global emissions be obtained.

In response to this recommendation, UNEP requested all Governments to provide the required information. The results are tabulated in the following pages. No attempt has been made to analyse the figures provided as it was felt that due to the relative paucity of information, any such analysis would be misleading.

COUNTRY	PRODUCTION		USE		COMMENTS
	F–11	F–12	F–11	F–12	
Australia	1974		1974		
			Aerosols		
	7,010 tonnes	8,963 tonnes	5,378 tonnes	7,131 tonnes	1. Figures based on Australian market surveys carried out by industry groups
			Refrigeration		
			292 tonnes	1,745 tonnes	2. All figures represent sales for calendar year
			Foam		
			1,340 tonnes	87 tonnes	
	1977		1977		
			Aerosols		
	5,864 tonnes	7,016 tonnes	4,207 tonnes	4,699 tonnes	3. 1974 is regarded as the peak year for production of CFM's for use in aerosols
			Refrigeration		
			276 tonnes	2,162 tonnes	
			Foam		
			1,381 tonnes	155 tonnes	
	1978		1978		
			Aerosols		
	6,139 tonnes	7,354 tonnes	3,776 tonnes	4,882 tonnes	
			Refrigeration		
			321 tonnes	2,349 tonnes	
			Foam		
			2,042 tonnes	123 tonnes	
Austria	NIL	NIL			
Bahamas	NIL	NIL			
Bahrain	NIL	NIL			Bahrain imports chlorofluorocarbons but figures are not available

COUNTRY	PRODUCTION		USE		COMMENTS
	F–11	F–12	F–11	F–12	
Bangladesh	NIL	NIL	Annual use aerosol/insect spray		
			89 tonnes	89 tonnes	
Barbados	NIL	NIL			
Brazil	1976 Aerosol 489 tonnes | 1,011 tonnes Non-aerosol 572 tonnes | 1,932 tonnes 1977 Aerosol 481 tonnes | 1,432 tonnes Non-aerosol 589 tonnes | 1,945 tonnes Aerosol 400 tonnes | 1,350 tonnes Non-aerosol 665 tonnes | 2,023 tonnes 1979 (Jan.-May) Aerosol 202 tonnes | 567 tonnes Non-aerosol 246 tonnes | 863 tonnes 1979 (Estimated total) Aerosol 346 tonnes | 1,039 tonnes Non-aerosol 693 tonnes | 2,144 tonnes				

COUNTRY	PRODUCTION		USE		COMMENTS
	F–11	F–12	F–11	F–12	
Burma					Information not yet available
Chile	NIL	NIL	1978 Plastic foam 58 tonnes | 6 tonnes Aerosols 14 tonnes | 421 tonnes Refrigeration 4 tonnes | 36 tonnes F–11 and F–12 combined Aerosols 17 tonnes		
Colombia					Information not yet available
Denmark	NIL	NIL	1977 Aerosol 1423 tonnes Foaming agent 1502 tonnes Refrigeration 948 tonnes Solvent, etc. 79 tonnes		Imports were 3,953 tonnes in 1977
El Salvador	NIL	NIL			Imports from FRG, UK and USA in unspecified amounts

COUNTRY	PRODUCTION		USE		COMMENTS
	F–11	F–12	F–11	F–12	
Finland	NIL	NIL	1978 Aerosols 930.5 tonnes Refrigeration and air conditioning 496 tonnes Plastic foam 887 tonnes Cleaning 6 tonnes		
Germany (Federal Republic of)	For aerosol use 1975 - 50,200 tonnes 1976 - 48,200 tonnes 1977 - 41,450 tonnes 1978 - 38,600 tonnes				(a) A decrease of 23.1% is shown from the reference year 1975 (b) Agreement reached between government and industry to decrease fluorocarbons in sprays by 30% from 1975 figures, may be realized by the end of 1979
Guatemala			Net Consumption 1974 151.5 tonnes 1978 247.25 tonnes		Imports 1974 152.5 tonnes 1978 500 tonnes (estimated) Increase in imports 228% Increase in consumption 163% Difference between imports and consumption is because of the re-export of some chlorofluorocarbons

COUNTRY	PRODUCTION		USE		COMMENTS
	F–11	F–12	F–11	F–12	
Guyana	NIL	NIL	Per annum in refrigeration 6 tonnes	14 tonnes	
Hungary			Per annum approximately 1,400 tonnes Mostly for refrigeration		Hungary intends to phase out the use of chlorofluoro-carbons
Ireland	NIL	NIL	508 tonnes per annum at most for aerosols, refrigeration, and in plastic foam industries		Overall usage is stable following a sharp decline in 1974/5 due to closure of two large aerosol filling factories
Israel					Information not yet available
Japan	An unofficial study in 1976 estimated the Annual production to be 44,134 tonnes				
Jordan	NIL	NIL			Imports chlorofluorocarbons but figures not available
Lao (People's Democratic Republic)	NIL	NIL	NIL	NIL	
Liberia	NIL	NIL	NIL	NIL	
Liechtenstein					(a) No information available (b) Liechtenstein normally orients its laws with those of Switzerland
Luxemburg	NIL	NIL			An inventory of the use of aerosols is envisaged
Malawi	NIL	NIL			
Malta	NIL	NIL			
Mauritius	NIL	NIL			

COUNTRY	PRODUCTION		USE		COMMENTS
	F–11	F–12	F–11	F–12	
New Zealand	NIL	NIL	1979 (Estimated) Aerosols: Personal/Household 520 tonnes Industrial 150 tonnes Refrigeration, Air Conditioning 50 tonnes Foam Manufacture 560 tonnes		from 1976 - 1979 (a) Reduction of a little less than 50% in aerosol usage (b) Small increase in refrigeration and air conditioning (c) 44% increase in foam manufacture
Niger	NIL	NIL	NIL	NIL	
Nigeria			Per annum 3,100 tonnes		
Norway	NIL	NIL	1978 Aerosols 900 tonnes Cooling agents Ca. 600 tonnes Foaming agents Ca. 600 tonnes		These figures cover the use of chlorofluorocarbons in goods produced in Norway for domestic purposes as well as for export. They do not however cover their use in important products.
Oman	NIL	NIL			

COUNTRY	PRODUCTION		USE		COMMENTS
	F–11	F–12	F–11	F–12	
Pakistan	NIL	NIL	Per annum 305 to 340 tonnes Mostly non-aerosol uses i.e. refrigeration and air conditioning. Only a small quantity is used in aerosols		
Panama	NIL	NIL			
Peru	NIL	NIL			
Poland	NIL	NIL	Per annum 5,000 tonnes imported and used in refrigeration, cosmetic industries and in the production of plant production chemicals		
Romania	NIL	NIL	1979 Imports were 293 tonnes	3034 tonnes used for aerosols, in the production of polyurethanes and refrigeration systems	
Rwanda	NIL	NIL			
Samoa	NIL	NIL			
Saudi Arabia	NIL	NIL			
Senegal					Imports chlorofluorocarbons for refrigeration but figures not available
Seychelles	NIL	NIL	NIL	NIL	
Singapore	NIL	NIL			

COUNTRY	PRODUCTION		USE		COMMENTS
	F–11	F–12	F–11	F–12	
Solomon Islands	NIL	NIL	NIL	NIL	
South Africa	1978 1,212 tonnes	3,324 tonnes	Uses 1978 Aerosol 1,116 tonnes	2,603 tonnes	Imports 1978 F–11: 1,199 tonnes F–12: 331 tonnes
			Foam Blowing 952 tonnes	236 tonnes	
			Air conditioning and Refrigeration 288 tonnes	1,125 tonnes	
Spain					Information not yet available
Swaziland	NIL	NIL			Aerosol sprays and insecticide sprays not manufactured but are imported
Sweden	NIL	NIL			Use of freons in aerosols legally banned since 1 July 1979 apart from exceptional cases
Switzerland	NIL	NIL	1977 F–11, F–12 and F–114 Aerosols 5,912 tonnes 1978 Aerosols 4,732 tonnes Non-aerosols 670 tonnes (estimated)		1. Exports from Switzerland were approximately 1977 - 590 tonnes 1978 - 470 tonnes 2. In February 1979 Switzerland gave permission for the use of dimethyl ether as a propellant thus allowing further reduction in the use of chlorofluoromethanes 3. Swiss authorities and industry are collaborating in working out a plan for further voluntary reduction in the use of F–11, F–12 and F–114 for aerosol usage 4. Restrictive measures may be taken in the future concerning chlorofluoromethanes depending on further evidence of the ozone depletion theory

COUNTRY	PRODUCTION		USE		COMMENTS
	F–11	F–12	F–11	F–12	
United Republic of Tanzania	NIL	NIL			Imports chlorofluorocarbons but figures not available
Thailand	NIL	NIL			Imports 1975 F–11: 284 tonnes; F–12: 504 tonnes; F–22: 195 tonnes 1976 280 tonnes; 780 tonnes; 280 tonnes 1977 569 tonnes; 739 tonnes; 310 tonnes 1978 612 tonnes; 1,097 tonnes; 453 tonnes 1979 (Jan-June 15) 362 tonnes; 423 tonnes; 249 tonnes
Tonga	NIL	NIL	NIL	NIL	
Uganda	NIL	NIL			
United Arab Emirates	NIL	NIL			
Upper Volta	NIL	NIL			
Venezuela	1976 1,204 tonnes | 2,683 tonnes 1977 921 tonnes | 2,128 tonnes 1978 1,200 tonnes | 4,136 tonnes 1979 (nine months) 670 tonnes | 3,427 tonnes				

Section V

WORLD PRODUCTION AND RELEASE OF CHLOROFLUOROCARBONS 11 AND 12 THROUGH 1978–PROVIDED BY THE CHEMICAL MANUFACTURERS ASSOCIATION

The world production and release of FC–11 and FC–12 are tabulated through 1978 (Appendices 1,2,3,4, and 5). The 1978 production figures were compiled by Alexander Grant and Company from data contributed by the twenty CMA-reporting companies. The procedure used to compute annual and cumulative figures for world production and release is described by McCarthy, Bower, and Jesson (Ref. 1). Previously reported production data through 1977 remains the same.

Eastern European production is based on the recently published USSR production data for 1968-1975 (Ref. 2). Total Communist production was estimated to be 1.15 times the reported USSR production. Data for 1976, 1977, and 1978 were extrapolated from the 1968-1975 history.

References

1. "The Fluorocarbon-Ozone Theory -I. Production and Release—World Production and Release of CCl_3F and CCl_2F_2 (Fluorocarbons 11 and 12) Through 1975", R.L. McCarthy, F.A. Bower, and J.P. Jesson. Atmospheric Environment, Vol. II, pp. 491-497 (1977).

2. "Effect of Freons and Halocarbons on the Ozone Layer of the Atmosphere and Climate", Professor Ye. P. Borisenkov and Candidate of Physical and Mathematical Sciences Yy. Ye. Kazakov (1977).

FLUOROCARBON PRODUCTION AND RELEASE—EXPANDED DATA—REPORTING COMPANIES ONLY

MILLION KILOGRAMS

FC -11 CUMULATIVE FC–11

	ANNUAL		TOTAL[1]			REFRIGERATION HERMETICALLY SEALED			REFRIGERATION NON-HERMETIC			BLOWING AGENTS CLOSED CELL FOAM			OPEN CELL AEROSOLS ALL OTHER PRODUCATION		
YEAR	PROD	REL	PROD	REL	UNREL	SALES	REL	UNREL	SALES	REL	UNREL	SALES	REL	UNREL	SALES	REL	UNREL
1931	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
1932	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
1933	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
1934	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
1935	.0	.0	.1	.0	.1	.0	.0	.0	.1	.0	.1	.0	.0	.0	.0	.0	.0
1936	.1	.0	.2	.0	.2	.0	.0	.0	.2	.0	.2	.0	.0	.0	.0	.0	.0
1937	.1	.0	.3	.1	.3	.0	.0	.0	.3	.1	.3	.0	.0	.0	.0	.0	.0
1938	.1	.0	.4	.1	.3	.0	.0	.0	.4	.1	.3	.0	.0	.0	.0	.0	.0
1939	.1	.1	.5	.2	.3	.0	.0	.0	.5	.2	.3	.0	.0	.0	.0	.0	.0
1940	.2	.1	.7	.3	.4	.0	.0	.0	.7	.3	.4	.0	.0	.0	.0	.0	.0
1941	.3	.1	1.0	.4	.6	.0	.0	.0	.9	.4	.6	.0	.0	.0	.0	.0	.0
1942	.3	.1	1.3	.5	.8	.0	.0	.0	1.2	.5	.7	.0	.0	.0	.0	.0	.0
1943	.4	.2	1.7	.7	1.0	.0	.0	.0	1.6	.7	1.0	.0	.0	.0	.0	.0	.0
1944	.4	.2	2.0	.9	1.1	.0	.0	.0	2.0	.9	1.1	.0	.0	.0	.0	.0	.0
1945	.4	.3	2.4	1.2	1.2	.1	.0	.0	2.4	1.2	1.2	.0	.0	.0	.0	.0	.0
1946	.7	.6	3.1	1.6	1.3	.1	.0	.0	2.4	1.5	.9	.0	.0	.0	.7	.3	.3
1947	1.3	1.2	4.4	3.0	1.4	.1	.0	.0	2.5	1.7	.7	.0	.0	.0	1.9	1.3	.6
1948	3.0	2.3	7.4	5.3	2.1	.1	.0	.0	2.5	2.0	.7	.0	.0	.0	4.7	3.3	1.4
1949	4.5	3.7	11.9	9.1	2.9	.1	.0	.1	3.0	2.2	.7	.0	.0	.0	8.9	6.8	2.1
1950	6.6	5.4	18.6	14.4	4.1	.1	.0	.1	3.4	2.5	.9	.1	.0	.1	15.0	12.0	3.1
1951	9.1	7.5	27.6	21.9	5.7	.1	.0	.1	3.9	2.7	1.2	.2	.0	.2	23.4	19.2	4.2
1952	13.6	10.8	41.2	32.7	8.5	.1	.0	.1	4.8	3.0	1.8	.4	.1	.3	35.9	29.6	6.3
1953	17.3	14.7	58.5	47.4	11.1	.1	.0	.1	3.9	3.4	2.8	.6	.1	.5	51.8	43.8	8.0
1954	20.9	18.3	79.4	65.7	13.7	.2	.0	.1	7.2	4.0	3.2	.9	.2	.7	71.1	61.4	9.6
1955	26.3	22.6	105.6	88.3	17.4	.2	.0	.2	8.8	4.3	4.1	1.3	.3	1.0	95.3	83.2	12.1
1956	32.5	28.2	138.1	116.5	21.6	.2	.0	.2	10.9	5.8	5.1	1.8	.4	1.3	125.2	110.3	15.0
1957	33.9	31.6	172.0	148.1	23.9	.3	.1	.3	13.7	7.1	6.7	2.4	.6	1.8	155.6	140.4	15.2
1958	29.5	29.7	201.6	177.8	23.8	.4	.1	.4	17.3	8.7	8.6	3.0	.8	2.2	180.9	168.2	12.6
1959	35.6	30.3	237.1	208.1	29.0	.5	.1	.4	21.1	10.8	10.4	3.9	1.1	2.9	211.5	196.2	15.3
1960	49.7	39.7	286.9	247.9	39.0	.7	.1	.6	25.9	13.3	12.6	6.0	1.6	4.5	254.2	232.9	21.3
1961	60.5	51.2	347.3	299.0	48.3	.9	.1	.8	31.5	16.5	15.0	8.8	2.2	6.6	306.2	280.2	26.0
1962	78.1	64.1	425.4	363.1	62.3	1.0	.1	.8	37.6	20.2	17.3	14.5	3.5	11.0	372.4	339.3	33.1
1963	93.3	78.5	518.7	441.7	77.0	1.2	.2	1.0	44.2	24.6	19.5	22.7	5.3	17.4	450.6	411.5	39.1
1964	111.1	93.2	629.8	534.9	94.9	1.5	.2	1.3	51.1	29.7	21.4	33.9	8.0	25.9	543.4	497.0	46.4
1965	122.8	106.3	752.6	641.2	111.4	1.8	.3	1.5	58.7	35.3	23.3	47.3	11.5	35.8	644.9	594.1	50.8
1966	141.0	119.0	893.7	760.2	133.4	2.1	.3	1.8	68.0	41.6	26.4	64.1	16.1	48.0	759.5	702.2	57.3
1967	159.8	135.1	1053.4	895.3	158.1	2.4	.4	2.0	77.7	48.5	29.1	83.9	21.9	61.9	889.5	824.5	65.0
1968	183.1	153.0	1236.5	1049.2	187.4	2.8	.5	2.3	87.8	56.2	31.6	109.3	29.5	79.8	1036.7	963.1	73.6
1969	217.3	178.4	1453.8	1227.6	226.2	3.3	.6	2.8	99.5	64.6	34.9	140.9	39.0	101.9	1210.1	1123.4	86.7
1970	238.1	202.8	1691.9	1430.4	261.6	4.0	.7	3.3	112.1	73.8	38.3	175.1	50.4	124.7	1400.8	1305.4	95.3
1971	263.2	222.7	1955.1	1653.1	302.0	4.7	.9	3.9	126.2	84.0	42.2	217.6	64.6	153.0	1606.6	1503.7	102.9
1972	306.9	250.8	2262.0	1903.9	358.0	5.8	1.0	4.7	142.1	95.2	46.8	269.3	82.0	187.3	1844.8	1725.7	119.1
1973	349.1	286.8	2611.1	2190.7	420.3	7.1	1.3	5.8	160.3	107.7	52.6	331.4	103.2	228.1	2112.3	1978.6	133.8
1974	369.7	315.4	2980.8	2506.1	474.7	8.6	1.5	7.1	179.3	121.4	57.9	393.3	127.2	266.1	2399.6	2256.0	143.6
1975	313.1	305.0	3293.9	2811.1	482.7	10.3	1.8	8.5	194.1	136.2	58.0	448.8	153.0	295.7	2640.6	2520.1	120.5
1976	339.8	295.3	3633.7	3106.4	527.3	15.6	2.2	13.3	215.8	152.4	63.5	500.9	180.8	320.1	2901.5	2771.0	130.4
1977	319.0	296.4	3952.6	3402.8	549.8	20.5	2.7	17.8	235.6	169.5	66.1	560.9	212.0	348.8	3135.7	3018.6	117.1
1978	295.6	273.6	4248.2	3676.4	571.8	26.9	3.3	22.6	257.4	187.6	69.8	621.4	246.0	375.4	3343.6	3239.6	103.9

FLUOROCARBON PRODUCTION AND RELEASE SUMMARY—EXPANDED DATA—REPORTING COMPANIES ONLY

MILLION KILOGRAMS

FC–12

FC–12 CUMULATIVE

FC–12

ANNUAL			TOTAL			REFRIGERATION HERMETICALLY SEALED			REFRIGERATION NON-HERMETIC			BLOWING AGENTS CLOSED CELL FOAM			OPEN CELL AEROSOLS ALL OTHER PRODUCATION		
YEAR	PROD	REL	PROD	REL	UNREL	SALES	REL	UNREL	SALES	REL	UNREL	SALES	REL	UNREL	SALES	REL	UNREL
1931	.5	.0	.5	.0	.5	.1	.0	.1	.4	.0	.4	.0	.0	.0	.0	.0	.0
1932	.1	.0	.7	.1	.6	.2	.0	.2	.5	.1	.4	.0	.0	.0	.0	.0	.0
1933	.3	.1	1.0	.2	.8	.3	.0	.2	.7	.2	.6	.0	.0	.0	.0	.0	.0
1934	.7	.2	1.7	.3	1.4	.4	.0	.4	1.3	.3	.9	.0	.0	.0	.0	.0	.0
1935	1.0	.2	2.7	.6	2.1	.7	.0	.7	2.0	.5	1.5	.0	.0	.0	.0	.0	.0
1936	1.7	.4	4.4	.9	3.5	1.1	.0	1.1	3.3	.9	2.4	.0	.0	.0	.0	.0	.0
1937	3.1	.6	7.5	1.5	5.9	1.9	.1	1.8	5.6	1.6	4.1	.0	.0	.0	.0	.0	.0
1938	2.8	.9	10.3	2.4	7.9	2.6	.1	2.5	7.7	2.3	5.4	.0	.0	.0	.0	.0	.0
1939	3.9	1.3	14.2	3.7	10.5	3.6	.2	3.5	10.6	3.6	7.1	.0	.0	.0	.0	.0	.0
1940	4.5	1.7	18.8	5.5	13.3	4.8	.2	4.5	14.0	5.2	8.8	.0	.0	.0	.0	.0	.0
1941	6.3	2.3	25.0	7.8	17.3	6.4	.3	6.0	18.7	7.4	11.3	.0	.0	.0	.0	.0	.0
1942	5.9	2.9	31.0	10.6	20.4	7.9	.5	7.4	23.1	10.1	13.0	.0	.0	.0	.0	.0	.0
1943	8.2	3.5	39.2	14.2	25.0	10.0	.7	9.3	29.2	13.4	15.6	.0	.0	.0	.0	.0	.0
1944	16.7	4.7	55.9	18.9	37.1	14.2	1.0	13.2	41.7	17.8	23.9	.0	.0	.0	.0	.0	.0
1945	20.1	6.1	76.0	25.0	51.0	19.3	1.4	17.9	56.7	23.6	33.1	.0	.0	.0	9.4	4.7	4.7
1946	16.6	11.9	92.7	36.9	55.7	21.2	1.9	19.3	62.1	30.3	31.6	.0	.0	.0	20.7	15.0	5.7
1947	20.1	19.0	112.8	56.0	56.8	23.4	2.5	20.9	68.7	38.4	30.3	.0	.0	.0	34.7	27.7	7.0
1948	24.8	22.2	137.6	78.2	59.4	26.2	3.3	22.8	76.8	47.2	29.6	.0	.0	.0	49.4	42.0	7.4
1949	26.1	24.2	163.7	102.4	61.3	29.1	4.3	24.6	85.3	56.1	29.2	.0	.0	.0	68.8	59.1	9.7
1950	34.6	27.1	198.3	129.5	68.8	32.9	5.5	27.4	96.5	64.9	31.7	.0	.0	.0	89.2	79.0	10.2
1951	36.2	30.2	234.5	159.6	74.9	36.9	6.9	30.0	108.3	73.6	34.7	.0	.0	.0	110.2	99.7	10.5
1952	37.2	31.5	271.7	191.1	80.6	41.1	8.6	32.4	120.5	82.8	37.7	.0	.0	.0	136.4	123.3	13.1
1953	46.5	35.5	318.2	226.6	91.6	46.2	10.6	35.6	135.6	92.7	42.9	.1	.0	.0	164.0	150.2	13.8
1954	49.1	40.3	367.4	266.9	100.4	51.7	12.8	38.9	151.6	103.9	47.7	.1	.1	.0	196.4	180.2	16.2
1955	57.6	45.2	425.0	312.1	112.9	58.1	15.3	42.8	170.4	116.5	53.9	.1	.1	.0	235.1	215.8	19.3
1956	68.7	52.6	493.6	364.7	129.0	65.7	18.0	47.6	192.7	130.8	62.0	.2	.2	.0	278.1	256.6	21.5
1957	74.2	59.8	567.8	424.5	143.3	73.6	21.0	52.6	215.9	146.7	69.2	.2	.3	.0	317.8	298.0	19.8
1958	73.4	62.6	641.2	487.1	154.2	82.1	24.2	58.0	240.9	164.6	76.3	.3	.4	.1	370.5	344.2	26.4
1959	87.6	69.4	728.8	556.7	172.1	91.8	27.6	64.2	265.9	184.5	81.4	.5	.6	.1	432.9	401.7	31.2
1960	99.4	83.2	828.3	639.9	188.3	102.5	31.4	71.1	292.0	206.2	85.8	.8	.9	.2	501.6	467.3	34.3
1961	108.5	93.2	936.0	733.2	203.6	113.8	35.4	78.3	320.3	229.5	90.7	1.1	1.4	.3	587.9	544.8	43.2
1962	128.1	107.1	1064.9	840.3	224.6	125.4	39.9	85.5	349.9	254.3	95.6	1.6	2.2	.6	689.6	638.8	50.8
1963	146.4	125.8	1211.3	966.1	245.1	137.9	44.8	93.1	380.9	280.3	100.6	2.8	4.0	1.2	812.0	750.8	61.2
1964	170.1	146.6	1381.4	1112.7	268.7	151.1	50.3	100.8	413.1	307.7	105.5	5.1	6.2	1.1	946.5	879.3	67.2
1965	190.1	165.6	1571.4	1278.4	293.1	166.8	56.2	110.6	450.7	336.7	114.1	7.4	8.7	1.4	1100.5	1023.5	77.0
1966	216.2	184.3	1787.6	1462.7	324.9	184.0	62.8	121.2	493.0	367.6	125.3	10.1	11.5	1.4	1276.1	1188.3	87.8
1967	242.8	208.3	2030.4	1670.9	359.4	203.6	70.1	133.5	537.7	401.0	136.8	12.9	14.6	1.7	1473.3	1374.7	98.6
1968	267.5	233.6	2297.9	1904.6	393.3	224.0	78.2	145.9	584.2	437.1	147.1	16.3	18.6	2.3	1691.8	1582.6	109.2
1969	297.3	260.1	2595.1	2164.6	430.5	246.2	87.0	159.2	636.2	476.4	159.7	21.0	23.5	2.5	1927.4	1809.6	117.8
1970	321.1	284.2	2916.2	2448.9	467.4	271.7	96.7	175.0	691.2	519.1	172.1	26.0	28.7	2.7	2177.6	2052.5	125.1
1971	341.6	304.8	3257.8	2753.7	504.1	297.9	107.3	190.6	750.9	565.3	185.7	31.4	39.0	3.6	2454.0	2315.9	138.2
1972	379.9	331.2	3637.7	3084.9	552.8	372.4	118.8	208.6	817.6	615.3	202.4	38.6	43.0	4.4	2761.0	2607.5	153.5
1973	423.3	366.5	4061.0	3451.4	609.6	361.3	131.5	229.9	891.4	669.5	221.9	47.4	52.3	4.9	3083.4	2922.2	161.2
1974	442.8	396.5	4503.8	3847.9	655.9	394.4	145.2	249.3	968.8	728.3	240.5	57.2	61.9	4.7	3352.5	3217.9	134.6
1975	382.1	383.4	4885.9	4231.3	654.5	427.1	160.1	267.0	1039.6	791.3	248.2	66.7	71.0	4.4	3626.7	3489.6	137.1
1976	410.7	364.4	5296.6	4595.7	700.9	485.3	176.9	308.4	1109.3	858.2	251.0	75.4	79.8	4.4	3846.4	3736.5	109.9
1977	382.8	344.9	5679.4	6940.7	738.8	550.7	195.2	355.6	1198.0	929.1	268.9	84.2	92.6	8.3	4031.6	3939.0	98.6
1978	359.2	309.8	6038.6	5250.5	788.2	608.3	215.1	393.2	1297.8	1003.8	294.0	100.9					

FLUOROCARBON PRODUCTION AND RELEASE SUMMARY—REPORTING COMPANIES ONLY

MILLION KILOGRAMS

	FC-11					FC-12				
	ANNUAL		CUMULATIVE			ANNUAL		CUMULATIVE		
YEAR	PRODUCTION	RELEASED	PRODUCTION	RELEASED	UNRELEASED	PRODUCTION	RELEASED	PRODUCTION	RELEASED	UNRELEASED
1931	.0	.0	.0	.0	.0	.5	.0	.3	.0	.5
1932	.0	.0	.0	.0	.0	.1	.0	.7	.1	.6
1933	.0	.0	.0	.0	.0	.3	.1	1.0	.2	.8
1934	.0	.0	.0	.0	.0	.7	.2	1.7	.3	1.4
1935	.0	.0	.1	.0	.1	1.0	.2	2.7	.6	2.1
1936	.1	.0	.2	.0	.2	1.7	.4	4.4	.9	1.5
1937	.1	.0	.3	.1	.3	3.1	.6	7.5	1.5	5.9
1938	.1	.0	.4	.1	.3	2.8	.9	10.3	2.4	7.9
1939	.1	.1	.5	.2	.3	3.9	1.3	14.2	3.7	10.5
1940	.2	.1	.7	.3	.4	4.5	1.7	18.8	5.5	13.3
1941	.3	.1	1.0	.4	.6	6.3	2.3	25.0	7.8	17.3
1942	.3	.1	1.3	.5	.8	5.9	2.9	31.0	10.6	20.4
1943	.4	.2	1.7	.7	1.0	8.2	3.5	39.2	14.2	25.0
1944	.4	.2	2.0	.9	1.1	16.7	4.7	55.9	18.9	37.1
1945	.4	.3	2.4	1.2	1.2	20.1	6.1	76.0	25.0	51.0
1946	.7	.6	3.1	1.8	1.3	16.6	11.9	92.7	36.9	55.7
1947	1.3	1.2	4.4	3.0	1.4	20.1	19.0	112.8	56.0	56.8
1948	3.0	2.3	7.4	5.3	2.1	24.8	22.2	137.6	78.2	59.4
1949	4.5	3.7	11.9	9.1	2.9	26.1	24.2	163.7	102.4	61.3
1950	6.6	5.4	18.6	14.4	4.1	34.6	27.1	198.3	129.5	68.8
1951	9.1	7.5	27.6	21.9	5.7	36.2	30.2	234.5	159.6	74.9
1952	13.6	10.8	41.2	32.7	8.5	37.2	31.5	271.7	191.1	80.6
1953	17.3	14.7	58.5	47.4	11.1	46.5	35.5	318.2	226.6	91.6
1954	20.9	18.3	79.4	65.7	13.7	49.1	40.3	367.4	266.9	100.4
1955	26.3	22.6	105.6	88.3	17.4	57.6	45.2	425.0	312.1	112.9
1956	32.5	28.2	138.1	116.5	21.6	68.7	52.6	493.6	364.7	129.0
1957	33.9	31.6	172.0	148.1	23.9	74.2	59.8	567.8	424.5	143.3
1958	29.5	29.7	201.6	177.8	23.8	73.4	62.6	641.2	487.1	154.2
1959	35.6	30.3	237.1	208.1	29.0	87.6	69.6	728.8	556.7	172.1
1960	49.7	39.7	286.9	247.9	39.0	99.4	83.2	828.3	639.9	188.3
1961	60.3	51.2	347.3	299.0	43.3	108.5	93.2	936.8	733.2	203.6
1962	78.1	64.1	425.4	363.1	62.3	128.1	107.1	1064.9	840.3	224.6
1963	93.3	78.5	518.7	441.7	77.0	146.4	125.8	1211.3	966.1	245.1
1964	111.1	93.2	629.8	534.9	94.9	170.1	146.6	1381.4	1112.7	268.7
1965	122.8	106.3	752.6	641.2	111.4	190.1	165.6	1571.4	1278.4	293.1
1966	141.0	119.0	893.7	760.2	133.4	216.2	184.3	1787.6	1462.7	324.9
1967	159.8	135.1	1053.4	895.3	158.1	242.8	208.3	2030.4	1670.9	359.4
1968	183.1	153.9	1236.5	1049.2	187.4	267.5	233.6	2297.9	1904.6	393.3
1969	217.3	178.4	1453.8	1227.6	226.2	297.3	260.1	2595.1	2164.6	430.5
1970	238.1	202.8	1691.9	1430.4	261.6	321.1	284.2	2916.2	2448.9	467.4
1971	263.2	222.7	1955.1	1653.1	302.0	341.6	304.8	3257.8	2753.7	504.1
1972	306.9	250.8	2262.0	1903.9	358.0	379.9	331.2	3637.7	3084.9	552.8
1973	349.1	286.8	2611.1	2190.7	420.3	423.3	366.5	4061.0	3451.4	609.6
1974	369.7	315.4	2980.8	2506.1	474.7	442.8	396.5	4503.8	3847.9	655.9
1975	313.1	305.0	3293.9	2811.1	482.7	382.1	383.4	4885.9	4231.3	654.5
1977	319.0	296.4	3952.6	3402.8	549.8	382.8	344.9	5679.4	4940.7	738.8
1978	295.6	273.6	4248.2	3676.4	571.8	359.2	309.8	6038.6	5250.5	788.2

FLUOROCARBON PRODUCTION AND RELEASE—EASTERN EUROPEAN COUNTRIES, ARGENTINA AND INDIA

MILLION KILOGRAMS

	FC-11					FC-12				
	ANNUAL		CUMULATIVE			ANNUAL		CUMULATIVE		
YEAR	PRODUCTION	RELEASED	PRODUCTION	RELEASED	UNRELEASED	PRODUCTION	RELEASED	PRODUCTION	RELEASED	UNRELEASED
1950	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
1951	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
1952	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
1953	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
1954	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
1955	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
1956	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
1957	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
1958	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
1959	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
1960	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
1961	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
1962	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
1963	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
1964	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
1965	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
1966	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
1967	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
1968	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
1969	1.7	.7	1.7	.7	1.0	11.3	4.4	11.3	4.4	6.9
1970	2.6	1.8	4.2	2.5	1.7	14.2	9.9	25.5	14.3	11.1
1971	2.9	2.3	7.2	4.8	2.3	15.8	12.0	41.3	26.3	15.0
1972	3.4	2.7	10.6	7.5	3.1	19.0	14.3	60.3	40.6	19.7
1973	3.6	3.0	14.2	10.5	3.7	21.8	17.1	82.0	57.7	24.3
1974	5.2	3.8	19.4	14.3	5.1	24.2	19.7	106.2	77.4	28.8
1975	7.9	5.6	27.3	19.9	7.4	30.8	23.8	137.0	101.1	35.9
1976	9.4	7.3	36.7	27.2	9.5	37.6	29.2	174.7	130.3	44.3
1977	10.1	8.3	46.8	35.5	11.3	39.1	31.9	213.8	162.2	51.5
1978	11.7	9.2	58.5	44.7	13.8	41.5	31.6	255.3	193.8	61.5
	12.3	9.9	70.9	54.6	16.2	42.0	31.1	297.3	224.9	72.4

FLUOROCARBON PRODUCTION AND RELEASE SUMMARY—WORLD TOTAL

MILLION KILOGRAMS

	FC-11					FC-12				
	ANNUAL		CUMULATIVE			ANNUAL		CUMULATIVE		
YEAR	PRODUCTION	RELEASED	PRODUCTION	RELEASED	UNRELEASED	PRODUCTION	RELEASED	PRODUCTION	RELEASED	UNRELEASED
1931	.0	.0	.0	.0	.0	.5	.0	.5	.0	.5
1932	.0	.0	.0	.0	.0	.1	.0	.7	.1	.6
1933	.0	.0	.0	.0	.0	.3	.1	1.0	.2	.8
1934	.0	.0	.0	.0	.0	.7	.2	1.7	.3	1.4
1935	.0	.0	.1	.0	.1	1.0	.2	2.7	.6	2.1
1936	.1	.0	.2	.0	.2	1.7	.4	4.4	.9	3.5
1937	.1	.0	.3	.1	.3	3.1	.6	7.5	1.5	5.9
1938	.1	.0	.4	.1	.3	2.8	.9	10.3	2.4	7.9
1939	.1	.1	.5	.2	.3	3.9	1.3	14.2	3.7	10.5
1940	.2	.1	.7	.3	.4	4.5	1.7	18.8	5.5	13.3
1941	.3	.1	1.0	.4	.6	6.3	2.3	25.0	7.8	17.3
1942	.3	.1	1.3	.5	.8	5.9	2.9	31.0	10.6	20.4
1943	.4	.2	1.7	.7	1.0	8.2	3.5	39.2	14.2	25.0
1944	.4	.2	2.0	.9	1.1	16.7	4.7	55.9	18.9	37.1
1945	.4	.3	2.4	1.2	1.2	20.1	6.1	76.0	25.0	51.0
1946	.7	.6	3.1	1.8	1.3	16.6	11.9	92.7	36.9	35.7
1947	1.3	1.2	4.4	3.0	1.4	20.1	19.0	112.8	56.0	56.8
1948	3.0	2.3	7.4	5.3	2.1	24.8	22.2	137.6	78.2	59.4
1949	4.5	3.7	11.9	9.1	2.9	26.1	24.2	163.7	102.4	61.3
1950	6.6	5.4	18.6	14.4	4.1	34.6	27.1	198.3	129.5	68.8
1951	9.1	7.5	27.6	21.9	5.7	36.2	30.2	234.5	159.6	74.9
1952	13.6	10.8	41.2	32.7	8.5	37.2	31.5	271.7	191.1	80.6
1953	17.3	14.7	58.5	47.4	11.1	46.5	34.5	318.2	226.6	91.6
1954	20.9	18.3	79.4	65.7	13.7	49.1	40.3	367.4	266.9	100.4
1955	26.3	22.6	105.6	88.3	17.4	57.6	45.2	425.0	312.1	112.9
1956	32.5	28.2	138.1	116.5	21.6	68.7	52.6	493.6	364.7	129.0
1957	33.9	31.6	172.0	148.1	23.9	74.2	59.8	567.8	424.5	143.3
1958	29.5	29.7	201.6	177.8	23.8	73.4	62.6	641.2	487.1	154.2
1959	35.6	30.3	237.1	208.1	29.0	87.6	69.6	728.8	556.7	172.1
1960	49.7	39.7	286.9	247.9	39.0	99.4	83.2	828.3	639.9	188.3
1961	60.5	51.2	347.3	299.0	48.3	108.5	93.2	936.8	733.2	203.6
1962	78.1	64.1	425.4	363.1	62.3	128.1	107.1	1064.9	840.3	224.6
1963	93.3	78.5	518.7	441.7	77.0	146.4	125.8	1211.3	966.1	245.1
1964	111.1	93.2	629.8	534.9	94.9	170.1	146.6	1381.4	1112.7	268.7
1965	122.8	106.3	752.6	641.2	111.4	190.1	165.6	1571.4	1278.4	293.1
1966	141.0	119.0	893.7	760.2	133.4	216.2	184.3	1787.6	1462.7	324.9
1967	159.8	135.1	1053.4	895.3	158.1	242.8	208.3	2030.4	1670.9	359.4
1968	184.8	154.6	1238.2	1049.9	188.3	278.8	238.0	2309.2	1909.9	400.2
1969	219.8	180.2	1458.0	1230.1	228.0	311.4	270.0	2620.6	2179.0	441.6
1970	241.1	205.1	1699.1	1435.2	263.9	336.9	296.2	2957.5	2475.2	482.3
1971	266.6	225.4	1965.7	1660.6	305.1	360.5	319.1	3318.1	2794.3	523.7
1972	310.5	253.8	2276.2	1914.5	361.7	401.7	348.3	3719.7	3142.6	577.1
1973	354.3	290.6	2630.5	2205.0	425.5	447.5	386.2	4167.2	3528.8	638.4
1974	377.6	320.9	3008.1	2526.0	482.1	473.6	420.3	4640.8	3949.1	691.7
1975	322.5	312.4	3330.6	2839.3	492.2	419.7	412.6	5060.5	4361.7	698.8
1976	349.9	303.6	3680.5	3141.9	538.6	449.8	396.3	5510.4	4758.0	752.4
1977	330.7	305.6	4011.2	3447.5	563.7	424.4	376.5	5934.7	5134.5	800.3
1978	307.9	283.6	4319.1	3731.1	588.0	401.2	340.9	6335.9	5475.4	860.6

LIST OF REPORTING COMPANIES

The following is a listing of the nineteen companies inclusive of any related subsidiaries and/or joint ventures, that reported production and release data:

1. Akzo Chemie B.V. (Holland)

2. Allied Chemical Corporation (U.S.)
   (a) Allied Chemical Canada Limited (Canada)
   (b) Quimobasicos, S.A. (Mexico)

3. Asahi Glass Co., Ltd. (Japan)

4. Australian Fluorine Chemical Pty. Ltd. (Australia)

5. Daikin Kogyo Co., Ltd. (Japan)

6. E.I. du Pont de Nemours & Company, Inc. (U.S.)
   (a) Du Pont de Nemours (Nederland) N.V.
   (b) Ducilo S.A. (Argentina)
   (c) Du Pont do Brasil S.A. (Brazil)
   (d) Halocarburos S.A. (Mexico)

7. Du Pont of Canada Limited (Canada)

8. Hoechst AG (West Germany)
   (a) Hoechst Iberia (Spain)
   (b) Hoechst do Brasil Quimica e Farmeceutica S.A.

9. Imperial Chemical Industries Limited (England)
   (a) African Explosives & Chemical Industries, Ltd.

10. I.S.C. Chemicals Ltd. (England)

11. Kaiser Aluminum & Chemical Corporation (U.S.)

12. Kali-Chemie Aktiengesellschaft (West Germany)

13. Mitsui Fluorochemicals Co., Ltd. (Japan)

14. Montedison S.P.A. (Italy)

15. Penwalt Corporation (U.S.)

16. Racon Incorporate (U.S.)

17. Rhone-Poulenc Industrie (France)

18. ShowaDenko, K.K. (Japan)

19. Ugine Kuhlmann, Produits Chimiques (France)
   (a) Pacific Chemical Industries Pty. Ltd. (Australia)
   (b) Ugimica S.A. (Spain)

20. Union Carbide Corporation (U.S.)
   (For years through 1977 only)

A TABULATION OF THE TOTAL PRODUCTION OF FC–11 ON AN ANNUAL BASIS

For the period 1931 through 1978 (from reporting companies)

Year	Production (note 1) (millions of pounds)	Year	Production (note 1) (millions of pounds)
1931	–	1954	46.1
1932	–	1955	57.9
1933	–	1956	71.6
1934	.1	1957	74.8
1935	.1	1958	65.1
1936	.2	1959	78.4
1937	.3	1960	109.6
1938	.2	1961	133.3
1939	.2	1962	172.2
1940	.4	1963	205.7
1941	.6	1964	244.9
1942	.7	1965	270.8
1943	.9	1966	310.9
1944	.8	1967	352.2
1945	.8	1968	403.7
1946	1.6	1969	479.0
1947	2.9	1970	525.0
1948	6.6	1971	580.2
1949	9.9	1972	676.5
1950	14.6	1973	769.6
1951	20.0	1974	815.1
1952	29.9	1975	690.2
1953	38.1	1976	749.2
		1977	703.2
		1978	651.6
		Total production	9,365.7

NOTE 1 — PRODUCTION AMOUNTS

These amounts exclude any production of a product used as an intermediate for chemical or plastic production.

A TABULATION OF THE TOTAL PRODUCTION OF FC–12 ON AN ANNUAL BASIS

For the period 1931 through 1978 (from reporting companies)

Year	Production (note 1) (millions of pounds)
1931	1.2
1932	.3
1933	.7
1934	1.5
1935	2.2
1936	3.8
1937	6.8
1938	6.2
1939	8.7
1940	10.0
1941	13.8
1942	13.1
1943	18.1
1944	36.9
1945	44.3
1946	36.7
1947	44.4
1948	54.6
1949	57.6
1950	76.2
1951	79.9
1952	82.1
1953	102.5
1954	108.3
1955	127.0
1956	151.4
1957	163.5
1958	161.9
1959	193.1
1960	219.2
1961	239.2
1962	282.4
1963	322.8
1964	375.0
1965	419.0
1966	476.6
1967	535.2
1968	589.7
1969	655.4
1970	707.9
1971	753.0
1972	837.5
1973	933.3
1974	976.2
1975	842.3
1976	905.5
1977	844.0
1978	791.9
Total production	13,312.9

NOTE 1 — PRODUCTION AMOUNTS

These amounts exclude any production of a product used as an intermediate for chemical or plastic production.

A TABULATION OF THE DEVIATION ESTIMATE OF TOTAL PRODUCTION OF FC–11 AND FC–12 APPLYING THE SUBMITTED ESTIMATE OF PROBABLE ERROR

(From reporting companies)

(Millions of pounds)

Chemical	Total production	Deviation (note 2)
FC–11	9,365.7	129.9
FC–12	13,312.9	164.6

NOTE 2 – CALCULATION OF DEVIATION

The deviation presented in Schedule 4 was computed by the square root of the sum of the squares method. A 95% confidence level was used for this calculation.

A TABULATION OF THE TOTAL FC–11 AND FC–12 SALES BY CATEGORY FOR YEAR 1978

(From reporting companies)

(Millions of pounds)

Sales

	Refrigeration hermetically sealed	Refrigeration non-hermetically sealed	Blowing agent closed cell foam	Blowing agent open cell foam
FC–11	12.0	48.0	133.4	104.9
FC–12	126.9	220.0	36.7	15.5
	138.9	268.0	170.1	120.4

	Aerosol propellant	All other uses	Total sales
FC–11	316.4	36.8	651.5
FC–12	360.9	24.5	784.5
	677.3	61.3	1,436.0

A TABULATION OF THE TOTAL FC–11 AND FC–12 SALES BY HEMISPHERE FOR THE PERIOD 1931 THROUGH 1978

(from reporting companies)

(Millions of pounds)

	Northern Hemisphere	Southern Hemisphere	Total Sales
FC–11	9,016.3	334.6	9,350.9
FC–12	12,703.9	570.3	13,274.2

A TABULATION OF THE TOTAL FC–11 SALES FOR REFRIGERATION AND CLOSED CELL FOAM BLOWING AGENT ON AN ANNUAL BASIS

For the period 1956 through 1978 (from reporting companies)

(Millions of pounds)

Year	Sales			
	Refrigeration hermetically sealed	Refrigeration non-hermetically sealed	Blowing agent closed cell foam	Total sales (three uses)
1978	12.0	48.0	133.4	193.4
1977	10.8	43.7	132.3	186.8
1976	11.5	47.8	114.8	174.1
1975	3.8	32.8	122.3	158.9
1974	3.4	41.9	138.5	183.8
1973	2.9	40.1	136.8	179.8
1972	2.2	35.0	114.0	151.2
1971	1.7	31.0	93.8	126.5
1970	1.4	27.9	75.3	104.6
1969	1.2	25.8	69.8	96.8
1968	.8	22.3	56.0	79.1
1967	.7	21.4	43.5	65.6
1966	.7	20.5	37.1	58.3
1965	.7	16.7	29.6	47.0
1964	.6	15.2	24.6	40.4
1963	.5	14.6	18.2	33.3
1962	.2	13.4	12.5	26.1
1961	.4	12.3	6.1	18.8
1960	.4	10.5	4.6	15.5
1959	.2	8.5	2.1	10.8
1958	.2	7.8	1.4	9.4
1957	.2	6.3	1.3	7.8
1956	.1	4.5	1.0	5.6
Total	56.6	548.0	1,369.0	1,973.6

A TABULATION OF THE TOTAL FC–12 SALES FOR REFRIGERATION AND CLOSED CELL FOAM BLOWING AGENT ON AN ANNUAL BASIS

For the period 1956 through 1978 (from reporting companies)

(Millions of pounds)

Year	Sales: Refrigeration hermetically sealed	Sales: Refrigeration non-hermetically sealed	Sales: Blowing agent closed cell foam	Total sales (three uses)
1978	126.9	220.0	36.7	383.6
1977	144.4	195.7	19.5	359.6
1976	128.2	153.6	14.2	296.0
1975	72.0	156.1	20.9	249.0
1974	73.0	170.7	21.7	265.4
1973	74.7	162.5	19.3	256.5
1972	65.2	147.1	16.0	228.3
1971	57.7	131.7	11.8	201.2
1970	56.2	121.3	11.1	188.6
1969	48.9	114.5	10.3	173.7
1968	45.0	102.5	7.5	155.0
1967	43.3	98.7	6.1	148.1
1966	37.8	93.1	6.1	137.0
1965	34.7	82.9	4.9	122.5
1964	29.0	71.0	5.1	105.1
1963	27.6	68.5	2.6	98.7
1962	25.7	65.2	1.2	92.1
1961	24.8	62.3	.7	87.8
1960	23.5	57.5	.6	81.6
1959	21.4	55.1	.4	76.9
1958	18.9	55.3	.2	74.4
1957	17.4	51.0	.2	68.6
1956	16.8	49.3	.1	66.2
Total	1,213.1	2,485.6	217.2	3,915.9

A TABULATION OF THE TOTAL PRODUCTION OF FC–11 AND FC–12 ON AN ANNUAL BASIS FROM FOUR INDIA AND ARGENTINA COMPANIES (NOTE 3)

(Millions of pounds)

	FC–11	FC–12
1968	.1	.6
1969	.1	.7
1970	.1	1.0
1971	.2	1.4
1972	.3	1.9
1973	1.3	2.8
1974	1.7	3.7
1975	1.8	3.7
1976	1.8	5.6
1977	4.4	9.0
1978	4.4	9.0
	16.2	39.4

NOTE 3–INDIA AND ARGENTINA PRODUCTION AMOUNTS

The amounts included were compiled from data submitted or estimated for the following companies:

(1) Tool Research S.A.

(2) I.R.A., S.A.

(3) Everest Refrigerents, Ltd.

(4) Navin Fluorine Industries

A TABULATION OF THE ESTIMATED PRODUCTION OF FC–11 AND FC–12 OF EASTERN EUROPEAN COUNTRIES (NOTE 4)

(Millions of pounds)

		Production
FC–11	(For the estimated period 1950—1978)	436.1
FC–12	(For the estimated period 1949—1978)	628.2

NOTE 4–PRODUCTION OF THE EASTERN EUROPEAN COUNTRIES

The data reported as the estimated production in the eastern European countries was compiled from averages of the estimates of production by the reporting companies who responded to the questionnaire on production in the eastern European countries.