# (PROCEEDINGS OF THE) UNEP/EEC/USA ECONOMIC WORKSHOP ON CHLOFLUORO CARBONS

# UNEP / EEC / USA ECONOMIC WORKSHOP ON CHLOROFLUOROCARBONS (CFC'S), 8-12 SEPTEMBER, 1986, VIRGINIA, UNITED STATES OF AMERICA

## PART 1

# UNEP ECONOMIC WORKSHOP

September 8-12, Leesburg, Va.

## AGENDA

**Sunday - September 7th**

| | |
|---|---|
| 7:30 p.m. - 9:30 p.m. | Steering Committee (UK Chair)<br>TOPICS: Final Agenda<br>Organization of Sessions<br>Allocation of papers to specific sessions |

**Monday - September 8th**

| | |
|---|---|
| 9:00 a.m. - 10:00 a.m. | Opening Remarks<br>-UNEP<br>-Workshop Chair (U.S.) |
| 10:00 a.m. - 10:30 a.m. | COFFEE BREAK |
| 10:30 a.m. - 11:00 a.m. | Steering Committee Report |
| 11:00 a.m. - 12:30 p.m. | TOPIC 6A: Effects on Demand (U.S. Chair) |
| 12:30 p.m. - 1:30 p.m. | LUNCH |
| 1:30 p.m. - 3:00 p.m. | 6A - Effects on Demand (cont.) |
| 3:00 p.m. - 3:30 p.m. | COFFEE BREAK |
| 3:30 p.m. - 4:00 p.m. | 6A - Effects on Demand (completion) |
| 4:00 p.m. - 5:00 p.m. | 6B - Effects on Atmosphere and Environment (EEC Chair) |
| 6:00 p.m. | BBQ |

**Tuesday - September 9th**

| | |
|---|---|
| 8:30 a.m. - 10:00 a.m. | 6B - Effects on Atmosphere and Environment (cont.) |

Tuesday cont.

| | |
|---|---|
| 10:00 a.m. - 10:30 a.m. | COFFEE BREAK |
| 10:30 a.m. - 12:00 | 6B - Effects on Atmosphere and Environment (completion) |
| 12:00 - 1:00 p.m. | LUNCH |
| 1:00 p.m. - 3:00 p.m. | 6C - Cost Effectiveness (UK Chair) |
| 3:00 p.m. - 3:30 p.m. | COFFEE BREAK |
| 3:30 p.m. - 5:30 p.m. | 6C - Cost Effectiveness (completion) |

EVENING FREE

Wednesday - September 10th

| | |
|---|---|
| 8:30 a.m. - 10:00 a.m. | 6D - Equity, Trade & Implementation (U.S. chairs) |
| 10:00 a.m. - 10:30 a.m. | COFFEE BREAK |
| 10:30 a.m. - 12:00 NOON | 6D - Equity, Trade & Implementation (cont) |
| 12:00 NOON - 1:00 p.m. | LUNCH |
| 1:00 p.m. - 2:00 p.m. | 6D - Equity, Trade & Implementation (completion) |
| 2:30 p.m. - 6:00 p.m. | TOUR OF WASHINGTON, D.C. |
| 6:00 p.m. - 9:00 p.m. | Reception at State Dept. Annex |

### Thurday - September 11th

| | |
|---|---|
| 8:30 a.m. - 10:00 a.m. | Evaluation of Control Strategies against Criteria (UNEP Chair?) |
| 10:00 a.m. - 10:30 a.m. | COFFEE BREAK |
| 10:30 a.m. - 12:00 | Evaluation of Control Strategies against Criteria (cont.) |
| 12:00 - 1:00 p.m. | LUNCH |
| 1:00 p.m. - 3:00 p.m. | Evaluation of Control Strategies against Criteria (cont.) |
| 3:00 p.m. - 3:30 p.m. | COFFEE BREAK |
| 3:30 p.m. - 5:00 p.m. | Evaluation of Control Strategies against Criteria (completion) |
| 6:00 p.m. | OATLAND'S PLANTATION TRIP |

### Friday - September 12th

| | |
|---|---|
| 8:30 a.m. - 10:00 a.m. | Conference Report (chair?) |
| 10:00 a.m. - 10:30 a.m. | COFFEE BREAK |
| 10:30 a.m. 12:00 NOON | Conference wrap-up (Workshop Chair leads) |
| 12:00 NOON | LUNCH |

* * *

Xerox's Schedule for Breaks and Meals (at their facilities)

| | |
|---|---|
| Breakfast: | 7:00 a.m. - 8:00 a.m. |
| Lunch | 11:30 a.m. - 1:15 p.m. |
| Dinner | 5:30 p.m. - 7:30 p.m. |
| Morning Break | 9:30 a.m. - 10:30 a.m. |
| Afternoon Break | 2:30 p.m. - 3:30 p.m. |

## UNEP Economic Workshop
## on
## Protecting the Ozone Layer
## Part II

## PARTICIPANTS LIST

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## Other Organizations

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Europur Technical Committee
(FEA)

Mr. Richard C. Knollys
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| | Mr. Donald G. Roberts<br>General Manager<br>Australian Fluorine Chemicals<br>151 Flinders Street<br>Melbourne 3000 |

## Additional Participants

| | |
|---|---|
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| Air/Water Pollution Report | Ms. Carolyn Long |
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| MUMA | Mr. Gerald F. Stofflet |
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| ABC | Ms. Sharon Young<br>ABC News<br>1717 DeSales<br>Washington, DC 20036 |

## WORKSHOP 2 PAPERS

### TOPIC 6a

**UNITED STATES**

1. Gibbs, M.J., (ICF Incorporated), "Control Strategy Options: Definition and Partial Evaluation" (also listed under Topic 6b)

2. Hoffman, J.S., (U.S. EPA), "The Impact of Control Strategy Alternatives in Meeting Future Demands for Chlorofluorocarbons"

**ATOCHEM**

3. Dupuy, P.M., (Professor at the University and at Paris Institute of Political Science), "The World Ceiling Production System of Chlorofluorocarbons and its Advantages" (also listed under Topic 6d)

**FEAA**

4. Knollys, R.C., "Impacts of Possible Strategies Controlling CFCs from a User Industry Standpoint"

**UNITED STATES**

5. Hammitt, J.K., (The RAND Corporation), "The Timing of Regulations to Prevent Stratospheric Ozone Depletion" (not available as of 9/5/86)

6. Wirth, D., and D. Doniger, (NRDC), "Anticipation of a CFC Phaseout: Who Will Take the Heat?" (not available as of 9/5/86)

**WORLD RESOURCES INSTITUTE**

7. Mintzer, I. "Limiting the Buildup: An Investigation of Policies to Control the Increase of Chlorine in the Stratosphere"

### TOPIC 6b

**COMMISSION OF THE EUROPEAN COMMUNITIES**

8. Brasseur, G., and De Rudder, A., "The Potential Impact on Atmospheric Ozone and Temperature of Increasing Trace Gas Concentrations" and C.F.P. Bevington. "Overview Paper on Topic 6B" 8bis

9. Based on calculations of Guy Brasseur and Anne De Rudder, "Potential Ozone Column Responses to Alternative Chlorofluorocarbon Control Strategies"

**FLUOROCARBON PROGRAM PANEL**

10. "Atmospheric Ozone: Response to Combined Emissions of CFCs, N2O, CH4, and CO2"

**NORWAY**

11. Isaksen, I.S.A., (Institute of Geophysics, University of Oslo), "Ozone Perturbations Studies in a Two-Dimensional Model with Temperature Feedback in the Stratosphere Included"

**UNITED STATES**

12.a Gibbs, M.J., (ICF Incorporated), "Control Strategy Options: Definition and Partial Evaluation"

12 b. Gibbs, M.J., (ICF Incorporated), "Analysis of the Importance of Various Design Factors in Determining the Effectiveness of Control Strategy Options"

13. Hoffman, J.S., (U.S. EPA), "Analysis of Stringency of Control Strategies to Achieve Alternative Ozone Depletion Limits"

14. Seidel, S., D. Tirpak, and J.S. Hoffman (U.S. EPA), "Potential Health and Environmental Effects of Ozone Depletion and Climate Change"

## TOPIC 6c

**UNITED KINGDOM**

15. Ambler, D.M., (Department of Trade and Industry, London), "An Assessment of the Economic Costs of Alternative Regulatory Strategies"

**UNITED STATES**

16. Anderson, Stephen O., (U.S. EPA), "Factors that Affect the Costs of Protecting the Stratosphere"

**BRITISH RUBBER MANUFACTURERS' ASSOCIATION**

17. "Chlorofluorocarbons in Flexible Foam Manufacture"

**JAPAN FREON GAS ASSOCIATION and JAPAN AEROSOL ASSOCIATION**

18. Kurosawa, K., (Steering Committee Chairman, JFGA), and K. Imazeki (Technical Committee Chairman, JAA), "Economy of the reduction measures which have been proposed as well as the newly proposed measure"

**ITALY**

19. Valiani, R., (LUISS), "Economic Instruments for the Control of CFCs"

**WORLD RESOURCES INSTITUTE**

20. Miller, A.S., (Visiting Assistant Professor, Washington College of Law, American University), "The Economic Risk Associated with Alternative Strategies to Protect the Ozone Layer"

## TOPIC 6d

**ATOCHEM**

21. Dupuy, P.M., (Professor at the University and at Paris Institute of Political Science), "The World Ceiling Production System of Chlorofluorocarbons and its Advantages"

**FEDERAL REPUBLIC OF GERMANY**

22. Gundling, L., (Research Fellow, Max-Planck Institute for Comparative Public and International Law, Heidelberg; and Lecturer at the University of Heidelberg), "The Global Production Capacity Cap: Equity, Trade Impacts, Implementation and Monitoring"

**UNITED STATES**

23. Anderson, Stephen O., (U.S. EPA), "Equity of Ozone Protection Strategies"

**SWEDEN**

24. "Net Use of CFCs -- A Technical Discussion Report".

**UNITED STATES**

25. Anderson, Stephen O., (U.S. EPA), "Trade Issues Related to CFC International Control to Protect the Ozone Layer"

## THURSDAY SESSION

**COMMISSION OF THE EUROPEAN COMMUNITIES**

26. Pearce, D.W., (Department of Economics, University College London), "The European Community Approach to the Control of Chlorofluorocarbons"

**CANADA**

27. Buxton, G.V., A. Chisolm, and J. Carbonneau (Environment Canada), "A Canadian Contribution to the Consideration of Strategies for Protecting the Ozone Layer"

**UNITED STATES**

28. Seidel, S.R., (U.S. EPA), "Analysis of Global Application of an EEC-Based Production Capacity Cap"

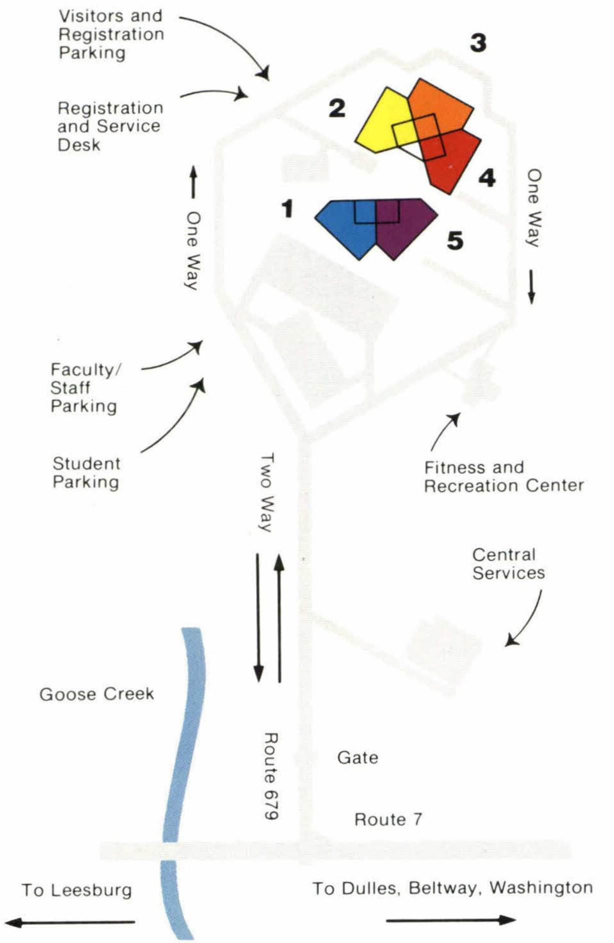
**JAPAN**

29. Araki, I., "A Possible Regulatory Strategy for the Control of Chlorofluorocarbons"

AUSTRIA

30. Austria, Federal Environmental Protection Agency.
Austrian Contribution to UNEP Workshop on CFC's
Part II (Leesburg)

## XICTMD



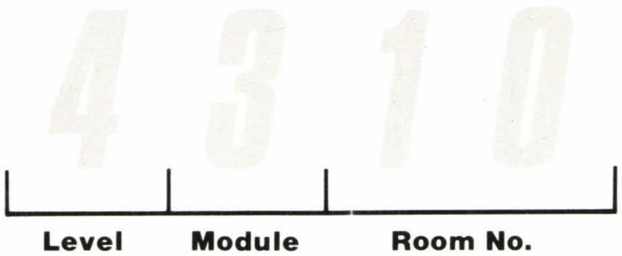
## Departure Information

Normal Friday afternoon departures:

Transportation leaves from all three Plazas at 3:00 P.M. for National Airport and 3:30 P.M. to Dulles Airport. Sign-out locations are by the stairs in the Student Dining Room for Plazas A and B serving modules 2, 3, and 4 and at Plaza C, serving modules 1 and 5. When you sign-out and turn in your room key a transportation pass will be given to you.

All other departures except Friday afternoon will leave from bus parking outside the Service Desk (module 1). Sign-out and turn in your room key at the Service Desk and a transportation pass will be provided.

## oom Numbering



All rooms are assigned a 4 digit number. In the example above, the room is located on the 4th level, module 3 (orange). From that point you can easily find the 10th room in that area.

| Class-rooms | Module | Floor |
|---|---|---|
| 2100s | 1 | Commons |
| 2200s | 2 | Commons |
| 2400s | 4 | Commons |
| 2500s | 5 | Commons |
| 3100s | 1 | 3 |
| 3200s | 2 | 3 |
| 3300s | 3 | 3 |
| 3400s | 4 | 3 |
| 3500s | 5 | 3 |
| 4100s | 1 | 4 |
| 4200s | 2 | 4 |
| 4300s | 3 | 4 |
| 4400s | 4 | 4 |
| 4500s | 5 | 4 |

**Emergency**
**Dial 1111**

| Extension | Commons Level | Module | Area |
|---|---|---|---|
| 6259 | Hair Styling Salon | 4 | A |
| | Cocktail Lounge | 2 | B |
| | Dining Room | 3 | A&B |
| | Faculty Offices | 1 | B |
| | | 2 | A |
| | | 4 | B |
| | | 5 | A&B |
| 6300 | Medical | 4 | A |
| 6259 | Gift Shop/Newsstand | 1 | A |
| 6260 | Service Desk | 1 | A |
| 1100 | Security | Admin | A |

**Symbols**
Thruwalk — 3rd floor ▬
Entrance ➤

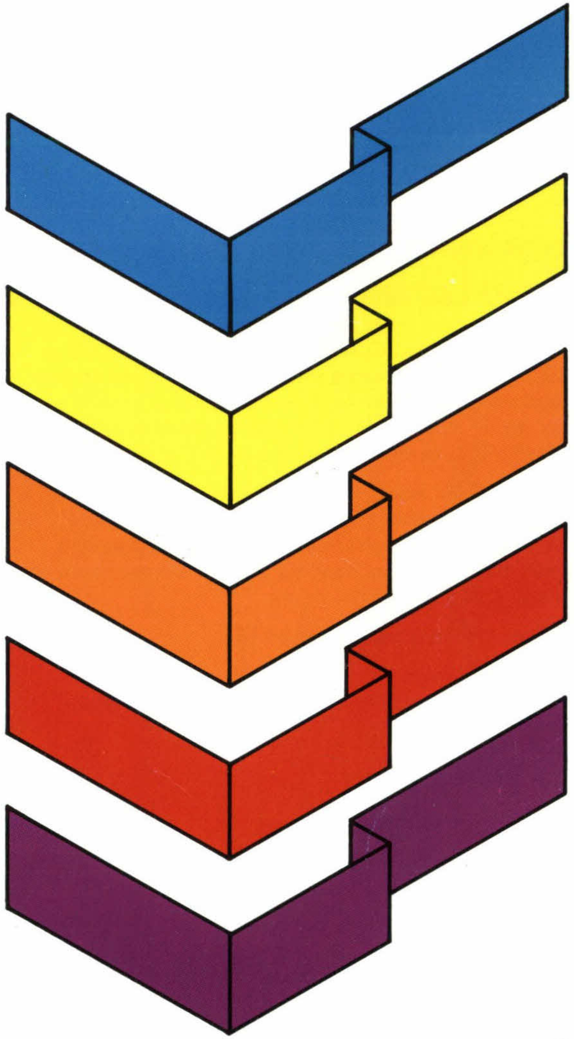
**Color Directory**
Module 1 🟦
Module 2 🟨
Module 3 🟧
Module 4 🟥
Module 5 🟪

XEROX

# Directory

3350

*International Center for Training and Management Development*



D

## Registration Procedures

*Arriving by Automobile:*

- Proceed to Visitors Parking Lot (15 minute parking limit).
- Walk down steps to Registration Service Desk in Module 1 (blue) and pick up registration package and residence room key.
- Drive to Plaza A, B, or C as indicated on the tag of your room key. Park in designated area of Plaza (parking limit 15 minutes) while unloading and carrying baggage to room.
- Immediately move car to appropriate parking lot:

  Residence Parking Permit — Student Parking Lot

  Staff Parking Permit — Staff Parking Lot

## Color Coding

There are five living/learning modules color coded as shown. Residence rooms are located along the outside perimiter with classrooms, laboratories and commons areas within the Center. All modules are connected by thruwalks to provide easy access from one to another.

Color will help you! Your residence key tag, your residence room door, and even your window shades (visible from outside the building) are color matched. Identify the education areas by colored stripes along the corridor above classroom doors.

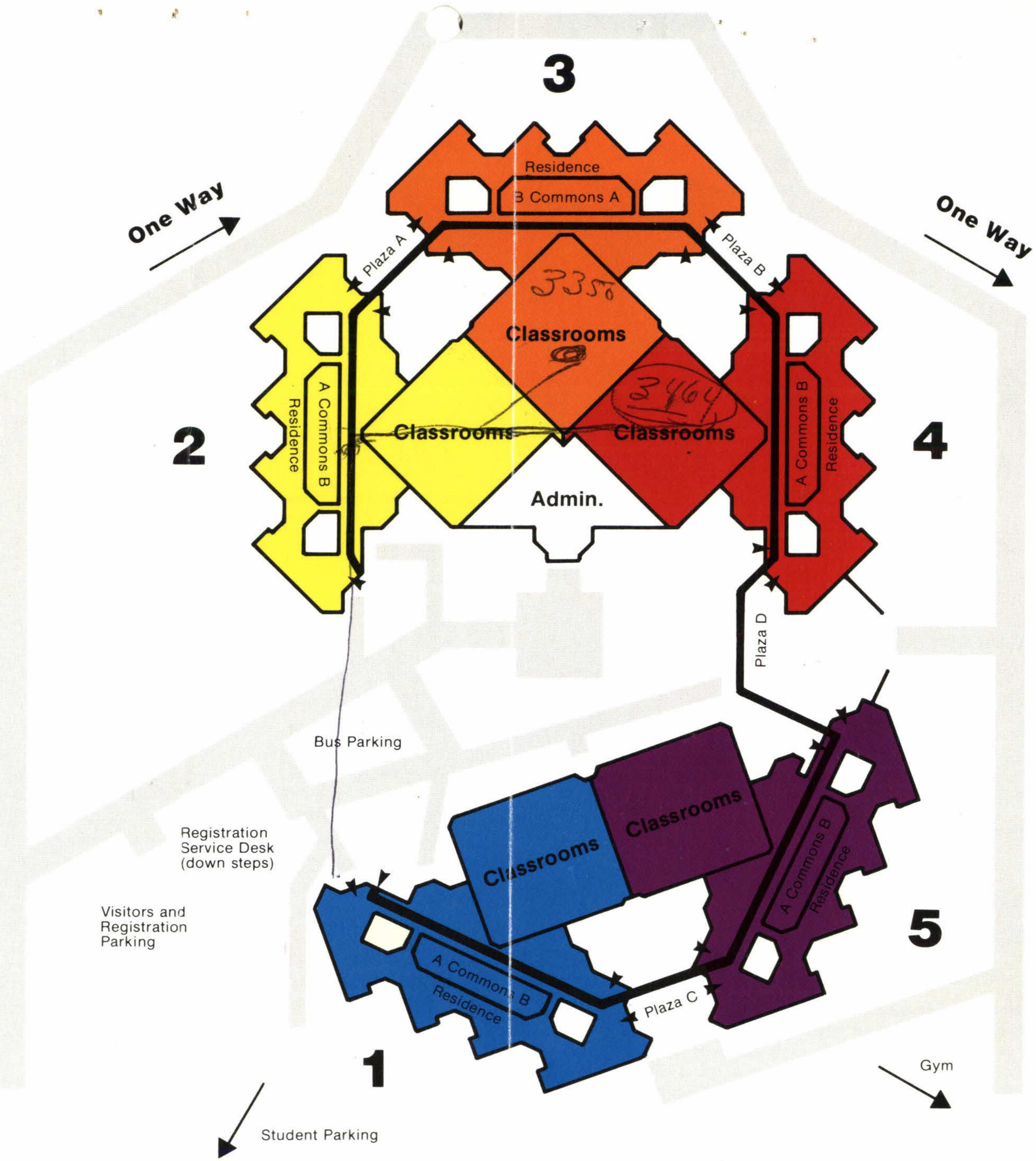
Personal mail may be addressed to:

Xerox Corporation
International Center for Training and Management Development
P.O. Box 2000
Leesburg, Virginia 22075

The Center telephone number is:
(703) 777-8000

## Dress Code

In keeping with the Xerox policy, regular business attire will be worn during normal business hours (8:00 A.M. to 5:00 P.M.).



## NOTE TO ALL PRESS AND PARTICIPANTS

Members of the press are advised that the entire workshop may only be reported as background, i.e., individuals and nations should not be specifically quoted or identified.

These guidelines have been established to enable free and open discussion among experts who are expressing their personal views, not the policy positions of their governments or sponsoring institutions.

Many participants in this workshop are not familiar with U.S. press traditions. Therefore, journalists desiring personal interviews are requested to clearly establish with interviewees at the outset whether their remarks are for background only or on the record.

# THE IMPACT OF CONTROL STRATEGY ALTERNATIVES IN MEETING FUTURE DEMANDS FOR CHLOROFLUOROCARBONS

by
John S. Hoffman*
U.S. Environmental Protection Agency

for
TOPIC 6A
UNEP WORKSHOP ON PROTECTING THE OZONE STRATOSPHERIC LAYER

Leesburg, Virginia
September 8-12, 1986

* This analysis contained in this paper is presented only for the purpose of technical discussion at this workshop. It does not, in any way, represent the official policy of the United States government.

* * * DRAFT: SUBJECT TO REVISION * * *

# THE IMPACT OF CONTROL STRATEGY ALTERNATIVES IN MEETING FUTURE DEMANDS FOR CHLOROFLUOROCARBONS

## ABSTRACT

A number of studies[1] have shown that the global demand for chlorofluorocarbons is likely to increase. Because CFCs persist in the atmosphere for decades and even centuries, the extent of future demand that can safely be met depends in part on emissions reductions made in the next ten to fifteen years. This paper analyzes the relationship between actions in the next fifteen years and the future demand that can be met, under a variety of assumptions.

* * * DRAFT: SUBJECT TO REVISION * * *

## CFCS PERSIST IN THE ATMOSPHERE

Unlike pollutants such as particulates that fall out of the atmosphere within weeks, CFCs remain in the atmosphere for long periods. Figure 1 gives the lifetimes as estimated by the Atmospheric Lifetime Experiment and other researchers.

### FIGURE 1

### CFCs PERSIST IN THE ATMOSPHERE

| Compound | Lifetime | Source |
|---|---|---|
| CFC-11 | 75 years | NASA (1986) |
| CFC-12 | 110 years | NASA (1986) |
| CFC-113 | 90 years | NAS (1984) |
| CFC-22 | 20 years | NAS (1984) |

Figure 1 shows the atmospheric lifetimes of CFCs as estimated by the Atmospheric Lifetime Experiment and other researchers.

A lifetime of "L" years means that 1/e (approximately 37%) of the releases in a given year will still be in the atmosphere "L" years later. CFC-12, for example, has a lifetime of 110 years. If 100 kilograms were released in 1987, 37 kilograms would still be in the atmosphere in the year 2097, 110 years later. Figure 2 shows the emissions loading that will remain in the atmosphere in the years 2000 and 2030, 13 and 43 years after a release in 1987.

## FIGURE 2

## ATMOSPHERIC LOADING FROM A 100 KG RELEASE IN 1987

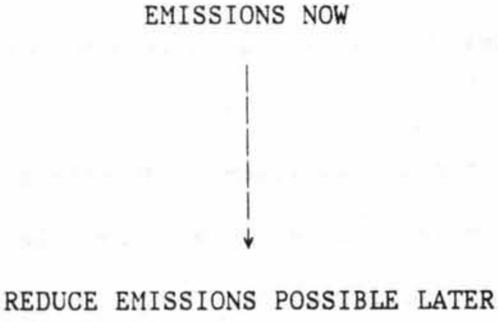
| | Initial Release | Kilograms Remaining in | |
|---|---|---|---|
| | 1987 | 2000 | 2030 |
| CFC-11 | 100 | 84 | 56 |
| CFC-12 | 100 | 89 | 68 |
| CFC-113 | 100 | 87 | 62 |
| CFC-22 | 100 | 52 | 12 |

Figure 2 shows the amount of CFCs that would remain in the atmosphere in 2000 and 2030, 13 and 42 years after a hypothetical release of 100 kilograms in 1987.

## EMISSIONS MADE IN THE SHORT TERM REDUCE EMISSIONS THAT WOULD HAVE TO BE MADE IN THE LONG TERM

Because emissions accumulate in the atmosphere, any limit that may ultimately be placed on concentrations will reduce the total emissions that can be allowed into the atmosphere. As Figure 3 states, emissions made in the short term use up some of the atmosphere's carrying capacity and necessarily displace emissions in the future.

FIGURE 3



For example, suppose we wanted to prevent concentrations from rising above current levels. Because past emissions are mostly still in the atmosphere we would have to severely curtail current emissions, as shown in Figure 4.

Clearly, the fact that current emissions are greater than current losses places us far from equilibrium and creates tremendous momentum for increasing atmospheric concentrations. A given increase in surface emissions will lead to a greater percent increase in atmospheric concentrations. Even constant emissions will lead to an increase in concentrations. For example, total emissions of CFC-11 and CFC-12 remained approximately constant from the early 1970's to the early 1980's (CMA, 1985), but their atmospheric concentrations doubled (Rasmussen and Khalil, 1986).

Because emissions accumulate in the troposphere, today's emissions may compete with future emissions if society were to settle on an allowable burden of CFCs in the atmosphere. For example, suppose that society wished to limit CFC-12 concentrations to 75% of the level in 2030 that would otherwise occur if emissions were to grow at 2.5%. If action were taken in 1987, there would still be room to meet future increases in demand. Growth in emissions could continue, but at a moderated rate of 1.12% per year. If actions were postponed to 2001, there would be no room to meet increase in demand. An emissions cut of 0.15% per year would be necessary to meet the concentrations limit.

Another way to think about this issue is to consider some scenarios and alternative control strategies that achieve comparable levels of ozone depletion. Figure 5 shows production for the period 1986 to 2025 for unrestrained growth of 2.5%, along with production that would occur in the 2010-2025 time frame for two different control strategies.

FIGURE 4a

CFC-12 EMISSION REDUCTION NECESSARY TO HOLD CONCENTRATIONS CONSTANT

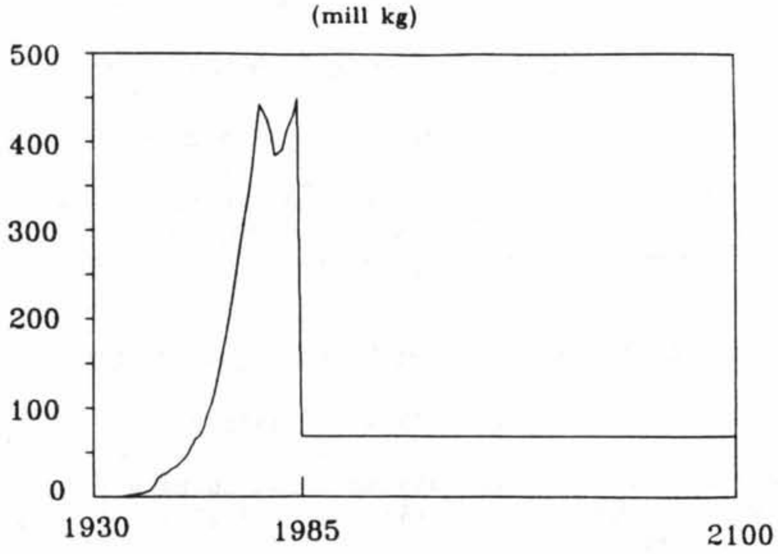
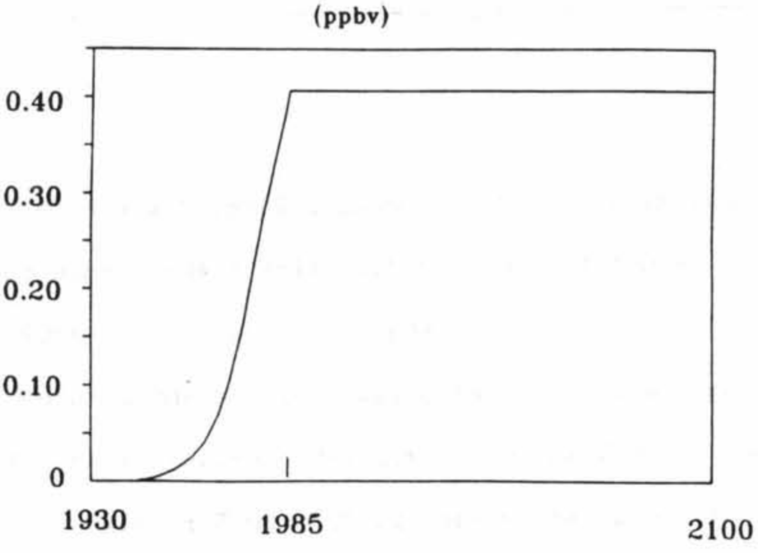


FIGURE 4b

CONSTANT CONCENTRATIONS OF CFC-12



Figures 4a and 4b show that CFC-12 emissions would have to be cut approximately 85% in order to hold atmospheric concentrations constant.

## FIGURE 5

## WAITING INCREASES THE SEVERITY OF ACTIONS
(Cumulative emissions in millions of kilograms)

UNRESTRAINED GROWTH AT 2.5%

| | 1985-2025 | 1985-2010 | 2010-2025 |
|---|---|---|---|
| NO ACTION | No cutback (59,548) | No cutback (30,590) | No cutback (28,960) |

POLICIES WITH APPROXIMATELY EQUAL EFFECTS

| | 1985-2025 | 1985-2010 | 2010-2025 |
|---|---|---|---|
| EARLY ACTION (0.85 kg per capita by 1991; aerosol ban)[1] | 31% cutback (40,675) | 24% cutback (23,150) | 34% cutback (19,060) |
| LATE ACTION (wait to 2008; cap at 1985 level)[1] | 31% cutback (40,975) | 7% cutback (28,450) | 58% cutback (12,230) |

[1] CFC 11, 12 only.

Clearly, the policies implemented make a large difference in the percent of demand that can be met in the 2010-2025 time frame. Both policies reach a cutback of 31% over 1985-2025. Waiting to take action to 2008 requires a 50% cut in a single year, and a 64% reduction over the entire use of CFCs. The earlier action in Figure 5 increases available emissions in 2010-2025 by 50%. The magnitude of the reduction needed in 2010-2015 is 34%, instead of 58%. Since deeper cuts are likely to require higher value added uses, the implciation of waiting is that postponing controls will reduce the ability to meet high value added demands later on.

## CONCLUSION

Any control strategy that fails to create incentives for reducing emissions in early years will reduce the capacity to meet future demands for CFCs for high value added uses.

## NOTES

[1] Projections of future demand for CFCs was a topic at the United Nations Environment Programme Workshop in the Ozone Layer, held in Rome, Italy from May 26-30, 1986. The papers that were submitted to the workshop were summarized in U.S. EPA, (1986), "Summary Paper for Topic #2: Projections of Demand for CFCs". Major individual papers include:

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* EUROPEAN COUNCIL OF CHEMICAL MANUFACTURERS FEDERATION
  European Fluorocarbon Technical Committee (EFCTC) (1985), Halocarbon Trend Study 1983 - 1995, EFCTC is a CEFIC Sector Group.

* EEC
  Bevington, C.F.P. (1986), Projections of Production Capacity, Production and Use of CFCs in the Context of EEC Regulations, Metra Consulting Group Ltd., prepared for the European Economic Community.

* FEDERATION OF EUROPEAN AEROSOL ASSOCIATIONS
  Knollys, R.C. (1986), Fluorocarbon Use in Aerosols -- A Trend Study 1984-1995 in Member Countries of the European Economic Community, prepared on behalf of The Federation of European Aerosol Associations.

* JAPAN
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## NOTES (continued)

* UNITED STATES

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Rasmussen, R.A., and M.A.K. Khalil (1986), "Atmospheric Trace Gases: Trends and Distributions Over the Last Decade", Science (232), 1623-1624.

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**WORKSHOP ON THE CONTROL OF CHLOROFLUOROCARBONS**

Dear Sirs,

You will find hereby, a paper from Professor DUPUY, submitted by french Government, related to topics 6a and 6d of the above workshop.

Yours sincerely,

P] M. VERHILLE

UNEP

WORKSHOP II

Leesburg (Virginia)

8 / 12 September 1986

# THE WORLD CEILING PRODUCTION SYSTEM OF CHLOROFLUOROCARBONS AND ITS ADVANTAGES

by P.M. DUPUY

(Professor at the University and at Paris Institute of
Political Science)

# THE WORLD CEILING PRODUCTION SYSTEM OF CFC AND ITS ADVANTAGES

## SUMMARY

Only a CFC 11 and 12 world ceiling production system contribute to a priori secure environmental protection of both the ozone layer and the ground temperature increase. It in fact forbids all consumption bolts and obliges humanity to preventively realize the potential danger they are facing.
The world production level must be regulated according to results coming from a monitoring system of high atmosphere. This system is thus in a permanent watch posit and by this way ensures the dependency of the economical restrictions brought about by any regulation to the imperatives of the planet's environment.
The production level fixed by the different States or groups of States is scientific ly controled through the monitoring system of CFC concentrations at ground level. It must moreover be much differentiated between AC and developing countries so that the first ones only will be affected and will generate the technical research for substitute products or processes achieving in this way successively the shift, the blocking and the lowering of the CFC world consumption.
This is created :

- an efficient system both on the ecological and on the economical points of view : flexible, liberal, technologically stimulating,
- an equitable system which takes into account the different development stages of the countries while supplying a global answer to a global problem.
- an acceptable system to the different states or groups of states.

Such a system naturally comes into the continuation of the Vienna Convention. It separates the normative functions from the scientific ones. It can later on be adapted to the "settling" of other similar problems.

P.M. DUPUY

I. INTRODUCTION

II. WORLD CEILING PRODUCTION SYSTEM FOR CFC 11 AND 12 (general introduct

III. QUALITIES OF A CEILING PRODUCTION REGULATION

- A. EFFICIENCY
  - 1) ECOLOGICAL EFFICIENCY
  - 2) ECONOMICAL EFFICIENCY
    - 2.1 A FLEXIBLE SYSTEM
    - 2.2 A LIBERAL SYSTEM
      - A) ADVANCED COUNTRIES' REACTIONS
      - B) DEVELOPING COUNTRIES' REACTION
    - 2.3 A STIMULATING SYSTEM
- B. EQUITY
  - 1) MATERIAL CHARACTERISTICS AND LEGAL SITUATION OF THE OZONE LAYER
  - 2) NECESSITY OF AN EQUITABLE DISTRIBUTION OF PRODUCING CAPACITIES LIKELY OF HAVING EFFECTS ON THE OZONE LAYER

IV. NORMATIVE TECHNIQUES AND IMPLEMENTING PROCEDURES

- 1) NORMATIVE FRAMEWORK
- 2) INSTITUTIONAL FRAMEWORK

# I. INTRODUCTION

The problem preoccupying us here concerns both stratospherical ozone and the globe's temperature since the ozone layer protects the biosphere from the harmful effects of solar ultraviolet radiation, controls the structure of the stratosphere and influences the Earth's climate.

This problem is considered as world size by the International Scientific Community.

The last CCOL meeting was held in Nairobi on 24 and 25 February 1986 under the aegis of the UNEP. "In summary there continues to be concern that both the total amount and vertical distribution of atmospheric ozone, the temperature structure and climate will be modified by changes in the atmospheric concentrations of several trace substances specially chlorofluorocarbons, carbon dioxides and nitrous oxides. Hence, the two issues of ozone modification and climate changes should be considered together."

In parallel to the recent Vienna convention for the protection of the ozone layer also adopted under the aegis of the UNEP, each regulation must have the following characteristics :

a) be international and not be drawn up by a country according to its own product and application problems,

b) have a scientific basis on which the whole Scientific Community agrees - the only way of transgressing local particularisms.

This leads to the fact that the type of regulation required must both :

- be susceptible of covering in an idential manner the whole of the products refered to in the CCOL report,
- be susceptible of being revised according to the evolutions of international science.

.../

The case of CFC only constitutes one particular aspect of a regulation which is liable to be extended to other worrisome substances owing to their action on the atmosphere..

What do we fear from CFC ?

At short term, 10 to 20 years, most probably very little according to the report cited by the CCOL.

On the otherhand, we have legitimate reasons to worry according to certain studies which have been published (for instance RAND, 2483.3 EPA). Even if the conclusions of this study are far from being recognized internationally (they will be debated at the Rome meeting in June 1986) it is impossible not to raise questions when you see the acceleration of the cumulated mass of chlorine products which is likely to be released into the atmosphere.

CFC 11 + 12

| Years | Annual World Product. $10^3$T | Coef. | Cumulated World Production $10^3$T. | Coef. |
|---|---|---|---|---|
| 1944 | $\simeq$ 0 | | | |
| + 40 | | | | |
| 1984 | 800 | 1 | 14,000 | 1 |
| + 40 | | | | |
| 2024 | from 1,115<br>3,400 | 1.39<br>4.25 | from 53,000<br>98,000 | 3,8<br>7 |

How shall we, all at the same time : protect ourselves against such an acceleration of the CFC requirements (schema 1), do so at the international level, draw up a law which will be liable of being revised according to scientific data, while sharing out the effort so as to avoid an answer :

- unefficient because of the global problem if only some States take restr[illegible]iv measures,
- dangerous if the States believe the problem is solved whence only some will have worried about it.

How shall we, moreover, if it is necessary, make it possible in the long run to take similar steps for other products ?

.../

It appears at any rate, just as the "employment, growth, technology" working group noticed, as a matter of fact, (created by decision of State and Governmental leaders at the 1982 Versailles sommet), that the international dimension of the environmental safety implies the increased cooperation from Governments and Industry on a basis of harmonized conceivings.

## II. WORLD CEILING PRODUCTION SYSTEM FOR CFC 11 AND 12 :

The regulation system which seems to best answer the preceding evaluated criteria is the following :

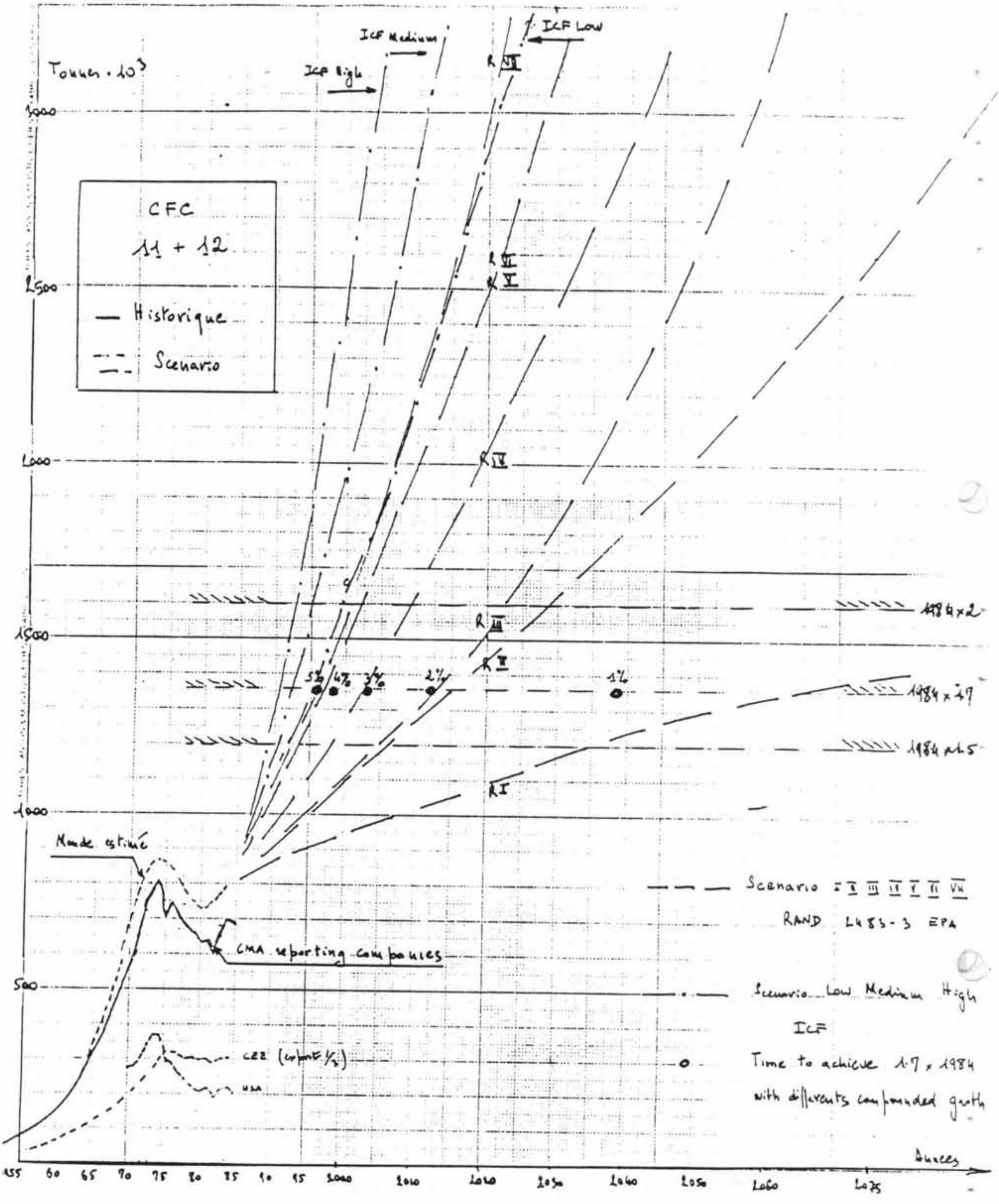
a) settling a world production level for CFC 11 + 12,
b) Fractionalize this production per development zone differentiated into advanced countries and others
c) control and adjust the level set up at the beginning if necessary.

Why, in the field of CFC, must we concentrate on the 11 and 12 only ?
First of all, in order to be pragmatic : "he who grasps at too much loses everything as they say in France. It is easy to guess that such a regulation will be very delicate to work. It would therefore be advisable to test the system before eventually wanting to include other CFC.
Next, because at present time, CFC 11 + 12 represent by far the most produced CFC ( $\simeq$ 80%) able to affect the ozone layer.
Lastly, because we can think it is almost certain that, if there will be a regulation for 11 and 12, this will have some influence on industrials and CFC users who will be inclined to avoid using the whole family of products to which these products belong.

### I) A world ceiling production for CFC 11 + 12

Such a ceiling is easily established using a multiplicator coefficient on the production known at a given date for example 1984. We call "X" such a coefficient. The world ceiling is obtained by "X"x (1984 Production). This excludes, on the world level, any connection with the different uses which are known to be very sensitive to the way of living, geographical location.... At the State level as it is already the case, Governments are of course able to set up specific contrainst. But, starting from this world production upper limit notion for CFC 11 + 12, it will have to be possible to regulate in a much more concrete manner at States or State groups level.

3.1


Tonnes · 10³
3000
2500
2000
1500
1000
500
CFC
11 + 12
— Historique
-·- Scenario
ICF High
ICF Medium
ICF Low
R VII
R VI
R V
R IV
R III
R II
R I
1984 × 2
1984 × 1.7
1984 × 1.5
5%
4%
3%
2%
1%
Monde estimé
CMA reporting companies
CEE (export ½)
USA
Scenario I II III IV V VI VII
RAND L483-3 EPA
Scenario Low Medium High
ICF
o Time to achieve 1.7 × 1984 with differents compounded groth
Années
1955
60
65
70
75
80
85
90
95
2000
2010
2020
2030
2040
2050
2060
2075

### II) Fixing an "X" level different between advanced countries (AC) and rest of the world :

(or R.O.W. for Rest of the Workd)

This notion is fundamental.

Without even having to refer ourselves to the RAND studies, we can believe that at long term the increase in local consumption will not fundamentally be caused by the AC which have already, owing to their living standards, been using these products for 40 years.

On the contrary it will be the other countries which, depending if the purchasing power of their population increases, will progressively have access to the finished products presently using CFC, cold, insulating, etc.

But under no circumstances should a regulation freeze positions in such a way that the AC would remain the only ones authorized to use CFC 11 + 12, the ROW being exluded from them for ever.

It in fact is compulsory that the ROW should develop with the least restrictions.

From these two considerations one concludes that "X" must be very different in the two sectors $X_1 < X < X_2$ ($X_1$ : advanced countries; $X_2$ : ROW) .

Such an approach has two fundamental advantages :

. for the AC ($X_1 < X$) this means that the impact of the regulation will only apply in fact to the AC with two corollaries :

- these countries having considerable research and innova~~ti~~ng means will be able, by force or even before being forced, to undertake researches for process or substitute products (process or product which, in the long run, the ROW will benefit of).
- Their being big consumers absolute value will be maintained at a low level.

. For the ROW, $X_2 \gg X$, not only the countries concerned will not be concerned at short term but contrarily will notice that to their advantage delocalizations will begin and one part of the products they are presently importing, locally produced, creating in this way richness instead of creating deficits in the balance of payments

You must add to this regulation a clause <u>forbidding the inversion of CFC flow rates</u>, presently AC → ROW. Otherwise, the legislator would have, by no means, solved the environmental problem but only finally shifted the production areas.

.../

EXAMPLE OF A CONCRETE APPLICATION :

Let us scientifically presume that a chlorous level corresponding finally at maximum to à production stabilized at 1,7 x 1984 CFC 11 + 12 is authorized :
For the AC we shall consider the regulation system as already applied in the CEE i.e. a maximum production of 480,000 T which, in comparison to 1984, corresponds to 1984 x 1,4 :
The AC will therefore have 1,4 x 1984

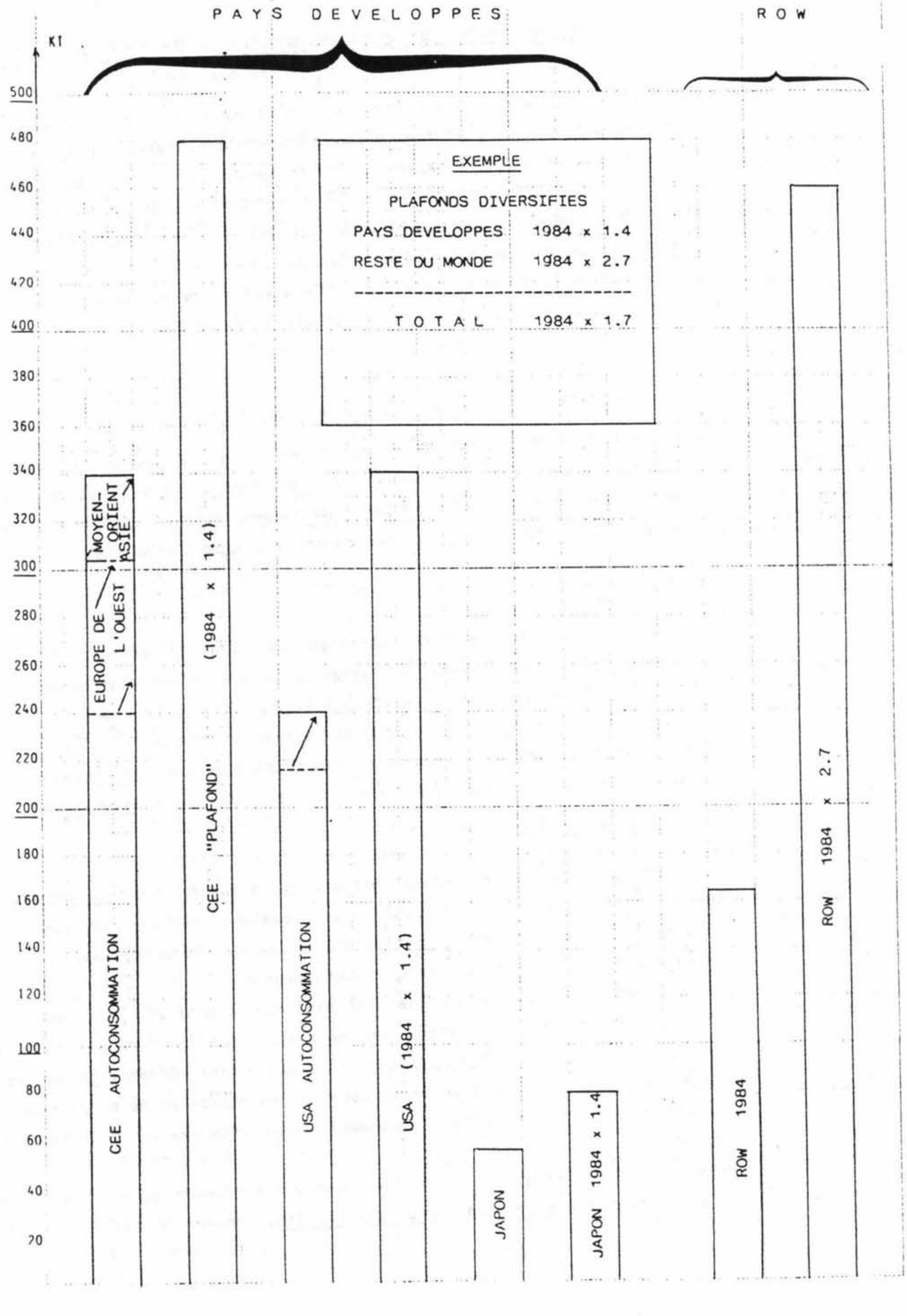
| | 1984 | COEFFICIENT | PRODUCTION CEILING | |
|---|---|---|---|---|
| CEE | 340 | 1,4 | 480 | |
| USA | 240 | 1,4 | 340 | |
| JAPAN | 55 | 1,4 | 80 | |
| ADVANCED COUNTRIES | 635 | 1,4 | 900 | ↗ + 4 |
| WORLD | 800 | 1,7 | 1,360 | |
| ROW | 165 | 2,7 | 460 | ↗↗ + 17 |

IMPORTANT NOTA :

The above example is only given as an indication. In fact :

1) It would be wise to analyse more deeply ROW so as to make sure that there are no other countries which ought to be classified AC (Australia...). Such reclassifications would bring a larger initiatory growth to the ROW.
2) The figures given are only indications. The author does not pretend knowing them exactly. They are given only in order to explain concretely the reasoning.
3) The 1,7 times the 1984 Production is only an hypothesis same as 1,4 for AC and 2,7 for ROW.

# F11 + F12


PAYS DEVELOPPES
ROW
KT
500
480
460
440
470
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
70
EXEMPLE
PLAFONDS DIVERSIFIES
PAYS DEVELOPPES 1984 x 1.4
RESTE DU MONDE 1984 x 2.7
TOTAL 1984 x 1.7
CEE AUTOCONSOMMATION
EUROPE DE L'OUEST
MOYEN-ORIENT ASIE
CEE "PLAFOND" (1984 x 1.4)
USA AUTOCONSOMMATION
USA (1984 x 1.4)
JAPON
JAPON 1984 x 1.4
ROW 1984
ROW 1984 x 2.7

## III) Continuous monitoring and adjustment of the first set up level at the world lev

It must be a legislative internal action of each country or group of countries to insure the reality of the ceiling. It is also interesting to cross-check by an independant method the reality of the implementation. This can be done at the world level by Ground Monitoring of the CFC concentration (see page 20).
But it is fundamental, because of variations of the atmosphere due to CFC or other substances (see CCOL report Nairobi 1986) that the ceiling can be adjusted after having been set up a priori. Such a system is continuously watched by the scientific community apart from legislators (see page 7).

## III) QUALITIES OF A CEILING PRODUCTION REGULATION

No CFC production control system is perfect. The one consisting in fixing a world production upper limit fractionned into differentiated (AC and CD) development areas however does seem to offer the best advantages, both on efficiency level and on equity of the results that one can rationally expect from them.

### A. EFFICIENCY :

The efficiency of a CFC control strategy must first be appreciated of course from an ecologic point of view, in its large sense i.e. on an environmental protection point of view (and, in fact, of stratosphere in the first place). But the main quality of a production ceiling system is that it enables to achieve a protection of environment while also being based on a constructive use of the market rules. Its ecologic efficiency is also based on an economic efficiency.

### 1. ECOLOGICAL EFFICIENCY :

The first guarantee of ecological efficiency is due to the deliberate international character of the world production ceiling system. This one corresponds to the international size of the alteration phenomenon of the ozone layer which we have already gone through at beginning of this report.
Any regulation based upon a unilateral determination of the said "essential" uses of CFC, made only by some States on the basis of evaluations due to their situation and to their strictly national interests would on the contrary be eminently subjective, and would lead at world level to an action so heterogeneous and dispersed that its efficiency would appear most problematic in terms of environmental protection.
Nevertheless, as we shall see further along, the production ceiling system, even if it guarantees the harmonization of the results, leaves to each State who will

.../

participate to it a broad margin of evaluation in the choice of control means of production and of the types of priority uses. One could say so as to conclude on this point " a world size problem requires a global regulation".

The second guarantee of ecological efficiency of the system recommended here is favorable to the fact that the world production level :

- would be a priori set up from precisely determined scientific criteria and which would benefit of a very large scientific consensus,
- would be likely, as we will see further along, to be periodically re-examined and systematically revised if the evolution of the scientific experience concernin the globe's atmosphere and its climate appears to require it, just in the same manner as the development of the other productions being able to cause interferenc with the effect of CFC 11 and 12 on the ozone layer ($CH_4$ and OH especially) could impose it.

If you consider some studies based on existing models already published (works of Owens, Brasseur, Sze, Isaksen) you can consider that coefficients of 1,5 1,7 or even twice the actual production would have no noticeable influcence on environment. This evaluation, linked to actual level of knowledge, gains all its value if you remember that the recommended system would be limited in time since it would determine at term a noticeable decrease, then beyond that, a drop in the global amount of CFC 11 and 12 production. You must never in fact forget (see infra) that the world production system can be analyzed in fact, for its effects, like a differed drying up strategy of CFC emissions in the atmosphere.

Lastly, the third factor of the ecological efficiency of the system is due to its simplicity, its globality and its easily controled character. Its simplicity is linked with the fact of using a univocal criterion - that of a production ceiling per zone of development. It does not get involved with problems of numbers which an arbitrary and heterogenous determination of the uses found to be "essential" by such country would bring about.

It applies to the whole CFC 11 + 12 uses and employs one quantitative criterion which renders control of its application easily verifiable : we all know in this respect the experiment of the network of the 5 atmosphere standard measuring stations regrouped within the Atmospheric Lifetime Experiment (ALE) renewed and improved today under the Global Atmospheric Gas Experiment (GAGE). Such Control Networks enable to check very accurately the figures presently supplied at world level (besides countries behind the Iron Curtain) to a private Audit Bureau (for the moment Grant Thorton) and published by CMA/FPP. Their value would double within the framework of a world ceiling production system with guaranteed control of its

.../

actual application through checking the production/emission amounts that the party states would regularly transmit to the appropriate organ (see infra).

The chances of actually applicating and of reaching really ecological efficiency strategy for controlling production are however only true if they do not suddenly impose brutal and eventually arbitrary constraint into the producing system as on the general economy of a country. The luck of environment rests here as for other domains in the economic realism of the mechanisms which are in charge of its protection. So as to be ecological, efficiency must first be economical.

## 2. ECONOMICAL EFFICIENCY :

The economical efficiency of the world production ceiling system depends mainly on three characteristics it includes :

It is a system which is :
- flexible,
- liberal (economically speaking),
- stimulating from a technological point of view.

### 2.1 : A FLEXIBLE SYSTEM :

We have already reminded this to you several times and we shall examine later on the institutional aspect, the recommended system would be placed, if one can say, into a state of permanent alert if the upper limits (world wide and regional) of production can be quickly modified should new information coming from the scientific world on the atmospherical and climatic incidences of the use of CFC. No limit, no ceiling should therefore never be considered as once and for all established. So will be set up for the world, out of scientific criteria, the necessary contraints prouved to be without any "laisser-aller" nor a priori.

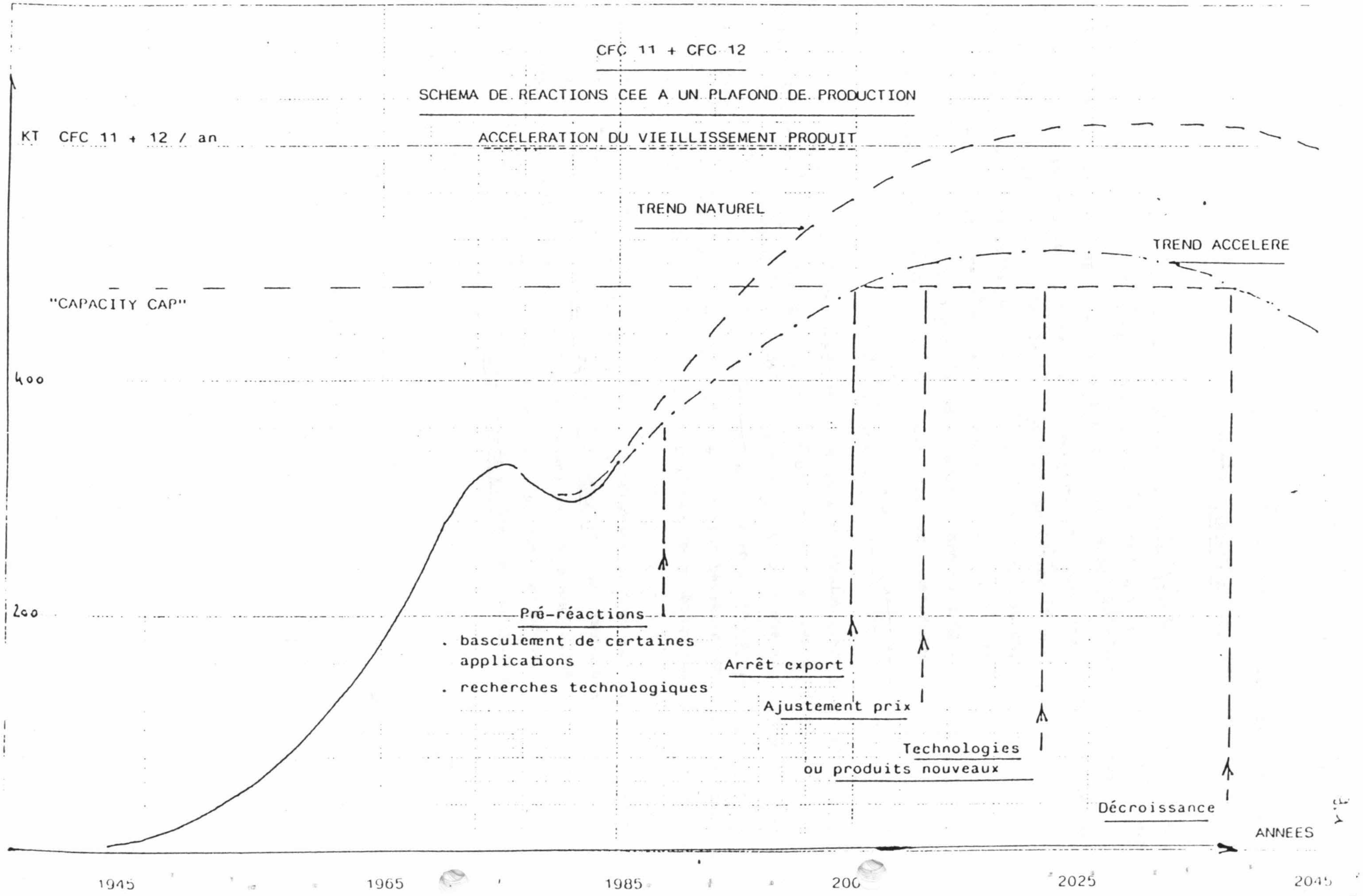
## 2.2 : A LIBERAL SYSTEM :

The very logic of the production ceiling system, sharpened by separating the ceilings for each development region, lies on the concrete use of the market laws. Present observation of the economical agents' attitude enables to forecast in particular the behaviors of anticipation or pre-reaction which result in acceleratin the classical ageing processes of the products including CFC and of unlocalizing production sites. Only the AC will be affected for a while by an increase in prices of finished products due to the supply and demand rule.
Such phenomenons require some explaining. We will examine below the market reactions separated at each development level of the considered countries.

### A) ADVANCED COUNTRIES' REACTIONS :

The enclosed drawing gives the reactions due to the production limit law as previously determined i.e. by leaving a free reaction to the market powers.
We are explaining them in the following paragraphes.
Pre-reactions : we already have been able to notice even before a regulation had been issued that the very fact of having exposed the problem had in itself influence the producers' behaviour.

This is how the fact of speaking of the problem linked with ozone, has in the USA aerosol domain changed the formulations even before the regulation was to be applied. Anticipation always takes place : road safety knows it well, who publish the forecaste rush hours, knowing well that in this way the forecast will become null ; drivers anticipate and modify their habits.


CFC 11 + CFC 12
SCHEMA DE REACTIONS CEE A UN PLAFOND DE PRODUCTION
ACCELERATION DU VIEILLISSEMENT PRODUIT
KT CFC 11 + 12 / an
TREND NATUREL
TREND ACCELERE
"CAPACITY CAP"
400
200
Pré-réactions
. basculement de certaines applications
. recherches technologiques
Arrêt export
Ajustement prix
Technologies ou produits nouveaux
Décroissance
ANNEES
1945
1965
1985
200
2025
2045

What would be the previsible pre-reactions ? Some will be positive in terms of environment : formulation transfer but mainly investment of technological researching efforts in order to discover substitutes or new techniques.
The first case of course applies to aerosol for which, if the consumer is educated, alternate solutions exist. With enough time, this would allow the consumer to get accustomed with the new formulations and would avoid loosing markets.
The second case, that of new techniques, can apply at middle term to cellular plastic and researching is beginning for this sector. For the cold technology nothing is happening yet.
Negative reactions will also occur : they will consist in tranferring production facilities into developing countries which are supposed to be less strict regarding regulations.
It will therefore be necessary to protect ourselves as much as possible from these perverse effects of the system by formulating in the international order the rule by which these types of transfers would be prohibited.

## The oncoming production limit :

As soon as production upper limits will approach, CFC will become much sought after products. The market will remain sollicited, whereas the offer will be limited. In such a case, the adjustment of supply and demand is done through the price.

We therefore will have a progressive price increase.

.../

Its consequences will be very different according to the application and especially according to the value of CFC contained in the final product.

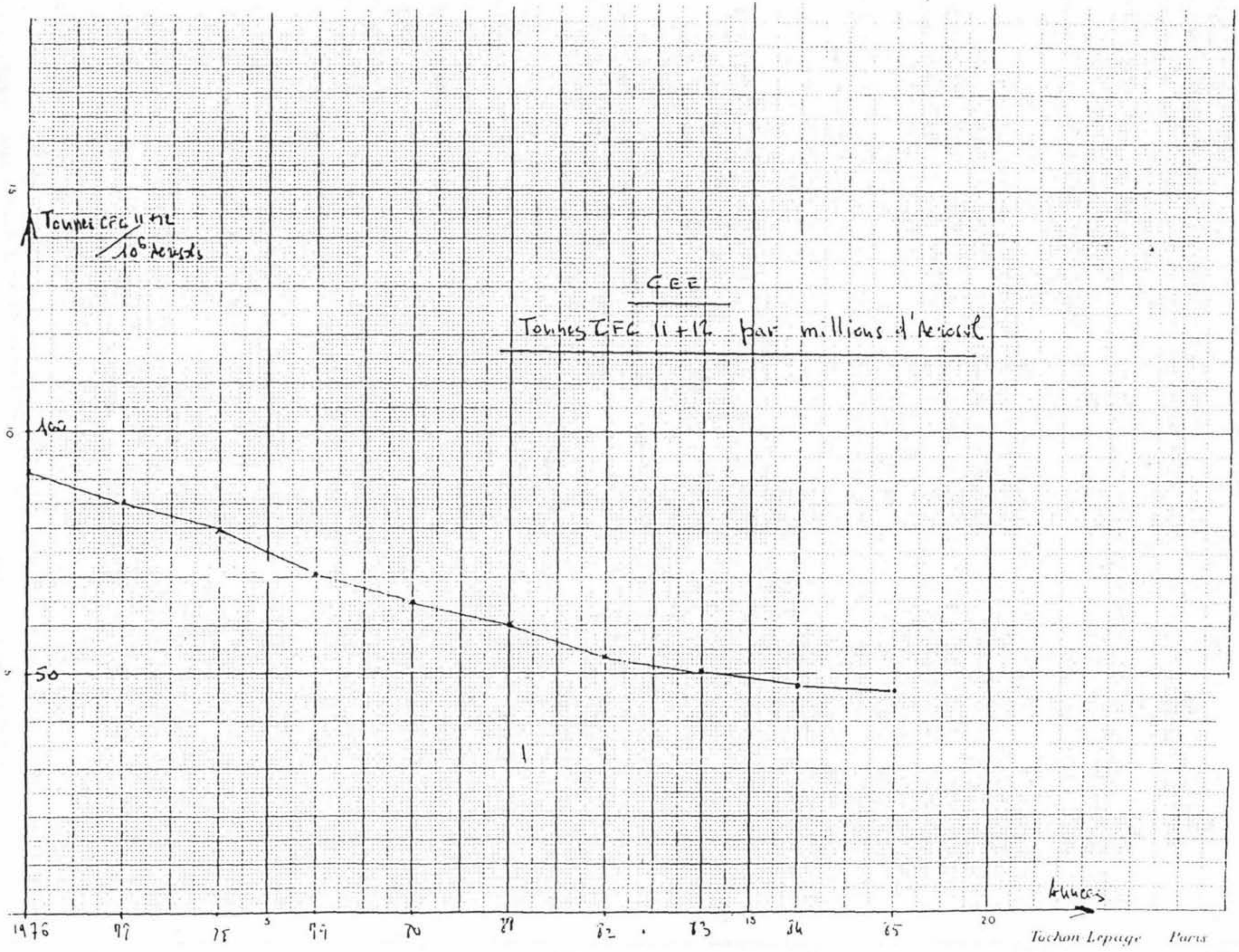
- Aerosol will most probably be the first hit since in the CEE there is already a capacity cap for that application and the formulations switch to butane propane. One can even imagine as we have seen earlier that this switch will take place before the price evolution occurs <u>preventively</u> (see schema CEE - CFC/aerosol).
- For foams, some studies reveal that if CFC prices double, other products will become competitive for the permanent insulation of houses, warehouses, etc. But prices would have to be multiplied by <u>7</u> before the $CO_2$ "foaming process" could be used for refrigerator insulation.

| PRICE OF CFC CONTAINED IN 1KG OF FOAM | PRICE CFC/1984 COEFFICIENT | PRICE OF FINISHED PRODUCT PER KG | |
|---|---|---|---|
| 0.9 | 1 | 12 | → CFC 11 "foaming process" |
| 1.8 | x 2 | 13.8 | → other competitive insulating products for cladding panels |
| 6.6 | x 7 | 18.6 | → $CO_2$ "foaming process" MDI decomposition |

- For the cold industry, the evolution will first of all be, with the same technologies, a switch over to other products not implicated in the ozone controversy. There might be other evolutions in the automobile coolants hermetically sealed systems in spite of a superior material price.

### <u>Ulterior evolution due to researching and innovations</u> :

The prices having been settled at a level such that the equilibrium between supply and demand could be reached, one can wonder if this situation will keep up.
A good example is what occurred when the oil prices raised in such a considerable manner. At a first stage, the market adapted itself to this new deal and there occurred considerable price increases for the consumer. This increase was only caused, for part, by the brutality of the oil increase which had not been forecasted. This is where the important notion of the time required to adapt mentalities and markets comes from.

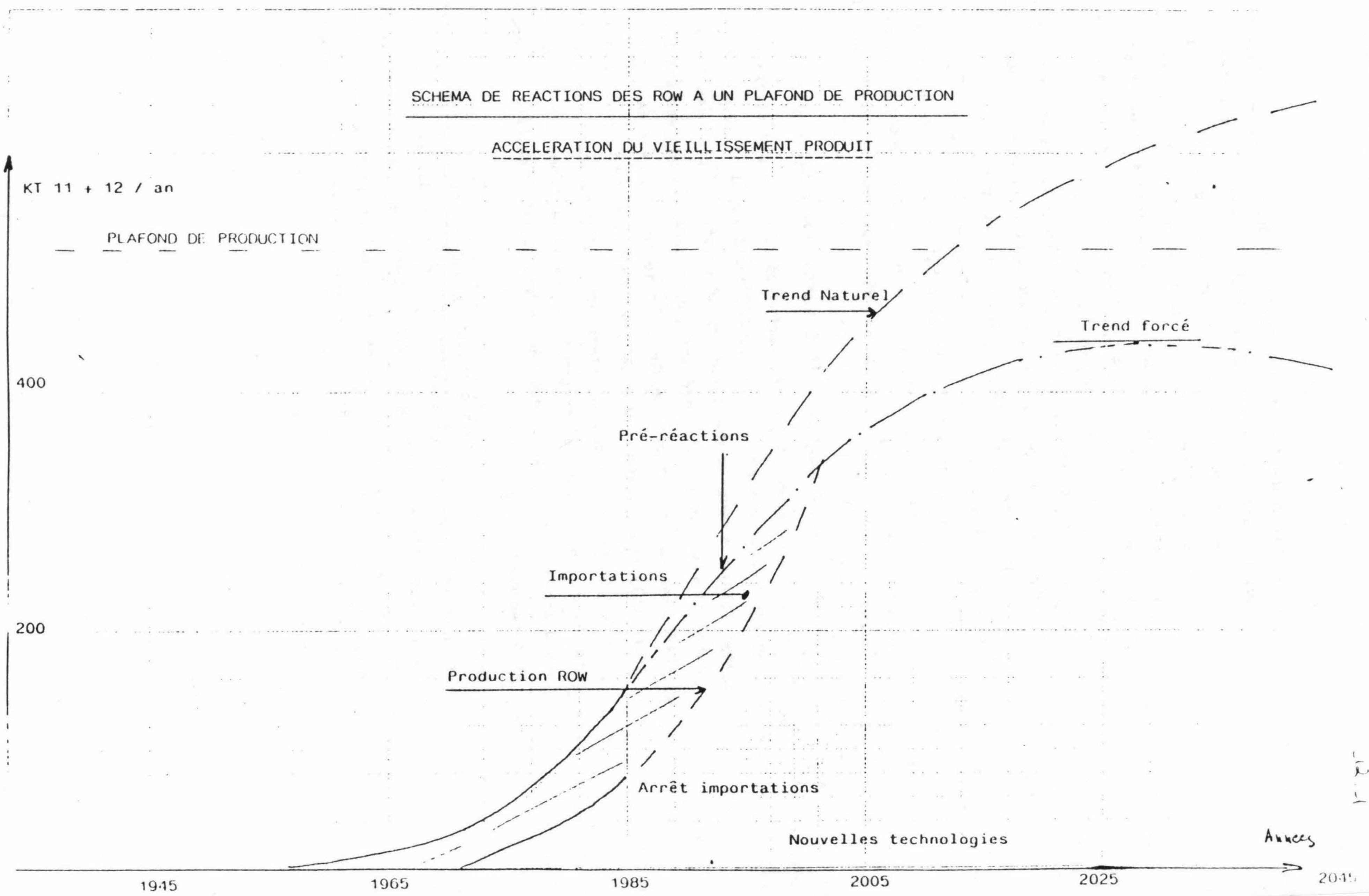

CEE
Tonnes CFC 11+12 par millions d'aerosol
Tonnes CFC 11+12 / 10^6 aerosols
100
50
1976
77
78
79
80
81
82
83
84
85
Années
5
10
15
20
Tochon Lepage Paris

But, faced with this challenge, technical improvements (energetic efficiency of automobile engines, inforced insulation of lodgings), switch overs to other techniques (nuclear power ascension) managed finally to reduce demand. This demand dropped in such proportions that prices had to adjust downwards to the new equilibrium (demand reduced faced with a similar supply then increased).
(Even with the low price the demand did not recover). For CFC, the same process, most probably, will occur.

B) DEVELOPING COUNTRIES' REACTION : (drawing page 12 bis)

The principle adopted is such that the regulation instituting a world ceiling production system should not affect them directly. Indirectly, some consequences are however expected.
First of all, as with the AC, the PVD markets will be affected by pre-reactions, i.e. adjustments similar to those of AC but slightly out of phase. We can evaluate that aerosol will be the first to be hit. However, we can more particularly expect two types of reactions.
In a first stage, as soon as the CFC prices are going to start increasing in the AC, there will be a tendency to sub-contract, in countries where prices will have stayed low, manufacturing of finished or semi-finished products using CFC. Some productions will be delocalized.
This phenomenon which already exists owing to lower labour costs, has chances this way of being accelerated. We can ask ourselves if we should oppose ourselves to this delocalization and if so, how could be take precautions against it ?
But specially in a second stage, a little later, once prices will have risen, the AC will stop exporting CFC. In order to grow in a normal way, PVD will therefore have to build CFC plants. There will be a production delocalization. Of course, this process is already partly on stream but it would be accelerated by the adoption of a ceiling production system. Would it not nevertheless be prejudicial from an ecologic point of view ? We can reasonnably say no. If, in fact, in a first stage, production of developing countries came for part in substitution to that of the AC, in a second stage, the technological advances acquired in industrialized countries would also reach the rest of the world (1).
You can see how, in this way, finally both in countries less developed than in others, the economic efficiency of the ceiling production system would rest on the dynamical use of the market laws.

(1) See for instance the alveolate plastic. If new CFC free technologies are invented, it is those technologies that these countries will use. For the cooling industry, if technologies using efficient thermodynamic products but which do not effect ozone are used in developed countries, it is these latter technologies which will be acquired.
Here again, we can observe that the influence of an international regulation of the ceiling production capacity only accelerates the process which normally exists.



SCHEMA DE REACTIONS DES ROW A UN PLAFOND DE PRODUCTION

ACCELERATION DU VIEILLISSEMENT PRODUIT

The liberal character of this system is apparent by the fact that orientation of tr production and the technological choices made by the different states would result from the evolution of the markets and would progressively take place while leaving to the most developed ones time to study thoroughly the necessary research work and without imposing to them suddenly or even gradually by stages priorily fixed arbitrarily, production transfers or sudden production unit shutdowns whose social consequences cannot be overlooked.

Developing countries would themselves find here, as we have seen, the opportunity of launching their own productive industries which would most probably have beneficial effects on their industrial sector without imposing to them, from outside, options which were picked by others. General liberalism would however be restrained in the commercial domain by the prohibition of an inverse flow of CFC products going from developing countries to AC and this in order to guarantee that the ceilin reached or about to be reached will be respected, at this stage, inside the in[illegible]trialized countries.

2.3) A STIMULATING SYSTEM : from a technologic point of view.

This last characteristic clearly results from the preceding developments : we have seen how anticipating the rise of CFC costs would bring an increase of the technolog researching aiming at the discovery of substitute products and of new techniques. In fact, it would mean to accelerate and encourage a process which has already begun while leaving to research people the time that is necessary for studying more thoroughly their works, which is the contrary to what would happen if industry was suddenly faced with a brutal interruption of production. We would in this way avoid the economical and social traumastism resulting from such an interruption and we would schedule the delays required to accomplish elaborate research studies, proof of their efficacity.

But let us remind you, this stimulating and beneficial effect on technological research is not one of the byways of the recommended system but a considerable asset the quicker in fact we manage to find substitute products ecologically neutral and economically profitable, the quicker we shall be in a position to give up first in industrialized countries, next in the developing countries, using CFC.

.../

But it would be difficult to convince that such a system is better than others, ev if efficient, it were in opposition with equity. We however will note that this is n the case.

## B. EQUITY :

Evaluating the equitable character of the world ceiling production system must essentially be done by reference to the possible separation of CFC production capac- ities into two categories of states : the first ones, already big producers and use are the industrialized countries. The others, also handicapped from this point of view, are the developing countries.

In fact, examining the material characteristics and the legal situation, still uncertain, of the ozone layer enable to positively maintain that it must be protect by each and everyone of us it being a resource of common interest for humanity. But everyone must also be able to benefit of the use of its limited absorption capacities of some chemicals such as CFC. Let us go over again these 2 points :

### 1 - MATERIAL CHARACTERISTICS AND LEGAL SITUATION OF THE OZONE LAYER :

The States having taken part in the 1985 Vienna convention negotiations for the pro ion of the ozone layer apparently did not want to risk to attempt describing precis the legal status of the ozone layer because of the different opinions some of them had on the matter. It is not our job to take a decision on this discussion. We will merely formulate here a few objective observations which, apart from any legal qualification of the ozone layer itself, should result in a certain quality of economical and material consequences which ought not be without having any influenc on the legal point of view.

a) The ozone layer consists first of all in an ecological unity. It is correct that its physical characteristics and especially its thickness can vary in time and in s but one must however consider it as a whole because of its natural unicity and it dependance to the others constitutive elements of the stratosphere.

b) In the second place, the population of all the States wherever it be located and whatever be its development level, is also reliant of maintaining this layer at a sufficient standard level.Let us recall in this respect that a reduction of th ozone layer, in proportions which are still not fully known, has or would have disas trous consequences of universal size, whether it be on human health due to the U.V. irradiation increase (sunburn, allergic reactions, skin and eye diseases, cancer of the skin, etc.) or on the natural medium (impact of forestal flora and productivity of a large quantity of plants particularly).

.../

As a result of all these characteristics as previously said, all the States are interested in the protection of this ecological unity which is also a common resource. It is of vital interest for actual and future populations of the planet. But if they are all equally tributary, they all have for the same reasons a same vocation of using, through this industrial activity the limited absorption capaciti which the ozone layer disposes of regarding some products.

### 2 - NECESSITY OF AN EQUITABLE DISTRIBUTION OF PRODUCING CAPACITIES LIKELY OF HAVING EFFECTS ON THE OZONE LAYER :

The situation in which is placed the International Community regarding the ozone layer recall in some respect the situation of the different categories of States (Industrialized or about to become so) regarding some new resources such as the frequency spectrum or the goestationary orbits (1), without mentioning here resourc which are not yet exploited but already having a precise legal status as for instanc the sea floor or the moon and the other celestial bodies.

Each of them has the same right to use them, but only some countries industrially and technologically advanced have already used a large portion of the exploiting possibilities of the frequency spectrum or the geostationary orbits.
Concerning the ozone layer, one must note the wish of the whole of the States which adopted the 1985 Convention to bear in mind "the situation and the particular requirements of developing countries" (3rd Preamble). They insisted on reminding in the same preamble the 21st principle of the Declaration of the United Nations on environment adopted in Stockholm in 1972 which we know places in balance the duty of the States of protecting environment and "the sovereign right to exploit their own resources according to their environmental policy".
It is in this frame of mind that should be adopted a control and regulating system of CFC ceiling productions which will not once again advantage the same category of industrialized countries and consolidate the established privileges of some States.
As shown earlier, the world ceiling production system, because it would be separated into development zones but also because it encourages the delocalization of CFC

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(1) On the "new resources" concept see the rules about the dispute about natural new resources/ The Settlement of Disputes on the New Natural resources, Colloque/Workshop 8-10 Nov. 1982, Academie de Droit International de la Haye Université des Nations Unies, Martinus Hygoff Publishers, The Hague/Boston/ London 1983, and P.D. DUPUY, "Technologies et ressources naturelles "nouvelles" et partagées" in Droit et Libertés fondamentales à la fin du XXème siècle, études offertes à Cl. A. Lolliard, Paris, Pédone, 1984.

.../

production units presently established from industrialized countries to developing countries would leave them the possibility of using the excess absorption capacity of the ozone layer whereas its mains users would quickly turn over to other techniqu their present production being much closer to the ceiling than that of the "Southern countries" ; these latters would in this manner have access to a certain amount of CFC uses (refrigeration, insulation, etc.) without lo longer having to depend on the "Northern countries" "if basing themselves on a national production coming from other countries of the same category". In other words, equity of the productio ceiling system results from the positive discrimination that it would create to the advantage of developing countries, by allowing them to profit of the industrial advantages and improvements in standards of living that the populations of industrialized countries benefitted from before them. This system would maintain their right of choosing industrial development sectors without seriously endangering the atmospheric environment.

To summarize, one can in this way conclude that the world ceiling production system articulated on differentiated development areas finds its ethical and normative inspiration sources amongst other elements :

- in the respect of the collective common property nature of the international community which is specific to the ozone layer and which should be placed under constant watch and protected.
- in the respect of the right of the less industrialized countries to determine freely their development choices as well as having access to certain types of daily commodity products using CFC.

This system will be impartial if it is based on these two principles.

Notwithstanding, it is nevertheless necessary that in order to carry out its achievement, it is necessary that the States' increased cooperation, which is imposed by legal obligation in the text of the Vienna Convention for the ozone layer safeguard (cf. especially articles 2 al. 2, art. 3, 4, and 5), be articulat around a few simple normative principles within the frame of an institutional structure at same time coordinated and decentralized. This is what we are going to examine hereunder.

.../

## IV - NORMATIVE TECHNIQUES AND IMPLEMENTING PROCEDURES :

The techniques and implementing procedures of the world production ceiling syste must secure both the application of the principles on which it is based and the maintain of the qualities which are his. That is to say that they have themselves to be flexible and not block neither the free interplay of the market rules where they are postive nor the expansion of the technolgical research studies and the international emission of their results. We shall successively examine the normat and the institutional frameworks which would be the most suitable.

### 1 - NORMATIVE FRAMEWORK

We must here both examine the container and the contents if one can say i.e. on t one side, the nature of formal statement instrument of the concerned principles rules and on the other side, the very substance of these standards.

a) The formal tool does appear at any rate of having to be of a conventional natu It is in fact necessary in order that the system be viable that the largest possi amount of States and even idealistically all the State members of the United Nati if not the whole of the World Community agree with the rules and principles which will have been clearly specified and as far as possible acknowledge their legal - compulsory nature.

International law of treaties, this having been said, is one of the least formal different solutions are possible :

- either that which is apparently the most simple and which best suits the recent diplomatic efforts of an additional protocole to the 1985 Vienna Convention which would relate specifically to chlorofluorocarbons.

- Or that of an autonomous framework convention on ozone layer protection agains the uncontroled use and production of CFC which would at any rate include basical the same rules. This solution for the opposite reasons as that which have just be explained higher up is undoubtedly far less logical. But one could eventually consider for diplomatic motives that it offers some advantages. The choice betwee these 2 options remains at Governmental level.

.../

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.../

b) The contents of this conventional tool was stated for a large part in the preceding chapter of this report.

- It should of course include the enunciation of the very principle of production limitation of CFC at world-wide level, the indication of this ceiling (quantified), and also that of the authorized maxima per development areas (industrialized countries, developing countries).
- It should be recalled that this system can only be established on the basis of a very large international scientific consensus concerning pertinent data which supposes encouraging scentific research studies and the free exchange of the informatic dealing with this researching, especially in the field of the composition and the reaction capacities of high atmosphere as well as in that of climatic evolution and in certain medical science and ecological sectors.

In general, from a substantial if not necessarily formal point of view, such a system can only be implemented in the direct continuation of the excellent arrangements already adopted at Vienna in the summer of 1985.

- For the rest, the advantage of the forecasted system and its liberal nature already described higher up, would avoid the States from having to establish a set of very heavy normative dispositions whether they be in the internal or internationa order.

It is once again through the free interaction between supply and demand that adjustments between the applications will be done. Each market will react according to the living standards of the habitants, of their living habits (culture, lodgings, climate). The States will not have to decree the "essential customs". The consumer will be the judge according to his own criteria, of what he finds essential i.e. of what he accepts to pay as excess cost.

It will however be necessary to indicate, in the concerned normative instrument, the stipulations required to rationalize the market dynamics in order that it will not produce any pervert effects. This is how will namely be set forth :

- the ban on imports of CFC products coming from developing countries to AC,

.../

- the ban on trade diversions so as to preserve the preceding principle
- raising of any obstacle to the transfer of CFC substitute technologies, discovered and condemned in industrialized countries and destined to developing countries.

Moreover, the conventional tool should include a stipulation instituting the obligation for the States who will be members of not importing any CFC products coming from other countries, industrialized or not but who would not become parties of the agreement.

## 2 - THE INSTITUTIONAL FRAMEWORK

The institutional framework that must be set up should facilitate cooperation of the States in the considered field while aiming particularly at two targets :

- On one side, checking at national and international levels, the accuracy of data supplied by industrialists and governments concerning their CFC 11 and 12 production.
- On the other side, the adaptability and the ability of the system to promptly react upon the evolution of the data and scientific technological experiences in the relevant domains.

This is why any institutional structure seems to compulsory have to include :
- in the first place, one or a couple of coordinating modules of legal and scientific activity of the States at a worldwide scale,
- in the second place, decentralized authorities in the appropriate regional surroundings and combining when required both the geographical and economical criteria.

Needless to say that, as far as possible, so as to avoid the risks to duplicate with, waste and administrative awkwardeness, the already existent substitute authorities should priorily be solicited rather than founding new authorities.

.../

This is why the idea of entrusting to the United Nations' programme for the environment (and to its CCOL) with the task of coordinating at world level. They would be in charge specially, on top of coordinating and centralizing the information coming from the State Members, of summoning at regular and close intervals, for instance every three years, a meeting of the State Members to compare results of research works under way and examine opportuneness and fiability of the production ceiling system set (1); these authorities could work in particular on the basis of the information supplied by the Global Atmospheric Gas Experiment (GAGE) (2) and in close collaboration with the scientific verification system of the emissions so as to organize alternate verification procedures.

At geo/economical region levels, one could also think of using certain existent international institutions. This could be the case particularly for the Common Market countries, for the CEE, or in the larger frame of the Western industrialized countries, of the OCDE. Some regional economical agreement already existing in other parts of the world could also perhaps be contemplated unless we prefer working with the various regional economical commissions of the United Nations. Here again, different options are possible and for which we are not qualified to decide.

At any rate the normative action on control of CFC production and its actual implementation as well as in fact the exchange of relevant scientific data will have to be done on various stages : national, regional, universal, a little like the action concerning the protection of marine domain (3).

The world ceiling production system could not however, like any other, be entirely efficient, if it was not based on the active collaboration of all the people who are concerned who are, in this case, all the States of the planet !

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(1) this authority could be the "Conférence des Parties" instituted by article 6 of the 1985 Vienna Convention. A double diplomatic structure will be necessary, on one side, scientifical and technical (control) on the other side.

(2) The GAGE (Global Atmospheric Gas Experiment) is expected to operate from November 1984 till October 1987, in the 4 stations selected to first cover the 4 subdivisions of equivalent mass to atmosphere... :

| | | | |
|---|---|---|---|
| Cape Meares-Oregon | 45°N | 124°W | NASA |
| Regged Point Barbados | 13°N | 59°W | CMA |
| Point Mataluta - American Samoa | 14°S | 171°W | NASA |
| Cape Grim-Tasmania | 41°S | 145°E | Australia |

CFC 11 and 12 are analyzed and results are then treated in parallel with a designer (AER).
It could eventually be opened to other mill countries conveniently located and fitted out with a similar method (same equipment and procedures)

(3) See part XII of ther United Nations' Convention on the new sea law.

# SUBMISSION FROM FEA[1] TO PART 11 OF THE
# UNEP WORKSHOP IN WASHINGTON SEPT. 1986

## IMPACTS OF POSSIBLE STRATEGIES CONTROLLING CFCs FROM A USER INDUSTRY VIEWPOINT.

by
R.C. Knollys

## INTRODUCTION

Since 1974 when attention was first focused on possible man made influences on ozone, a number of regulatory controls have been introduced in various countries. These have affected the fluorocarb producing industry, aerosol manufacturers, the distributive trades and consumers. The controls selected have had differing impacts and provide pointers for possible future measures.

## SELECTION OF OBJECTIVES

Recognising that the Washington Workshop is about choice of regulatory strategy, there are two fundamental approaches to be evaluated;

a) Strategies designed to reduce immediately emissions of CFCs.
b) Strategies designed to place a limit on emissions at some point in the future, or at a particular level.

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[1] Federation of European Aerosol Associations (see Appendix).

The approaches adopted in the USA, Canada, Sweden and Norway have taken the early scientific evidence as a call to make immediate reductions in CFC emissions and the ban on the main aerosol uses of CFCs followed.

The EEC approach was to limit the total output of CFCs which effectively prevented an increase in CFC manufacturing potential and to achieve an immediate reduction in the biggest user sector - aerosols.

The relative effectiveness of the two approaches and their impacts are major issues in proposing future action.

## TIMESCALES INVOLVED

What concerns us today is the possible effect of emissions which have occurred in the past and those anticipated in the foreseeable future . It is suggested, that provided a flexible control is selected, further changes either in the science or in consumption patterns can be suitabl accommodated at the appropriate time. Such flexibility of approach can have considerable merit.

In Part 1 of the Workshop, both the validity and relevance of long term emission forecasts were questioned. It is unnecessary now to decide what action may be needed in 50 or 100 years time even i demand patterns for CFCs rise steeply, because action can be taken at the appropriate time if the estimated to be maximum safe level of usage is approached.

CONTEXT OF CONTROLS

The Vienna Convention on the ozone layer addressed the possible impact of a wide variety of chemicals on the ozone layer and the need for further co-operation in study of these effects and possible changes in the environment.

Release of CFCs was selected as a particular area for immediate discussion and a call made for the preparation of a protocol. Once this is prepared, it will have to be seen in the broader context of many differing chemical emissions, which are both from man made and natural sources, and the need for balance will be important[2]. Again the benefits of flexibility can be seen where, for example, an alternative chemical to CFCs is subsequently shown to have some potentially harmful effect.

2. CCOL Science summary Feb. 1986

## END USE CONTROLS

Selection of end use controls is not seen to provide a satisfactory answer to limiting CFC emissions because:

(a) **The choice of the industrial sectors selected for control** can be made only **on a subjective basis.**

(b) **The total level of emissions may at best be checked temporarily and it is possible even then a degree of complacency can exist relating to other sectors which are not directly affected by such controls.**

**By way of example the ineffectiveness of** a ban on CFCs in aerosols can be **illustrated** using projections submitted **to Part 1 of the Workshop by**[3] **Rand:**

**Projected world consumption of CFCs 11 & 12 for all uses in** thousands of tonnes

| | 1985 | 2000 |
|---|---|---|
| | 785.2 | 1180 |
| of which aerosol use accounts for: | | |
| | 209.3 | 215 |

**If total aerosol** use of CFCs were **removed by the year 2000 the total** remaining **in that year would still be 965 tonnes which represents a 23% increase on 1985.**

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[3] Product Uses and Market Trends for Potential Ozone Depleting Substances 1985 - 2000 by Rand pp 8 9 10

## IMPACT ON INDUSTRY

a) Part 1 of the Workshop in Rome addressed at some length whether or not the aerosol industries had suffered from CFC regulations where these had been harsh. Evidence produced indicated that over a 10 year period those countries which had imposed selective bans on CFCs in aerosols had:

(i) seen a reduction in aerosol production.

(ii) failed to obtain the benefits of production growth achieved in countries which had taken a more moderate approach.

It seemed that there was at least some degree of relationship between loss of production and the banning of CFCs in certain aerosol products, especially toiletries.

b) The impact of a total ban on CFC propellants can also be severe due to the high costs of equipping to handle alternative flammable materials. This often includes the need to relocate a plant from a built-up area and some, especially small companies, may be forced to cease filling and to go out of business.

continued/.....

b) continued/.....

Examples illustrating this point were given in papers prepared for the Rome Workshop[4].

The more flexible approach adopted by the EEC allows industry to adapt as a whole to the needs for control. This may mean larger companies taking the main burden of conversion but if the desired result is achieved with a less severe penalty to industry in total this approach is to be favoured.

4. Effects of Swedish Regulations governing CFCs in aerosol products. Consequences of the Norwegian ban on the manufacture and import of aerosols etc., where CFCs are used as propellant.

## THE INCREASING BURDEN OF CFC REDUCTION

The approach followed by the EEC calling for a 30% reduction in use of CFC 11 and 12 in aerosols compared with the tonnages used in 1976 has in effect imposed a CFC usage cap on the EEC aerosol industry. Since the year this reduction took effect (1981) the numbers of aerosols filled has grown by 23.5% to 1984 - the net effect in unit terms in 1984 is equal to a 43% reduction in CFCs. If the production figures are projected forward to 1995 and the FEA estimate of 13.3% further growth in aerosol litreage is assumed, the EEC usage cap will then be equal to a 50.8% CFC reduction per unit.

| | 1976 | 1981 | 1984 | 1995 |
|---|---|---|---|---|
| a) Units produced in EEC (millions) | 2036 | 2071 | 2557 | 2897 |
| b) CFC tonnage permitted (indexed) | 100 | 70 | 70 | 70 |
| c) CFC reduction per unit (b ÷ a) | - | 31.2% | 44.3% | 50.8% |

The effect is somewhat similar to the effect of a production cap. Thus in Europe there is an increasing pressure on the aerosol industry to reduce its dependence on CFCs, as a result of the 30% reduction. The aerosol industry has reacted to such pressure by continuing to encourage :

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5. Fluorocarbon use in Aerosols a Trend Study 1984 - 1995 in member countries of the EEC.

(a) Development of formulations using mixtures of CFC and other propellants where the alternatives to CFC are unsatisfactory on their own.

(b) Development of safety standards and practices which are essential when filling and storing flammable products.

(c) Investment in new filling plant equipped to handle alternative propellants.

In this dynamic situation industry can balance the conflicting pressures involved without sacrificing product quality or safety. It is also a situation in which companies are less likely to be driven out of business.

## CONCLUSIONS

This paper has attempted to show that what is described as a flexible approach to regulation is more effective and more equitable than imposing usage bans in some industry sectors. Particular points addressed include:

a) The need to choose a control which is appropriate at the time of selection to the current needs and yet capable of adaptation as circumstances change.

b) The need to balance the possible environmental effects of CFCs with the effects of other chemicals - both those used as substitutes and others which are disassociated.

c) The ineffectiveness in the long term of implementing use control over one emission source while allowing total production of CFCs to go unchecked.

d) The ability of industry to adapt to a usage limit whereas a a ban will lead to some loss of product quality and also will inevitably drive some, especially small companies out of business.

Finally, we believe that the economic pressures arising from capacity limitation would force industries to work out acceptable ways of reducing their dependence on CFCs and that such an approach is also equitable.

R.C. Knollys.
July 1986.

## APPENDIX

The Federation of European Aerosol Associations is based in Brussels at 49 Square Marie-Louise. Its members are national aerosol associations located in Europe as follows:

| | | |
|---|---|---|
| A.B.A. | Association Belge des Aerosols | (Belgium) |
| A.E.D.A. | Asociacion Espanola de Aerosoles | (Spain) |
| A.F.N. | Aerosolforbundet Norge | (Norway) |
| A.I.A. | Associazione Italiana Aerosol | (Italy) |
| A.I.B. | Aerosol Industriens Brancheforening | (Denmark) |
| A.P.A. | Associacao Portuguesa de Aerosois | (Portugal) |
| A.S.A. | Assoziation der Schweizerischen Aerosolindustrie | (Switzerland) |
| B.A.M.A. | British Aerosol Manufacurers Association | (UK) |
| C.F.A. | Comite Francais des Aerosols | (France) |
| F.A.A. | Suomen Aerosoliyhdistys r.y. | (Finland) |
| H.A.A. | Hellenic Aerosol Association | (Greece) |
| I.A.A. | Internatinal Aerosol Association | |
| I.G.A. | Industrie-Gemeinschaft Aerosole e.V. | (Germany) |
| J.D.A. | Jugoslavensko Drustvo za aerosole | (Yugoslavia) |
| N.A.V. | Nederlandse Aerosol Vereniging | (Nederlands) |
| Oe.Ae.V. | Osterreichische Aerosol-Vereinigung | (Austria) |
| S.A.A. | Svenska Aerosolfloreningen | (Sweden) |

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# WORKING DRAFT

# THE TIMING OF REGULATIONS TO PREVENT STRATOSPHERIC OZONE DEPLETION

James K. Hammitt

September 1986

WD-3137-RC

Prepared For

The Rand Corporation

Rand
SANTA MONICA, CA. 90406

# PREFACE TO THE WORKING DRAFT

This Working Draft presents an analysis of the desirability, from a global economic perspective, of whether to immediately adopt additional regulations to limit emissions of potential ozone depleting chemicals or to await improved scientific understanding of the potential ozone depletion phenomenon and its possible consequences before deciding. It is one of a series of papers written at The Rand Corporation on policy issues associated with potential ozone depletion, and relies heavily on some of the earlier papers.

This Working Draft is being circulated for comments and suggestions. It has not been formally reviewed and is subject to revision, and it is not a final Rand publication and should not be cited or quoted. Formal publication will occur only after it has been revised to reflect comments from Rand and outside reviewers.

Stratospheric ozone is important because the ozone layer helps shield the earth from harmful ultraviolet radiation. Increases in ultraviolet radiation may threaten human health, speed deterioration of certain materials, reduce crop yields, and have a wide range of potentially disruptive ecological effects. Atmospheric models developed and tested over the last decade suggest that global human emissions of potential ozone depleters may promote chemical reactions that reduce stratospheric ozone, thereby increasing ultraviolet radiation with its concomitant effects. Substantial scientific uncertainty persists about whether human emissions of these chemicals actually threaten stratospheric ozone concentrations and, if they do, whether lower ozone levels actually threaten human health and other activities at the earth's surface. Policy makers must act in the face of this uncertainty, however, and Rand's work is designed to help them act with the best information available.

To that end, The Rand Corporation is developing a series of reports addressed to analysts and policy makers responsible for policy decisions on emissions of potential ozone depleters in the United States and elsewhere. These documents report the results of research that includes extensive literature reviews, interviews with knowledgeable officials associated with the production and use of potential ozone depleters, and formal chemical, cost, economic, and statistical analyses. The series should also interest the much broader audience of analysts and decision makers whose organizations would feel the effects of government policies with respect to emissions of such chemicals.

Published papers in the series include the following:

- A. R. Palmer, W. E. Mooz, T. H. Quinn, and K. A. Wolf, *Economic Implications of Regulating Chlorofluorocarbon Emissions from Nonaerosol Applications*, R-2524-EPA, June 1980.
- A. R. Palmer, W. E. Mooz, T. H. Quinn, and K. A. Wolf, *Economic Implications of Regulating Nonaerosol Chlorofluorocarbon Emissions: An Executive Briefing*, R-2575-EPA, July 1980.
- K. A. Wolf, *Regulating Chlorofluorocarbon Emissions: Effects on Chemical Production*, N-1483-EPA, August 1980.
- A. R. Palmer and T. H. Quinn, *Economic Impact Assessment of a Chlorofluorocarbon Production Cap*, N-1656-EPA, February 1981.
- A. R. Palmer and T. H. Quinn, *Allocating Chlorofluorocarbon Permits: Who Gains, Who Loses, and What Is the Cost?* R-2806-EPA, July 1981.
- W. E. Mooz, S. H. Dole, D. L. Jaquette, W. H. Krase, P. F. Morrison, S. L. Salem, R. G. Salter, and K. A. Wolf, *Technical Options for Reducing Chlorofluorocarbon Emissions*, R-2879-EPA, March 1982.
- E. M. Sloss and T. P. Rose, *Possible Health Effects of Increased Exposure to Ultraviolet Radiation*, N-2330-EPA, July 1985.
- T. H. Quinn, K. A. Wolf, W. E. Mooz, J. K. Hammitt, T. W. Chesnutt, and S. Sarma, *Projected Use, Emissions, and Banks of Potential Ozone-Depleting Substances*, N-2282-EPA, January 1986.
- F. Camm and J. K. Hammitt, *An Analytic Method for Constructing Scenarios from a Subjective Joint Probability Distribution*, N-2442-EPA, May 1986.

- F. Camm, T. H. Quinn, A. Bamezai, J. K. Hammitt, M. Meltzer, W. E. Mooz, and K. A. Wolf, *Social Cost of Technical Control Options to Reduce the Use of Potential Ozone Depleters in the United States: An Update*, N-2440-EPA, May 1986.
- J. K. Hammitt, K. A. Wolf, F. Camm, W. E. Mooz, T. H. Quinn, and A. Bamezai, *Product Uses and Market Trends for Potential Ozone-Depleting Substances, 1985-2000*, The Rand Corporation, R-3386-EPA, May 1986.
- W. E. Mooz, K. A. Wolf, and F. Camm, *Potential Constraints on Cumulative Global Production of Chlorofluorocarbons*, R-3400-EPA, May 1986.

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## SUMMARY

Human emissions of chlorofluorocarbons (CFCs) and related chemicals may promote chemical reactions that reduce the concentration of stratospheric ozone and contribute to the expected global warming (the "greenhouse effect"). Depletion of stratospheric ozone could increase the quantity of ultraviolet radiation penetrating to the earth's surface, which could have significant adverse consequences for humans and other animals and plants. However, the extent of ozone depletion and the severity of the resulting consequences associated with projected emission levels are extremely uncertain. Future ozone concentrations are calculated by complex atmospheric models that have not been completely reconciled with the limited available atmospheric measurements of ozone and other trace gas concentrations. Moreover, there are believed to be substantial lags between emission of potential ozone depleting chemicals and consequent effects on ozone concentrations, and between production and emission of these chemicals. As a result, by the time it becomes apparent whether or not potential ozone depletion is a serious threat to global welfare it may be too late to prevent serious adverse consequences.

This paper analyzes a narrow question, but one that is at the heart of this policy issue: Should emissions of potential ozone depleters be reduced immediately, or should we wait several years to improve our understanding of the likelihood and effects of ozone depletion? Regulating immediately creates the risk of incurring economic costs that later prove to have been unnecessary. Waiting for better information creates the risk that emission reductions, should they be necessary, will be more costly.

This analysis takes a global economic perspective. It abstracts from issues related to international coordination of emission-limiting regulations. It is based on the following simplified decision problem: We face the choice of whether to impose emission-limiting regulations now or await better information. Regardless of the decision taken, we will learn whether emission reductions are necessary in several years.

At that time additional regulations may be imposed if necessary. The problem is structured so that the environmental consequences are the same regardless of whether immediate regulations are imposed. The only risk to waiting for better information is that regulations, if necessary, may be more costly. Thus, the analysis abstracts from the possibilities that it is already too late to prevent significant ozone depletion, or that we will not learn whether ozone depletion is a serious problem until it is too late to prevent it.

Whether the expected costs of imposing immediate regulations or awaiting better information and then regulating only if necessary are smaller depends on the probability that emission-limiting regulations will be required. The results of the analysis are characterized by a "critical probability" defined so that immediate regulations will have lower expected cost if and only if the probability that regulations will be necessary exceeds this value.

The critical probability is calculated from a model that incorporates detailed information on the cost of reducing emissions and the likely growth of demand for potential ozone depleters, based on earlier Rand work. It depends primarily on the quantity of emission reductions that may be required and the discount rate used to compare present and future costs. For a wide range of assumptions about the likely growth and elasticity of demand for potential ozone depleters, the possibility of technological innovation that reduces the cost of emission reductions, the rate at which improved information will become available, and the horizon used for limiting emissions and calculating costs, the critical probability is remarkably consistent.

If only limited emission reductions are likely to be necessary immediate regulations are never cost justified, regardless of the probability that such reductions will be necessary. If significant emission reductions may be necessary, whether or not immediate regulations are cost-effective depends on the discount rate. Using a 3 percent real discount rate, immediate regulations will have lower expected costs if the probability that emission reductions will be necessary exceeds the critical probability of about 0.3 to 0.5. Smaller discount rates reduce the critical probability, larger rates increase it. For rates of about 1 to 5 percent the critical probability varies only modestly, about one-tenth lower or higher. Using a 10 percent discount rate, however, increases the critical probability to 0.8 or more. Thus, if a 10 percent rate is appropriate immediate regulations are not cost effective unless emission reductions are almost certain to be necessary.

These results are by necessity based on an extensive set of detailed assumptions about potential ozone depleter use. The assumptions are based on the most detailed information available but the data are limited, especially for regions outside the United States. An important effect of this limitation is that the data do not allow calculation of the costs of restricting cumulative emissions over the next 35 years by more than about half (approximately equivalent to continuing emissions at 1985 levels). Subject to this one exception, however, the remarkable stability of the results across alternative sets of assumptions suggests that the results are not overly sensitive to the specific assumptions chosen.

# CONTENTS

Section

## FIGURES

# I. INTRODUCTION

Release of chlorofluorocarbons (CFCs) and several related chemicals to the atmosphere may lead to reductions in the concentration of stratospheric ozone and contribute to changes in the Earth's climate through the "greenhouse effect." Each effect could threaten global and human welfare: Depletion of stratospheric ozone would increase the quantity of ultraviolet radiation reaching the Earth's surface, potentially increasing human skin cancer incidence, promoting cataracts in humans and other animals, and causing other adverse effects to animals, plants, and valuable materials. The "greenhouse effect" is expected to cause a general global warming that would affect climate and weather patterns, sea levels, and agricultural productivity.

The effects of CFCs and other potential ozone depleters are uncertain. The atmospheric transport and chemical processes leading to stratospheric ozone depletion are not completely understood. Projections of future depletion are based on complex simulation models that have not been reconciled with limited available measurements of the concentration of ozone and other trace gases. Moreover, the effect of any quantity of potential ozone depleters depends on the concentrations and emissions of other gases that are emitted through natural as well as human activities. However, the effects of potential ozone depleter emissions are expected to be long-lived: these gases are expected to remain in the atmosphere for periods of 50 or 100 years or more.[1]

Potential ozone depleters are man made chemicals. They are released to the atmosphere solely as a consequence of their use in a wide range of industrial processes and consumer products. CFC-11 and CFC-12 are probably the most important: they are produced in substantial

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[1] Most of the scientific research has focused on ozone depletion. The projected global warming is likely to be caused as much by carbon dioxide emissions (largely from burning fossil fuels) as by releases of other gases. For more information on the state of the science of ozone depletion and the contribution of potential ozone depleters to global warming see National Academy of Sciences (1976, 1979, 1982, 1984), Ramanathan et al. (1985), and Watson et al. (1986).

quantities and are believed to be moderately efficient ozone depleters. CFC-11 is used largely as an aerosol propellant (except in the United States, where most such uses were banned in 1978), as a blowing agent for manufacturing rigid insulating and flexible cushioning foams, and as a refrigerant in chillers (large industrial and commercial air conditioning systems). CFC-12 is also used as an aerosol propellant (outside the United States), as a blowing agent in foam manufacturing, and as a refrigerant in automotive air conditioners, chillers, home and retail food refrigeration equipment.

Other important potential ozone depleters include the solvents CFC-113 and methyl chloroform, carbon tetrachloride, Halon-1211 and Halon-1301. CFC-113 is used primarily in manufacturing electronic equipment, but also in dry cleaning and other applications. Methyl chloroform is a general purpose solvent used in a variety of manufacturing processes. It is believed to be a relatively inefficient ozone depleter, but is emitted in large quantities. Carbon tetrachloride is used largely to produce CFC-11 and CFC-12, although some may be used as a solvent or grain fumigant. Halon-1211 and Halon-1301 are fire extinguishing agents used in portable extinguishers and total flooding systems. Although only small quantities are produced, the Halons are thought to be the most efficient ozone depleters.[2]

The relationship between commercial use and atmospheric release of the potential ozone depleters varies with the application. In some uses, such as aerosol propellants, the chemical is inevitably released to the atmosphere as the product is consumed. In other applications, such as insulating foam and refrigeration equipment, the chemical is contained in a sealed unit and is released only through unintended leakage or after product disposal. The quantities of potential ozone depleters contained in such products represent a bank that may or may not eventually reach the stratosphere. In any case, the existence of this bank results in a substantial delay between production and release of the chemicals. This delay is on the order of 10 to 20 years for most

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[2] See Hammitt et al. (1986) or Palmer et al. (1980) for more information on the uses of these chemicals.

refrigeration equipment, and may be 50 or 100 years or more for rigid insulating foams.

Because of the long atmospheric residence times and the substantial delay between initial consumption and emission of potential ozone depleters, preventive regulations may be desirable. Even though our current understanding of the science of ozone depletion and global warming is incomplete, it may be wise to limit releases now rather than to await future scientific developments before deciding whether regulations are necessary. Simply stated, by the time our understanding of these phenomena has developed to a state that allows us to confidently assess the relationship between potential ozone depleting emissions and environmental consequences, it may be too late to avert significant adverse effects. Whether these adverse consequences would be ultimately reversible is not known; in any event, they are likely to persist for a human generation or more.

Thus, the essential policy question is whether to impose additional regulations to restrict emissions now (the United States and several other countries adopted some regulations in the late 1970s), thereby incurring economic losses that may later prove to have been unnecessary, or to await future scientific developments and thereby risk higher abatement costs and potentially serious adverse environmental changes. This report attempts to provide insight into this question by comparing the expected economic costs of alternative regulatory strategies. Specifically, it characterizes the degree of belief about the severity of the potential ozone depletion problem such that the expected economic cost of awaiting future scientific revelations is smaller or greater than the expected cost of imposing interim regulations now. Because the alternative regulatory strategies are constructed to produce equivalent ozone depletion, it is not necessary to estimate the benefits of reducing depletion and the economic costs may be compared directly.

The focus of this report is on the question of whether the world as a whole should impose additional regulations on emissions of potential ozone depleters now or await future developments before deciding. It abstracts from the important issues associated with coordinating action among nations. These issues may be important in determining how to structure regulations and how much ozone depletion to risk. However, the question of whether to adopt additional regulations now is logically prior to that of how to structure such rules.

The analysis also abstracts from the possibility that we may not learn whether ozone depletion is a serious problem until it is too late to prevent it.

The following section describes the methodology used to address this timing issue. Section III presents the results of the analysis and Section IV discusses the ramifications and important extensions to the methodology.

## II. METHODOLOGY

The ultimate effects of emitting potential ozone depleters to the atmosphere are uncertain. Formally, this uncertainty can be characterized by a subjective probability distribution function f(e) relating the changes in global and human welfare to the time path of emissions.[1] The subjective distribution function f(e) will shift over time as scientific research increases our understanding of the likelihood and extent of ozone depletion, climatic change, and the resulting effects on activities that directly affect human, animal, and plant welfare. Increased understanding should reduce the variance of f(e) as it lessens the range of plausible consequences. The mean of f(e) may also shift as we learn more about the relationships between emissions and ultimate consequences.

Optimal restrictions on emissions of potential ozone depleters will depend on f(e) and will change over time as f(e) shifts. In general, one would expect that the desirability of limiting emissions now, and the stringency of the appropriate limitation, would be positively correlated with subjective estimates of the likelihood and severity of adverse consequences. In addition, since it will generally be less costly to obtain a fixed reduction in cumulative emissions if the reduction is spread over a longer period, one might expect that a strategy of imposing at least some emission restrictions now would always be less costly than risking the possibility of having to impose much harsher restrictions later. As the analysis described below will demonstrate, however, the expected economic cost of imposing regulations to limit emissions now, as opposed to waiting several years for improved understanding of the consequences of those emissions, depends on the relative costs of reducing emissions now and in the future. Depending on the subjective estimate of the likelihood of having to restrict

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[1] e represents a vector of emissions of each potential ozone depleter over time, and f(e) may be a vector valued function describing the likelihood of consequences measured in many dimensions. For expositional convenience, however, consider f(e) to be scalar valued.

emissions, either immediate regulations or a "wait and see" strategy may be less costly.

## A MODEL OF THE DECISION PROBLEM

The analysis described here is based on the stylized decision problem represented in Fig. 1. There, the problem has been simplified to its essentials. The decision is whether to impose a set of specified emission-limiting regulations now or await future information. Independent of that decision, new information will become available at a fixed future date. At that time, the subjective distribution function for the ultimate consequences of potential ozone depleter emissions will degenerate into a point mass at one of two points, characterized as "good" and "bad news." In the event of "good news" we will learn that there is not a serious problem, and no emission restrictions are required. If emission regulations have not already been imposed, no restrictions will be required (branch 1 in the decision tree). If

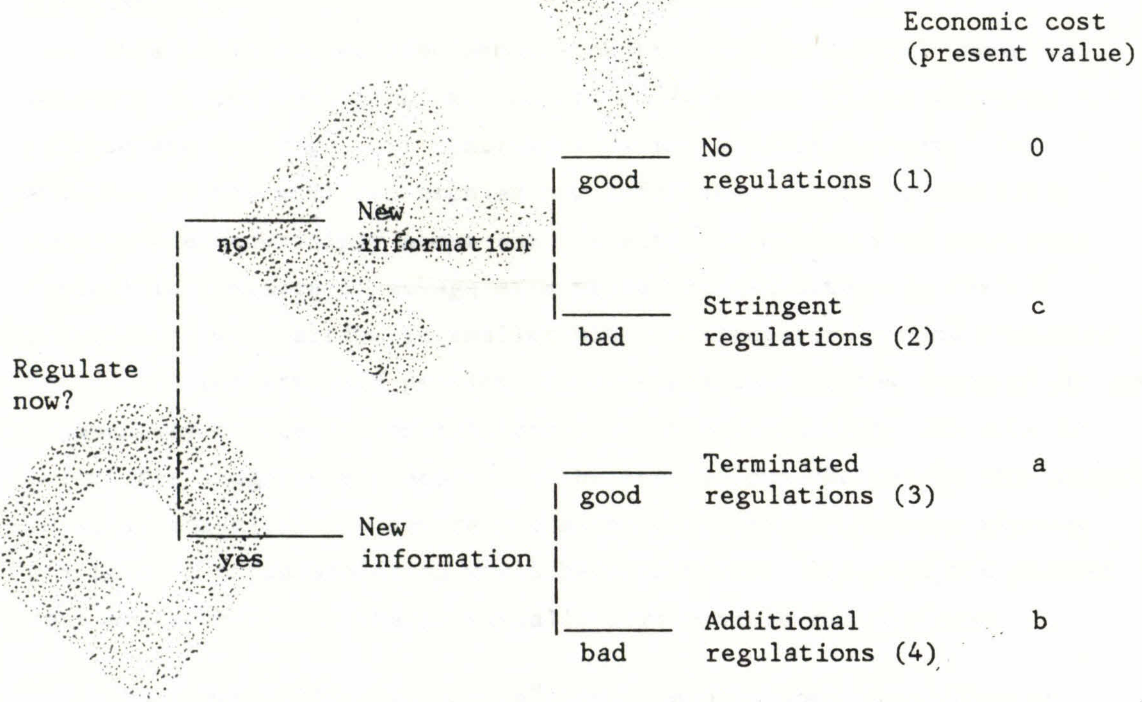

Fig. 1 -- Decision framework for regulating potential ozone depleters

restrictions have already been imposed, they can be relaxed or abolished (branch 3).[2] In the event of "bad news," we will learn that significant emission limitations are required. If regulations have not already been adopted then stringent restrictions will be necessary (branch 2), and if regulations have been adopted some additional regulations may still be required (branch 4).

The levels of emission restrictions incorporated in Fig. 1 are chosen so as to equalize the environmental consequences of the immediate regulation and no immediate regulation branches. It is assumed that the new information will arrive early enough that significant adverse effects can be prevented by the imposition of sufficiently stringent regulations at that time. Thus the only penalty for awaiting the new information before regulating is the lost opportunity to distribute any required emission reductions over a longer period, and thereby potentially reduce their cost. Since the environmental consequences do not depend on whether regulations are adopted immediately or not, the analysis reduces to a comparison of the expected economic costs of the alternatives.

This stylized decision problem abstracts from several important features of the real problem. First, many aspects of the stylized problem are discrete, not continuous as in the real problem. For example, in the stylized problem new information that substantially reduces the uncertainty about the ultimate consequences of emissions arrives in a discrete package at a predetermined date. In reality, information will arrive in smaller bits at irregular, random intervals. Second, in the stylized problem the date and type of new information are independent of the chosen regulatory strategy. In fact, the rate of scientific progress may depend on the regulations chosen: In the extreme case, if emissions are severely limited we might never learn whether significant ozone depletion would have occurred. The stylized problem does not account for the potentially irreversible effects that

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[2] More generally, "good news" could require some limitation on emissions. In this case, mild regulations would be required at branch (1) and existing regulations could be relaxed, but not necessarily terminated, at branch (3).

regulation may have on demand and industry, or for transactions costs associated with regulations and the possibility that an advanced notice of impending regulations may reduce the cost of regulation. Finally, the stylized problem abstracts from the issue of choosing the appropriate level of emissions, and consequently environmental and welfare consequences to accept. This issue may be solved in principal by a comparison of the costs of environmental degradation and those of emission control. There may also be interactions between whether controls have been imposed and the level of ozone depletion to accept later, but these are not considered here. Despite these simplifications, the stylized problem elucidates many of the issues pertinent to the decision.

In the stylized problem, when the decision of whether to impose immediate regulations is made the subjective distribution function f(e) is binomial. It assigns probability p to the chance that the new information will reveal that substantial emission reductions are required, and the complementary probability (1 - p) to the chance that reductions will not be necessary. Conditional on the levels of emission reductions associated with each outcome and with the level of immediate regulations proposed, one can solve the stylized decision problem for the "critical probability" q. This value separates the set of possible prior beliefs about the likelihood of good and bad news into two classes: those for which immediate regulations are expected to be less costly than waiting for new information before deciding whether to regulate, and those for which they are expected to be more costly. If the subjective probability that the new information will be bad news is higher than this critical probability q, immediate regulations will be less costly (in expected value); if the subjective probability is lower, they will be more costly.

The analysis described here focuses on this critical probability q. This parameter summarizes the degree of belief that ozone depletion and climatic change will become significant problems that is required in order to believe that imposing emission-limiting regulations now is a cost-justified strategy.[3] The results presented in Sec. III describe how

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[3] Evaluating alternatives policies by their expected economic costs alone may be inadequate, particularly when the potential outcomes are far apart. See Raiffa (1968).

this critical probability depends on a number of features of the decision problem, including the likely severity of the welfare consequences of emissions (reflected in the degree of emission restrictions that are appropriate) and the date at which significant new information will become available. That section also describes the sensitivity of the critical probability to alternative assumptions about the likely growth in demand for potential ozone depleters, the elasticity of demand for them and the possibility of future innovation that reduces the cost of reducing emissions, and the discount rate used to calculate the present value of future costs.

## COMPARATIVE STATICS OF THE CRITICAL PROBABILITY

The critical probability q is the probability that equalizes the expected costs of imposing immediate regulations or awaiting the new information. It solves the formula

$$q = \frac{a}{a + (c - b)} \qquad (1)$$

where a, b, and c are the present values of the economic costs of following branches (3), (4) and (2) of the decision tree respectively. If the subjective probability that emission regulations will be necessary exceeds q, the expected cost of adopting the proposed immediate regulations will be smaller than the expected cost of awaiting new information before deciding whether to act.

The critical probability q depends on the costs of all of the branches of the decision tree, discounted to the present. The term a represents the present value of the costs of near term regulations. If the new information indicates that emission regulations are not necessary the existing regulations will be terminated, so a includes only costs incurred between now and the date of new information. As a ranges from zero to infinity q ranges from 0 to 1. Thus, if the present value of near term costs is small, q will be small, and even if the subjective probability of having to impose future regulations is small immediate regulations will be cost-justified. Similarly, if a is large, immediate regulations will not be cost-justified unless the probability of having to impose regulations in the future is high.

The second term in equation (1), (c - b), represents the present value of the cost savings due to spreading the emission reduction over a longer period, contingent on emission restrictions being necessary. As (c - b) ranges from zero to infinity, q ranges from 1 to 0. If (c - b) is large, q will be small, and immediate regulations will be cost-justified even if the subjective probability of needing to reduce emissions is small. The term (c - b) is not necessarily positive. Because it measures the difference in the present value of costs, if the discount rate is high relative to the additional cost of imposing sharper emission reductions later instead of modest reductions now, (c - b) may be less than zero. In this case, there is no possible cost saving to beginning regulations now and immediate regulations can not be cost-justified regardless of the subjective probability of having to impose future regulations.[4]

## PARAMETERS OF THE MODEL

To allow comparison of the expected costs of regulating now versus awaiting future information the emission paths corresponding to the two main branches of the decision tree must impose equivalent risk of environmental damage. In the model, alternative regulatory trajectories are assumed to impose equivalent environmental risk if the cumulative weighted emissions of the seven main potential ozone depleters through a fixed horizon are equal. Clearly, cumulative emissions under different regulatory trajectories can not be equal at all dates; however, variations in the timing of emissions on a scale significantly shorter than that of the the long atmospheric residence times of the potential ozone depleters should have little effect on ozone depletion at the horizon and beyond.[5]

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[4] Depending on whether the absolute value of (c - b) exceeds a, q will be less than 0 or greater than 1. Technical innovation that is expected to reduce the costs of emission reductions over time may also lead to values of (c - b) that are less than zero.

[5] The potential ozone depleters are believed to differ in the efficiency with which a unit mass of each contributes to ozone depletion. The weighting factors approximate the relative depletion efficiencies of each potential depleter, although the actual depletion

The horizon used for analysis is 2020. Immediate regulation is characterized as regulations beginning at the start of 1988, and the new information is assumed to arrive in time to allow additional regulations to be implemented at the beginning of 1995. The choice of dates is based on several considerations. Given the current pace of international and U.S. deliberations, the beginning of 1988 appears to be the earliest possible date at which regulations could be implemented.[6] The choice of 1995 as the date for new regulations or termination of existing regulations as appropriate allows just over eight years from the present for the development of new scientific understanding and the design and implementation of regulations, if necessary. If a decision is made to await further information before deciding whether to regulate one must be prepared to wait several years in order to allow significant scientific progress. However, eight years should allow substantial improvements in our understanding of the environmental consequences of potential ozone depleter emissions, especially considering the rapidly developing programs for measurement of ozone and other trace gas concentrations (National Academy of Sciences, 1984). The sensitivity of the results to the choice of a date for possible additional regulations is tested by repeating the calculations using 2000 as the date at which new regulations can be imposed, if required.

Setting the horizon at 2020 is intended to allow sufficient time for regulations beginning in 1995 or 2000 to offset unregulated growth

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efficiencies may vary with the quantities of each potential depleter and of other trace gases in the atmosphere. The factors used are the same as those used in Camm and Hammitt (1986): CFC-11, CFC-12, CFC-113, and carbon tetrachloride--1.0; methyl chloroform--0.1; Halon-1211 and Halon-1301--10.0. The assumption that, conditional on cumulative weighted emissions, future ozone concentrations are insensitive to variations in the timing of emissions is supported by preliminary calculations using Connell's (1986) approximation to the Lawrence Livermore National Laboratory one-dimensional atmospheric model results.

[6] Even this date appears optimistic. The U.S. Environmental Protection Agency has announced that it will determine whether additional U.S. regulations are warranted by November 1987 (*Federal Register*, Vol. 51, No. 7, January 10, 1986). International negotiations are proceeding on a parallel schedule.

in emissions in the period before the new information arrives. Because of the long lags between production and emission, and between emission and ultimate effect on ozone concentration, there is a substantial delay between changes in production and reversal of any trend in ozone concentration. Thus, if the ozone concentration is falling in 1995 or 2000, even if production of potential ozone depleters were abruptly reduced or even halted the ozone concentration would likely continue to fall for a period, and would not recover to its 1995 or 2000 level for perhaps 20 years.[7]

A number of alternative strategies for immediate regulation are compared with the option of awaiting new information and then regulating only if necessary. For each of these alternatives the critical probability q is calculated as a function of the total cumulative emissions that can be tolerated. The strategies differ in the stringency of pre-information regulations compared to the stringency that will be imposed post information if regulations are required then.[8]

## CALCULATION OF RESOURCE COSTS AND CRITICAL PROBABILITIES

Calculation of the critical probability q for any proposed immediate regulation requires calculation of the present value of the resource costs of alternative regulatory trajectories (the values of a, b, and c in Fig. 1). These resource costs are measured as areas under the demand curves for each chemical. The calculations are performed by a computer program that simulates annual demand curves for each application of the potential ozone depleters over the period 1985 through 2020.

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[7] This conclusion is based on projected time paths of ozone concentration in Wuebbles (1983), Stordal and Isaksen (1986), and calculations using Connell's (1986) approximation. The effect of the choice of horizon is explored by additional calculations using 2010 as the horizon.

[8] For each probability of bad news, there is an optimal level of pre-information regulations (including the possibility of no regulations). But since the calculations required to determine this optimal level require extensive iteration, critical probabilities are calculated for only a few representative levels of pre-information regulations.

The regulatory trajectories assume that the regulations will consist of surcharges imposed on the use of potential ozone depleters, where the surcharges are proportional to the relative ozone depletion efficiencies of each chemical. Using a surcharge, the effective price of the potential ozone depleters can be increased so that consumers will switch to alternative products and manufacturers will substitute alternative chemicals, more conservative processes, or other technological options that become cost effective. The size of the surcharge can be varied to induce the desired amount of emission reductions. The use of such a surcharge induces manufacturers and consumers to adopt the economically efficient set of emission reduction steps, thereby minimizing the annual resource costs of reducing emissions. To minimize the present value of the cost of limiting cumulative weighted emissions the surcharges should rise over time at the discount rate that firms and consumers use in making investment and consumption decisions.[9]

If a surcharge is applied, the resource costs of the regulation can be measured by the area under the demand curve for each chemical between the unregulated price and the price including surcharge.[10] Other regulatory programs, such as marketable permits or command and control, could also be applied. These alternative programs would impose the same costs, unless they fail to induce the most efficient emission control technologies. In that case, the resource costs would be higher than those calculated.[11] Thus, the assumption that regulation will be

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[9] This conclusion is based on analogy with the solution for optimal pricing of an exhaustible resource (Fisher, 1981). Although the stratospheric ozone may not be an exhaustible resource, since it can likely tolerate unlimited emissions of potential ozone depleters if the emissions occur at a sufficiently low rate, the optimal regulatory trajectory to limit ozone depletion should be approximately the same over the relatively limited time period considered.

[10] The resource cost is the reduction in economic surplus due to the surcharge: the area bounded by the demand curve, the unregulated price and the price plus surcharge, and the quantity demanded under the surcharge. See Camm et al. (1986) for further discussion.

[11] See Palmer and Quinn (1981a, 1981b) for discussion of the relative advantages of various types of potential ozone depleter regulations.

characterized by a surcharge is primarily a convenient device to allow calculation of the resource costs of the regulation.

A total of 28 annual demand curves for specific chemicals and applications are calculated, for the 36 years from 1985 through 2020. The 28 annual curves measure demand for potential ozone depleter use in 14 applications each in the United States and in the rest of the world. These curves, and their movement over time, are based on earlier Rand work.

The shapes of the demand curves are based on the estimates in Camm et al. (1986) of the chemical prices at which manufacturers would substitute other chemicals or production processes. The curves include the known technological options that are likely to be adopted if the effective price of the potential ozone depleters were to increase by no more than \$5.00 per pound (a 5 to 10-fold increase). Camm et al. focus on technological options in the United States, and discuss the differences between the United States and other countries that may limit the applicability of their findings to other countries. However, because no better estimates of the demand curves in other countries are currently available, the simulations here assume (with one exception) that firms in other countries would respond in the same manner as U.S. firms.[12]

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[12] There are several differences between the demand curves employed in this simulation and those developed in Camm et al. (1986): (1) The simulation assumes that non-U.S. CFC-11 and CFC-12 use as an aerosol propellant would begin to decline after their prices doubled (to \$1.02 and 1.32 per pound), and that use would thereafter decline linearly reaching only 5 percent of initial use if the price rose \$5 per pound. (2) Camm et al. (1986) do not make any estimate of the reduction in demand for Halon-1211 and Halon-1301 at elevated prices. The simulation assumes their demand curves have constant elasticity equal to -0.32. The Halons currently cost about \$2.00 per pound. Thus a \$1.00 increase would reduce simulated demand by 12 percent; a \$5.00 increase would reduce it 33 percent. (3) Camm et al. did not explicitly report technological options for reducing methyl chloroform emissions, but these are similar to those for CFC-113. The simulation uses a curve for methyl chloroform that is based on that for CFC-113 but adjusted for the difference in the price of the two chemicals. (4) Camm et al. also did not assess demand for the relatively minor uses of carbon tetrachloride other than use as a precursor to CFC-11 and CFC-12. The simulations assume these other uses would not fall with a price increase of less than \$5.00 per pound. (5) Finally, in some applications Camm et al. report two demand curves, depending on how widely options they identify as cost effective at current prices have been adopted. In these cases the simulated demand curves are half way between the two.

The simulated demand curves move over time to account for likely growth in demand for chemical use in each application. The likely growth is described in Camm and Hammitt (1986) and Hammitt et al. (1986). These documents develop a set of projected demand scenarios, based on historical trends, analysis of specific products, and projected general economic growth. The scenarios are related to a subjective probability density function that describes the likelihood that future demand will fall in any specified interval. In the standard case, demand is assumed to grow along the median projection.[13]

The resource costs and cumulative weighted emissions associated with any regulatory trajectory (defined by the path of the surcharge over time) are calculated using a computer program. These results are used by a second program to calculate the critical probability associated with a specified set of proposed immediate regulations and level of acceptable cumulative emissions.

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[13] Hammitt et al. (1986) projects demand for each of the major applications of the seven principal potential ozone depleters, within the United States and outside, through 2000. Camm and Hammitt (1986) extend the projected aggregate global demand for these chemicals through 2040. To calculate emissions beyond 2000 the current simulations assume that demand for chemical use in all applications of a chemical grow at the same rate.

## III. RESULTS

The level to which cumulative weighted emissions can be constrained depends on the date at which emission regulations are imposed and the stringency of the regulations. Fig. 2 illustrates the effect of these factors. The abcissa indicates the initial base surcharge, ranging between zero and five dollars. In this standard case, demand for potential ozone depleters is assumed to grow at the median rates described in Camm and Hammitt (1986) and Hammitt et al. (1986), and the surcharge increases 3 percent per year. The three lines in the figure correspond to regulations beginning in 1988, 1995, and 2000. In the absence of regulations (that is, with a surcharge equal to zero), global cumulative weighted emissions from 1985 through 2020 would total about 63.5 million metric tons. If regulations were to begin in 1988, limiting emissions to 50 million metric tons would require an initial world-wide surcharge of about $0.90 per pound, limiting emissions to 40 million metric tons would require an initial surcharge of about $1.87 per pound, and the minimum attainable level of cumulative emissions, if the initial surcharge were limited to $5.00 per pound, would be about 32.5 million metric tons.[1] If regulations were not initiated until 1995 larger surcharges would be necessary to limit emissions to the same levels: A 50 million metric ton limit would require a surcharge beginning at $1.22 per pound, and a 40 million metric ton limit would require a surcharge beginning at $2.83 per pound. The smallest attainable cumulative emissions, if regulations did not begin until 1995, would be about 37.2 million metric tons. If regulations were not

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[1] The weights used for calculating cumulative weighted emissions, and the surcharges applied to each chemical, are proportional to their approximate estimated relative ozone depletion efficiencies. The surcharge applied to methyl chloroform would be one-tenth the base surcharge listed in the text and the surcharges applied to the Halons would be ten times the base surcharge. Thus, limiting weighted emissions to 40 million metric tons would require a surcharge of about $1.87 per pound for CFC-11, CFC-12, CFC-113 and carbon tetrachloride, a surcharge of about $0.19 per pound for methyl chloroform, and a surcharge of about $18.70 per pound for Halon-1211 and Halon-1301.

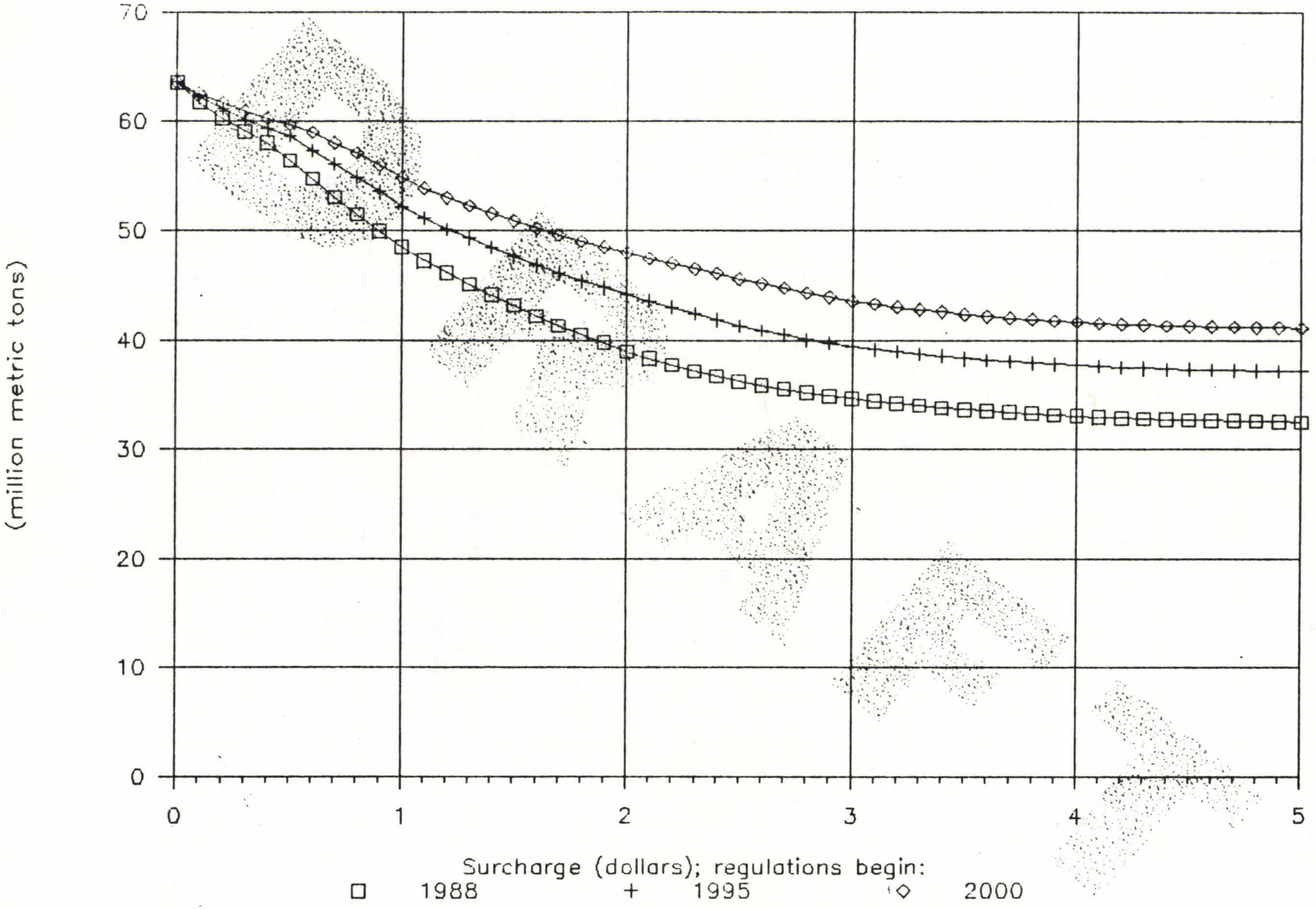

Fig. 2 -- Cumulative weighted emissions as a function of date and stringency of regulations

imposed until 2000, the range of attainable cumulative emissions is further reduced, and even higher surcharges would be required to hold emissions to any attainable level.

Fig. 2 illustrates the inelasticity of the demand for potential ozone depleters: Even with surcharges of several dollars per pound, compared with unregulated prices on the order of 50 cents per pound, cumulative emissions over the next 35 years fall by no more than half.[2] It appears to be nearly impossible to limit cumulative emissions to the level corresponding to constant 1985 emissions, the scenario often assumed for atmospheric model calculations. Constant 1985 emissions through 2020 would total 35.2 million metric tons. According to the calculations summarized in Fig. 2, limiting cumulative emissions to this level would require an initial surcharge of $2.80 per pound if regulations begin in 1988, and would not be possible if regulations were delayed until 1995.

In part, the difficulty of reducing emissions reflects the emissions that will occur from the currently existing banks contained in rigid foam and refrigeration equipment. A more important factor, however, is the superior performance of the potential ozone depleters in many applications, requiring large price increases before manufacturers and consumers will substitute alternative chemicals. There is great uncertainty about the technological alternatives that might be adopted if surcharges of several dollars per pound were to be imposed, however. Although current estimates, such as those in Camm et al. (1986) and Palmer et al. (1980), suggest that substitution possibilities are limited, a surcharge of several dollars per pound would create a strong incentive to develop alternative manufacturing processes and products. Consequently, estimates of the minimum attainable emissions using a surcharge of no more than $5.00 per pound are particularly uncertain.

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[2] Current average U.S. prices per pound, based on United States International Trade Commission (1984), are: CFC-11--$0.51, CFC-12--$0.67, carbon tetrachloride--$0.16, and methyl chloroform--$0.30. The International Trade Commission does not publish data for CFC-113 or the Halons but industry sources suggest the following average prices per pound: CFC-113--$0.89, Halon-1211--$1.95 and Halon-1301--$2.20.

The resource costs (deadweight losses) associated with restrictions that reduce potential ozone depleter emissions are substantial. Fig. 3 illustrates the present value (in 1985 using a discount rate of 3 percent) of the resource costs associated with a surcharge beginning at the level indicated on the abcissa and increasing at 3 percent per year. By using Figs. 2 and 3 one can estimate the resource cost associated with any achievable level of cumulative weighted emissions. For example, to limit cumulative emissions through 2020 to 50 million metric tons requires a surcharge beginning at $0.90 per pound, if regulations begin in 1988. As shown by Fig. 3, the present value of the associated resource cost is $14,400 million. If the regulations are not implemented until 1995 the required initial surcharge of $1.22 per pound is associated with a resource cost of $15,800 million in present value.

## THE CRITICAL PROBABILITY

Fig. 4 illustrates the critical probability q that determines whether the expected cost of immediate regulations is greater or smaller than the expected cost of awaiting new information. The critical probability varies with the cumulative emissions that can be tolerated and with the proposed level of immediate regulations. Fig. 4 describes the critical probability for each level of cumulative weighted emissions (measured along the abcissa in millions of metric tons), where the proposed immediate regulations are set so that no additional restrictions will be required if the new information obtained by 1995 indicates that emission-limiting regulations are necessary. For example, assume that the subjective distribution function f(e) described in Sec. II corresponds to a situation in which the new information to be received by 1995 may indicate either that cumulative emissions through 2020 must be limited to 55 million metric tons, or that the 63.5 million metric tons of emissions that would occur without regulations will be acceptable. The proposed immediate regulations consist of a base surcharge of $0.59 per pound, increasing 3 percent per year through 2020. This surcharge is just sufficient to hold cumulative emissions to 55 million metric tons (compare Fig. 2). If the new information indicates that cumulative emissions must be limited to 55 million metric

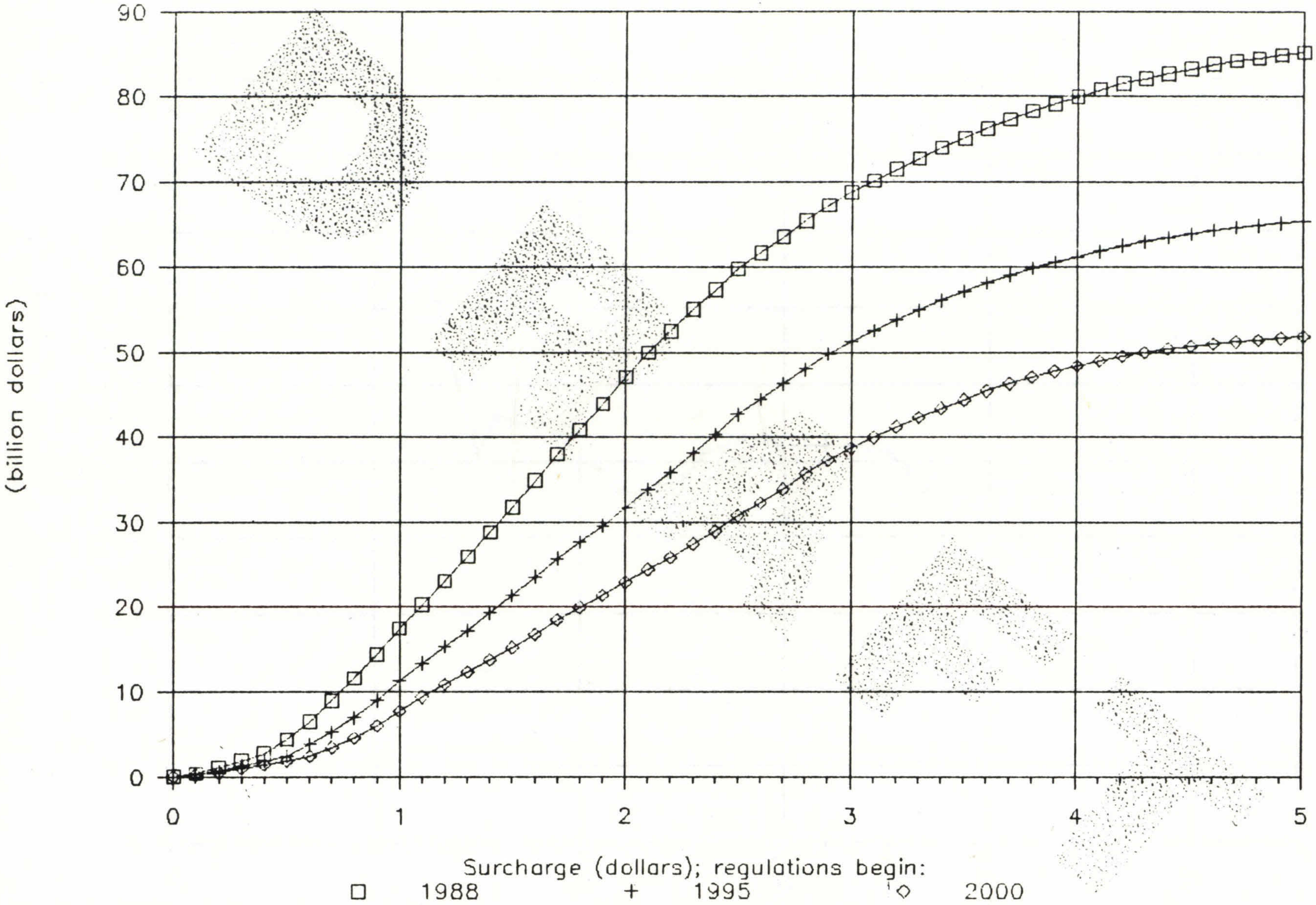

Fig. 3 -- Present value of resource cost as a function of date and stringency of regulations

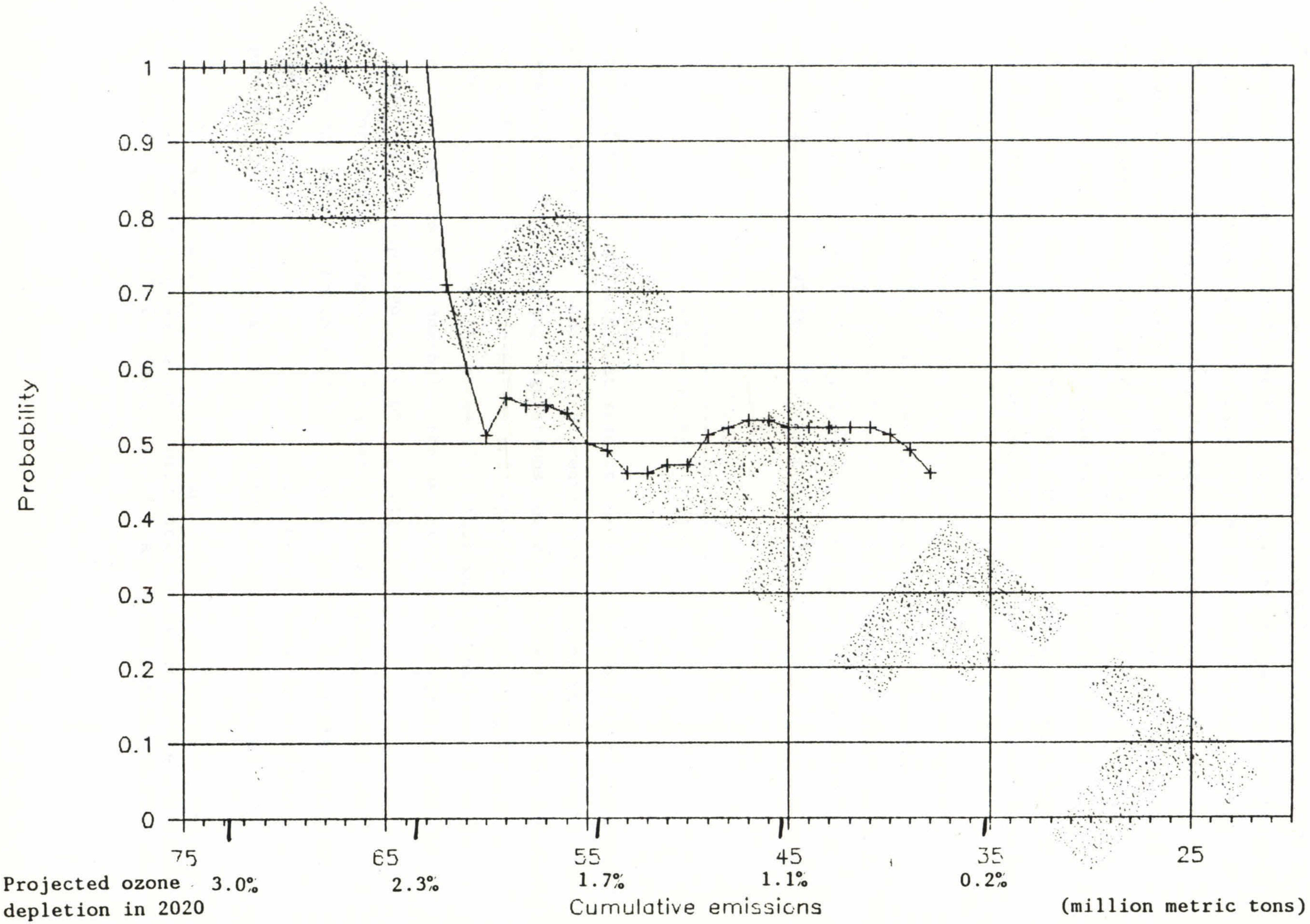

Fig. 4 -- Critical probability: standard case

tons, no additional regulations will be required in 1995 (branch 4 of the decision tree in Fig. 1). If the new information indicates that no regulations are required, the surcharge will be dropped in 1995 (branch 3 in Fig. 1), and no further costs will be incurred. Alternatively, if the proposed immediate regulations are not adopted, and the new information indicates that cumulative emissions must be limited to 55 million metric tons, it would be necessary to impose a surcharge of \$0.79 per pound in 1995 that would increase 3 percent annually (branch 2 in Fig. 1). If the new information indicates cumulative emissions of 63.5 million metric tons can be tolerated, no regulations would ever be imposed (branch 1 in Fig. 1).

The critical probability q can be calculated from the present values of the resource costs associated with each of these four possibilities. The values a, b, and c (corresponding to branches 3, 4 and 2 in Fig. 1) are \$622 million, \$6,172 million, and \$6,785 million.[3] Using equation (1) of Sec. II, the critical probability

$$q = \frac{622}{622 + (6{,}785 - 6{,}172)} = 0.50.$$

Thus, if the probability that regulations limiting cumulative emissions to 55 million metric tons will be required is greater than one-half, the expected cost of imposing regulations now will be less than the expected cost of awaiting new information and imposing stricter regulations in 1995 if necessary. If the probability that such regulations will be required is less than one-half, the expected costs of waiting will be lower than the expected costs of regulating now.

The critical probability varies with the level of cumulative emissions that can be tolerated. As shown in Fig. 4, if the potential limit is between about 60 and 38 million metric tons the critical probability is about one-half. Over this domain the critical

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[3] These are estimates of the present value of the economic cost (or deadweight loss) associated with world-wide imposition of the specified surcharges through 2020. The values of b and c are plotted in Fig. 3.

probability is nearly constant. The small, erratic variations are probably due to the varying curvature of the functions relating cumulative emissions to the required surcharge and associated resource costs (illustrated in Figs. 2 and 3) and approximations in simulating the demand curves.[4] If the potential emission limit is 63 million metric tons or more, the critical probability is 1.0, and the expected cost of immediate regulations can not be lower than the expected cost of waiting, regardless of the subjective probability that emission restrictions will be required. Finally, if emissions might need to be limited to 37 million metric tons or less, the critical probability is undefined: Since it is not possible to limit emissions to this level using the simulated demand curves it is not possible to calculate the resource costs of alternative regulatory paths.

For reference, the abcissa of Fig. 4 also indicates the projected decrease in column ozone in 2020 corresponding to each level of cumulative emissions.[5] One way of thinking about the results in Fig. 4 is that by 1995 we will learn either that these depletion estimates are correct, or that potential ozone depletion is not an important problem (because it will not occur, or because the consequences will not be serious). Then whether or not immediate regulations are cost-effective depends on the level of potential depletion we can accept. If depletion of 2.3 percent or more is acceptable, immediate regulations can not be cost-effective regardless of the probability that ozone depletion will occur. If depletion of less than 0.2 percent is unacceptable, it is not possible to calculate the critical probability without additional information on the costs of reducing emissions more than allowed by the simulated demand curves. Finally, if the tolerable level of depletion is between 0.2 and 2.3 percent, immediate regulations may be cost-effective depending on whether the probability that ozone depletion will occur exceeds about 0.5.

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[4] The algorithm approximates the demand curves with step functions that have steps at $0.10 intervals.

[5] These estimates are calculated using the Lawrence Livermore National Laboratories one-dimensional atmospheric model and the emissions corresponding to the production growth scenarios developed in Camm and Hammitt (1986) and Hammitt et al. (1986).

## THE EFFECTS OF ALTERNATIVE PROPOSED CURRENT REGULATIONS

Fig. 4 illustrates the critical probability for the choice between awaiting new information and imposing stringent regulations now. In that case, the proposed immediate regulations are so stringent that no additional regulations will be required even if the new information indicates emission limitations are necessary. These are the regulations that would be least costly if we knew that it was necessary to limit cumulative emissions to some specified level. If the probability that such regulations will be required is less than one, less stringent regulations should have lower expected cost.

Fig. 5 describes the critical probabilities corresponding to a set of milder immediate regulations. The line labelled "1.0" is the same as the line in Fig. 4. The other lines describe the critical probabilities for the choice between awaiting new information and regulating now at less stringent levels. Each of these lines corresponds to proposed immediate surcharges that are smaller than the surcharge that will be necessary in 1995, if the new information indicates regulations are needed, by a fixed factor. Specifically, the lines labelled "0.75," "0.50," "0.25," and "0.10," correspond to regulations beginning in 1988 for which the surcharge follows a path from 1988 to 1994 that is smaller than its path from 1995 to 2020 by a factor of 0.75, 0.50, 0.25, and 0.10.[6]

As shown in Fig. 5, the critical probability first falls with the proposed stringency of the immediate regulations, then rises. The line corresponding to immediate regulations that impose a surcharge only 75 percent as large as the post-1995 surcharge ("75 percent regulations") is below the 100 percent regulation line, and the 50 percent regulation line is even lower. In contrast, the critical probability for immediate regulations that are only 25 percent as stringent as the post-1995 regulations is almost equal to the critical probability for 50 percent

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[6] For the line labelled "1.0," the surcharge in year t satisfies the formula $s_{1.0}(t) = s_{1.0}(1985) \times (1.03)^{(t-1985)}$. For the other lines, labelled by the factor f, the surcharge in year t satisfies the formula $s_f(t) = f \times s_f^*(1985) \times (1.03)^{(t-1985)}$ if $t < 1995$; $s_f(t) = s_f^*(1985) \times (1.03)^{(t-1985)}$ otherwise.

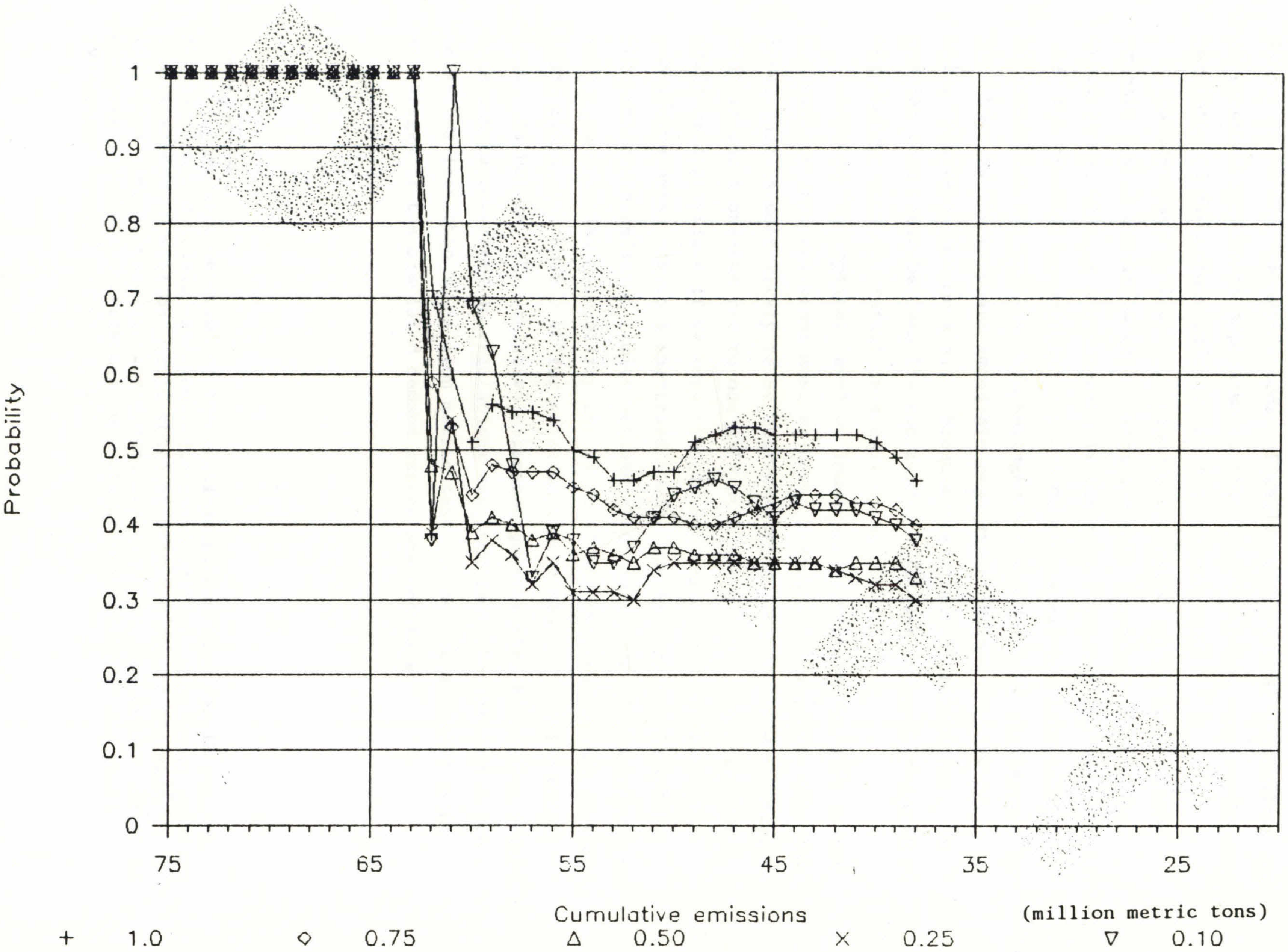

Fig. 5 -- Critical probability as a function of the stringency of proposed immediate regulations: standard case

regulations if the acceptable cumulative emissions must be limited to less than 50 million metric tons. Finally, the critical probability for 10 percent regulations approximates that for 75 percent regulations over the interval from about 53 to 37 million metric tons.[7]

As discussed in Sec. II, although one might expect the critical probability to decline with the stringency of the proposed immediate regulations, this is not necessarily the case. Recall from equation (1) that the critical probability depends on two terms: the near term costs of regulation (a) and the cost savings from implementing regulations now (c - b). As the proposed immediate regulations become increasingly mild, both terms become small. Because the critical probability q is similar to a ratio between the two terms, a decline in the stringency of regulations need not result in a decline in q.

Although the optimal level of immediate regulations depends on the probability that emissions must be restricted, Fig. 5 suggests that the level that is most likely to be cost-effective consists of a surcharge that is about one-quarter to one-half as large as the surcharge that would be appropriate if we knew that it were necessary to restrict cumulative emissions to a specified limit (100 percent regulations). For cumulative emission limits between about 50 and 37 million metric tons, the critical probability for 25 or 50 percent regulations is about 0.35, rising to about 0.45 for emission limits near 60 million metric tons. As before, if cumulative emissions greater than 63 million metric tons can be tolerated no regulations are required, whereas cumulative emissions less than 37 million metric tons can not be achieved using surcharges if the simulated demand curves are accurate.

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[7] The erratic behavior of the critical probability for 10 percent regulations and modest emission reductions (that is, cumulative emission limits around 60 million metric tons) is probably due to the step functions used to simulate the demand curves. The grid is too coarse to accurately reflect differences in costs corresponding to the small surcharges imposed in these cases.

## SENSITIVITY OF THE RESULTS TO THE CHOICE OF PARAMETERS

The following subsections describe the sensitivity of the critical probability to the specific parameters chosen. As will be shown, variations in most of the parameters have little effect on the qualitative results. Variations in the assumed growth of demand for potential ozone depleters affect the cumulative emission limits that can be attained, but have little effect on the critical probability for intermediate emission limits. The only parameter that has a major effect on the critical probability is the discount rate used to calculate the present value of the resource costs associated with each regulatory trajectory.

The results illustrated in Fig. 5 represent a standard case. The following subsections illustrate the effect of variations in model parameters by comparing results of alternative calculations to those shown in Fig. 5. For ease of comparison, all of the Figures use the same scale.

### Alternate Planning Horizon

The choice of 2020 as the horizon, or the date through which cumulative emissions and costs are calculated, has little effect on the calculated critical probabilities. Fig. 6 illustrates the critical probabilities for 50 percent regulations using a horizon of 2020 (as in the standard case) or 2010. The line for the alternate horizon is displaced from the standard line, since 10 fewer years of emissions are counted, but for the range of cumulative emissions for which the critical probability is non-trivial (not equal to 0 or 1), it is about the same as the critical probability calculated with the standard horizon.

### Alternate Date of New Information

Fig. 7 illustrates the effect on the calculated critical probability of a difference in the date at which new information on the severity of ozone depletion will be available. As shown there, if the new information will become available only in time to allow regulations beginning in 2000, the critical probability is slightly smaller than if

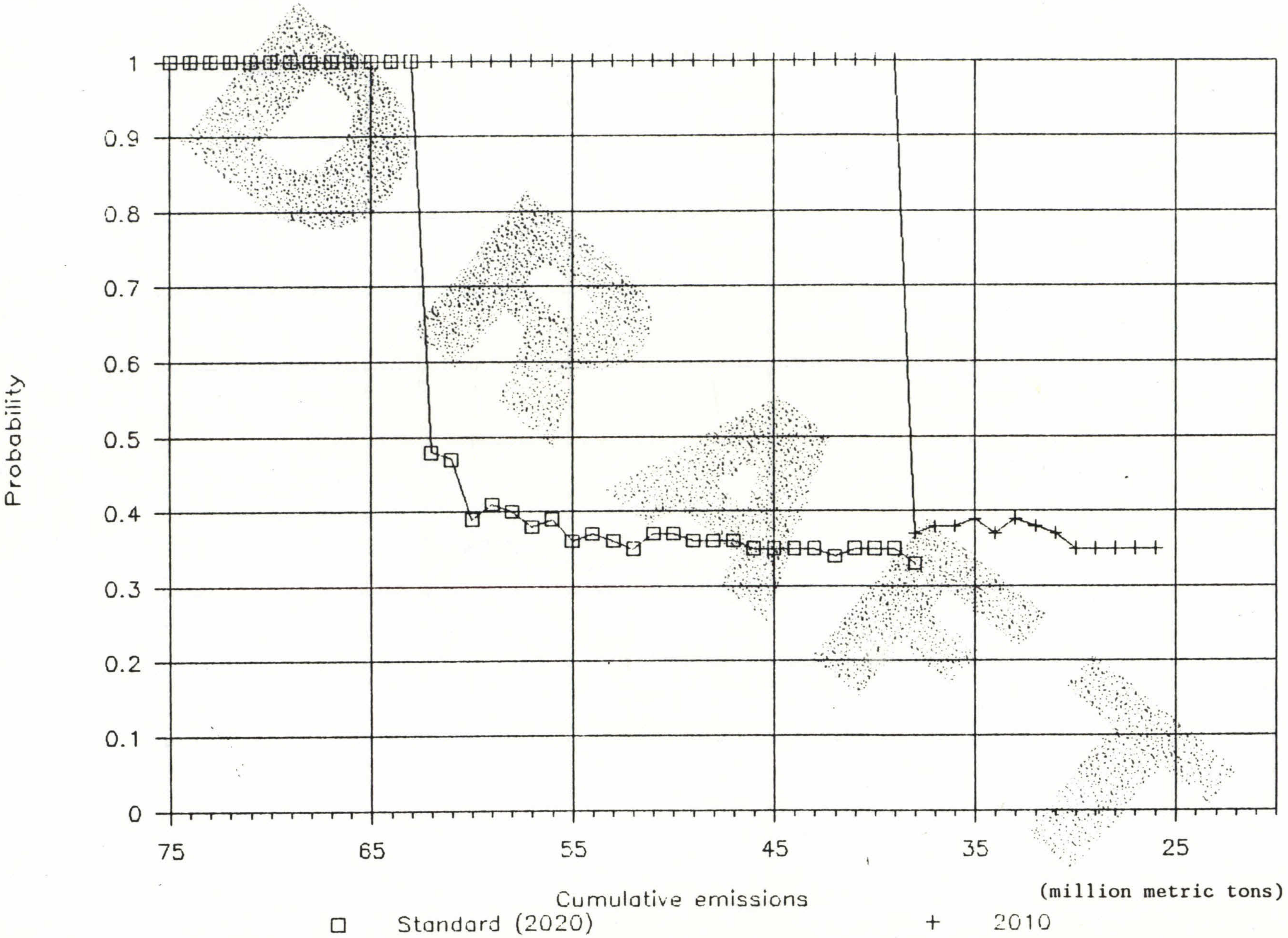

Fig. 6 -- Alternate horizon: 50 percent regulations

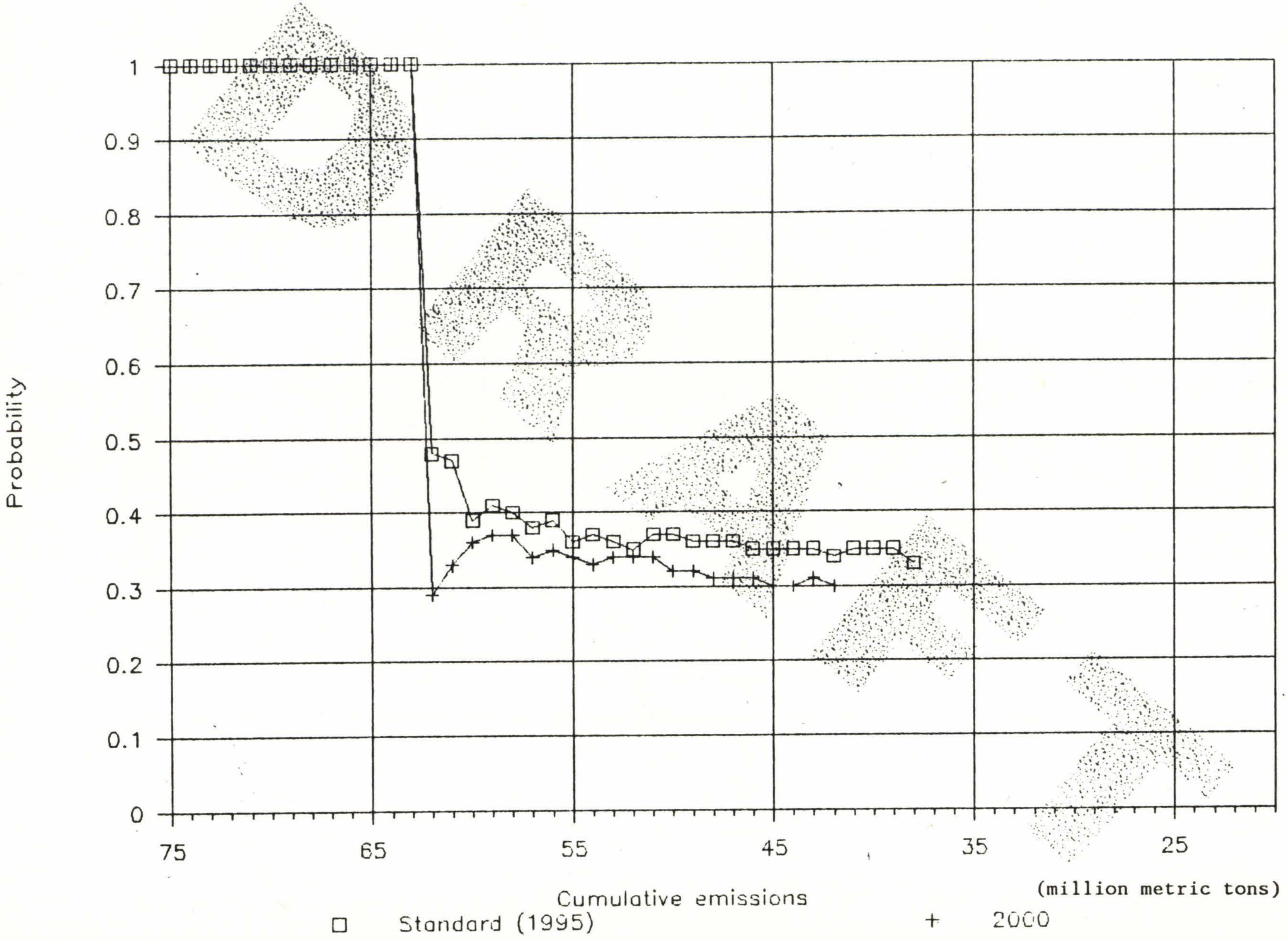

Fig. 7 -- Alternate date of new information: 50 percent regulations

the information will be available in time to implement regulations in 1995. That is, whatever level of emission reductions may be required, if immediate regulations are less costly in the standard case, they will also be less costly if the new information will not arrive until later. Moreover, the delay to 2000 limits the range of emission reductions that can be attained since regulations beginning in 2000 can not restrict cumulative emissions to less than about 41 million metric tons. Thus, the longer we must wait to learn whether the potential ozone depletion problem is a serious one, the more likely it is that immediate regulations will be less costly.

### Alternate Demand Growth Rates

The standard case examined above assumes that demand for potential ozone depleters grows in accordance with the median scenario developed in Camm and Hammitt (1986) and Hammitt et al. (1986). Fig. 8 illustrates the effect of alternate demand growth scenarios on the cumulative emissions that can be attained and the critical probability. In addition to the standard case, the figure illustrates the critical probabilities corresponding to demand growth at the 25th and 75th percentile scenarios developed in those documents. The 25th and 75th percentile demand growth scenarios are intended to span a range of growth scenarios such that the actual demand growth is as likely to fall within the range as without. These two scenarios consequently represent reasonable high and low growth outcomes.

The levels of cumulative emissions that can be achieved are significantly affected by the demand growth rate. If demand grows at only the 25th percentile rate, cumulative emissions will not exceed 54.5 million metric tons, even in the absence of regulations (under the standard, 50th percentile, growth scenario limiting emissions to this level would require an initial surcharge of $0.62 per pound if regulations began in 1988). In contrast, if demand grows at the high 75th percentile rate, unregulated cumulative emissions would total almost 73 million metric tons, and even the maximum $5.00 per pound surcharge would only limit cumulative emissions to 36.6 million metric tons.

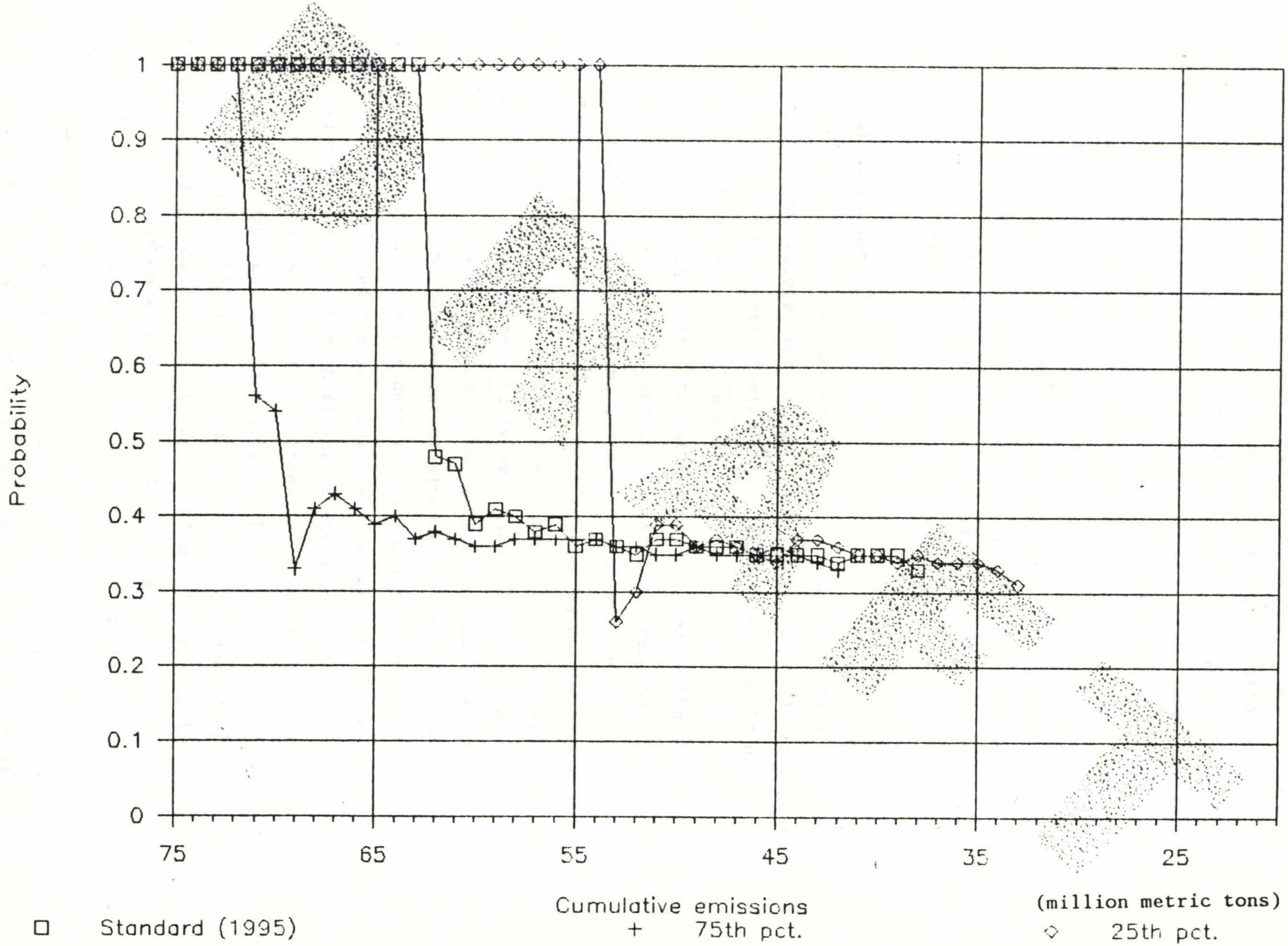

Fig. 8 -- Alternate demand growth: 50 percent regulations

Changes in the expected rate of demand growth shift the critical probability curve horizontally. Expected high growth limits the range of cumulative emissions for which awaiting new information is less costly, and expands the range for which immediate regulations are less costly. Expected low growth has the opposite effect. However, except for this effect, changes in expected demand growth have little effect on the critical probability. As illustrated by Fig. 8, except when it is undefined or equal to one, the critical probability for 50 percent regulations ranges between about 0.35 and 0.40 for all three demand growth scenarios. If emissions may need to be limited to about 45 or 50 million metric tons, uncertainty about the future rate of demand growth has almost no effect on the critical probability.

## Potential Technological Innovation

Technological innovation may reduce the future costs of reducing potential ozone depleter emissions. Such innovation could include the development of substitute chemicals or alternative products or manufacturing processes that release smaller quantities of these chemicals. Although these alternatives may not reduce the demand for potential ozone depleters at unregulated prices, they could become cost effective at the higher prices associated with regulations.

Technological innovation can be simulated by making the demand curves progressively more elastic over time. In the standard case the demand curves expand geometrically over time: The demand at a given surcharge is the same fraction of unregulated demand in every year. With innovation, the development of alternative emission-reducing technologies would further reduce the demand for potential ozone depleters at regulated prices. The specific innovation scenario considered here involves significant reductions in the future cost of emissions reductions. Under this scenario, innovation affects all chemicals and applications identically. For every five year period except the first (1985-1990) the demand curves for each application are multiplied by a constant elasticity function. The elasticity of this function increases in each five year period. By the final period (2016-2020) its elasticity is -0.6.[8] The effect of this procedure is to

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[8] The constant elasticity function is $q(p) = q_0(p) \times (1 + p/p_0)^h$, where $q(p)$ is the quantity demanded at surcharge $p$, $q_0(p)$ is the initial

make the demand curves in each succeeding five year interval progressively more elastic. Compared with the standard case, the final period demand curve is substantially more elastic: At a surcharge of \$1.00 per pound the demand is only 56 percent as large, at a \$3.00 per pound surcharge it is 34 percent as large, and at a \$5.00 per pound surcharge it is only 26 percent of the demand in the standard case.[9]

The effect of the substantial simulated increase in elasticity is similar to the effect of lower demand growth illustrated in Fig. 8. As shown in Fig. 9, expected innovation shifts the critical probability curve to the right. For mild cumulative emission limits (about 60 million metric tons) the critical probability rises to 1.0: immediate regulations are never cost-justified. Innovation also increases the emission reductions that can be achieved using surcharges, thereby increasing the domain on which the critical probability can be calculated down to about 30 million metric tons. Over the range of intermediate emission limits, technological innovation has little effect. Innovation also reduces the cumulative emissions that can be achieved, to about 20 million metric tons in this case (if regulations begin in 1988).[10]

## Potential Additional Consumer Substitution

The simulated demand curves generally assume that consumer substitution to other products will have little effect on demand for potential ozone depleters. This is due to the typically small share of the cost of the final product attributable to these chemicals (see Camm et al., 1986). For example, only one or two dollars worth of CFC-12 is contained in a home refrigerator or automobile air conditioner costing hundreds of dollars. However, to assess the sensitivity of the calculated critical probability to the possibility that the extent of

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demand function, $p_0$ is the unregulated price of the chemical, and h is the incremental elasticity. The incremental elasticities in each period are: 1985-1990, 0.0; 1991-1995, -0.1; 1996-2000, -0.2; 2001-2005, -0.3; 2006-2010, -0.4; 2011-2015, -0.5; and 2016-2020, -0.6.

[9] These calculations assume an unregulated chemical price of \$0.60 per pound, which is approximately the price of CFC-11 and CFC-12.

[10] The erratic behavior of the calculated critical probability for modest emission reductions is probably due to the coarseness of the grid used in the demand simulations.

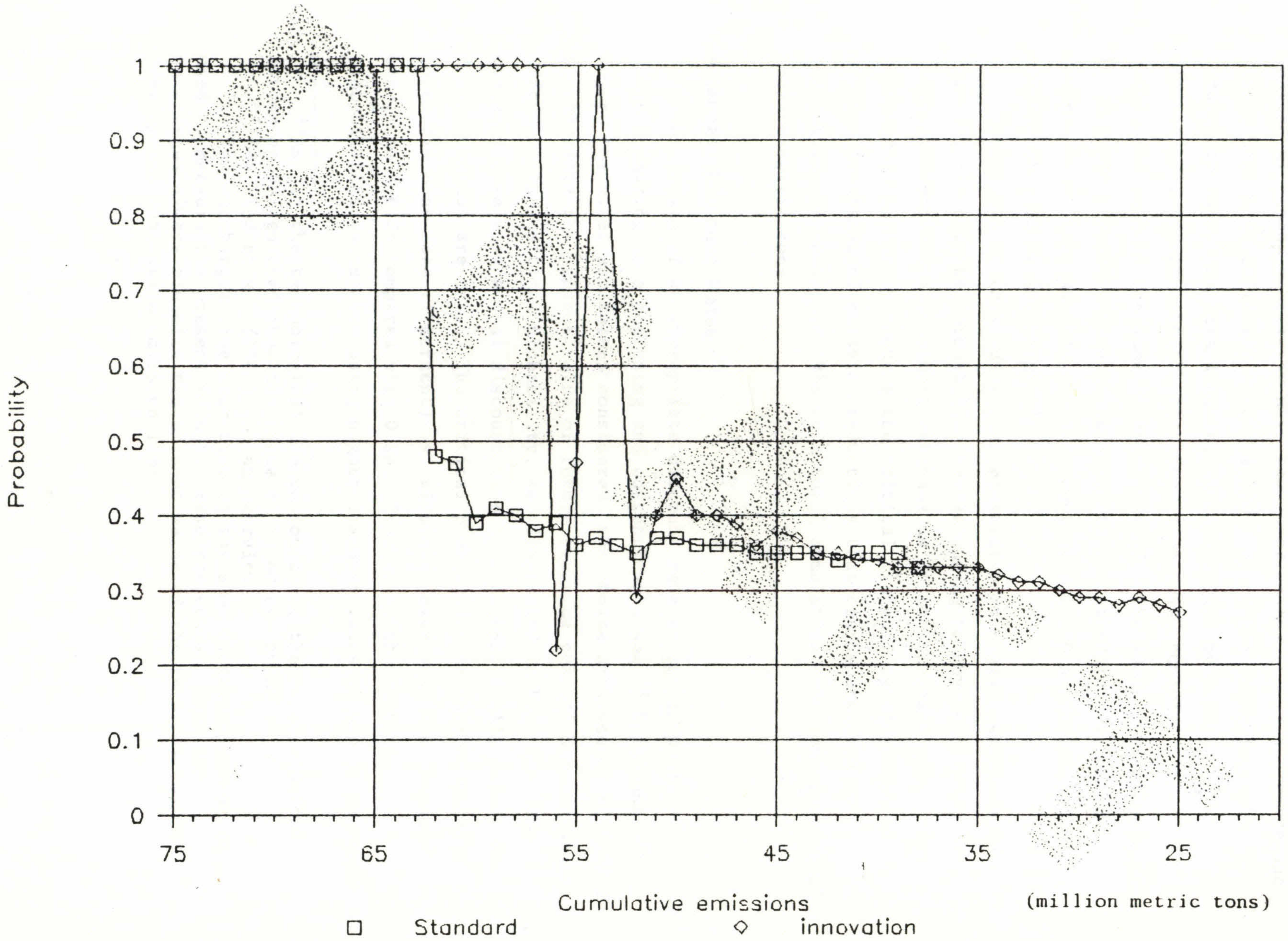

Fig. 9 -- Technological innovation: 50 percent regulations

consumer substitution has been underestimated (alternatively, that other sources of demand elasticity have been overlooked) the simulated demand curves were made uniformly more elastic. As in the technological innovation case, the demand curves are multiplied by a constant elasticity function. Unlike the innovation case, however, the elasticity used is the same in every period. The additional elasticity is -0.1 which reduces demand, relative to the standard case, by 9 percent at a \$1.00 surcharge, 16 percent at a \$3.00 surcharge, and 20 percent at a \$5.00 surcharge.[11]

The effect of this additional elasticity is small. As shown by Fig. 10, the critical probability corresponding to any level of cumulative emissions is almost the same as in the standard case. The additional elasticity reduces the critical probability slightly and extends the range of emission reductions that can be achieved by regulations beginning in 1988 to a total cumulative emission of about 27 million metric tons.

### Alternate Discount Rates

The choice of an appropriate discount rate to use in public decision making is a confusing and contentious issue.[12] Unfortunately, unlike the other parameters considered, the choice of discount rate used to calculate the present value of future resource costs[13] has a dramatic effect on the critical probability, as illustrated in Fig. 11. The standard case uses a real discount rate of 3 percent. (All prices in the simulation are real.) The critical probability calculated using a lower discount rate (1 percent) is uniformly lower than the standard case, about 0.28 compared with 0.36. Similarly, the critical probabilities calculated using higher discount rates (5 and 10 percent)

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[11] As for the technological innovation case, these calculations assume an unregulated chemical price of \$0.60 per pound.

[12] See Lind et al. (1982) for an overview.

[13] The surcharges rise over time at the same discount rate as is used to measure the present value of resource costs. Thus the surcharges always minimize the present value of the resource cost of meeting any cumulative emission limit.

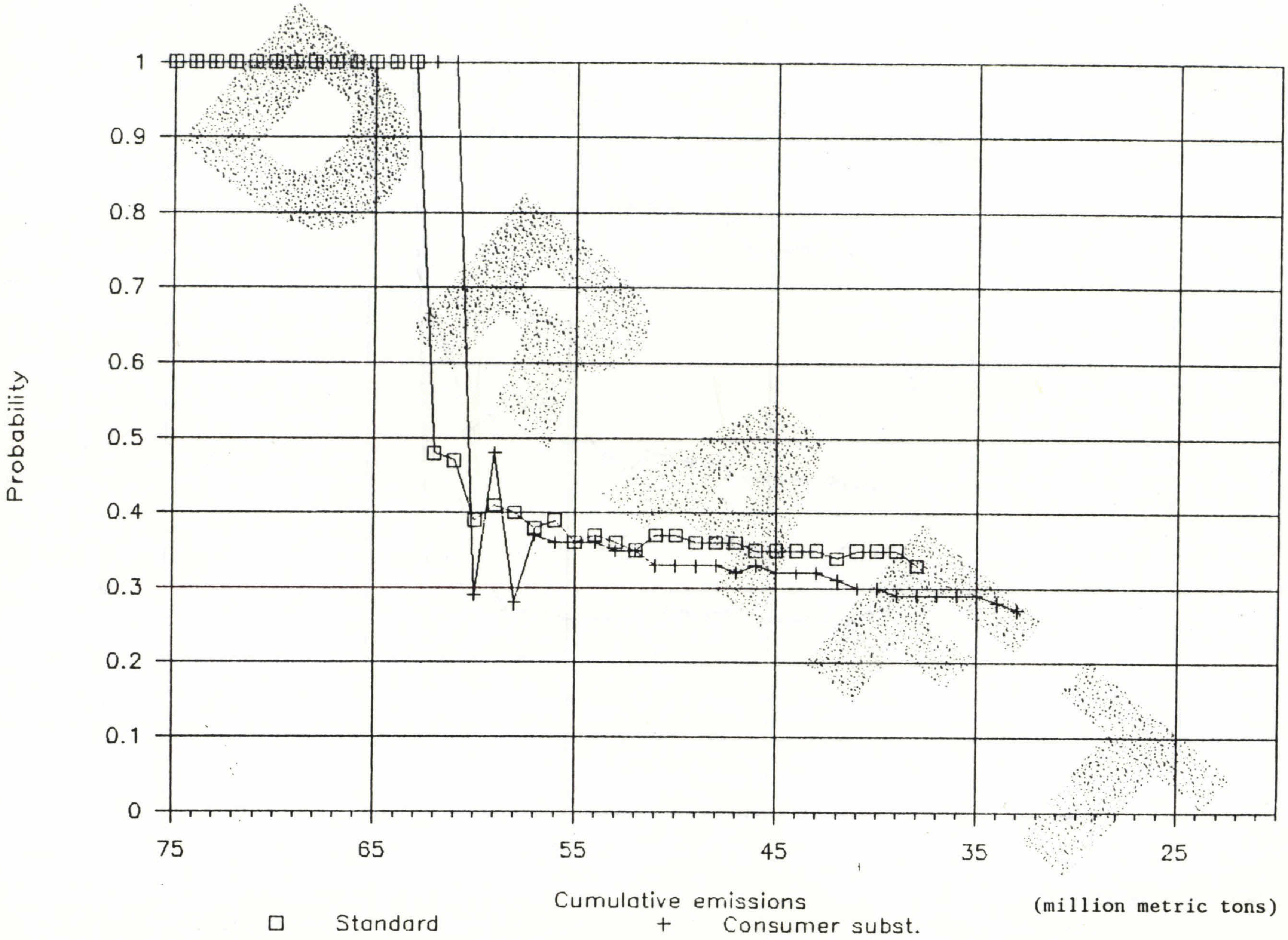

Fig. 10 -- Additional consumer substitution: 50 percent regulations

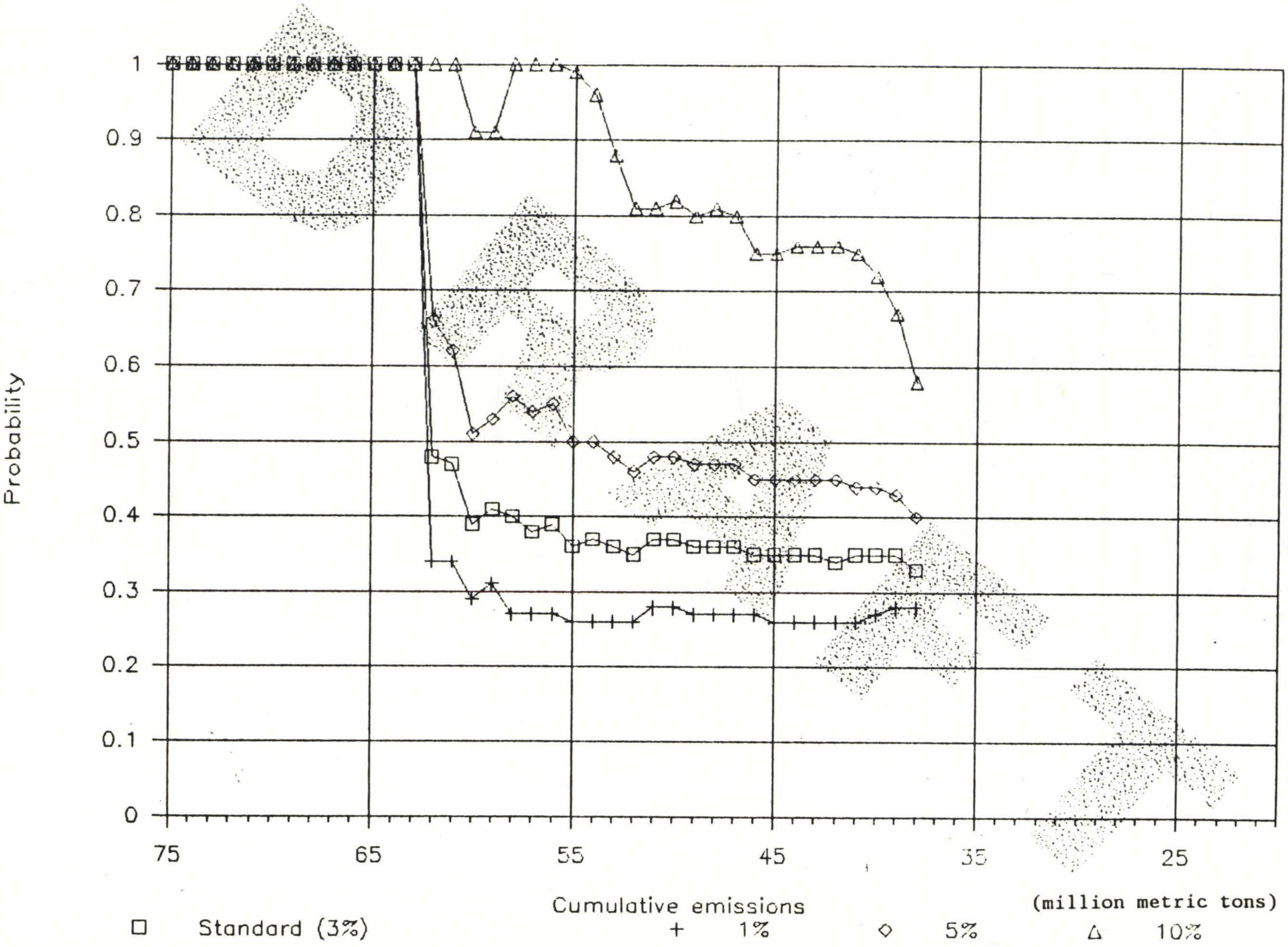

Fig. 11 -- Alternate discount rates: 50 percent regulations

are substantially higher. Using a 10 percent real discount rate it is not cost-effective to impose regulations now unless the probability that substantial emission reductions will be necessary is high, about 0.8.

The discount rate has such a significant effect because it directly affects both terms in the formula that determines the critical probability (equation (1) in Sec. II). A large discount rate reduces the present value of future costs, and consequently their difference (c - b), relative to near term costs a. Consequently, it increases the critical probability. Similarly, a low discount rate increases the present value of future costs and the difference (c - b), and thus decreases the critical probability. Intuitively, if one cares little about future costs (uses a high discount rate) it is unlikely to be cost-effective to incur costs now to potentially reduce future costs.

## IV. CONCLUSIONS

The results of the calculations reported here are striking. They suggest that the determination of whether immediate regulations to reduce the risk of ozone depletion and global warming are justified by an expected resource cost analysis depends almost entirely on the degree to which emissions may need to be restricted, and on the discount rate used to compare costs incurred at different times.

If the potential adverse consequences of ozone depletion and global warming associated with projected emissions are so severe that future emissions may have to be substantially reduced (equivalently, if continued emissions at 1985 rates result in unacceptable environmental changes), it is not possible to calculate the critical probability without additional information on the costs of obtaining emission reductions larger than those allowed by the simulated demand curves. Alternatively, if serious adverse consequences can be averted by relatively mild reductions in projected emissions it is almost certainly cost-effective to wait several years to improve our understanding of the relationship between emissions and effects on the environment and global welfare.

If the degree of emission reductions that may be required is somewhere between these extreme cases, whether or not immediate regulations are cost-effective depends primarily on the probability that emission reductions will be required and the discount rate used to evaluate future costs. This intermediate range of cumulative emission limits corresponds to emission paths that are currently projected to reduce average column ozone concentrations in 2020 by about zero to 2.5 percent (see Fig. 3).

The model described here allows calculation of a "critical probability" for which the expected resource costs incurred either by adopting specified immediate regulations or by waiting several years for improved scientific information are equal. If the probability that emission reductions will be required is greater than this critical probability the strategy of adopting regulations immediately will impose lower expected resource costs; if the probability is lower, waiting for new information will be cost-effective. Using a real discount rate of 3 percent, the critical probability is between about 0.3 and 0.5 for a wide range of proposed immediate regulations and alternative assumptions concerning the appropriate horizon to use in planning regulations, the rate at which new information about the consequences of atmospheric releases will be developed, the elasticity of the demand curves, and technological innovation that may increase that elasticity over time. Changes in the expected growth of demand for potential ozone depleters affect the ranges of emissions that can be attained without regulations, and by the maximum simulated surcharge. Between these limits, however, the critical probability is virtually unaffected.

Changes in the discount rate used to compare present and future costs are more important. Alternative discount rates of 1 and 5 percent affect these results modestly, decreasing or increasing the critical probability about 10 percentage points. Using a very high discount rate, like 10 percent, increases the critical probability to about 0.8 or more. Thus, the more future costs are discounted, the less likely it is that immediate regulations will reduce expected costs.

If immediate regulations are cost-effective, the choice of the appropriate stringency remains. The optimal stringency depends on the probability that restrictions will be necessary. For a specified potential emission limit, the level of immediate emission reductions that is most likely to be cost-effective is modest, corresponding to surcharges perhaps one-quarter to one-half as large as the surcharge that would be appropriate if one knew that emission reductions would be required. Thus, if it might be necessary to reduce projected cumulative emissions through 2020 by 20 percent (to about 50 million metric tons), a reasonable set of immediate regulations would be equivalent to a surcharge beginning at about $0.25 to $0.50 per pound.

The current analysis is limited in several important aspects. Perhaps most important is the limited available data on the shape of demand curves outside the United States. In large measure, the simulated demands outside the United States mimic those within. Second, improved information on the alternatives to potential ozone depleters that would become cost effective at higher surcharges is needed. The simulated demand curves do not extend far enough to allow calculation of the resource costs associated with reducing cumulative emissions to levels significantly less than that associated with constant 1985 emissions. Moreover, although the simulation suggests that the possibility of technological innovation that reduces the costs of reducing emissions has relatively little effect on the cost-effectiveness of immediate regulations, it would be valuable to better understand the types of innovation that may occur.

This analysis has not addressed several important issues associated with the decision of whether to adopt additional emission-limiting regulations in the near future. The most obvious of these is the assessment of the quantity of emission reductions that may be required. The severity of the consequences associated with alternative emission levels is the most important factor in determining whether immediate regulations are appropriate. In principle, the appropriate level of emissions to accept can be determined by comparing the costs of incremental reductions to the consequences of potentially increased ozone depletion and climatic change. But the step from principle to application is huge: Measurement of the costs of environmental change is fraught with difficulties. Moreover, the acceptable level of emissions may also depend on distributional considerations such as the allocation of emission reductions among countries.

Other important issues include possible effects of imposing emission-limiting regulations that can not be reversed if regulations are removed, and potential reductions in the cost of regulations if they are preceded by substantial advance notice.

Potential ozone depletion and climatic change are global issues: Their effects, if realized, will be felt world-wide. This report explicitly avoids the important issues associated with the coordination of action among independent nations. It focuses instead on the logically prior question of whether, from a global perspective, immediate regulations may be appropriate. The results of this analysis suggest that whether immediate regulations are cost-justified depends primarily on the quantity of future emissions that is acceptable and the likelihood that regulations to limit emissions to that level will be necessary.

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# PREPARING FOR A CFC PHASEOUT:

## Who Will Be Left In The Cold?

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at the
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on
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Scientific models continue to project significant destruction of stratospheric ozone by certain chlorofluorocarbons (CFCs) and related compounds. Reality, in fact, may be much worse than even the model projections: An unexpected hole is opening up in the ozone layer over the Antarctic each springtime Growing each year, the hole has reached a fifty percent deficit, and it may be related to CFCs. CFCs are also potent contributors to the "greenhouse" effect, which could result in temperatures increases in as little as 15 years that are greater than any seen in the previous 100,000.

The grave risks to human health and the environment from these changes were most recently synthesized at the UNEP/EPA International Conference on Health and Environmental Effects in June, and are well known to this audience. As we said then, the prospects are, without any exaggeration, disastrous.

As you all know, later this year the nations of the world will convene negotiations to develop an international accord for control of these compounds. In previous negotiations, the positions ranged between allowing CFC growth to continue essentially unrestricted for several more decades to capping production at current levels. We believe it is now evident, however, that further CFC growth cannot even be contemplated, and that even the current levels of CFC use and emissions are far higher than the global environment can bear. It is increasingly clear that the protection of our planet requires rapid and sharp reductions in emissions of damaging CFC compounds. It is increasingly obvious that governments cannot continue to put off major cuts in CFC production, use, and emissions.

At the June UNEP/EPA Conference, we proposed a global production cut of 80 percent over five years, and a global phase-out over ten years, of those CFCs and related industrial compounds that can deplete ozone or contribute to global warming. We called cuts over this period, rather than for an immediate ban, not because we think the planet has time to spare. To the contrary, the current evidence shows that the stratosphere is already being altered and the climate already overheated. Consequently, public health and the environment are already at grave risk. A ten-year phase-out, however, is a practical period in which to bring forth safe alternatives to these substance, if CFC producers and users start to plan for this transition now.

We submit today that from the point of their own economic self-interest, the only prudent course for domestic and international CFC producers and users to follow in their internal planning is to prepare for this sort of phase-out, not for stable or growing CFC production. In this paper we want to explore strategies available to the different industrial sectors in the face of such a prospect. Who in industry will be ready for the post-CFC world? Who is running the risk of being caught short? What kinds of planning should each sector be doing now, in order to be ready in time?

## The Producers

In the current situation, the highest priority should be given to rapidly developing chemical alternatives to $CFC_{11}$ and $CFC_{12}$, which are presently the dominant compounds in the market. Unfortunately, CFC manufacturers in the United States have repeatedly stated that research into substitutes has actually been reduced in recent years. The reason, quite plainly admitted, is that producers see little reason to develop even the most promising substitutes if they must sell for several times the price of $CFC_{11}$ and $CFC_{12}$, and if $CFC_{11}$ and $CFC_{12}$ are allowed to remain in unrestricted use. Undoubtedly the situation is similar for producers in other countries.

The managers of these corporations, however, would be well advised to think twice about this strategy. CFC producers in North America and Europe are the companies that will bear the bulk of the blame, not to mention liability, when the chemicals they produce have harmed health and the environment. They will also be responsible for hardships to the public when uses of CFCs are curtailed and no alternatives are available.

Liability and public relations aside, these companies are also jeopardizing their own long-term economic interests by putting off research into substitutes. Thinking defensively, if a phase-out is an inevitable environmental necessity, producers that have no substitutes to offer may find themselves in a very tight spot indeed when production and emission curbs begin to take effect. Thinking offensively, the producer which is first with safe alternatives may reap a business bonanza. In fact, the optimal strategy for the producer with a lead in the race for alternatives would be to promote a rapid governmental phase-out of $CFC_{11}$ and $CFC_{12}$.

Current CFC producers are a small group of companies with enormous resources that can be devoted to research. That work cannot be delayed any longer, however. Substitutes must be not only technically feasible, but also safe. Toxicological testing of alternative chemicals, if it still has not commenced, will take several years. It is far better to begin this process immediately than to continue mortgaging both the health of the public and the future of the industry.

## The Users

In the United States, as in other countries, CFC producers are large companies relatively small in number. By contrast the "users" of CFCs are numerous, but often small. The uses to which these companies put CFCs vary considerably, from foam blowing, to refrigeration, to solvent applications, to aerosol propellants. These "user" companies typically do not have the resources to engage in a large-scale effort to develop alternative chemicals. Some users may be able to turn to ready substitutes, like cardboard packaging in place of foams for fast foods, eggs, and other groceries. Others, however, including even such giants as exist in the electronics industry, may have few immediately available options.

Within industry, users have the most to lose if alternatives are unavailable when restrictions on current CFC uses take effect. Unlike producers, which are large, diversified firms for whom CFCs represent only a fraction of revenues, users can often be highly dependent on a single application of CFCs. By failing to search for alternatives, producers are leaving these user companies "out in the cold" when access to CFCs is curtailed. The public will also suffer if it has to forego many of the useful benefits that products manufactured with CFCs provide.

It has been particularly disturbing to watch these user companies allow their policy on CFC regulations to be determined by large and powerful producers with relatively little at stake. The interests of users and producers are actually quite dissimilar. Producers that oppose regulation of CFCs and that defer the search for alternatives are gambling little compared to users. It is the users, not the producers, that will suffer most when these chemicals become unavailable or restricted.

As a result, managers of user corporations, no less than the producers, would be well advised to think twice about their current strategy. With a CFC phase-out looking more and more necessary, it is decidedly against users' interests to continue their alliance with the producers. User companies looking to their own self-interest should begin strongly pressuring their suppliers to look for safe CFC substitutes.

Wise users should also greatly accelerate their own search for ways of making their products and services without CFCs at all. Just as for producers, a phase-out offers rewards to the swift and penalties to the slow. In the United States during the 1970s, many companies found economic advantage in being the first to offer alternatives to CFC aerosol propellants. "Environmentally Safe" and "Contains No Fluorocarbons" became advertising advantages to the first purveyors of pump sprays.

The same option lies open to the fast food company that packages burgers in cardboard, the supermarket chain that puts eggs back in paper containers, and others. Like producers with a head start in the search for CFC substitutes, users with a lead in these areas will find economic advantage in supporting a CFC phase-out.

## The Time Element: Build Your Roof Before It Starts To Rain

There is another reason why we think the industry -- especially CFC users -- should embrace a planned phase-out starting now rather than its traditional policy of wait-and-see. As other papers presented here convincingly demonstrate, such policy of delay greatly endangers CFC users, because it would likely require an absolutely precipitous ban on CFC uses later, with no time for adjustment.

Despite predictions of dire health and environmental consequences, some in industry -- principally producers -- are still arguing that we can afford to wait 10-20 more years before taking significant control action. Advocates of the wait-and-see policy still argue that some deus ex machina may intervene and somehow make the problem go away. Faith in such a policy requires betting completely against more than ten years of consistent scientific theory and empirical results supporting the current predictions of worldwide damage and danger. We know of few bookmakers -- or more to the point, insurers -- who would take this bet today.

Nonetheless, the advocates of delay assure us even that if the adverse predictions do come true, it will still be possible to cut off CFC use, apparently over an even shorter period than we have proposed. Such a policy goes sharply against the economic interests of CFC users. Absent the deus ex machina, preventing or even mitigating grave damage ten or twenty years from now will require a ban in CFC production virtually overnight. In such a scenario the CFC industry -- especially users -- will be incredibly disrupted. If no one has planned for alternatives, users will have to leave CFCs virtually immediately and they will have nowhere to go.

This may be the ultimate reason why it is crucial for users to pressure producers for development of alternatives now. Users should consider whether their economic position vis a vis the producers gives them sufficient leverage. Can users take the chance that producers will leave them in the cold? They may conclude that their most prudent option is to join in support of a planned, predictable phase-out starting now, so as to make sure the producers undertake the development of substitutes.

## Conclusion

To sum up, the development of alternatives is a crucial element of preparing for CFC reductions. Various segments of industry should closely scrutinize their own interests in this debate. Are producers truly acting in their own interest by failing to anticipate markets for CFC alternatives? Are users missing the opportunity to protect their interests by failing to call upon producers to get on with research?

When the effects of ozone depletion and global warming become broadly apparent, it is this industry that will bear the blame and liability. In contrast, if the advance planning is done to assure that substitutes are available when necessary CFC reductions take hold, both industry and the public will benefit.

REVIEW DRAFT: DO NOT CITE OR QUOTE

# LIMITING THE BUILDUP:
## An Investigation of Policies to Control the Increase of Chlorine in the Stratosphere

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## INTRODUCTION

Growing concern about the effects on the stratosphere of chlorofluorocarbons (CFCs) and other ozone-modifying substances led to the March 1985 signing by twenty countries of the Vienna Convention to Protect the Ozone Layer. A protocol to implement that convention and reduce the risk of ozone depletion in the stratosphere is now under development. A number of alternative policy strategies are being suggested for reducing the risk of ozone depletion.

A key contributor to increased risk of ozone depletion is the continued buildup of chlorine in the stratosphere due to CFC emissions. Chlorine atoms are known to participate as catalysts in a series of reactions which convert ozone to diatomic oxygen and to other compounds. This study evaluates the effect of two types of control strategies designed to limit the buildup of chlorine in the stratosphere.

A model is used in this study to test the effect on chlorine buildup of three policies to limit the total production of the two largest-selling CFCs, CFC-11 and CFC-12, and three policies limiting specific uses of these compounds. Two criteria are used to evaluate the impacts of these policies on the buildup of chlorine in the atmosphere. The two criteria are (1) the timing of atmospheric commitment to eventual chlorine concentrations ranging from four to fifteen parts per billion by volume (ppbv) and (2) the anticipated level of chlorine commitment in 2075. The policies are applied one at a time to a single projection of future emissions of CFC-11 and CFC-12, a "base case" called Case "A". The timing and extent of chlorine buildup in the policy scenarios are compared to the projected levels of buildup in the unmodified Case A scenario and to the projected buildup in a second scenario which assumes a higher rate of growth in CFC production and no policy interventions. This second scenario is called Case "B". The growth rates in annual CFC production in both Case A (approximately 1% per year) and Case B (approximately 2.6% per year) are within the range of future growth rates discussed at the Rome Workshop.

## PROPOSED CONTROL STRATEGIES

The policy scenarios which test limits on total production of CFC-11 and CFC-12 are called "Current Capacity", "Zero Growth", and "Phase Down". The policy scenarios which test limits on particular applications are called "Aerosol Ban", "Foam Ban", and "Loss Reduction".

This study assumes that no major new markets or applications for CFC-11 and CFC-12 are developed during the simulation period (i.e., 1985 to 2075). In Case A, Case B, and the cases which test the effects of limits on the level of annual production of these two CFCs, the allocation of production among the various applications is assumed to remain in about the same proportions as that observed in 1984. In the cases which test the effects of policies to control specific uses, the allocation of production among various applications is altered by the implementation of use controls.

To the extent that production and use of other CFCs grows rapidly in the period between 1980 and 2075, the analysis presented here will understate the potential buildup of chlorine in the atmosphere. Production, use, and emissions of other CFCs were not modelled due to a lack of detailed data. However, it is known that production of other CFCs is already substantial. For example, production of CFC-113 is growing rapidly and in 1986 is approaching the production level of CFC-11 in the U.S..

The production control policies tested in this study represent international agreements to cap the total production of CFC-11 and CFC-12 at three alternate levels: (1) at the level of current installed capacity, i.e., approximately 1.24 million metric tons (restricting growth in approximately 2010); (2) at the level of estimated 1984 production in the Chemical Manufacturers Association (CMA) reporting countries, approximately 0.7 million metric tons (restricting growth in 1987); and (3) at a sharply reduced level, phasing down production by 75% from 1990 to 2000 (reaching about 0.2 million tons at the turn of the century), and by another 75% in the next 25 years (to a level of approximately 0.05 million tons in 2025). The policies simulated here which apply controls to specific applications allow the shifting of CFC-11 and CFC-12 production over time from a prohibited use to an allowed application. These control policies include: (1) a global ban on non-essential uses of aerosols (amounting to a 95% reduction in aerosol use below that projected in Case A, starting in 1990, with the displaced output shifted progressively into non-aerosol applications over a ten-year period); (2) a ban on foam-blowing applications with the available production shifted to refrigeration applications, starting in 1990; and (3) a performance standard which would require, in effect, a 75% reduction in manufacturing and disposal losses in foam-blowing and refrigeration applications.

A principal criterion used in this study to evaluate these policy options is the date at which the atmosphere is committed to a particular level of future chlorine concentration not the date at which that concentration of chlorine can first be observed. The difference is that the date of commitment is a function of the observable concentrations of CFC-11 and CFC-12, and not dependent on the date of actual decomposition of these compounds into atoms of chlorine and other species, which may be a number of years later. Once emitted into the atmosphere, it is inevitable that these molecules will eventually dissociate and the consequent risk of ozone depletion will increase. We use the commitment date criterion for the purposes of policy analysis because once the CFC emissions occur, the situation is irreversible.

The model used to allocate future production to specific end-uses and to estimate future emissions is a model developed for EPA, based on data from the Chemical Manufacturers Association. This model is based on work by ICF (1986). The model used to convert future emissions trajectories to atmospheric concentrations is based on the approach reported in Dickinson and Cicerone (1986).

## RESULTS

Table 1 illustrates the projected commitment to increased concentrations of atmospheric chlorine in each scenario. This analysis indicates that the rate of growth in production in CFC-11 and CFC-12 can have a substantial impact on the timing and magnitude of chlorine commitment in the stratosphere. The Case A scenario leads to a commitment to 14 parts per billion by volume (ppbv) of chlorine in the atmospheric in 2075. (See Table 1.) The atmospheric commitment is projected to reach 4 ppbv in 1995 and 10 ppbv in 2050. The Case B scenario commits the atmosphere to 33 ppbv of chlorine in 2075. This scenario implies a commitment of 10 ppbv in 2030 and 15 ppbv in 2045.

The three scenarios which investigate policies to limit total production show a range of results. With a cap set at the level of current capacity in place, there is no material change in the trajectory of chlorine buildup compared to Case A until about 2040. In the Current Capacity scenario, chlorine commitment in 2075 is 11 ppbv versus 14 in Case A. The Zero Growth scenario, in which output is limited to approximately the level of 1984 production, delays the chlorine buildup significantly beyond the Case A projections. The atmospheric commitment to 8 ppbv is postponed to 2060 compared to 2035 in Case A. The 2075 commitment in this scenario is only 7 ppbv. In the more extreme Phase Down scenario, the commitment in 2075 is limited to 3 ppbv. The higher commitment levels are postponed beyond the projection period used in this study.

The three scenarios which examine the effects of use controls demonstrate less of an impact on the timing of chlorine buildup than do the Zero Growth and Phase Down production control scenarios. This result reflects the assumption made in each of the use control scenarios that the market is allowed to recover demand displaced through the imposition of controls by shifting production from prohibited applications to allowed uses. This pattern of market response has been observed in the decade following the U.S. ban on non-essential applications of aerosols. The net effect of this pattern of demand shift and market recovery is a delay of not much more than ten years in the commitment to each level of chlorine concentration.

This result suggests that a policy to limit manufacturing and disposal losses could achieve as large a delay in chlorine commitment as a policy to ban aerosol applications globally. This is a surprising and unanticipated result which implies that the benefits of policies to promote recapture and recycling of CFCs may be larger than previously expected. Uncertainties in the estimates of current loss rates in manufacturing and disposal activities preclude making any policy recommendation based on this analysis alone. This result deserves further investigation to determine whether it is robust under different assumptions about future loss rates and future rates of growth in production.

## CONCLUSIONS

The major conclusion of this study is that neither of the principal initiatives recently proposed to reduce the risk of ozone depletion (i.e., the Toronto Group proposal of a global ban on aerosol use and the European Community proposal of a production cap set at the level of current capacity in place) is adequate to limit the future buildup of atmospheric chlorine. More specifically, this analysis finds that:

(1) The controls on specific uses of CFCs evaluated here (which allow production output to shift in the short term from proscribed uses in order to meet increased demands in uncontrolled applications) do not substantially reduce the risk of chlorine buildup in the atmosphere. Such measures appear only to delay the buildup of chlorine for a brief period.

(2) Limits on production of CFC-11 and CFC-12 can substantially reduce the risk of chlorine buildup only if the ceilings on production are set at levels significantly below the level of current capacity in place.

(3) Strategies which involve a combination of policy measures applied to CFC-11 and CFC-12 and policies which control the production and use of other CFCs may further reduce the risk of chlorine buildup. Although deserving of detailed analysis, such policies have not been tested in this study.

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## TABLE 1

### COMMITMENT TO CHLORINE BUILDUP IN THE STRATOSPHERE FROM CFC-11 AND CFC-12

| SCENARIO | | Year of Commitment to | | | | | Total Commitment in 2075, ppbv |
|---|---|---|---|---|---|---|---|
| | | 4 ppbv | 6 ppbv | 8 ppbv | 10 ppbv | 15 ppbv | |
| CASE B | (1) | 1995 | 2010 | 2020 | 2030 | 2045 | 33 |
| CASE A | (2) | 1995 | 2015 | 2035 | 2050 | NA | 14 |
| PRODUCTION LIMITS | | | | | | | |
| Current Capacity | (3) | 1995 | 2015 | 2035 | 2060 | NA | 11 |
| Zero Growth | (4) | 2005 | 2045 | 2060 | NA | NA | 7 |
| Phase Down | (5) | NA | NA | NA | NA | NA | 3 |
| USE LIMITS | | | | | | | |
| Aerosol Ban | (6) | 2000 | 2020 | 2040 | 2055 | NA | 13 |
| Foam Ban | (7) | 2000 | 2015 | 2035 | 2050 | NA | 14 |
| Loss Reduction | (8) | 2000 | 2020 | 2040 | 2060 | NA | 12 |

NOTES:

1. The Case B scenario assumes growth in production of CFC-11 and CFC-12 at an average annual rate of 2.6% per year and no change in the allocation of production among principal applications.

2. The Case A scenario assumes growth in production of CFC-11 and CFC-12 at an average annual rate of 1.0% per year and no change in the allocation of production among principal applications.

3. The Current Capacity scenario assumes that annual production of CFC-11 and CFC-12 is limited to approximately 1.24 million metric tons, the approximate capacity of currently available facilities.

4. The Zero Growth scenario assumes that annual production of CFC-11 and CFC-12 is limited to approximately 0.7 million metric tons, the approximate level of production in the CMA reporting countries for 1984 starting in 1987.

5. The Phase Down scenario assumes a reduction in CFC-11 and CFC-12 output of 75% over ten years, from 1990 to 2000, and a further reduction from these levels over the next 25 years.

6. The Aerosol Ban scenario assumes a reduction of 95% below the production levels projected for aerosol applications of CFC-11 and CFC-12 in the Case A scenario, starting in 1995. The scenario further assumes that this production is shifted to non-aerosol applications over a ten year period, so that total production in 2005 is approximately equal to that projected in Case A.

7. The Foam Ban scenario assumes a reduction of 95% below the production levels projected for foam applications of CFC-11 and CFC-12 in the Case A scenario, starting in 1995. The scenario further assumes that this production is shifted to other non-aerosol applications over a ten-year period, so that the total level of production in 2005 is approximately equal to that projected in Case A.

8. The Loss Reduction scenario assumes that manufacturing losses in foam-blowing and refrigeration applications are reduced by 30% in 1995, 50% in 2005, and 75% in 2015. It further assumes that disposal losses in refrigeration applications are reduced by 50% in 1990 and by 75% in 2010 below the levels projected in Case A.

9. The commitment to chlorine buildup presented here assumes that total chlorine commitment is a constant 1.5 ppbv greater than that due to CFC-11 and CFC-12 alone. This assumption understates the contribution to chlorine buildup from other CFCs.

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# UNEP WORKSHOP ON CONTROL OF CHLOROFLUOROCARBONS

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## OVERVIEW PAPER ON TOPIC 6B

by

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## 1. SOURCES AND SCOPE OF PAPERS CONTRIBUTED

Topic 6B relates to the identification and analysis of possible regulatory strategies for chlorofluorocarbons (CFCs) in terms of their:

**effects on the atmosphere and the environment, including the use of model calculations of the effects of control measures.**

Eight papers specifically relating to this topic were contributed and they are listed in Annex A.

Three papers provide the results of some specially commissioned model calculations of the effects of various CFC and other trace gas emission scenarios. One-dimensional models are used by Brasseur and De Rudder [1], and also by Atmospheric and Environmental Research, Inc. (AER) calculations made for a paper presented by the Fluorocarbon Program Panel (FPP) of the US Chemical Manufacturers Association (CMA), [2]. A two-dimensional model is used by Isaksen [3] in calculations made for the Norwegian Department of Environment. A digest of the Brasseur and De Rudder paper is submitted by the sponsors, the Commission of the European Communities, [4], and is designed for a non-specialist readership.

Three papers prepared for the US Environmental Protection Agency (EPA) analyse aspects of CFC control strategies. Hoffman (EPA), [5] draws on the results of 2-D model calculations in assessing the stringency of the control measures needed to achieve alternative ozone depletion limits at a latitude of 50°N. Gibbs (ICF), [6], considers control options in terms of eight factors and discusses their influence on the overall effectiveness of strategies. In another paper by Gibbs [7], sixteen control strategy options are evaluated in terms of ozone depletion and equilibrium global warming at 25-year intervals over the period 2000 - 2075.

The potential effects of ozone depletion and climate change on health and the environment are reviewed by Seidel, Tirpak and Hoffman, (EPA), [8]. The authors draw on some 73 papers presented at a UNEP/EPA conference on these topics in June, 1986, and other recently published material.

In the following overview of the model calculations other recently published work is cited as well as the papers prepared for the Workshop, and the additional references are included in Annex A. The overview of the other contributions for Topic 6B relates only to the material in those papers.

## 2. MODEL CALCULATIONS OF ATMOSPHERIC RESPONSE TO COMBINED EMISSIONS OF TRACE GASES

### 2.1 Preface

In recent months, several model calculations have been performed to estimate the quantitative effects on the ozone layer of increasing concentrations in the atmosphere of gases such as the chlorofluorocarbons, carbon dioxide, methane and nitrous oxide. These species are radiatively active and, together with water vapor and ozone, contribute to the so-called greenhouse effect of the atmosphere. Most of these gases also initiate complex chemical reactions which partly control the chemical composition of the atmosphere and, in particular, the ozone density. The stability of the ozone layer towards increasing emissions of trace gases is of great importance since ozone absorbs harmful ultraviolet solar radiation (and therefore protects the biosphere) and plays a major role in the thermal budget of the stratosphere (with important consequences on the general circulation of the atmosphere).

Simulations based on different models with similar chemical schemes for prescribed perturbations are presented in a recently published WMO/NASA report (1986) [9]. The executive summary of this report (NASA, 1986) [10] indicates that "models which include projected continuation of the observed increases in all of these gases [CFCs 11 and 12, methyl chloroform, methane, nitrous oxide, and carbon monoxide] show little effect on the ozone column (less than 3%) in the next 70 years unless the chlorofluorocarbon release rate increases by more than 1.5% per year. For example, after 70 years, a 10% ozone depletion is calculated for a CFC growth rate of 3% per year. However, even when predicted changes in the ozone column are small, a significant vertical and latitudinal redistribution of ozone is predicted, which affects stratospheric structure". This report also mentions that the models predict the present distribution of trace gases quite well, but that a close examination of these models reveal disturbing detailed disagreements, which limit our confidence in the predictive capability of these models. This will require careful measurement of critical species to be carried out over long time periods. Finally the report points out that problems of ozone change and climate change should be considered together and that what has been previously thought of as the carbon dioxide-climate problem should more properly be thought of as the trace gas-chemistry-climate problem.

Several papers on the same subject are in preparation or have been submitted to scientific journals. Connell and Wuebbles (1986) [11], for example, have presented a detailed analysis of the processes involved in the ozone balance and, with their one-dimensional chemical-radiative model, have calculated the effect of projected trends in the concentration of a number of gases over the next 90 years. Stordal and Isaksen (1986), [12] have estimated ozone perturbations with their two-dimensional (altitude-latitude) model. They conclude that the average global ozone column would be reduced by 6.5% in year 2030 (compared to 1960), assuming a 3%/yr increase in the chlorine emission, a 1%/yr increase in the surface mixing ratio of methane and a 0.25%/yr increase in the nitrous oxide mixing ratio. Growth in the carbon dioxide content is not considered since their model does not include temperature feedback effects. The work of Stordal and Isaksen also shows that latitudinal gradients in the ozone concentration are modified by the perturbation. It indicates that, when all the chlorocarbon emissions are stopped, the minimum in the ozone column abundance is reached after about 5 years and that the efficiency of the recovery increases with the growth rate in the methane density.

## 2.2 Modelling Studies Contributed for the UNEP Workshop

2.2.1 Two 1-D model studies have been submitted. One is presented by the Fluorocarbon Program Panel of the Chemical Manufacturers Association (CMA), [2] based on calculations made by Atmospheric and Environmental Research, Inc (AER). The conclusions from this work are as follows:

a) Even in the absence of CFCs, we would be likely to see changes in ozone concentrations affecting both total column and distribution.

b) Limiting CFC emissions to present day levels would not be expected to lead to significant changes in column ozone.

c) Limiting CFC emissions to twice 1984 levels would be expected to result in only small (-3.5%) changes in total column ozone although vertical ozone distribution would be modified. A lower rate of methane growth in later years would not significantly change this result.

d) If CFC emissions were to grow to twice the 1984 levels by 2008 before cutting back to the 1984 level of emissions, changes in total column ozone would be expected to be small and similar to those in which emissions never exceed the 1984 level.

The second study by G. Brasseur and A. De Rudder (Institut d'Aeronomie Spatiale, Brussels, Belgium), [1], was sponsored by the Commission of the European Communities, which has also provided a digest [4], concentrating on the results of particular relevance to the Workshop discussions. The main findings are the following:

1) Calculations based on time-dependent scenarios and assuming a 3%/yr growth for CFC 11 and CFC 12 production with a capacity cap of 1.5 times the 1985 production level, indicate that the reduction in the ozone column in the period 1940-2100 is less than 10%, assuming that the concentration of all other precursor gases remains unchanged. If, however, the concentrations of these latter gases are increasing according to the scenarios adopted in this study, the maximum ozone depletion is 2.8% and occurs in year 2060. The slow recovery predicted afterwards results

essentially from increasing concentrations of ozone in the troposphere (due to enhanced $CH_4$ amounts). If, in addition, a 6% increase is assumed for CFC 113 (with a production which never exceeds that of CFC 11), the maximum ozone depletion (appearing in year 2070) is 4.2%. If a capacity cap of 2.0 times the 1985 production level is adopted for CFC 11 and 12 instead of 1.5, the ozone reduction is enhanced by about 1% in the second half of the 21st century. Finally, if no capacity cap is applied, the ozone depletion calculated for a 3%/yr growth rate in the production of CFC 11 and 12 becomes significantly larger than 10% after year 2050, even if a ban is imposed for the use of CFCs as propellant agents in aerosols. In this case the ozone response is delayed by a few years.

ii) Even if the changes in the ozone column remain limited, large variations in the local concentration of $O_3$ appear in certain altitude ranges. For example, in the upper stratosphere near 40 km, reductions of 60 to 70% in the ozone concentrations are predicted. These large numbers have a small influence on the ozone column since (1) at these heights, the ozone density represents less than 10% of the density near 20-25 km and (2) the reduction in the upper stratosphere is partly balanced by an ozone increase at lower levels. However, these large local changes have potential effects on dynamic parameters, and these effects need to be investigated by multi-dimensional models such as general circulation models (GCM).

iii) Despite numerous improvements in our understanding of atmospheric chemistry in the last decade or so, large uncertainties (a factor 2-3) are associated with calculated variations in the ozone column. Errors arise not only because of uncertainties in measured rate constants or absorption cross sections, or eventual missing chemistry in the model, but also because of a lack of knowledge in the budget of active nitrogen, of approximations made in the treatment of radiative transfer and of simplified treatment of atmospheric transport.

A comprehensive comparison of these two studies is not straightforward as the scenarios and the model conditions adopted are not identical. Some model cases however are very close, so that a comparison is possible within certain limits. For example, scenario 2A of the CMA calculations (constant CFC emissions at the 1984 level; 1%/yr increase in methane, 0.55%/yr in carbon dioxide, and 0.25%/yr for nitrous oxide) is similar to scenario 3a of Brasseur and De Rudder (constant CFC emissions at the 1985 level; 1%/yr in methane, about 0.5%/yr in carbon dioxide and 0.25%/yr for nitrous oxide). The CMA model predicts a maximum reduction in the ozone column of about 1% in year 2045 (compared to 1960), while the model of Brasseur and De Rudder shows a maximum ozone depletion of about 1.5% in year 2040 (compared to 1940). If a 3%/yr increase is assumed for CFC-11 and CFC-12 while the trend in the concentration of the other trace gases remains identical to the previous case, the maximum ozone depletion is found to be 3.5% in 2060 in the first model (in which a capacity cap of 2.0 times the 1984 production level is assumed for the CFCs). In the second model, the maximum reduction in the ozone column is 2.9% in 2065 (for a capacity cap of 1.5 times the 1984 production level of CFC 11 and 12) and 5.1% in 2080 (if the capacity cap is now 2.0 times the 1985 production level and the emission of CFC 113 is assumed to increase by 6%/yr with a cap equal to the production of CFC 11).

It may thus be concluded that the agreement between these two studies is good. Connell and Wuebbles have also indicated that there is essential agreement between their model and the model published earlier by Brasseur et al. (1985) [13] and based on different scenarios.

All these model calculations indicate that the ozone concentration and the temperature are expected to vary in the atmosphere, as a result of increasing emissions of trace species. The reduction in the ozone column should however remain limited if a capacity cap is applied to the global production of CFCs. For example, if a 3%/yr increase is assumed in CFC 11 and CFC 12 production, with a capacity cap of twice the present production level, the average reduction in the ozone column abundance should be smaller than 5%. Significant reductions in the ozone concentration should occur in the upper stratosphere but they are expected to be partly compensated by an ozone increase in the lower stratosphere and in the troposphere.

### 2.2.2 Two-dimensional model study

Isaksen [3] has used a time-dependent two-dimensional model to predict at different latitudes the changes in the ozone column abundance. As in the 1-D studies of Brasseur and of CMA/AER, a 0.25%/yr and a 1%/yr increase is assumed for the concentrations of $N_2O$ and $CH_4$ respectively. For the CFCs however, in contrast to the other two studies, no capacity cap is assumed for their production rate. Three scenarios are adopted: they correspond to 1.2%/yr, 3.0%/yr and 3.8%/yr increases in the emission rate. Corresponding growth rates seem to be adopted for other chlorocarbons but this is not clearly indicated.

The findings of Isaksen are consistent with the other model calculations. In addition, it is shown that significant latitudinal variations in the ozone depletion should be expected, with the largest effects at the highest latitudes. For example, if a 3% per year is adopted for the growth in the chlorocarbons, the depletion in the ozone column predicted for spring 2030 is 8.2% at 40°N, 11.5% at 50°N and 14.8% at 60°N. The largest decrease appears to occur in late winter or early spring.

It should be noted that all 2-D models predict larger ozone depletion at high latitude. The magnitude of this latitudinal effect may however vary from one model to another (see the WMO/NASA report, to be published), as it directly depends on the strength of meridianal transport of species such as $NO_x$ or $CH_4$. It is thus dependent on the type of representation which is adopted for the large-scale transport processes.

Isaksen also indicates that the chlorocarbon emission rate adopted for the next 20-30 years will have a pronounced impact on ozone through the end of the next century. As in other models, the rate at which total ozone is restored if the ClC emissions are controlled also depends on future increases in the $CH_4$ concentration.

## 3. ANALYSIS AND EVALUATION OF CONTROL STRATEGIES

### 3.1 Preface

In three papers prepared for the EPA by Hoffman [5] and Gibbs [6], [7], the authors utilise the results of model calculations in analysing control strategy options in relation to their component factors, and for evaluating the outcome of alternative control scenarios in respect of ozone depletion and global warming.

### 3.2 Stringency of Control Measures Needed for Limiting Ozone Depletion

Hoffman [5] considers that the variation in ozone column thickness with latitude should be taken into account when setting the goals of a control strategy, and that two-dimensional (altitude/latitude) models therefore provide a more meaningful tool than one-dimensional models for assessing control options in respect of their effectiveness in protecting human health and welfare.

The author analyses the emission reductions which would be needed to limit ozone depletion to 1%, 2% and 5% depletion relative to 1960 at latitude 50°N, which would prevent the majority of the world's population from experiencing higher levels of depletion.

Drawing on the results of 2-D model calculations by Stordal and Isaksen, it is concluded that to meet ozone depletion limits of one or two percent at 50°N reductions in CFC 11 and 12 emissions significantly below 1980 levels would be required, possibly along with reductions in other ozone depleting substances including Halons. An ozone depletion limit of 5% at 50°N could be achieved by reducing all chlorinated chemical emissions to 1980 levels and eliminating all Halon emissions, providing methane concentrations continue to grow at 1%/yr. If measures were taken to reduce methane or nitrous oxide emissions to limit global warning, then more stringent action to reduce emissions of ozone depleters would be needed to meet the same depletion limits.

## 3.3 Influence of Design Factors on Control Strategy Effectiveness

Gibbs [6] defines control strategy options in terms of eight factors:

a) Coverage : the chemicals covered by the strategy

b) Stringency : the permitted production level

c) Method : the means whereby the stringency level is achieved

d) Timing : the times at which the measures are implemented

e) Participation : the portion of the world assumed to participate in the control strategy

f) Trade : whether trade in CFCs or CFC containing products is permitted

g) Substitution : whether the effects of substitute chemicals are considered

h) Trace gases : whether trace gas concentrations are assumed to increase without control, or the growth assumed to be reduced by 50%.

Nine control strategies are listed, of which five apply to CFC 11 and 12 only, two also include CFC 22 and 113, and two add $CCl_4$, $CH_3CCl_3$ and Halons 1211 and 1301 to the four CFCs. The control methods are a capacity limit in one case and a production limit in the others, all assumed to be implemented in 1991.

Graphs are presented of potential ozone depletion with time and showing the effects of

- different levels of coverage, stringency and participation.

- substitution of CFC 11 and 12 by a (hypothetical) substitute chemical when production reaches 200% of the 1985 level
- reduction in the growth rates of $CO_2$, $N_2O$ and $CH_4$ emissions to 50% of the base case.

Another graph shows the results of a trade off between coverage and stringency.

### 3.4 Partial Evaluation of Control Strategy Options

In a second paper by Gibbs [7], the first part is devoted to the definition of control strategies and is contributed for Topic 6A. In the second part, for Topic 6B, 24 control strategies are defined in terms of the eight factors listed above in Section 3.3 and evaluated in respect of ozone modification (global average depletion) and equilibrium global warming in the years 2000, 2025, 2050 and 2075. There is no discussion of the results.

The author refers to these estimates as partial evaluations because a number of other major factors are not taken into account, including:

- costs of control
- fairness and equity
- efficiency
- ease of implementation
- ability to monitor compliance
- incentives for compliance and innovation

## 4. POTENTIAL HEALTH AND ENVIRONMENTAL EFFECTS OF OZONE DEPLETION AND CLIMATE CHANGE

The paper entitled as above by Seidel, Tirpak and Hoffman [8] is the only one submitted for this part of Topic 6B. It is based on recently published papers including those presented at the UNEP/EPA Conference on this subject field in June 1986. Effects are discussed under the following headings:

**Ozone depletion effects on:**

- Non-melanoma skin cancer
- Cutaneous malignant melanoma
- The immune system and resistance to infections
- Aquatic organisms
- Accelerated weathering of polymers
- Urban smog

**Climate change impacts on:**

- Agriculture and forestry
- Water resources
- Sea level rise

The ozone depletion effects listed above are each presented under four sub-headings: Overview; Population at Risk; Summary of Research; and Selected Bibliography.

Thus the paper essentially comprises a collection of literature reviews and it would be difficult to provide an overview of overviews without being unduly selective.

The general impression gained is of the difficulty in making persuasive quantitative predictions because of the multiplicity of factors involved, the difficulties of practical experimentation - especially in respect of effects on human health, and the problems of constructing adequate models for representing climate changes.

Most of the effects discussed are adverse, although the enhancement of plant growth by higher levels of carbon dioxide and increased photosynthesis is mentioned as a possible offsetting result.

## REFERENCES

### a) Papers Contributed for Workshop Topic 6B

1. Brasseur, G. and De Rudder, A. 'The Potential impact on atmospheric ozone and temperature of increasing trace gas concentrations', (Paper sponsored by the Commission of the European Communities, 1986).

2. Fluorocarbon Program Panel of the Chemical Manufacturers Association (CMA): 'Atmospheric ozone: response to combined emissions of CFCs, $N_2O$, $CH_4$ and $CO_2$', based on calculations by Atmospheric and Environmental Research, Inc. (AER), (1986).

3. Isaksen, I.S.A., 'Ozone perturbations studied in a two dimensional global model with temperature feedback in the stratosphere included', (paper sponsored by Norwegian Department of Environment 1986).

4. Commission of the European Communities: 'Potential ozone column responses to alternative chlorofluorocarbon control strategies', based on calculations by G. Brasseur and A. De Rudder (1986).

5. Hoffman, J.S. (USEPA), 'Analysis of stringency of control strategies to achieve alternative ozone depletion limits' (1986).

6. Gibbs, M.J., 'Analysis of the importance of various design factors in determining the effectiveness of control strategy options', (paper prepared for USEPA, 1986).

7. Gibbs, M.J., 'Control Strategy options: definition and partial evaluation' (paper prepared for USEPA,1986).

8. Seidel, S., D. Tirpak and J.S. Hoffman, (USEPA), 'Potential health and environmental effects of ozone depletion and climate change' (1986).

### b) Other references cited in the Overview

9. World Meteorological Organisation (WMO) and National Aeronautics and Space Administration (NASA), 'Atmospheric ozone 1985: Assessment of our Understanding of the Processes Controlling its present distribution and Change', WMO Global Ozone Research and Monitoring Project Report No.16, to be published, 1986.

10. National Aeronautics and Space Administration (NASA), 'Present State of knowledge of the Upper Atmosphere: An Assessment Report, Processes that Control Ozone and other climatically Important Trace Gases by R.T. Watson, M.A. Geller, R.S. Stolarski and R.F. Hampson, NASA Reference Publication 1162, May 1986.

11. Connell, P.S. and D.J. Wuebbles, 'Ozone perturbations in the LLNL one-dimensional model - Calculated effects of projected trends in CFCs, $CH_4$, $CO_2$, $N_2O$, halons over 90 years'. Preprint, 1986.

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FINAL VERSION

# UNEP WORKSHOP ON THE CONTROL OF CHLOROFLUOROCARBONS

Phase 2 - Washington DC, September 1986

# Potential ozone column responses to alternative chlorofluorocarbon control strategies

Paper submitted for Topic 6 (b) by

Commission of the European Communities,
Directorate-General for the Environment,
Consumer Protection and Nuclear Safety

Based on calculations by
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with compliments

## SUMMARY

A digest is provided of a recent study by Guy Brasseur and Anne de Rudder in which a coupled chemical-radiative-transport one-dimensional time dependent model was used to predict the long term effects on atmospheric ozone and temperature of a range of CFC 11, 12 and 113 emission scenarios. The full report on that study is being presented at the Workshop, and this digest - which is written for non-specialists - concentrates on the ozone depletion predictions for CFC production growth and control scenarios which also take account of rising concentrations of the trace gases $CO_2$, $CH_4$ and $N_2O$, together with constant emissions of carbon tetrachloride and methyl chloroform.

The model predicts that with unrestricted growth of CFC 11 and 12 production at 3% per year, total ozone column depletion would exceed 10% by year 2050 and increase rapidly thereafter. An immediate global ban on CFC use in aerosols would retard this effect by only a few years.

If a global production limit of 1.5 times the total 1984 production of CFC 11 and 12 is introduced, then growth of the output of these CFCs at 3% per year until the limit is reached, coupled with 6% per year growth of CFC 113 production to a limit equal to that for CFC 11, would lead to a maximum predicted ozone depletion of 4.2% by year 2070. The addition of a ban on CFC use in aerosols would reduce the maximum depletion by less than 1% and delay it by perhaps 10 years.

These results suggest that it would be prudent to place some limit on the global production of CFC 11 and 12, but that there would be little advantage in applying early restrictions on any existing application sector.

## 1. INTRODUCTION

In preparation for Topic 6 of the UNEP Workshop on the Control of Chlorofluorocarbons (CFCs) the Commission of the European Communities invited Professor G. Brasseur[1] to study the potential long term effects on atmospheric ozone and temperature of a range of CFC emission scenarios, taking into account the interacting influences of emissions of other gases into the atmosphere which are known to be important in this context. The study was performed with an advanced 1-D (one dimensional) model.

A full account of this investigation by Brasseur and De Rudder is presented in a separate paper for the Workshop[2]. It is a detailed scientific exposition which will not be easy reading for the non-specialist, but the findings have a major bearing on the assessment of possible regulatory strategies for CFCs.

In this paper, which has been prepared by Metra Consulting Group Limited, London, in collaboration with Professor Brasseur, a digest of the key results of his study is provided and discussed in relation to the principal alternative CFC regulatory options which are under review.

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[1] Belgian Institute of Space Aeronomy, Brussels, (currently on leave to National Center for Atmospheric Research, Boulder, USA).

[2] 'The Potential Impact on Atmospheric Ozone and Temperature of Increasing Trace Gas Concentrations', Guy Brasseur and Anne De Rudder, (August 1986).

## 2. CASE STUDY SCENARIOS

The 15 scenarios formulated for study are listed in Table 1. The CFC production and other variables were as follows:

### Chlorofluorocarbons

The CFCs in the scenarios are the three most extensively produced fully halogenated compounds: CFC 11 and CFC 12 which are mainly used in aerosols, refrigeration and foam plastics; and CFC 113 which is mostly used as a cleaning solvent. Although the production of CFC 113 is currently at a much lower level than that of CFC 11 and 12, it has risen rapidly in recent years and may have considerable growth potential because of the use of CFC 113 in the electronics industries. Other commercially produced CFCs have been excluded because, having regard to their short atmospheric lifetimes and/or the low level of production, they have a comparatively small potential to perturb the ozone layer.

The alternative production growth rates assumed in the scenarios are zero and 3% per year for CFC 11 and 12, and zero, 3% and 6% per year for CFC 113. For CFC 11 and 12 global production and use constraints are imposed in some cases, viz. global production limits of 1.5 and 2.0 times the level of production in year 1984, and a global ban on use in aerosols assumed to have been implemented in year 1984. In no case is the production of CFC 113 allowed to exceed that of CFC 11.

Figures 1 and 2 illustrate the growth with time of emissions of CFC 11, 12 and 113 in the scenarios listed in Table 1.

The historical production and emission database for CFC 11 and 12 relates to statistics of production and use compiled by independent accountants from annual returns reported by companies under the scheme administered by the US Chemical

Manufacturers Association (CMA). For CFC 113 estimates provided by industry have been used. The CFC data thus excludes production in China, the USSR and other Eastern bloc countries.

**Chlorocarbons**

Only two man-made chlorocarbon compounds have tropospheric stability and production levels such as to have significant ozone perturbation potential. These are carbon tetrachloride ($CCl_4$) and methyl chloroform ($CH_3$ $CCl_3$), and they have both been included in the scenarios with constant 1980 release rates, as illustrated in Figure 3. Allowance has also been made for the emission of methyl chloride ($CH_3Cl$) from the oceans and other natural sources.

**Other trace gases from terrestrial sources**

On the basis of measurements and estimates reported by other investigators, assumptions are made on the historical and future growth of emissions and atmospheric concentrations (termed 'mixing ratios') of the following chlorine free gases released from natural sources and human activities.

Carbon dioxide ($CO_2$)
Methane ($CH_4$)
Nitrous oxide ($N_2O$)

The projected growth with time of the mixing ratios of these three gases is shown in Figure 4.

## 3. THE MODEL

The one-dimensional model used in the Brasseur study is capable of calculating changes with time in the ozone content and temperature of the atmosphere over a range of altitude, and of the surface temperature of the earth, both under steady state trace gas concentrations and time dependent emission scenarios. In making these calculations the model has facilities for taking account, in varying degrees of complexity, of:

- the rates at which substances injected into the air at ground level are transported upwards through the troposphere and into the stratosphere,
- the numerous chemical changes and interactions among the various trace gas species which occur in the upper atmosphere due to photo-decomposition and temperature dependent chemical reaction rate coefficients,
- the temperature changes caused by the absorption, transmission and emission of radiation by trace gas species. These changes induce alterations in trace gas concentrations causing further temperature changes, ie temperature and chemical feedback effects, and the model can deal with these by repeating the calculations until radiative equilibrium is attained.

Since the model is able to represent the interaction of all these processes it can be described as a coupled chemical-radiative-transport one-dimensional time dependent model.

## 4. RESULTS

### 4.1 Interpretation

Before reviewing the outcome of the model calculations three aspects of ozone modification need to be stressed:

**Variation with altitude**

- The concentration of ozone in the atmosphere varies with altitude, the maximum occurring in the stratosphere at altitudes of 20 to 25 km. The protective effect of ozone in filtering out harmful ultra-violet radiation from the sun is a function of the total vertical ozone column. It follows that a large percentage change at altitudes where the ozone concentration is low can have a smaller effect on total column ozone than a much smaller percentage change at altitudes where the concentration is high, and it is important to bear this in mind when viewing graphs showing percentage changes in ozone concentration at different levels.

**The role of chlorine**

- The decomposition of stratospheric ozone due to CFCs and chlorocarbons (ClCs) is primarily due to the action of active chlorine atoms formed by photodissociation of the parent compounds. Some CFCs have a much higher ozone depletion potential than most chlorocarbons because they are not destroyed in the troposphere and therefore diffuse up into the stratosphere. A few chlorocarbons are important, however, because the combinations of emission tonnage and atmospheric lifetime are such as to permit them to contribute significant amounts of active chlorine in the stratosphere.

**Time lag between emission and effect**

There is a considerable delay between a change in the rate of CFC or ClC emission at the earth's surface and the resultant effect on ozone. This is due to the time taken for the organic chlorine to reach the stratosphere, and for the subsequent processes to occur in which free chlorine is formed by photochemical decomposition, and eventually removed by conversion to hydrogen chloride, which diffuses back into the troposphere and is 'rained out'. Thus, if the rate of CFC emission on earth is reduced, the amount of free chlorine in the stratosphere, and its consequent effect on ozone, will continue to increase for some years due to continuing diffusion of CFCs into the stratosphere from the existing bank of previous releases into the troposphere.

### 4.2 Model Runs

The model runs which most closely simulated actual conditions were those in which the model was operated in its most advanced mode, taking account of radiative and chemical feedbacks. The results highlighted in this paper are largely from the 'advanced mode' runs, since these are the most relevant to the discussion of CFC control strategies.

For investigational purposes the model was also operated in simpler modes, ie without radiative and/or chemical feedback, for example to compare the results with those previously obtained with earlier models, and a comprehensive presentation of all the results is given in Brasseur's paper.

### 4.3 Steady State Responses to Trace Gas Perturbations

Notwithstanding the remarks in the preceding paragraphs, it is instructive to consider the possible effects of varying the concentrations of each trace gas individually, while holding the others constant. The results of runs with these simple perturbations, but including temperature and chemical feedbacks are summarised in Table 2. The principal features are as follows:

## Carbon dioxide

A doubling of the $CO_2$ content of the atmosphere reduces the temperatures in the stratosphere, resulting in an increase in ozone concentration in that region. Total column ozone is calculated to increase by 1.8%, and the temperature at the earth's surface is indicated to rise by about 2K.

## Methane

Doubling the methane concentration, which would occur in about 70 years at the present observed rate of increase, would increase the total ozone column by 2.4%, while surface temperature would rise by about 0.4K.

## Nitrous oxide

By contrast with $CO_2$ and methane, the effect of injection of nitrous oxide under otherwise constant conditions is to **reduce** the ozone column. Nitrous oxide levels are forecast to rise more slowly than those of $CO_2$ and methane and if the current concentration rises by a factor of 1.2, the model predicts 1.4% depletion of the ozone column and a negligible change in surface temperature. Even doubling the $N_2O$ content is estimated to increase surface temperature by less than 0.3K.

## CFCs

If the amount of inorganic chlorine in the atmosphere is allowed to rise to the level predicted when steady state conditions are reached at present and constant emission levels of CFC 11 and 12, then the model predicts significant ozone depletion in the stratosphere, compensated by some increase in the troposphere, and a total column depletion of 5.0%. Surface temperature would rise by 0.4K.

Combined steady state perturbations

If the calculated ozone column and earth surface temperature changes quoted above are added, the ozone column variation is -2.23% and the surface temperature change is +2.83K. But if the model takes account of all the perturbations simultaneously the ozone depletion is -1.11% and the temperature change is +2.71K. This non-linear behaviour is found to be most pronounced at altitudes above 35km, where the effects of $CO_2$ and the CFCs are largest.

## 4.4 Time-varying responses for multiple perturbations of all the trace gases

We now move on to runs with the full advanced model, taking simultaneous account of all the trace gases included in the scenarios, with estimated rates of emission increase for the non-CFC gases, and a number of permutations of possible production rate increases, global limits for CFC 11, 12 and 113 production and a global ban on CFC 11 and 12 usage in aerosols. These are the cases nos. 3 to 7 listed in Table 1.

Total ozone column modification

a) Scenarios with global production limits but no aerosol ban

In Figure 5A, the graphs of Cases 3a, 3b and 3c show the total ozone column changes with time for constant CFC 11 and 12 production at the 1984 level. Case 3a excludes the effect of CFC 113 while Cases 3b and 3c includes CFC 113 growth at 3% and 6% per year respectively. In each case the ozone content rises slightly between 1940 and 1970 because, during that period, the positive effects of carbon dioxide and methane marginally exceed the depleting effects of ClCs and nitrous oxide, but the effect is never larger than 0.1%. After 1970 ozone depletion begins, mainly due to anthropogenic chlorine, and the decrease is greater in Cases 3b and 3c due to the effect of CFC 113. Eventually, (after year 2040 in Case 3a, and year 2060 in Case 3c), the ozone column depletion is arrested and the column begins to increase again due to the influence of rising methane concentrations, which promote removal of active chlorine from the stratosphere.

In Figure 5B, the graphs of Cases 5a, 5b and 5c show the corresponding projections with a CFC 11 and 12 growth rate of 3% per year but a production limit of 1.5 times the 1984 production level. As in Cases 3a, 3b and 3c, after a small increase before 1970 the ozone column starts to decrease to reach a maximum reduction of 2.8% in year 2060 in Case 5a (No CFC 113), and a maximum depletion of 4.2% in 2070 in Case 5c (CFC 113 rising at 6% per year).

In Case 7, represented in Figure 6, CFC 11 and 12 production is allowed to rise at 3% per year up to 2.0 times the 1984 level, with CFC 113 also rising at 6% per year, until it reaches the production level of CFC 11; in this case the maximum ozone depletion reaches about 5.2%.

### b) Scenarios with a global aerosol ban

In Figure 7, the graph of Case 6 shows the effect of delaying the commencement of 3% per year growth of CFC 11 and 12 production by introducing a global ban on the use of these CFCs in aerosols in 1984. In comparison with the corresponding scenario but without an aerosol ban, Case 5c, the result is a smaller extent of depletion, the difference being less than 0.5% until year 2055, and less than 1% in year 2100.

By contrast, Figure 8 shows the effect of introducing an aerosol ban but allowing unrestricted growth of CFC 11 and 12 production at 3% per year. As in Case 6, the aerosol ban initially delays ozone depletion, which is less than 2% before 2015, but reaches 10% in 2060 and 30% in 2080.

## Ozone profile changes

Modifications of the total ozone column represent the integration of increases and decreases which may occur at any one time at different altitudes.

For Case 5c, which represents limited CFC production without an aerosol ban, the graph in Figure 9 of percentage change in ozone with altitude for years 2000, 2040, and 2100 shows that ozone is depleted at heights above 25 km with maximum depletion at about 40 km, while below 25 km the ozone increases. Figure 10 shows how ozone changes with time at various altitudes for Case 5c.

## 5. LIMITATIONS IN DATA AND THE MODEL

The database for CFC production and release up to 1984 is thought to be reasonably satisfactory, although it omits estimates for China, the USSR and Eastern bloc countries. It must be stressed, however, that the rates of increase assumed in the scenarios have no firm foundation and are not to be regarded as estimates or even as informed guesses. In the first phase of the Workshop the difficulty of making forecasts with any confidence for even five years ahead was recognised, but it was accepted that for modelling purposes it would be reasonable to consider growth scenarios for CFC 11 and 12 in the range 0 to 5% per year, and a 3% compound rate was adopted for the Brasseur case studies. The growth rates used for CFC 113 in the scenarios are also no more than assumptions.

Changes in the emission rates of the other trace gases will depend, for example, on future patterns of agriculture and fertiliser usage, and on fossil fuel consumption. The assumptions made in the scenarios selected are broadly in line with those currently adopted by other modellers, and are based mainly on recently observed trends in atmospheric concentrations, but there can be no assurance that these trends will continue.

It must be remembered that relatively small figures for total ozone depletion may represent the difference between two large figures, ie a large decrease in ozone at high altitudes and a substantial increase at low altitudes. Small errors in the two parent figures can introduce a large percentage error in the difference figure. This point is illustrated in the graphs of the total ozone column profiles in Figure 9.

Brasseur also lists a number of physical and chemical factors which introduce uncertainties into the predicted responses of the atmosphere to changes in trace gas emissions and concentrations. It is difficult to discuss these factors without going into the science in greater depth than is warranted in this paper, but the elaborations which Brasseur and his co-workers have made in the 1-D model have tended to increase the extent of calculated ozone depletion compared with earlier models and the results are believed to be conservative, i.e. to represent **upper limits** of possible depletion.

There are inherent limitations in the capabilities of 1-D models and these are likely to be considered during the Workshop, when some results using 2-D models are expected from other investigations.

## 6. IMPLICATIONS OF MODEL RESULTS FOR CFC CONTROL STRATEGIES

Taking the scenarios which include rising atmospheric concentrations of the trace gases $CO_2$, $CH_4$ and $N_2O$, with constant emissions of the chlorocarbons $CCl_4$ and $CH_3CCl_3$, the following results from running the model in its advanced mode, i.e. with radiative and chemical feedback, are particularly relevant to the formulation of CFC control strategies:

a) With unrestricted growth of the production of CFCs 11 and 12 at a rate of 3% per year, total column ozone depletion relative to year 1940 would exceed 10% by year 2050 and increase rapidly thereafter. The imposition of a global ban on CFC use in aerosols would retard this effect by only a few years.

b) With a growth of 3% per year in CFC 11 and 12 production and the adoption of a global production limit of 1.5 times the 1984 production total for CMA reporting companies, coupled with 6% per year growth of CFC 113 production to a limit equal to that for CFC 11, ozone depletion compared to 1940 would reach a maximum of 4.2% by year 2070, followed by some recovery thereafter. The addition of an aerosol ban would reduce the maximum depletion by less than 1%, and delay it by perhaps 10 years. If the global production limit were to be 2.0 instead of 1.5 times the 1984 level, the maximum ozone depletion would become about 5.2% instead of 4.2%.

c) In all the CFC production growth scanarios examined, ozone depletion is predicted to be less than 1.5% in year 2000.

These results suggest that it would be prudent to adopt and implement global CFC production limitation measures during the next ten years, but they do not provide grounds for early action to limit usage in any existing application sector.

To improve the accuracy of the CFC production and emission database used in model calculations it is most desirable to obtain substantially complete annual global statistics for CFC 11, 12 and 113 as soon as possible.

It is clearly also important to sustain ozone monitoring by direct measurement so as to provide a check on model predictions, and to develop an early detection system for any untoward trends.

**TABLE 1 : CASE STUDY SCENARIOS**

| Case No. | CFC 11 and 12 production | | | CFC 113 production | Chloro-carbons | Other trace gases | |
|---|---|---|---|---|---|---|---|
| | Rate of increase (Note 1) %/year | Limit (Note 2) | Ban on use in aerosols | Rate of increase to limit (Notes 1&3) %/year | $CCl_4$ and $CH_3 CCl_3$ Emission | $CO_2, CH_4, N_2O$ Mixing ratio | Temperature feedback |
| 1, | 3 | No | No | Not included | | Constant | Yes |
| 1 | 3 | No | No | | | | No |
| 2, | 3 | Yes 1.5 | No | Not included | | Constant | Yes |
| 2 | 3 | Yes 1.5 | No | | | | No |
| 3a | 0 | - | - | Not inc. | Emissions assumed constant at 1980 level in all scenarios except Case 8 where they are not included | Increases | Yes |
| 3b | 0 | - | - | 3 | | | |
| 3c | 0 | - | - | 6 | | | |
| 3d | 0 | - | - | 0 | | | |
| 4 | 3 | No | Yes | 6 | | Increases | Yes |
| 5a | 3 | Yes 1.5 | No | Not inc. | | Increases | Yes |
| 5b | 3 | Yes 1.5 | No | 3 | | | |
| 5c | 3 | Yes 1.5 | No | 6 | | | |
| 6 | 3 | Yes 1.5 | Yes | 6 | | Increases | Yes |
| 7 | 3 | Yes 2.0 | No | 6 | | Increases | Yes |
| 8 | Not included | - | - | Not included | | Increases | Yes |

Notes: (1) 'Not included' means the effect of the CFC(s) is not taken into account by the model in that particular case.

(2) (1.5) means that production is limited to 1.5 times the actual CFC 11 and 12 production in 1984 by CMA reporting companies.

(3) CFC 113 production is assumed never to increase above the level of CFC 11 production.

**TABLE 2**

**Ozone column variation and earth surface temperature changes for steady state trace gas perturbations with chemical and temperature feedback**

| **Trace gas concentration change** | **Ozone column change %** | **Surface temperature change °K** |
|---|---|---|
| $CO_2$ x 2.0 | + 1.82 | + 1.99 |
| $CH_4$ x 2.0 | + 2.35 | + 0.38 |
| $N_2O$ x 1.2 | - 1.40 | + 0.06 |
| CFC (11 & 12) x 7.5 | - 5.00 | + 0.40 |
| Combined | - 1.11 | + 2.71 |

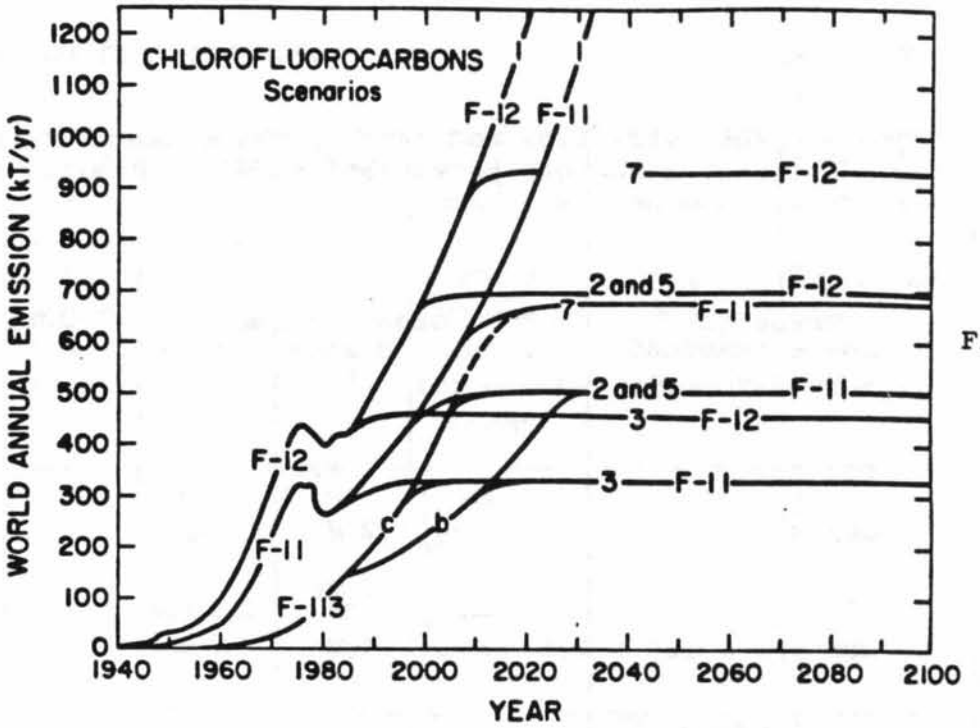

CHLOROFLUOROCARBONS
Scenarios
WORLD ANNUAL EMISSION (kT/yr)
YEAR
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1940
1960
1980
2000
2020
2040
2060
2080
2100
F-12
F-11
7
F-12
2 and 5
F-12
7
F-11
2 and 5
F-11
3
F-12
3
F-11
F-12
F-11
F-113
c
b

Fig. 1

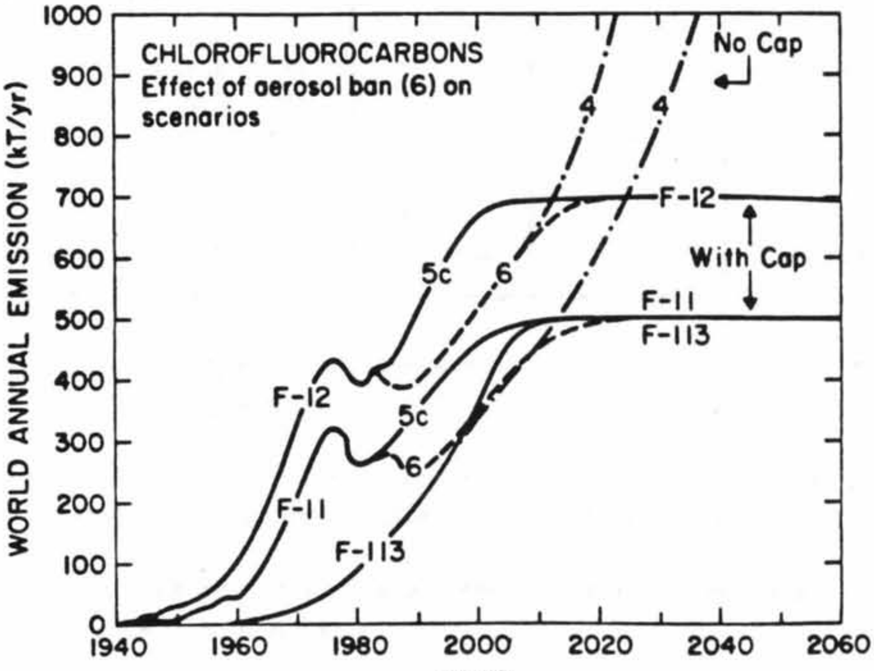
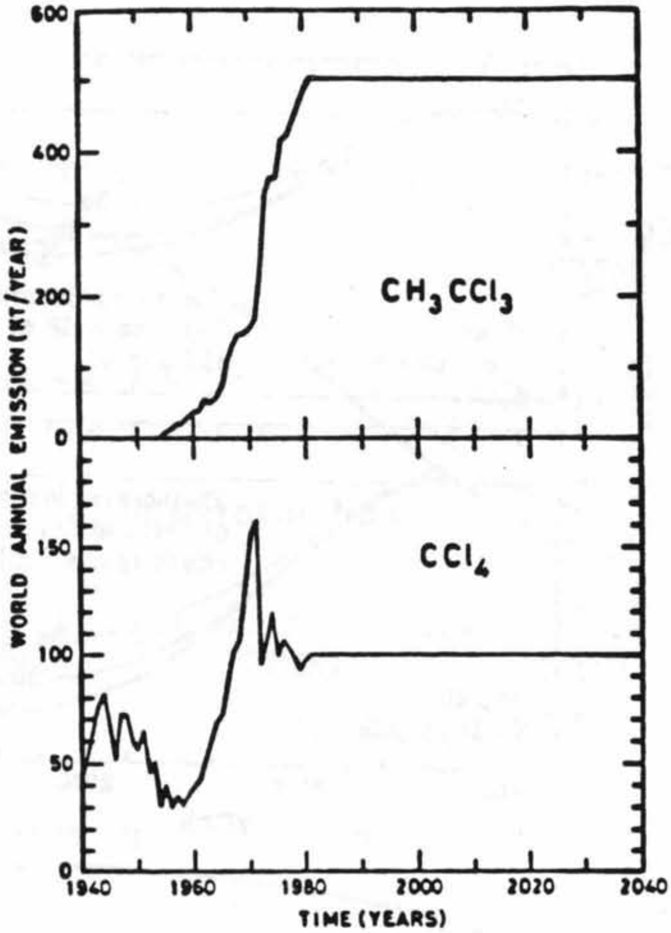

CHLOROFLUOROCARBONS
Effect of aerosol ban (6) on scenarios
WORLD ANNUAL EMISSION (kT/yr)
YEAR
0
100
200
300
400
500
600
700
800
900
1000
1940
1960
1980
2000
2020
2040
2060
No Cap
4
4
F-12
With Cap
5c
6
F-11
F-113
F-12
5c
6
F-11
F-113

Fig. 2

Fig. 3

Chlorocarbon Emission Scenarios



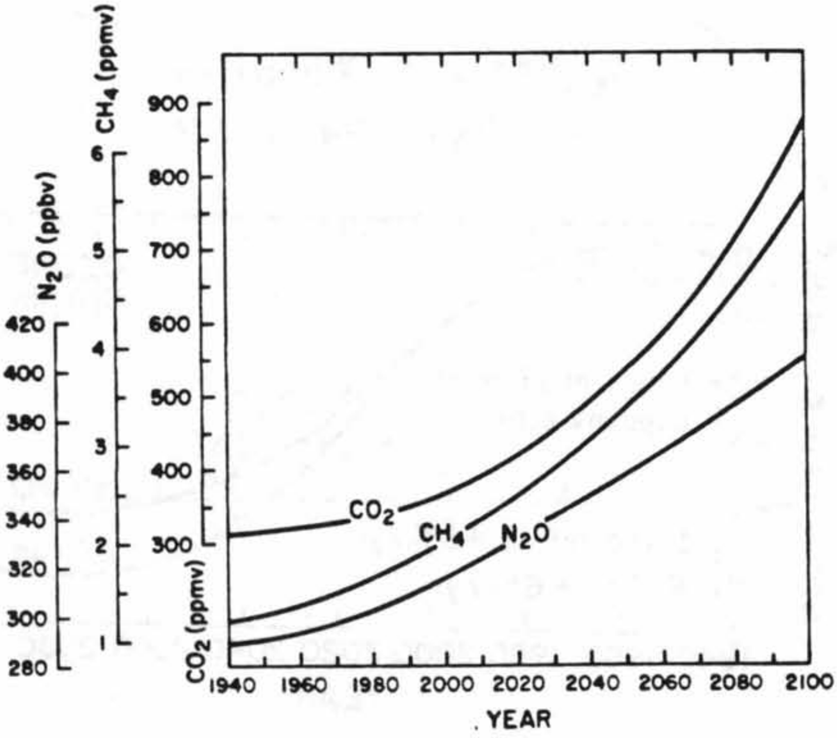


Fig. 4 Scenarios for $CO_2$ mixing ratio
and tropospheric CH [illegible]
[illegible]

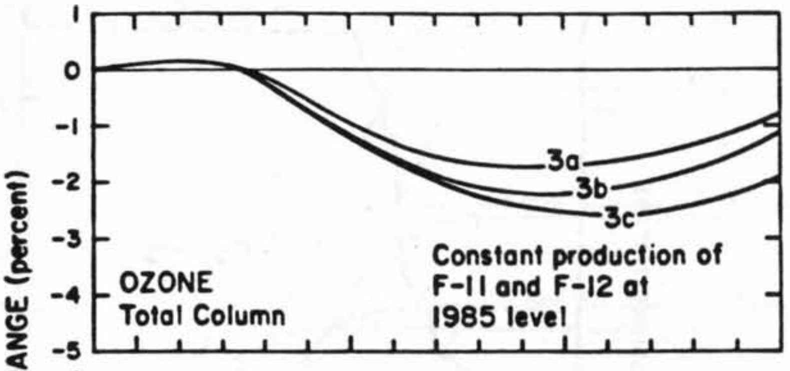


Fig. 5A

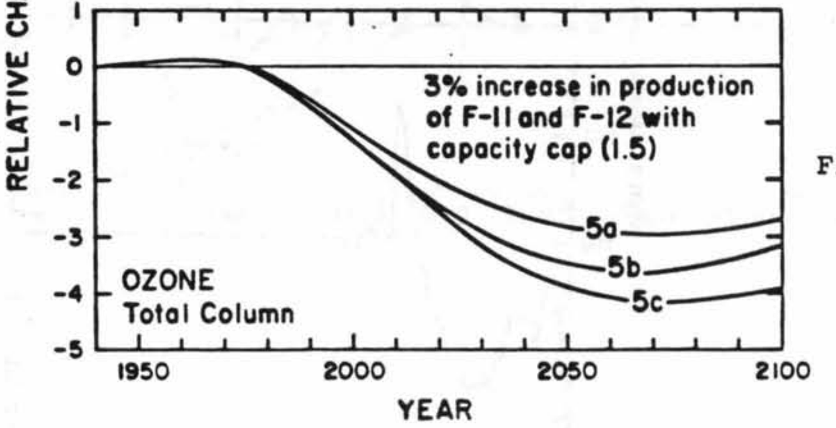


Fig. 5B

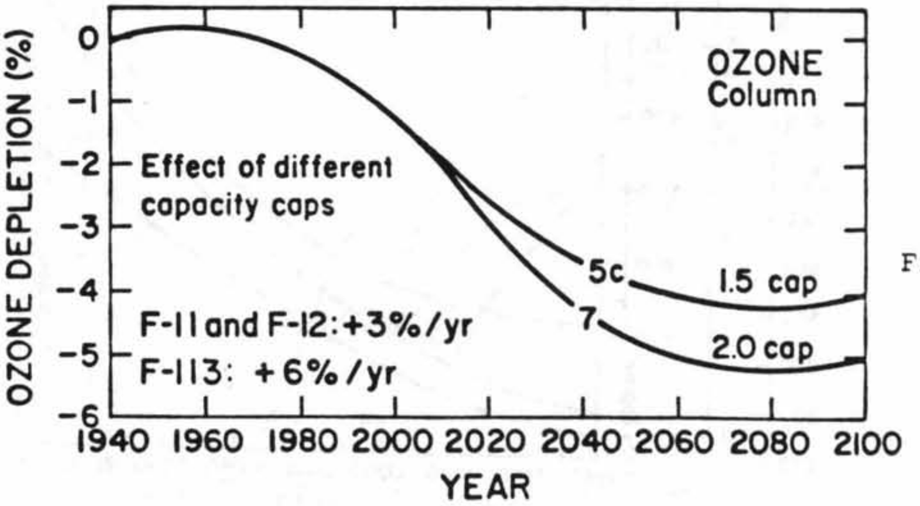


Fig. 6

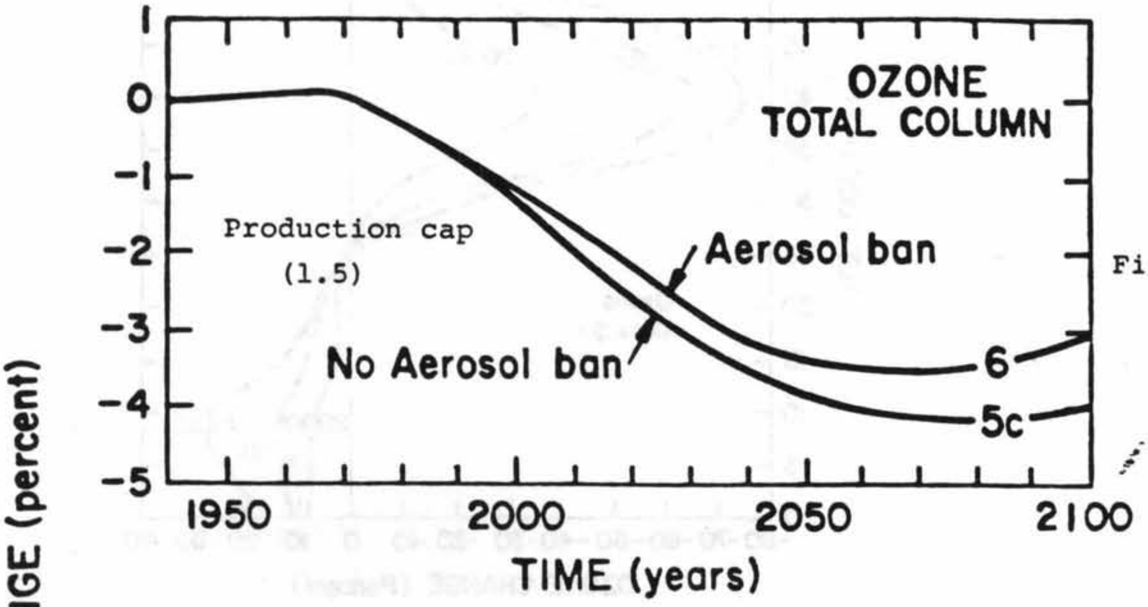

OZONE
TOTAL COLUMN
Production cap
(1.5)
Aerosol ban
No Aerosol ban
6
5c
1
0
-1
-2
-3
-4
-5
1950
2000
2050
2100
TIME (years)
RELATIVE CHANGE (percent)

Fig. 7

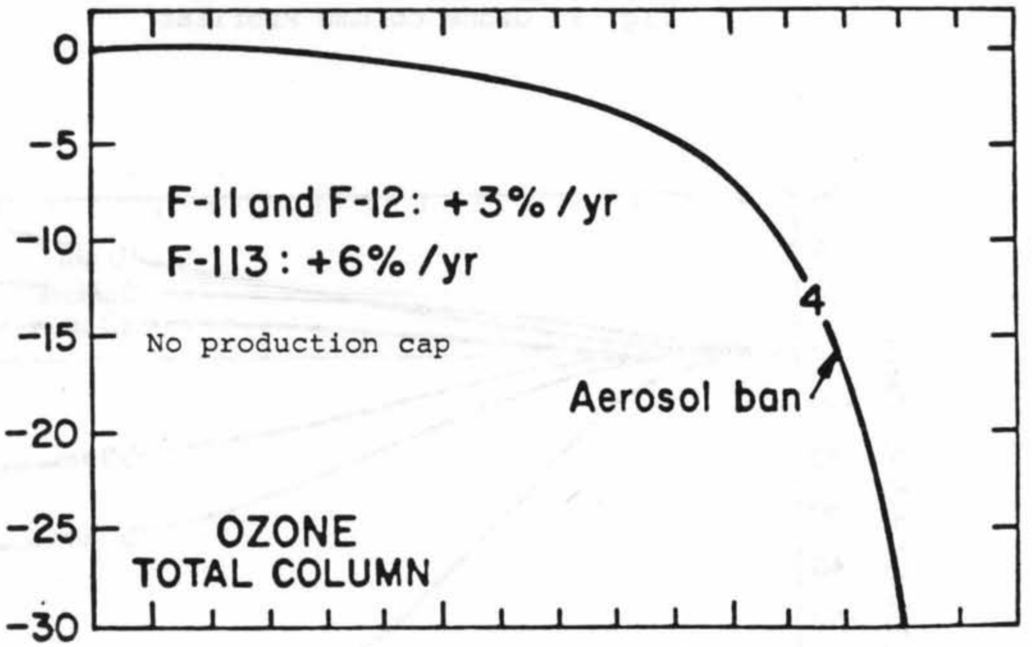

F-11 and F-12: +3% /yr
F-113 : +6% /yr
No production cap
4
Aerosol ban
OZONE
TOTAL COLUMN
0
-5
-10
-15
-20
-25
-30

Fig. 8

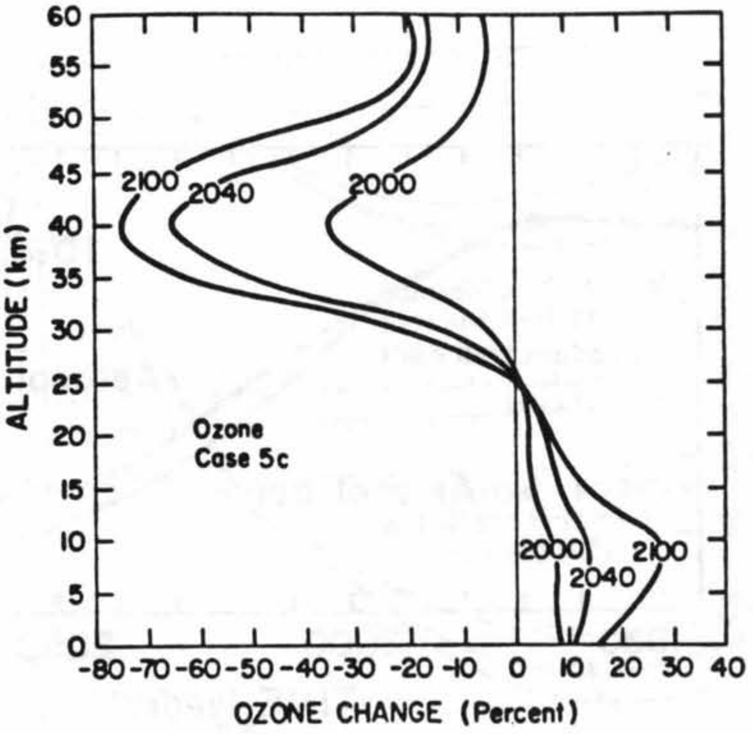


Fig. 9 Ozone Column Profiles

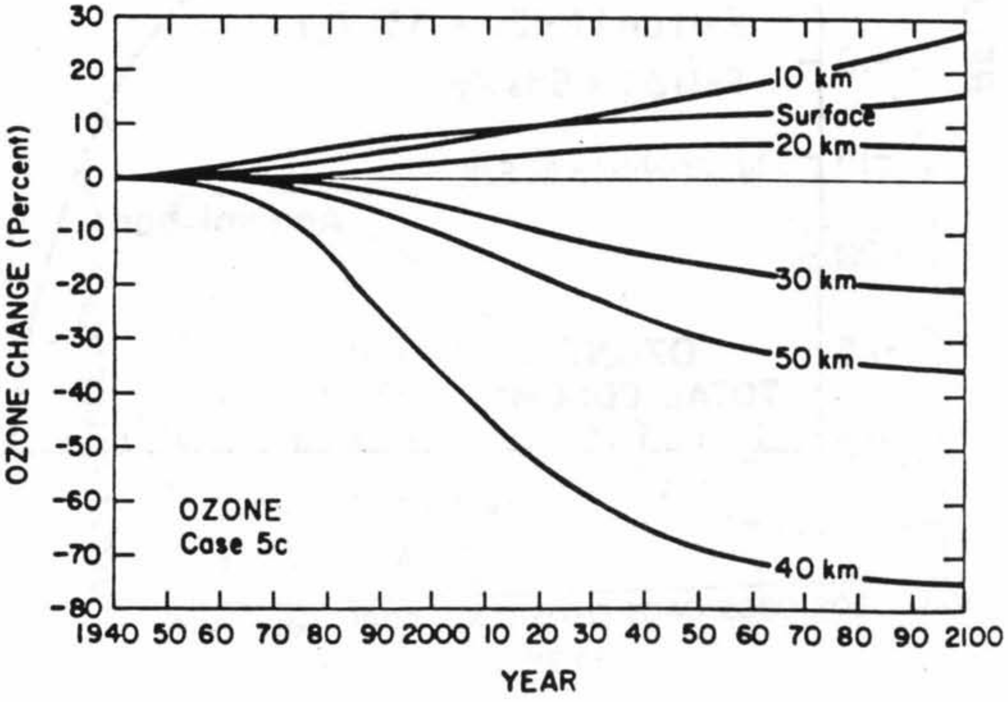


Fig. 10 Ozone Change [illegible]