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Wall Street Journal

Bid for Global Chemical Emissions Limit Expected at 40-Nation Meeting on Ozone

By Barry Meier
And Robert E. Taylor
Staff Reporters of The Wall Street Journal

As concern over damage to the earth's protective ozone layer mounts, a bid to set the first world wide controls on the use of industrial chemicals is looming.

The Reagan administration, following an earlier shift by the U.S. chemical industry, has decided to seek a world wide cap and a gradual phase out of emissions of chemicals believed to deplete the stratospheric ozone, which shields the earth from cancer-causing ultraviolet rays.

That position and emission control policies developed by other nations will be put forward next month at a meeting of some 40 nations in Geneva, Switzerland, to hammer out global limits on the use and emissions of ozone-destroying chemicals.

If successful, the meeting could set a precedent in dealing with global pollution problems, say activists and industry officials. "I think that if we can make this work, we can handle other problems in the same way," said Daniel Dudek, an economist with the Environmental Defense Fund, an activist group. He is a member of the U.S. delegation to the forthcoming Geneva talks, which are sponsored by the United Nations.

But Mr. Dudek and others say that major difficulties lie ahead in crafting an international accord on the ozone issue. Earlier attempts to agree on similar plans have floundered. Other nations have been less apt than the U.S. to call for controls on ozone-destroying chemicals. And major disputes still exist on the extent of controls needed to protect the ozone layer.

The Reagan administration's views were spelled out in a fact sheet released by the Environmental Protection Agency and in a State Department cable to U.S. embassies. The cable informs embassies on the goals the U.S. will pursue at the Geneva meeting.

Since the 1970s, scientific studies have indicated that several industrial chemicals, including chlorofluorocarbons and halons, destroy ozone through a complex chemical interaction. Chlorofluorocarbons, or CFCs, are widely used as refrigerants, solvents and foaming agents. Halons, produced in smaller quantities than CFCs, are used in fire extinguishers. Concern about ozone loss led to a U.S. ban in the 1970s on using CFCs as propellants in aerosol cans.

The debate over the chemicals' use was recently rekindled by reports of substantial ozone loss over the South Pole and elsewhere. Following those reports, Du Pont Co., the nation's largest CFC producer, said for the first time that it would support world wide global controls on emissions of ozone destroying compounds.

Chemical industry officials and some environmentalists have long argued that control of ozone-destroying chemicals is a global issue that won't be corrected by unilateral U.S. regulatory action. The EPA's latest draft of risk assessment calculates that unless chemical emissions are curbed, increased ultraviolet radiation from ozone depletion is likely to cause 40 million skin cancers in the U.S., 800,000 of them fatal, over nearly the next two centuries. The risk assessment also said ozone depletion would cause 12 million cataracts. It said the effects of ozone-depletion would initially be small but increase greatly in later years.

The EPA's model assumes that CFC production would continue to grow at about 2.5% per year. The ultraviolet rays also weaken plastic polymers, reduce some crop yields, harm some marine life and could cause climatic changes, according to the EPA draft.

The industrial impact of a global limit on emissions of ozone destroying chemicals would vary, depending on how such a pact is structured. Most concepts essentially are market driven, that is, restrictions would force up the price of using the chemical compounds, thus leading industrial users to seek alternative processes and materials. That also would give chemical companies market incentives to develop new compounds less injurious to the ozone layer.

"It is critical, however, to ensure that any global scheme results in meaningful limits on production rather than shifting production from one country to another," said Mr. Dudek of the Environmental Defense Fund.

Research on alternatives by Du Pont and other U.S. producers was dropped in the early 1980s when government pressure to regulate ozone-destroying chemicals eased. A Du Pont official estimated it would take about five years to develop alternative chemicals.

The recent shift in the government's stance reflects the change in industry's position. "There is a clear consensus that the ozone layer is in jeopardy," said Richard Benedick, the State Department official who will lead the U.S. delegation at Geneva.

Mr. Benedick said that the U.S. is planning to push for incentives intended to "narrow" emissions of the chemical, but hasn't yet decided how great a cutback is needed. "It's a question of what the science will justify," he said. While Du Pont and other industry officials have contended that current production rates are acceptable, others have argued that sharp cuts are needed to produce lower emissions.

Nearly all ozone-destroying chemicals produced are eventually released into the atmosphere. Because of their composition, the chemicals can remain in the atmosphere for 100 years or more before breaking down.

Mr. Benedick said that U.S. consular officials are sounding out other nations on the ozone issue. Irving Mintzer, a senior associate at the World Resources Institute, called the U.S. move "a very positive step." He said it would "push the discussion much further toward specific controls."

The U.S. stance follows a proposal by Canadian officials to control global use of ozone-destroying chemicals by allocating the emissions among nations on the basis of their gross national products and populations.

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...attributed the increase to defense electronics, one of the defense industry's fastest growing sectors, and higher volume and profitability in commercial avionics and telecommunications.

Declines in 2 Operations

Improvements in the two businesses offset Rockwell's slumping automotive and general industries businesses. Automotive earnings fell to $6.2 million from $30.7 million...

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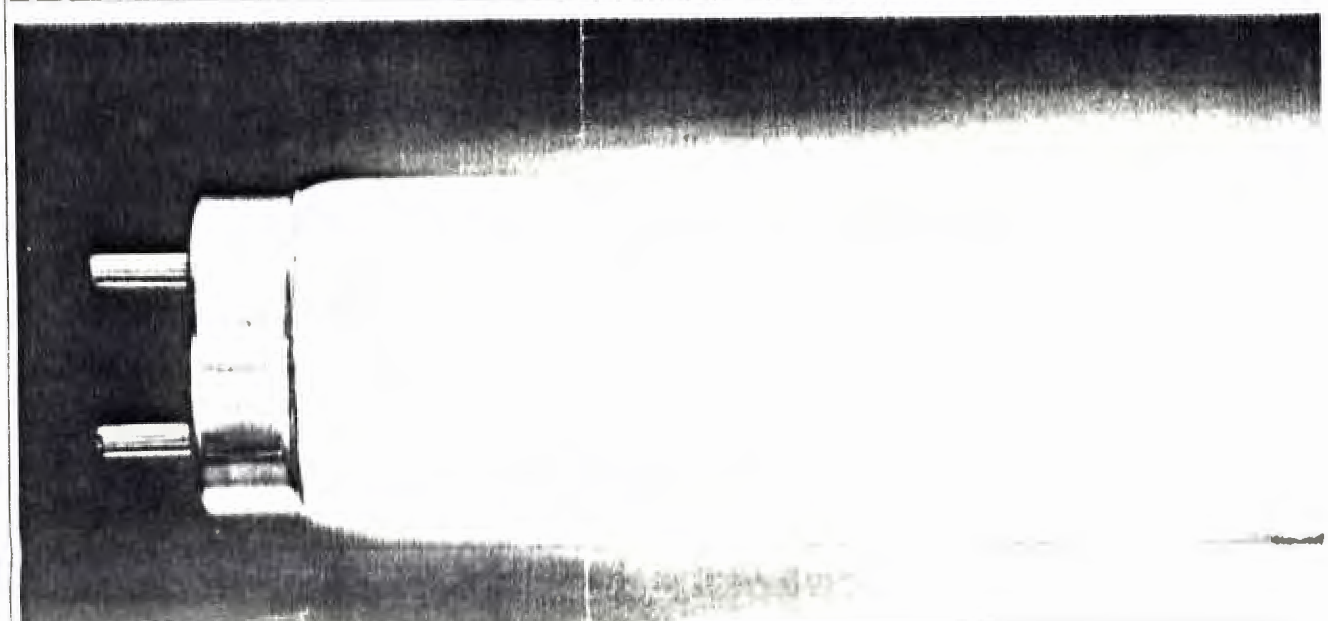

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OZONE POLICY

BY GUY DARST

WASHINGTON (AP) -- THE SPRINGTIME DEPLETION OF PROTECTIVE OZONE OVER ANTARCTICA NOW SEEMS TO BE MATCHED ON A SMALLER SCALE OVER THE ARCTIC IN SPRING AND FALL, A GOVERNMENT SCIENTIST SAID TUESDAY.

THE SCIENTIST, DON HEATH, DISCLOSED HIS FINDINGS BY COINCIDENCE ON THE SAME DAY THAT MANUFACTURERS AND MAJOR USERS OF CHEMICALS THAT ATTACK THE OZONE LAYER SAID THEY WOULD SUPPORT AN INTERNATIONALLY AGREED LIMIT ON PRODUCTION CAPACITY.

THE CHEMICALS ARE CHLOROFLUOROCARBONS, OR CFCS, WIDELY USED IN REFRIGERATION, PRODUCTION OF FOAM INSULATION AND PACKAGING AND, OUTSIDE THE UNITED STATES, AS AN AEROSOL PROPELLANT.

''ON THE BASIS OF CURRENT INFORMATION, WE BELIEVE THAT LARGE FUTURE INCREASES IN FULLY HALOGENATED CFCS -- THE MOST DURABLE ONES, THOUGHT TO CONTRIBUTE MOST TO OZONE DEPLETION -- WOULD BE UNACCEPTABLE TO FUTURE GENERATIONS,'' SAID RICHARD BARNETT, CHAIRMAN OF THE ALLIANCE FOR A RESPONSIBLE CFC POLICY.

''FULLY HALOGENATED'' MEANS CONTAINING THE MAXIMUM NUMBER OF ATOMS LIKE CHLORINE.

THE MOST WIDELY USED CFCS, VALUABLE FOR THEIR NON-FLAMMABLE, NON-TOXIC QUALITIES, CAN LAST 100 YEARS. CHLORINE LIBERATED IN THEIR BREAKUP THEN BREAKS DOWN OZONE 15 TO 25 MILES ABOVE THE EARTH'S SURFACE.

OZONE IS A POLLUTANT AT LOW ALTITUDES BUT, BY FILTERING THE SUN'S ULTRA-VIOLET RAYS HIGH UP, MAKES LIFE ON EARTH POSSIBLE. EACH 1 PERCENT DECLINE IN HIGH-ALTITUDE OZONE MEANS AN ESTIMATE 20,000 EXTRA CASES OF SKIN CANCER IN THE UNITED STATES.

HEATH, AN ATMOSPHERIC PHYSICIST AT THE NASA GODDARD SPACE FLIGHT CENTER IN SUBURBAN WASHINGTON, SAID IN AN INTERVIEW THAT HIS EXAMINATION OF 1978-1984 DATA FROM THE NIMBUS 7 SATELLITE SHOWS THAT OZONE OVER THE ARCTIC IS FALLING AT ABOUT 1.5 PERCENT TO 2.0 PERCENT PER YEAR.

OTHER NIMBUS 7 DATA CONFIRMED THE FINDING OF BRITISH SCIENTISTS LAST YEAR THAT STARTING IN THE 1970S, SPRINGTIME ANTARCTIC OZONE CONCENTRATIONS FALL DRASTICALLY FOR A MONTH OR TWO, WITH THE MAXIMUM DECLINE GREATER EACH YEAR -- ABOUT 40 PERCENT BELOW NORMAL LAST OCTOBER.

THE ARCTIC RESULTS SHOW AN ACCELERATION DURING FEBRUARY AND OCTOBER OF AN OTHERWISE STEADY DECLINE, HEATH SAID. IN THOSE MONTHS, THE DECLINE PICKS UP TO A RATE THAT WOULD EQUAL ABOUT 2.5 PERCENT IF CONTINUED FOR AN ENTIRE YEAR.

SEVERAL COMPUTER MODELS OF THE ATMOSPHERE HAVE SAID SMALL DECLINES SHOULD BE APPARENT BY NOW. HEATH'S FINDINGS, IF THEY HOLD UP, WOULD BE THE FIRST CONFIRMATION OF THE MODEL PREDICTIONS IN THE NORTHERN HEMISPHERE.

PEAK DELINES OCCUR OVER SPITZBERGEN, THE NORWEGIAN ISLAND GROUP ABOUT 700 MILES FROM THE NORTH POLE, HE SAID.

''THE DATA I HAVE ARE CONSISTENT WITH (THE LATEST MODELS) RESPECT TO LATITUDE AND SEASONAL VARIATION, EXCEPT LARGER,'' HEATH SAID.

''IT DOESN'T NECESSARILY MEAN THAT FLUOROCARBONS ARE MAKING THINGS WORSE, JUST THAT THERE ARE SOME PHOTOCHEMICAL PROCESSES GOING ON THAT IS DESTROYING THE OZONE. ... THE IMPORTANT THING IS THAT IT HAS THE SIGNATURE OF THE PREDICTIONS OF FLUOROCARBONS.''

THE COUNTRIES OF THE EUROPEAN COMMON MARKET ALREADY HAVE AGREED TO LIMIT CFC PRODUCTION CAPACITY, THOUGH AT A LEVEL WELL ABOVE CURRENT PRODUCTION.

MEMBER NATIONS OF THE UNITED NATIONS ENVIRONMENT PROGRAM MEET IN VIENNA IN NOVEMBER TO DISCUSS INTERNATIONAL REGULATIONS, AND BARNETT, A VICE PRESIDENT OF YORK INTERNATIONAL CORP., SAID HIS GROUP HAD BEEN TOLD BY THE STATE DEPARTMENT THAT ITS POSITION WOULD HELP U.S. NEGOTIATORS.

BARNETT SAID THERE WAS NO SINGLE THING THAT PROMPTED THE NEW POSITION -- ''IT JUST SEEMED LIKE THE RESPONSIBLE THING TO DO ... TO AVOID ARRIVING AT A FUTURE PROBLEM.''

THOUGH HIS POLICY STATEMENT SAID THE U.S. GOVERNMENT AND THE UNITED NATIONS CONFERENCE SHOULD ''CONSIDER ESTABLISHING A RESONABLE GLOBAL LIMIT ON THE FUTURE RATE OF GROWTH OF FULLY HALOGENATED CFC PRODUCTION CAPACITY,'' HE SAID IN AN INTERVIEW THAT IF SCIENTIFIC FINDINGS SUPPORTED AN INTERNATIONAL DECISION ACTUALLY TO CUT CAPRACITY AND PRODUCTION, HIS ORGANIZATION WOULD BACK THE DECISION.

BARNETT'S STATEMENT WAS WELCOMED BY ENVIRONMENTAL GROUPS PRESSING FOR ACTION AGAINST CFCS.

''IT'S A STEP FORWARD,'' SAID IRVING MINTZER, SPECIALIST IN OZONE FOR THE WORLD RESOURCES INSTITUTE.

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''IT'S A GOOD THING TO SEE THAT THEY HAVE RECOGNIZED THE EXISTENCE OF THIS PROBLEM,'' SAID DAVID DONIGER OF THE NATURAL RESOURCES DEFENSE COUNCIL. ''THE WHOLE DEBATE IS SHIFTING OVER FROM 'SHOULD WE LET GROWTH CONTINUE OR HAVE A CAP?' TO 'SHOULD WE CONTINUE AT CURRENT LEVELS OR CUT WAY BACK, MAYBE EVEN PHASE IT OUT?'''

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ANNALS OF CHEMISTRY

IN THE FACE OF DOUBT

FOR a time in the nineteen-seventies, no environmental problem caused a greater stir in the United States than the revelation that chlorofluorocarbon gases were thought to be rising into the stratosphere and depleting the ozone layer. Ozone is a gas formed by the action of sunlight on oxygen, and it can be found everywhere in the atmosphere from ground level to the top of the stratosphere, some thirty miles above the surface of the earth. The threat posed by chlorofluorocarbons to the ozone layer, which shields the earth from harmful solar radiation, had been proposed as a theory by Professor F. Sherwood Rowland and Dr. Mario J. Molina, both of the Department of Chemistry of the University of California at Irvine, in the summer of 1974; the announcement received extensive coverage in the press and on television, and captured the imagination of the nation's consumers, who, through the use of aerosol sprays containing chlorofluorocarbon gases as a propellant, were directly contributing to the threat. Troubled by the notion that the touch of their fingertips on the valves of aerosol cans containing hair spray, shaving cream, deodorants, insecticides, and the like might spell disaster for mankind, they proceeded to reduce their purchase of these products, and fired off more letters to Congress on the issue than they had on any other since the Vietnam War. When the existence of the hazard was substantiated by a government-sponsored study published in September of 1976, officials of the Environmental Protection Agency, the Food and Drug Administration, and the Consumer Product Safety Commission decided to restrict the nonessential uses of chlorofluorocarbons. In the autumn of 1978, the E.P.A. and the F.D.A. imposed a ban on the manufacture and use of the compounds as propellants in aerosol sprays. At that point, public concern about the problem virtually disappeared, for most Americans were persuaded that whatever calamity might have been in store for the ozone layer had been averted.

During the nearly eight years since then, the government has spent several hundred million dollars on research relating to the depletion of stratospheric ozone by chlorofluorocarbons, and estimates of this depletion have gone up and down in roller-coaster fashion as a succession of committees convened by the National Academy of Sciences and the National Aeronautics and Space Administration have assessed and reassessed the problem. Generally speaking, the conclusions of the members of these committees—atmospheric scientists of renown from all over the world—have reflected uncertainties: on the one hand, there has been general agreement that chlorofluorocarbons would gradually deplete ozone in the upper stratosphere, twenty to thirty miles above the earth; on the other hand, no consensus has been reached on just how rapidly or severely this might occur. In May of 1985, however, scientists of the British Antarctic Survey, which is based in Cambridge, England, published an article in the international scientific journal *Nature* reporting large and unexpected losses of ozone in the stratosphere above the Survey's station on the Antarctic coast at Halley Bay. As might be expected, these losses have proved highly disturbing to the world's scientific community.

The total amount of ozone in the atmosphere can be estimated by measuring the intensity of selected wavelengths of solar ultraviolet radiation arriving at the earth's surface. The distribution of ozone at various altitudes of the stratosphere, where about ninety per cent of all ozone occurs, can be determined by measuring the intensity of ultraviolet radiation as the sun's angle changes through the day. The validity of this technique has been confirmed by direct chemical measurements made from high-altitude balloons. Since 1957, the scientists of the British Antarctic Survey had been estimating the amount of ozone in the atmosphere above Halley Bay between October and March—months during which there is sunlight in Antarctica—and since 1977, it turned out, they had been observing a steady decline in ozone but had not notified the scientific community of the finding, because they mistrusted their measurements. However, when they began to observe similar losses of ozone at a second measuring station—at the Argentine Islands, about a thousand miles to the northwest

—they were persuaded to trust the Halley Bay data, which showed that the kind of ultraviolet radiation known to be harmful to human skin had increased tenfold and that the ozone layer above Antarctica had decreased by almost forty per cent. In August of 1985, their observations of Antarctic ozone depletion were confirmed by a reassessment of data collected by NASA's Nimbus 7 satellite. Since 1978, Nimbus 7 had been taking measurements of ozone from a vantage point six hundred miles above the earth, but its low readings of ozone levels above Antarctica had been automatically discarded by the project's computer. NASA's atmospheric scientists, daunted by the prospect of having to pore over two hundred and fifty thousand separate ozone measurements taken by Nimbus 7 each day, had chosen to program their computers not to record exceptionally low ozone levels, because such levels had never been observed and might be expected to have resulted from faulty measurements. Suffice it to say that when Nimbus 7 confirmed the British observations of ozone depletion above Antarctica it became clear that—far from having been averted—the calamity that Rowland and Molina had predicted for the ozone layer back in 1974 might have come sooner than anyone expected.

Dr. Rowland had become interested in chlorofluorocarbons in the winter of 1972, when he learned that one of them—trichlorofluoromethane—had been found throughout the troposphere, which is the six-to-ten-mile-high portion of the atmosphere that lies between the surface of the earth and the stratosphere. Both trichlorofluoromethane and dichlorodifluoromethane—a companion gas that was also found to be ubiquitous in the troposphere—had been synthesized in 1928 by chemists in the General Motors research laboratories who were trying to find a nontoxic, nonflammable refrigerant. Dichlorodifluoromethane has been used ever since as a coolant in refrigerators and automobile air-conditioners, and, starting in the early nineteen-fifties, it was mixed with trichlorofluoromethane as an aerosol propellant. Trichlorofluoromethane is also used extensively as a foaming agent in the manufacture of polyurethane. At the time when Rowland became interested in the chlorofluorocarbons, their pervasiveness in the troposphere was regarded as harmless; the two gases had been used industrially for more than forty years, and were known to be chemically inert. Rowland, however, wondered where the gases were going and what would become of them, and in the autumn of 1973 he and Dr. Molina, a photochemist from Mexico City, who was a member of his research group, decided to investigate the matter.

Chlorofluorocarbons, like all molecular gases, are decomposed by short-wavelength ultraviolet light from the sun—a process known as photolysis. Such decomposition can occur only in the stratosphere—from twelve to twenty-three miles above the surface of the earth. Below that, almost all short-wavelength ultraviolet light is absorbed by the ozone layer before it can interact with chlorofluorocarbons. Rowland and Molina decided after careful study that chlorofluorocarbons, because of their relative insolubility in water, could not be removed from the atmosphere by rainfall or by dissolution in the oceans, and, because of their chemical inertness, could not be broken down rapidly by any other known mechanisms in the troposphere. They concluded that the several million tons of chlorofluorocarbons estimated to be floating about in the troposphere—an amount about equal to the total amount ever manufactured—would eventually rise into the stratosphere, where they would be photolyzed by ultraviolet light, releasing atoms of chlorine in the process. Rowland and Molina now determined that each atom of chlorine released in the stratosphere would almost instantly seek out and react with a molecule of ozone—an extremely unstable substance—and that this would initiate an extensive and complex catalytic chain reaction in which, over a period of a year or so, tens of thousands of molecules of ozone would be converted into molecular oxygen and thus eliminated from the stratosphere. They calculated that if chlorofluorocarbons continued to be manufactured and used at the 1972 worldwide rate of almost a million tons a year the amount of chlorine released annually from their decomposition in the stratosphere would within a century or so be sufficient to roughly double the annual rate of removal of ozone known to occur naturally, chiefly through a reaction initiated by nitrogen oxides converted in the stratosphere from nitrous oxide released as a result of bacterial action in the soil. If the rate of ozone destruction doubled, there would be a tremendous increase in the kind of solar radiation known to be most detrimental to plant and animal cells, with consequences that could conceivably disrupt, and perhaps destroy, the biological systems of the earth. Moreover, the two scientists realized that even if the use of chlorofluorocarbons were to cease at once—an unlikely event, since their production had been doubling every seven years since the early nineteen-fifties—destruction of part of the ozone layer was foreordained, because the chlorofluorocarbons already in the troposphere were rising into the stratosphere, and so constituted a planetary time bomb.

In June of 1974, Rowland and Molina described their findings in *Nature*, and in September they presented their data at a meeting of the American Chemical Society, in Atlantic City. By that time, they had calculated that if chlorofluorocarbon production continued at the present rate, between seven and thirteen per cent of the ozone layer would be destroyed in about a hundred years. Their calculation was based on a principle known as steady state. This condition would arise in a hundred years or so, and the rate of destruction of chlorofluorocarbons by ultraviolet radiation would then be equal to the rate of their influx into the atmosphere. During this century, however, the rate at which chlorofluorocarbons are being destroyed by ultraviolet light has lagged well behind their influx, and as a result the amount of the compounds in the atmosphere has steadily increased.

Rowland and Molina told the Chemical Society meeting that the increase of ultraviolet light resulting from ozone depletion would cause a significant rise in the worldwide incidence of skin cancer and might also cause crop damage. They went on to warn that ozone depletion might even shift stratospheric temperatures sufficiently to create changes in the world's weather patterns. They predicted that if nothing was done in the next decade to prevent further release of chlorofluorocarbons the vast reservoir of the gases that would have built up in the meantime would provide enough chlorine atoms to insure continuing destruction of the ozone layer for much of the twenty-first century. They urged that the use of the compounds as aerosol propellants be banned.

The Atlantic City meeting triggered its own chain reaction. Environmentalists called for an immediate halt to the purchase of aerosol sprays containing chlorofluorocarbon propellants, which by then accounted for the largest and best-known commercial use of the two gases, and the threat to the ozone layer was soon making headlines from one end of the country to the other. That autumn, the National Academy of Sciences announced that it would conduct a full-scale investigation of the hazard, and in December the Subcommittee on Public Health and Environment of the House Committee on Interstate and Foreign Commerce held two days of hearings to consider legislation that would regulate—or possibly ban—the manufacture of the gases.

Meanwhile, the chlorofluorocarbon industry had responded to the situation by pointing out that ozone depletion by chlorofluorocarbons was a hypothesis based upon computer models of the stratosphere—that no real proof existed that the two gases could rise into the stratosphere, let alone that they could lead to the destruction of ozone. E. I. du Pont de Nemours & Company, the chief manufacturer of chlorofluorocarbons, announced soon after the Atlantic City meeting that the industry would finance studies of the problem, which would be undertaken by scientists at several universities and would take three years to complete. Pending the first results of the industry-sponsored research, du Pont maintained, there was no reliable evidence that chlorofluorocarbons posed a hazard to ozone—or, for that matter, that the chain reaction worked out by Rowland and Molina could occur at all. A du Pont official testifying before the Subcommittee on Public Health and Environment declared that until there was actual proof to support the ozone-depletion theory government regulation of chlorofluorocarbons was unwarranted. He added, however, that if credible evidence should be developed to show that the compounds posed a threat to human health du Pont would cease to produce them.

Perhaps mindful of the adverse effects of regulatory legislation in a time of recession, Congress took no action on either of two bills that had been drawn up to deal with the problem. In January of 1975, the President's Council on Environmental Quality and the Federal Council for Science and Technology created a task force to conduct an intensive study of the situation. The panel included representatives of seven Cabinet departments and five government agencies. In June, its members issued a report stating that release of chlorofluorocarbons into the atmosphere was a legitimate cause for concern. Unless new scientific evidence was found to remove this concern, the task force felt, it would probably be necessary to restrict the uses of the two chemicals, and they proposed that if their assessment was confirmed by the National Academy of Sciences federal regulatory agencies should put such restrictions into effect by 1978. (In March, the Academy had appointed a Panel on Atmospheric Chemistry to look into the chlorofluorocarbon problem for its Climatic Impact Committee. This committee had originally been established to assist the Department of Transportation's Climatic Impact Assessment Program, set up in 1971 to investigate the threat posed to the ozone layer by nitrogen oxides and other emissions from the exhausts of supersonic transports.) The task force called for international coöperation on the problem, noting that foreign countries accounted for about half the world's chlorofluorocarbon production and use, and that the effects of the compounds upon stratospheric ozone transcended national boundaries.

As might be expected, the chlorofluorocarbon and aerosol-spray industries bitterly opposed the findings of the report, which, by recommending that regulation be considered, undermined their contention that chlorofluorocarbons should be regarded as innocent until they were proved guilty. In fact, industry representatives went to the White House and tried, unsuccessfully, to have the report suppressed, on the ground that it was premature. Du Pont issued a statement pointing out that the task force was proposing restrictions "before the scientific evidence is available to make an informed judgment as to whether such restrictions are necessary," and that this was "tantamount to prejudging the results of research, which, if it is to be thorough, will take at least three years to complete." Be that as it may, no sooner had the report been released than the governor of Oregon, Bob Straub, signed a bill banning the sale of spray cans containing chlorofluorocarbons by March of 1977; and in the summer of 1975 the New York legislature passed a measure requiring such products to carry a label stating that they contain chlorofluorocarbons, which may harm the environment. In other states, however, industry lobbyists helped prevent the passage of similar restrictions by arguing that legislative action should await the report being prepared by the National Academy of Sciences, which was due in the spring of 1976. And du Pont continued to urge delay by taking out double-page advertisements in newspapers and magazines across the country which informed readers that "to act without the facts—whether it be to alarm consumers, or to enact restrictive legislation—is irresponsible." Such appeals appeared to fall upon sympathetic ears in Congress, where, in spite of the fact that additional hearings had produced detailed evidence to corroborate the theory of ozone depletion, a consensus had developed that the decision to regulate could be put off until the Academy completed its study. Meanwhile, the nation's consumers had begun voluntarily reducing their purchase of aerosol sprays, and a number of cosmetic manufacturers had abandoned chlorofluorocarbon propellants in favor of alternative methods of delivery, such as pump sprays.

In the winter of 1975-76, a draft of the forthcoming Academy report was circulated for review; it contained the estimate that continued release of chlorofluorocarbons at the 1973 level would result in the destruction of about fourteen per cent of the ozone layer by the time a steady state was reached. This estimate was slightly above the upper limit of the depletion range that had been predicted by Rowland and Molina. At the same time, however, an element of uncertainty was introduced into the ozone-depletion hypothesis by none other than Rowland and Molina themselves. They had conducted some experiments showing that the chain reaction between chlorine and ozone, which would be initiated by the decomposition of chlorofluorocarbons in the stratosphere, would itself interact with the chain reaction taking place between ozone and naturally occurring nitrogen oxides. The result would be the formation of chlorine nitrate—a compound that would temporarily disrupt the working of both chains, and prevent either one from depleting ozone as rapidly as each had been predicted to do alone. When the two men announced their findings, in February, scientists who were engaged in modelling stratospheric chemistry were thrown into confusion, for the new data indicated at first that previous estimates of ozone depletion might have to be drastically lowered.

This unexpected development was also dismaying to the members of the National Academy of Sciences group. Apprehensive lest the stratosphere hold other surprises in store, and concerned about their public credibility, they postponed their report for several months while the modellers wrestled with the problem. In the end, the modellers determined that the inclusion of chlorine nitrate in the stratospheric scenario would indeed reduce the long-term depletion of ozone by chlorofluorocarbons—to about seven per cent, the lower end of the range that had been predicted by Rowland and Molina. Meanwhile, industry public-relations groups had capitalized on the situation by holding press conferences designed to sow doubt about the validity of the ozone-depletion theory. Stories appeared in a number of prominent newspapers suggesting that Rowland and Molina had been proved wrong, that the chlorofluorocarbon threat had been exaggerated, and that the ozone layer was safe after all.

BECAUSE the chlorine-nitrate episode served to underscore the uncertainties in stratospheric chemistry, the National Academy of Sciences' long-awaited report—it was finally issued in September of 1976—was, many observers felt, considerably more cautious in tone than it might otherwise have been. The report consisted of two separate documents—a highly detailed study of the scientific findings, by the Panel on Atmospheric Chemistry, and an over-all assessment of the problem, by the Committee on Impacts of Stratospheric Change (which had replaced the Climatic Impact Committee). The committee's report incorporated the panel's findings in less technical form, and it attracted widespread attention in the press, because it addressed itself to the sensitive political issue of regulation. However, it received mixed reviews, because its conclusions and recommendations were riddled with caveats and qualifications.

The authors of the report upheld the ozone-depletion hypothesis that had been worked out by Rowland and Molina and confirmed the lower range of their depletion estimate, concluding that continued release of chlorofluorocarbons at the 1973 rate could eventually cause a reduction of up to fifty per cent of the ozone in the upper stratosphere and approximately seven per cent of the total atmospheric ozone. At the same time, they left considerable room for doubt by placing the seven-per-cent figure in a range of uncertainty of between two and twenty per cent. They did agree that such depletion would greatly increase the amount of ultraviolet radiation able to reach the surface of the earth and could thus lead to a larger incidence of skin cancer and to harmful effects on plants and animals. Moreover, the report not only concurred with Rowland and Molina's warning that chlorofluorocarbons might cause climatic changes by altering temperatures in the stratosphere but also pointed out that by absorbing infrared radiation from the ground the compounds would add to the "greenhouse effect" already being created by the increasing amount of carbon dioxide that was finding its way into the atmosphere through the burning of fossil fuels. At the time, increased levels of these gases were expected to cause a rise in global temperatures, which threatened to eventually cause a melting of polar ice and a significant rise in sea level.

When it came to recommending how to deal with the chlorofluorocarbon problem, however, the committee members were prone to temporize. Having stated that selective regulation of the compounds "is almost certain to be necessary at some time and to some degree of completeness," they added that "neither the needed timing nor the needed severity can be reasonably specified today." By way of justifying this, they concluded that the costs of postponing the decision to regulate would not amount to "more than a fraction of a per cent change in ozone depletion for a couple of years' delay." They then expressed confidence that new measurement programs would reduce the uncertainties about how much of the ozone layer would eventually be destroyed. And on that hopeful note they proceeded to recommend against the imposition of immediate restrictions.

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The language of the National Academy of Sciences report left room for widely differing interpretations of just what the Academy was recommending. On the day after the report's release, the *Times* ran a story under the headline "SCIENTISTS BACK NEW AEROSOL CURBS TO PROTECT OZONE IN ATMOSPHERE," while the Washington *Post* headed its account "AEROSOL BAN OPPOSED BY SCIENCE UNIT." In other quarters, the document was assessed in similarly conflicting fashion. Environmentalists pointed out that it provided confirmation of Rowland and Molina's theory of ozone depletion by chlorofluorocarbons, while industry public-relations people trumpeted the fact that the Academy had not found sufficient evidence to warrant regulation. Du Pont, for its part, issued another position paper, declaring that the Committee on Impacts of Stratospheric Change had reached "what was obviously a difficult, but, we believe, correct decision."

Two days later, a powerful rebuke to the Academy's equivocal assessment of the problem was delivered by Russell W. Peterson, the chairman of the President's Council on Environmental Quality, who spoke at the International Conference on Problems Related to the Stratosphere, at Utah State University. Peterson, a former governor of Delaware, had worked as a chemist for du Pont for twenty-six years, and he now declared that "the problem of determining prudent public policy in the face of scientific doubt recurs again and again as some chemicals developed for specific purposes prove to have—or threaten to have—unanticipated side effects." He asserted that "we cannot afford to give chemicals the same constitutional rights that we enjoy under the law," and that "chemicals are not innocent until proven guilty," and he concluded by calling upon the federal regulatory agencies to begin developing rules to restrict the discharge of chlorofluorocarbons into the atmosphere. Peterson's call for action was echoed by officials of the Environmental Protection Agency and the Consumer Product Safety Commission, who also spoke at the conference. It was given further impetus by the revelation that recent balloon measurements in the stratosphere had detected the presence of chlorine oxide—a compound formed by the reaction of chlorine and ozone, and a necessary participant in the catalytic chain reaction predicted by Rowland and Molina. Before the end of the year, the E.P.A. and the F.D.A. announced that they were initiating rules to phase out the use of chlorofluorocarbons as aerosol propellants.

In the spring of 1977, the regulatory agencies came up with a joint timetable, known as Phase One, which called for banning the bulk manufacture of chlorofluorocarbon propellants as of October 15, 1978; for banning the manufacture of aerosol products containing chlorofluorocarbon propellants as of December 15, 1978; and for prohibiting interstate shipment of the existing stocks of these products as of April 15, 1979. However, in spite of widespread public belief that further ozone depletion would be averted by such action, the fact was that the proposed restrictions could at best provide only a partial solution to the problem. For one thing, nearly half the chlorofluorocarbons produced in the United States were being used in the manufacture of products like polyurethane foam and as a coolant in refrigerators and in automobile air-conditioners. For another, since the United States produced only half the world's total output of the compounds, a ban on chlorofluorocarbon propellants in this country would reduce the worldwide problem by only a quarter.

To deal with the domestic aspect of the situation, the E.P.A. announced that in the summer of 1978 it would propose a Phase Two timetable, for reductions in the non-aerosol uses of chlorofluorocarbons. This plan was shelved by the agency when it appeared that suitable substitutes for chlorofluorocarbon coolants in refrigerators and air-conditioners would be expensive and hard to come by. It was also decided that further regulatory action in the United States should be deferred until other nations could be persuaded to reduce their use of the compounds as propellants in aerosol sprays. However, in spite of strong appeals for international coöperation made by the State Department and the E.P.A. during the next few years, the major chlorofluorocarbon-producing nations of Europe, as well as Japan and the Soviet Union, refused to take regulatory action. Indeed, between 1976 and 1979 only Sweden, Canada, and Norway joined the United States in enacting measures to reduce chlorofluorocarbon emissions. Elsewhere, and especially in England and France, scientists and government officials expressed considerable skepticism about the extent of the hazard; they conceded that Rowland and Molina's ozone-depletion hypothesis might be correct, but they advocated a wait-and-see approach, claiming that there were too many uncertainties in atmospheric chemistry to warrant regulation of an important industry.

The validity of the wait-and-see approach received something of a jolt in the summer of 1977, when scientists at the National Oceanic and Atmospheric Administration, in Boulder, Colorado, undertook to remeasure the rate of one of the reactions between nitrogen oxides and hydrogen oxides, and found it to be about forty times as fast as had been indicated by previous laboratory measurements. Hydrogen oxides are formed in the stratosphere from hydrogen atoms released through various chemical reactions involving water vapor and methane, and, like nitrogen oxides and chlorine, they initiate a chain reaction that contributes to the natural removal of ozone. The discovery of the increased reaction rate with nitrogen oxides meant that earlier estimates of nitrogen oxide's ability to deplete ozone would have to be drastically scaled down; nitrogen-oxide emissions from S.S.T.s, which since the early nineteen-seventies had been under indictment as a killer of ozone, could henceforth be expected to play a far less important role in the scenarios of ozone destruction which were being compiled by atmospheric scientists. Another corollary of the new measurement was that chlorine nitrate—the compound whose unexpected appearance on the stratospheric stage in 1976 had resulted in cutting previous estimates of ozone depletion in half—was now thought to be not nearly as effective in retarding ozone depletion as had previously been believed. When scientists included the revised reaction-rate data in their computer models of the stratosphere, their predictions for ozone destruction by chlorofluorocarbons went back up. In 1979, the National Academy of

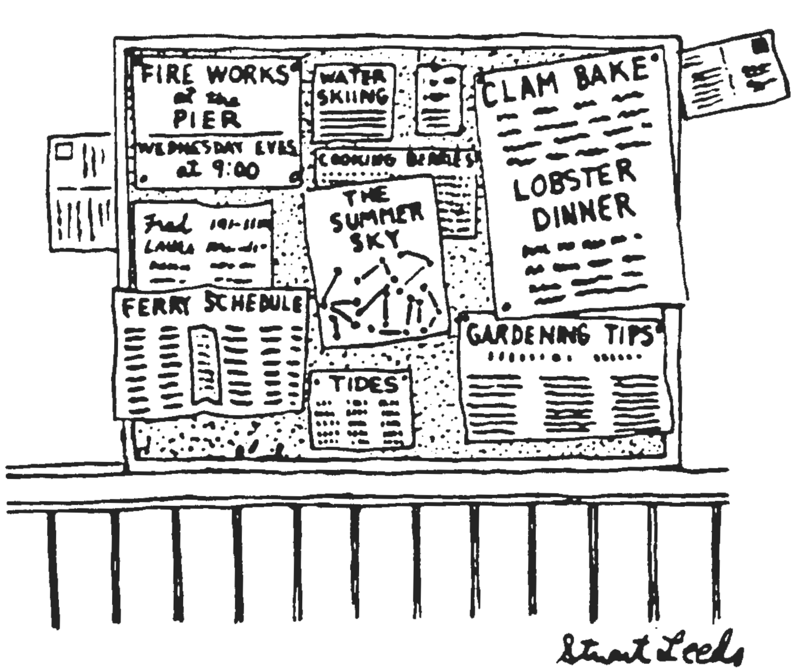
Sciences issued a second report on the hazard, which estimated that if the compounds continued to be emitted at the 1977 rate eventual depletion of the ozone layer would total sixteen and a half per cent, with a three-out-of-four chance that the depletion would fall somewhere between nine and twenty-four per cent.

In spite of the fact that the predicted severity of the ozone problem had more than doubled within a span of three years, the Academy's new report received relatively little attention in the press, and the public remained largely unaware that the Academy's experts had described the hazard in considerably more forthright and foreboding terms than had been the case in 1976. Among other things, they warned that increased ultraviolet radiation, in addition to producing thousands of additional cases of skin cancer, could have intolerable consequences for the world's food supply by reducing crop yields, killing the larvae of several important seafood species (including shrimp and crab), and destroying microörganisms at the base of the marine food chain. They supported worldwide elimination of the use of chlorofluorocarbon aerosol propellants. They also pointed out that other uses of the compounds throughout the world were increasing at such a rate that even if a ban on chlorofluorocarbon propellants were put into effect immediately, emissions from other uses would equal the current levels within seven to ten years, and they urged that a coördinated international policy be developed for dealing with the problem. They stated that the wait-and-see approach was "clearly not a prudent strategy," concluding that if the decision to control chlorofluorocarbon emissions was postponed until a crucial depletion of the ozone layer was observed the slow but inexorable movement of the gases into the stratosphere would double that depletion within twenty years and cause prolonged exposure to dangerous levels of ultraviolet radiation for decades to come.

In keeping with past policy, the chlorofluorocarbon industry wasted no time in criticizing the National Academy of Sciences' latest assessment of the problem. On the day the report appeared, du Pont issued a statement declaring—once again—that predictions of ozone depletion by chlorofluorocarbons were based not on actual measurements but on theoretical calculations. "No ozone depletion has ever been detected, despite the most sophisticated analysis," du Pont pointed out, adding that "all ozone-depletion figures to date are computer projections based on a series of uncertain assumptions." According to du Pont, scientific studies being conducted by government and industry would require from two to four more years to obtain the evidence needed to answer such questions as whether chlorofluorocarbons could break down chemically in the troposphere and whether destruction of the ozone layer was actually taking place.

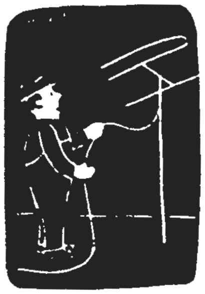
Some observers felt that du Pont, which had asked for several additional years of research on two previous occasions, was stalling. However, the company's latest position was supported in part by a study that members of the Stratospheric Research Advisory Committee had conducted for the United Kingdom's Department of the Environment during 1978 and 1979. Although the British investigators agreed with the National Academy of Sciences that the amount of ozone in the stratosphere could eventually fall by as much as sixteen per cent if the release of chlorofluorocarbons continued at the current rate, they concluded that the validity of the ozone-depletion hypothesis remained in doubt, because of the many uncertainties still prevailing in the knowledge of stratospheric chemistry and in modelling technology. They called for voluntary steps to reduce chlorofluorocarbon emissions, but they declared that for the time being strict regulation of the chemicals was unwarranted. Not surprisingly, chlorofluorocarbon manufacturers on both sides of the Atlantic lined up solidly behind this approach to the problem, and du Pont issued yet another statement, this one calling for a "resolution of the scientific differences between the National Academy of Sciences and the British Department of the Environment."

WHATEVER scientific differences remained to be resolved to the satisfaction of du Pont, it had become clear in other quarters that only strenuous international efforts would be able to protect stratospheric ozone against further depletion by chlorofluorocarbon emissions. In March of 1980, the Council of the European Economic Community, whose then nine-nation membership accounted for about a third of the world's consumption and production of the chemicals, asked each of its members not to increase production capacity of the compounds, and to achieve a thirty-per-cent reduction in the use of chlorofluorocarbons as aerosol propellants by the end of 1981. In April, representatives of Canada, Denmark, the Federal Republic of Germany, the Netherlands, Norway, Sweden, and the Commission of the European Communities agreed at a conference in Oslo that a wait-and-see policy toward the hazard was unacceptable, and called upon all major chlorofluorocarbon-producing nations to reduce emissions from both aerosol and non-aerosol uses of the compounds. Representatives of the United States Environmental Protection Agency, who also attended the Oslo meeting, described the hazard as "one of the leading environmental issues of the decade," and—hoping to ameliorate the problem as well as to encourage further action on the part of the Europeans—made a proposal to freeze the annual production of chloro-



fluorocarbons in the United States at the 1979 level, of five hundred and fifty-one million pounds. Later in the month, the governing council of the United Nations Environment Programme recommended that its member governments reduce chlorofluorocarbon uses and not increase production capacity of the chemicals. In September, Japan announced that it intended to take similar action.

Here in the United States, where the lost market in aerosol propellants had been largely made up by increased use of chlorofluorocarbons in refrigeration, liquid fast-freezing, automobile air-conditioning, industrial solvents, and the manufacture of plastic foams, industry officials were up in arms about the E.P.A.'s plan to curtail chlorofluorocarbon production. A lobbying group called the Alliance for Responsible CFC Policy, made up of producers and industrial users of chlorofluorocarbons, was formed during the summer of 1980 to head off any further attempts to regulate the chemicals. It was able to make use of such sensitive election-year issues as the faltering economy and the country's changing mood with regard to environmental causes, and its purpose was, according to one of its spokesmen, "to convince the government—Congress, the White House, and anyone else—that E.P.A.'s proposal to restrict CFCs is ill-advised."



In spite of the new lobby, the E.P.A., during the first week of October, went ahead and published advance notice in the *Federal Register* of its latest proposals to control chlorofluorocarbon emissions. By this time, the agency had come up with two possible solutions to the problem. The first, known as the mandatory-controls approach, would place an indirect ceiling on chlorofluorocarbon uses through restrictions on production or through standards based upon technology. Under this system, the E.P.A. could ban certain industrial uses of the chemicals and could require their recovery and recycling in the manufacture of plastic-foam products. It could also require the substitution of less hazardous compounds as refrigerants in certain types of refrigeration equipment. The second solution, which the agency described as "a more efficient method of reducing the environmental and human health risk," was known as the economics-incentive approach. Under this plan, a ceiling on total chlorofluorocarbon production would be established through a system of permits, which could be either directly allocated to makers and users of the compounds or auctioned off to those who were willing to pay the highest price.

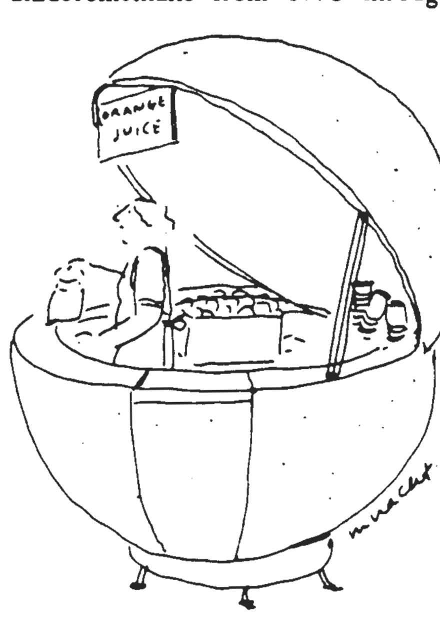
As might be expected, industry reaction to the proposed rulemaking was highly unfavorable. A du Pont spokesman declared that the ozone problem could not be solved by unilateral action on the part of the United States. He added that "the E.P.A. should attempt to gain international scientific consensus on whether there is a potential problem and, if so, how the world community should address it." An E.P.A. official replied that from five to ten years might pass before sufficient data could be acquired to conclusively prove the theory of ozone depletion by chlorofluorocarbons, and pointed out that all the chlorofluorocarbons produced in that period would make their way into the stratosphere. "If we wait until 1990 to make the decision, it could be too late," he said.

Thanks to a combination of public apathy and an intensive campaign waged by the Alliance for Responsible CFC Policy, only four out of more than two thousand written comments that were sent to the E.P.A. over the next three months supported its latest proposals for limiting chlorofluorocarbon emissions. Combined with the newly elected Reagan Administration's vociferous bias against environmental regulation, this response was more than enough to cause the agency to back away from its announced intention of issuing new rules in the spring of 1981. The E.P.A. was further encouraged to relax its rulemaking timetable when improved measurements of several chemical-reaction rates caused atmospheric scientists to lower their predictions of the extent of ozone depletion. They now estimated long-term depletion to be in the range of five to nine per cent.

During the summer of 1981, it became apparent that a wholesale reevaluation of the E.P.A.'s position on chlorofluorocarbons was under way. In July, an official of the agency told members of the House Subcommittee on Anti-Trust and Restraint of Trade Activities, who were meeting to consider the effect of additional chlorofluorocarbon restrictions on small businesses, that no decision to regulate was in the offing and that the E.P.A. was "extremely sensitive to the needs of small businesses." Another indication that the E.P.A. was changing its policy had come when Anne Gorsuch, the new agency administrator, testified at her Senate confirmation hearings, in May, that she understood that the theory of stratospheric ozone depletion was "highly controversial," and that there was a "need for additional scientific data before the international community would be willing to accept it as a basis for additional government action." Attempts to legislate a new outlook for the E.P.A. were made in September, when draft bills introduced into the House and Senate to amend the Clean Air Act proposed to shift the focus of the agency's activity from regulation to research, and to restrain it from imposing additional restrictions on the production and use of chlorofluorocarbons until there was "clear scientific evidence" to show that they were a threat to human health and the environment. By calling upon the E.P.A. to measure actual depletion of the ozone layer before taking further action, the bills were, of course, extending the presumption of innocence to chlorofluorocarbons. Meanwhile, data collected by NASA's Nimbus 4 and Nimbus 7 satellites indicated that ozone at the twenty-five-mile altitude of the stratosphere, where the maximum destructive effect of chlorofluorocarbons was expected to occur, had been depleted by several per cent between 1970 and 1979.

Here on earth, where the so-called "ozone debate" was entering its eighth year, spokesmen for the chlorofluorocarbon industry were assuring everyone that careful monitoring of ozone levels around the world could provide an early-warning system for ozone depletion. Considerable publicity was also given to a scheme whereby instruments designed not only to measure ozone but also to detect chemical reactions that might be depleting it would be carried to an altitude of twenty-five miles by a balloon four hundred and fifty feet in diameter and then lowered and raised through the stratosphere on a twelve-mile-long synthetic line that —as it happened—had been developed and manufactured by du Pont. Billed as the world's biggest yo-yo, the new device was supposed to undergo testing before the end of 1981. However, difficulties encountered in design and construction soon put this plan way behind schedule. The first test flight of the balloon did not take place until 1982; the first measurements were not taken until 1984, and then the instruments simply confirmed that chlorine oxide was present in the upper stratosphere in quantities sufficient to deplete ozone; and subsequent difficulties with faulty balloons have postponed further flights.

The amendments to the Clean Air Act were bitterly debated in Congress during the autumn of 1981, and the industry continued its campaign against further regulation of chlorofluorocarbons. In October, the Chemical Manufacturers Association released its analysis of figures gathered from measuring stations operated by governments around the world; this analysis indicated that ozone levels in the earth's atmosphere had actually *increased* during the nineteen-seventies. Toward the end of the year, the association reported that since 1974 there had been a twenty-per-cent decrease in the production and release of chlorofluorocarbons throughout the world. By the spring of 1982, however, both sets of data furnished by the industry were called into question by observations from other sources. In the first week of April, researchers from the National Oceanic and Atmospheric Administration described the results of a study showing that the total amount of atmospheric ozone over North America had decreased by about one per cent between 1961 and 1980. At the same time, Professor Rowland and some of his colleagues announced the findings of a study showing that chlorofluorocarbon concentrations in the atmosphere had almost tripled within the last ten years, and that total release of dichlorodifluoromethane from 1976 through 1979 was almost thirty-five per cent greater than the estimate given out by the Chemical Manufacturers Association.



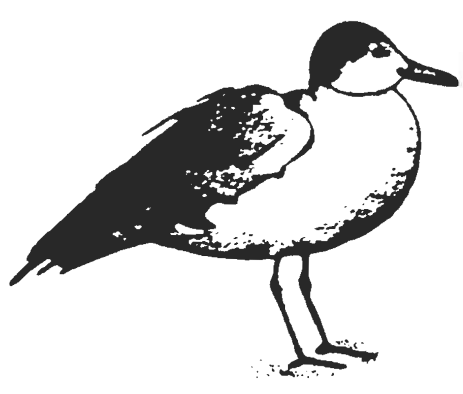
As it turned out, word of these developments was overshadowed by press coverage of yet a third National Academy of Sciences report, which had been issued on the last day of March. The latest study contained little that was new in the realm of stratospheric chemistry—its prediction that eventual depletion of the ozone layer would fall within the range of between five and nine per cent was based upon calculations that had been made a year before and published by the World Meteorological Organization and NASA—but it presented an unusually grim analysis of the human-health hazards that would result from such a depletion, warning that the accompanying increase in ultraviolet light would cause much more skin cancer than had previously been suspected, and would also cause painful irritation of the eyes and have adverse effects upon the body's immune system. Yet in spite of these ominous conclusions the new Academy report was greeted from one end of the country to the other by newspaper headlines declaring that the threat to the ozone layer was not as serious as had been thought —a comfortable assessment that depended upon comparison of the latest Academy estimate of ozone depletion with the one that had appeared three years earlier, in its 1979 report, which had predicted that the long-term loss could be as high as sixteen and a half per cent. It was less comforting to compare the most recent forecast with the seven-to-thirteen-per-cent depletion range that Rowland and Molina had predicted when they first brought their worrisome findings to public attention, back in 1974. Indeed, when this comparison was made it was clear that their original estimate of ozone depletion had held up remarkably well over the years—especially in light of the many uncertainties that had characterized the course of atmospheric chemistry. It was equally clear that during this whole period precious little had been done to resolve the problem the two scientists had described, and that its outcome, like the chlorofluorocarbons, remained in the air.

AT this point, with no apparent end to the controversy in sight, I decided to fly out to California and pay a call upon Professor Rowland, whom I had first met in 1974, in order to get his reaction to the situation. Originally a specialist in the chemistry of radioactive isotopes, he is a large, patient man in his late fifties, who regards his career as having been relatively uneventful until he became involved with chlorofluorocarbons, and who recalls ironically that his only previous brush with controversy occurred when, in 1971, following the discovery that swordfish and tuna contained high levels of mercury, he and some colleagues drew the ire of environmentalists by demonstrating that these levels were in fact no higher than those found in specimens of swordfish and tuna that had been preserved in alcohol for decades. Since 1974, however, he had been very much in the thick of the dispute surrounding the ozone-depletion hypothesis that he and Molina had worked out, and had spent much of his time and energy describing the scientific background of the ozone problem at congressional hearings, before state legislative committees, for various federal and state regulatory agencies, to university audiences, and at international meetings around the world. He had also been elected to the National Academy of Sciences and the American Academy of Letters and Sciences, and had received the American Physical Society's Leo Szilard Award for Physics in the Public Interest.

At the time of my visit—in April of 1982—I found him in the cluttered office he occupies on the top floor of the Physical Sciences Building, a fortresslike structure on the sprawling fifteen-hundred-acre campus of the University of California at Irvine. When I asked him how he felt about the current state of the long-drawn-out debate that he and Molina had initiated, he smiled grimly and handed me a newspaper clipping containing the announcement that the Pennwalt Corporation was investing ten million dollars to modernize and expand its chlorofluorocarbon plant at Calvert City, Kentucky. "As you can see, industry has become so confident that there will be no further regulation of chlorofluorocarbons that it is increasing its capacity to manufacture them," he said. "I feel as if we had circled the board and returned to Square One. Meanwhile, of course, I'm concerned that time is running out for the ozone layer."

The inability to resolve the chlorofluorocarbon problem, Rowland said, reflected a failure on the part of society to come to grips with an issue whose consequences were less than certain, and this failure had, in his opinion, been brought about by indecisiveness on the part of the scientific community, timidity on the part of the regulatory agencies, ignorance on the part of the public, inconsistency on the part of the press, indifference on the part of other nations, and obstruction and obfuscation on the part of industry. "The authors of the first National Academy of Sciences report established a debilitating precedent at a crucial time in the whole affair when they advocated a delay in regulation for a year or two and tried to justify it on the ground that the resulting accumulation of chlorofluorocarbons in the atmosphere would produce only a minor additional loss of ozone," he said. "In so doing, they gave the impression that we could continue to put off finding a solution to the problem indefinitely, and that is exactly what industry has been urging ever since. As for the regulatory agencies, their subsequent decision to impose a ban solely on the use of chlorofluorocarbons as aerosol propellants fragmented the problem, and inadvertently created the idea in the mind of the public that it had been solved when in fact it had been only partly alleviated. The news media played a role in the rise of this misconception. Of course, the press was instrumental in bringing the chlorofluorocarbon problem to public attention, but once the partial ban was announced most newspaper accounts conveyed the false impression that the matter had been taken care of. Then, as the novelty of the story wore off, the press lost interest and failed to describe the growing complexity of the issue as it unfolded over the next few years. The result is that relatively few people appear to understand the magnitude of what is happening. For example, it is not well known that chlorofluorocarbon molecules, no matter where they are released, disperse very quickly throughout the atmosphere, and that an emission in Europe, say, will sweep across Asia and the Pacific and reach the California coast in about a month. Few of our fellow-citizens seem to realize that the damage now being inflicted upon the ozone layer above the United States—or, for that matter, above any other nation—is cumulative damage caused by chlorofluorocarbons that have been released throughout the world. People are unaware of the importance of obtaining international agreements to deal with the threat. English and French atmospheric scientists have always been skeptical of our concern for the ozone layer. At first, many of them chose to think that it was a ploy directed against their joint Concorde project, and later they carried their skepticism into the discussions of international control of chlorofluorocarbon emissions. Moreover, along with other major European chlorofluorocarbon-producing nations, the English and the French have resented our suggesting that they cut down on their use of chlorofluorocarbons in aerosol sprays while we continue to use huge quantities of chlorofluorocarbons to air-condition our automobiles and make plastic-foam products, such as packages for fast foods. Here again, you see, the partial ban has come back to haunt us."

When I asked Rowland why he thought his fellow-scientists had for the most part failed to take a strong stand on the chlorofluorocarbon issue, he replied that scientists generally avoid speaking out on any subject with which they are not wholly conversant, and rarely become involved in controversial matters unless they are appointed to a study group by some such organization as the National Academy of Sciences. "Chemists, in particular, have tended to feel stigmatized by all the adverse publicity that has surrounded their profession in recent years," he said. "Their reaction to environmental problems caused by chemicals—whether it's the pollution of Love Canal, the contamination of ground water, or the destruction of the ozone layer—is frequently a defensive withdrawal from public involvement. Many of them are convinced that such problems are either nonexistent or grossly exaggerated. For those of us who are concerned with the stratosphere, the problems are somewhat different. We are fascinated by the incredible complexity of the chemical reactions that occur up there, and we take great delight in trying to understand them in every last detail. We find it profoundly exhilarating, for example, to attempt a prediction and then obtain confirmation of it by making an actual measurement—or, conversely, to come up with a new and unexpected measurement that sends us back to revise our mathematical models. The trouble is, we have become so absorbed in the minutiae of our work that we tend to spend our time filling in elaborate details and sometimes fail to see things in sufficiently large perspective. Over the past eight years, I have probably been to more than a hundred scientific meetings about the ozone problem—meetings that were attended by at least half of the thousand or so atmospheric scientists who are conversant with this problem—and I have never failed to wonder at how completely the sheer technical aspects of stratospheric science dominate such gatherings, and how little discussion, either formal or informal, is given to the implications of ozone depletion upon plants, crops, fish, weather, or, for that matter, human health.



"Another problem, in my view, is the fact that the chlorofluorocarbon panel of the Chemical Manufacturers Association has become an important source of financing for atmospheric research, with the result that a substantial number of our finest atmospheric scientists are being supported in their work by companies engaged in the manufacture of chlorofluorocarbons. It may prove easier for those scientists to suggest new studies of the ozone layer and different techniques for measuring chemical reactions in the stratosphere than to call for regulatory action against chlorofluorocarbons. In any case, we find ourselves, one way or another, in the midst of a large-scale experiment to change the chemical construction of the stratosphere, even though we have no clear idea of what the biological or meteorological consequences may be."

Researchers in the Department of Transportation's Climatic Impact Assessment Program, Rowland told me, decided in the early nineteen-seventies that the maximum tolerable amount of long-term worldwide ozone depletion would be any detectable change. "At that time, assuming some improvement in measuring capabilities, this was estimated to be one-half of one per cent," he said. "Later, the members of the National Academy of Sciences' Committee on Impacts of Stratospheric Change suggested that an eventual two-per-cent reduction of ozone might be acceptable. Today, it is the assessment of the chlorofluorocarbon industry that we can afford to wait until we have measured an actual loss of one and a half per cent. The fact is, of course, that none of these estimates of what degree of depletion would be tolerable have been based upon science. All of them represent guesswork, crossed fingers, and wishful thinking. No one has the slightest way of knowing, for example, what amount of ozone depletion is required to produce an important shift in the climate of the earth. We do know, however, that if *another* eight years go by without our taking adequate steps to reduce chlorofluorocarbon emissions approximately four million tons of chlorine will have been added to the twelve million tons that are now estimated to be floating about in the atmosphere. We also know that if we continue on our present course enough chlorine will eventually make its way into the stratosphere to create a dangerous situation. What we don't know is how far in the future the point of danger lies—or, for that matter, whether it has already been passed. At this point, it seems obvious that we have only two alternatives. We can continue the large-scale experiment on the stratosphere which is now in progress, in order to determine what its consequences may be. Or we can discontinue the experiment, for the simple reason that its consequences may prove to be disastrous for mankind. One thing we cannot do is undo what we have done. Even if a total, worldwide ban on chlorofluorocarbons were put into effect today, the level of ozone destruction in the upper stratosphere would continue to increase until the end of this century and would persist with gradually decreasing severity throughout the next. All things considered, it seems sensible to discontinue the experiment as rapidly as possible. As a first step, I would make the same recommendation that was made by the authors of the National Academy of Sciences' report of 1979. I would urge that the use of chlorofluorocarbons as aerosol propellants be banned on a worldwide basis without further delay. I would also urge that all nations proceed to reduce sharply their use of these chemicals in other nonessential applications."

DURING the next two years, the debate over the ozone layer continued to be carried on largely out of public sight and mind, and without much urgency, as laboratory experiments to remeasure and refine the rate of various chemical reactions taking place in the stratosphere further reduced the estimate of long-term ozone depletion by chlorofluorocarbons. As a result of some of these experiments, stratospheric ozone losses from nitrogen oxides emitted by high-flying S.S.T.s were once again estimated to be significant. At the same time, actual measurements at ground level showed that there was a slow but steady increase in the concentration of other atmospheric gases—nitrous oxide, for one, and methane, which is produced primarily by bacterial action in rice fields, in swamps, and in the digestive tracts of cattle and other domestic animals. Since it had been known for two decades that concentrations of carbon dioxide in the atmosphere were also increasing, this meant that predictions of changes in the chemical composition of the atmosphere were going to continue to require the assessment and analysis of a mixture of gases. A fourth National Academy of Sciences report, issued in February of 1984, depicted the stratospheric scenario in terms of a whole new set of chemical uncertainties.

To begin with, the authors of the latest report reduced their estimates of eventual ozone depletion from chlorofluorocarbons from the five-to-nine-per-cent range to a two-to-four-per-cent range. Their new prediction was again based on the assumption that the yearly emission of chlorofluorocarbons would remain unchanged over the next century; it was also based on an estimated increase of ozone in the lower atmosphere—an estimate based on revised chemical-reaction rates—which was expected to partly offset a heavy loss of ozone in the high stratosphere resulting from the invasion of chlorofluorocarbons. However, when they took into account the combined effect of carbon dioxide, methane, nitrous oxide, and the nitrogen oxides emitted by subsonic aircraft, the authors of the Academy's 1984 report were able to predict that the total ozone level in the atmosphere might actually *rise* by one per cent over the next few decades. They arrived at this happy possibility by calculating that the increasing level of carbon dioxide and its consequent absorption of infrared radiation would eventually lower stratospheric temperatures, thus slowing down chemical reactions that remove ozone; that methane reacting with chlorine atoms in the stratosphere would prevent the chlorine from reacting with and depleting ozone; that the decomposition of nitrous oxide in the stratosphere would increase concentrations of nitrogen oxides, which would react with chlorine compounds to form chlorine nitrate, the gas that disrupts the ozone-depleting chain reactions of both chlorine and nitrogen; and that the nitrogen oxides emitted by subsonic aircraft in the lower stratosphere would be photolyzed by sunlight to form ozone.

In the end, the Academy's report contained good news and bad news. The good news was that the growing concentrations of so-called trace gases might ameliorate the problem of ozone destruction by chlorofluorocarbons. The bad news was that some of these gases could enhance the dreaded greenhouse effect; chlorofluorocarbons, for example, are known to be at least ten thousand times as efficient as carbon dioxide in preventing the escape of infrared radiation. In view of the immense difficulty of quantifying the separate and combined effects of carbon dioxide, methane, nitrous oxide, and nitrogen oxides, it was not surprising that the authors of the latest report should attempt to outline the uncertainties inherent in their findings. They pointed out that if chlorofluorocarbon emissions were to increase at a rate of three per cent per year, and if measures were taken to reduce carbon-dioxide and nitrogen-oxide emissions from airplanes, the total ozone level in the atmosphere could decrease by as much as ten per cent by the year 2040. Still, they took comfort in the fact that between 1970 and 1980 detailed statistical analysis had found "no discernible trend" in the total amount of ozone in the atmosphere.

As might be expected, the press response to the report tended to emphasize its decreased estimate of ozone depletion and to ignore its prediction of dire consequences if chlorofluorocarbon emissions were to rise. The reaction of the chlorofluorocarbon industry was also unsurprising. "It shows we don't have an imminent crisis on our hands," Donald R. Strobach, the manager of environmental programs at du Pont's Freon Products Division, said of the report. "What we have is time to research in a rational way." But even as he and the authors of the report were assuring the nation and the world that no drastic changes in the level of ozone were expected in the next few decades, meteorologists who were engaged in measuring ozone with ultraviolet spectrometers at stations in the Northern Hemisphere were finding that ozone concentrations in the atmosphere had in fact fallen sharply since late 1982. Scientists at the Swiss government's ozone-monitoring facility at Arosa, Switzerland, reported that the 1983 ozone average in the atmosphere above their measuring stations was fully eight per cent below the annual average for the previous half century and was the lowest yearly value they had ever recorded; meteorologists at the West German government's weather station at Hohenpeissenberg, in the Bavarian Alps, recorded an ozone reduction of seven per cent in 1983—the lowest in the station's twenty years of operation; and researchers in Toronto found that the five stations of the Canadian government's ozone-monitoring network had measured an average ozone reduction over Canada of three per cent. As a result of these and other measurements from around the world, scientists at the National Oceanic and Atmospheric Administration calculated that during the first half of 1983 there had been a drop of between five and seven per cent in ozone concentrations over the entire Northern Hemisphere.

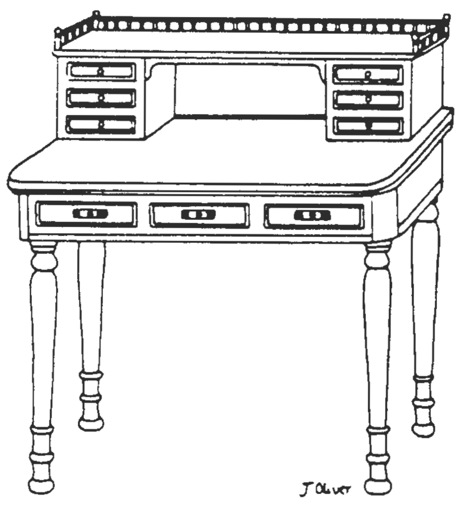
This staggering loss of ozone was not publicly reported in the United States until the autumn of 1984, and when I first heard about it—at the end of June, ten years almost to the day after the publication of Rowland and Molina's original hypothesis of ozone depletion by chlorofluorocarbons—I decided to pay another call upon Rowland, to find out if he had any light to shed upon the situation. Since my visit two years earlier, he had won the American Chemical Society's Award for Creative Advances in Environmental Science and Technology; he had been a co-winner of the Tyler Award in Ecology and Energy, with Molina and Harold S. Johnston, of the University of California at Berkeley, whose work on nitrogen oxides in the stratosphere had stimulated the debate over the environmental effects of S.S.T.s. Rowland had also served for two years on the Acid Rain Peer Review Panel of the Executive Office of the White House. "Most of the ozone loss in 1983 occurred in the lower stratosphere—between twelve and twenty miles in altitude," he told me. "What is surprising is that not only were most of the predicted effects of chlorofluorocarbons expected to take place in the high stratosphere—about twenty-five miles above the earth—but no strong effects of any chemicals were predicted in the lower stratosphere. No one yet knows why ozone levels dropped so sharply in the lower stratosphere in 1983, but it could have been related to the presence of particles of sulfuric acid and other gaseous debris that were thrown into the atmosphere by the eruption of the Mexican volcano El Chichon in April of 1982. My colleagues and I are currently investigating the possibility that there might be some reaction between chlorine nitrate and other molecules, such as water, on the surfaces of the volcanic debris, but the precise chemical connection between them remains a mystery that will probably not be solved for some time. Whatever the outcome, the loss of ozone in 1983 serves not only to emphasize our lack of understanding of chemistry in the lower stratosphere but to call into question our ability to make accurate predictions about what is happening there. Remember that the atmospheric models cited in the most recent National Academy report suggested that an *increase* in ozone should be expected in that very region. Remember also that while the predictions for the lower stratosphere have fluctuated widely over the past decade, all the calculations have shown that continued use of chlorofluorocarbons will eventually cause losses of ozone as high as fifty per cent in the upper stratosphere. Thus, it stands to reason that the high stratosphere is an ideal place to seek evidence of ozone depletion by chlorofluorocarbons. As it happens, statisticians from the University of Wisconsin and the University of Chicago reported a few weeks ago that analysis of data provided by thirteen stations in the Northern Hemisphere and Australia, all of which used ultraviolet spectrometers to measure ozone in the atmosphere, showed what they called 'statistically significant negative ozone trends' in the upper stratosphere. These data confirmed previous measurements, by NASA satellites, of ozone loss in the upper stratosphere, which had been occurring since 1970. Back in 1974, an official of the du Pont Company told a congressional subcommittee that if credible evidence should be developed to show that chlorofluorocarbons posed a hazard to human health du Pont would stop manufacturing them. These days, the chlorofluorocarbon industry appears to have decided that it does not intend to consider any evidence credible as long as there is the slightest doubt about the validity of any part of the ozone-depletion hypothesis. Thus, credible evidence becomes impossible to achieve—simply because there will always be some degree of uncertainty in measuring atmospheric changes and there will always be discrepancies in the mathematical models that simulate chemical reactions in the stratosphere. For this reason, one can expect industry to keep on asking for more time, to conduct other investigations. The tactic is known as studying the problem to death, and—considering what is at stake—it is a blatantly cynical one. We have been studying the chlorofluorocarbon problem for more than ten years now, and during each of these years at least a million tons of chlorofluorocarbons, worth more than a billion dollars, have been sold throughout the world. That's the bottom line as far as the chemical companies are concerned. The bottom line for the rest of us is that during each of these ten years a million tons of chlorofluorocarbons, containing at least five hundred thousand tons of chlorine, have been added to the atmosphere, and that sooner or later all this chlorine will be unleashed in the stratosphere to attack the ozone layer."

When I asked Rowland if he thought there was much chance of preventing this, he shook his head and said he did not. "As a professional scientist, I hate to have to admit that," he said. "After all, what's the use of having developed a science well enough to make predictions, if in the end all we're willing to do is stand around and wait for them to come true? But, from what I've seen over the past ten years, nothing will be done about this problem until there is further evidence that a significant loss of ozone has occurred. Unfortunately, this means that if there is a disaster in the making in the stratosphere we are probably not going to avoid it."

A POWERFUL indication that the disaster Rowland had been predicting for a decade might be at hand arose just a few months after our talk. In October of 1984, the atmospheric scientists of the British Antarctic Survey who had been disregarding their ozone measurements taken at Halley Bay—which had recorded a steady loss of stratospheric ozone above Antarctica since 1977, with especially large temporary decreases every October during that seven-year period—had begun to observe similar losses at their measuring station in the Argentine Islands. Late in December, the British scientists submitted to *Nature* their paper describing the large losses of ozone above Antarctica—losses they characterized as "a dramatic change." But when their paper was published, in May of 1985, there was almost no reaction either in the press or within industry or government circles. Among the members of the world's atmospheric-science community, there was an initial call for more information and for corroboration. This was quick in coming, for by August the atmospheric scientists who were assessing data collected by NASA's Nimbus 7 satellite had belatedly reprogrammed their computers to stop rejecting indications of severe ozone loss just because such low levels had never been seen before. As a result, they were able not only to confirm the disturbing observations of their British colleagues but to provide a detailed map of an enormous hole that had appeared in October of 1983 in the ozone layer above the Antarctic continent. The loss of ozone above Antarctica that month had approached forty per cent, and by October of 1985 was nearly sixty per cent. Moreover, a new analysis of data that had been collected by the satellite between 1978 and 1984 showed that there had been a significant decline of ozone over that period in all latitudes of the globe.

The autumn of 1985 saw a frantic scramble among atmospheric scientists to account for this latest phenomenon. None of the existing atmospheric models upon which they had depended for estimating ozone depletion were predicting large-percentage losses of ozone until the middle of the twenty-first century. Some of the scientists now assumed that their models had omitted certain critical chemical reactions—for example, the possible interaction of chlorine nitrate with water or hydrogen chloride on the surfaces of stratospheric particles, such as the ice crystals that are formed during the cold polar night. Other scientists tried to explain the hole in the Antarctic ozone layer as the result of a special meteorological condition, in which ozone-depleted air from the upper stratosphere might somehow subside upon the Antarctic continent during the months of darkness, or in which ozone-poor air from the lower atmosphere might somehow be drawn up into the stratosphere. Most of them tended to agree, however, that the large ozone losses above the Antarctic were associated with the rapid increases in chlorofluorocarbon concentrations in the atmosphere over the previous decade. The trouble was that, as usual, none of the explanations of ozone depletion could be proved by actual measurement of chemical processes in the Antarctic atmosphere. This, as usual, allowed the chlorofluorocarbon industry to suggest that any connection between chlorofluorocarbons and ozone depletion in the Antarctic rested on theory. Indeed, Dr. Robert Orfeo, a scientist with the Allied Corporation—the nation's second-largest producer of chlorofluorocarbons—declared on a Cable News Network television program that any such linkage amounted to "sheer speculation."

Dr. Rowland, for his part, reacted to the news by pointing out in interviews that the chlorofluorocarbon industry's often repeated assurances that there would be ample early warning of any serious ozone depletion had turned out to be worthless. He also pointed out that for nearly twelve years the prevailing assumption of industry, government, and many members of the scientific community had been that his and Molina's original hypothesis of ozone depletion by chlorofluorocarbons would prove to have been overestimated, and that the appearance of a vast hole in the Antarctic ozone layer tended to show just the opposite. And he concluded that the margin of safety for the world's ozone layer was so thin that no nation should any longer permit the release of chlorofluorocarbons in any form. In short, he now advocated a worldwide ban on virtually all uses of the compounds.



During the winter, I telephoned Rowland and asked him to explain how and why the unexpected loss of ozone was taking place in the stratosphere above Antarctica, and why the depletion was so pronounced in October. To begin with, he told me that atmospheric scientists were not certain about the precise chemistry that occurs in the Antarctic stratosphere and that very few balloon measurements of it had been made. "What is known is that Antarctic meteorology between May and November—roughly the time of Antarctic winter and early spring—is dominated by a rotating air mass called the polar vortex," he said. "This air mass is still dominant in September at the start of the Antarctic spring, which means that any decomposition product such as chlorine nitrate has for the most part remained sequestered in total darkness for many months and has been essentially unaffected by solar radiation. My colleagues and I believe that during this time there is a strong possibility that the chlorine nitrate interacts with molecules of water or hydrogen chloride on the surfaces of stratospheric ice particles, thus forming even more reactive chlorine compounds. When these compounds are struck in September by the first sunlight of the Antarctic spring, they decompose immediately and commence the chlorine chain reaction that results in very rapid destruction of ozone. The depletion is all the greater because as a result of the sun's low angle on the horizon the ultraviolet component of Antarctic sunlight is filtered out, which means that almost no ozone is being formed by the natural reaction of short-wavelength ultraviolet radiation on molecular oxygen. The problem is further exacerbated by the fact that ozone-bearing air masses from other latitudes do not migrate to the Antarctic until November, when the sun rises high enough above the horizon to heat the Antarctic air, causing the polar vortex to break up and the hole in the ozone layer to be filled once again with ozone-rich air from elsewhere. The trouble is that in spite of this annual replenishment there is about six to ten per cent less ozone over Antarctica during the summer and fall these days than there was twenty years ago. In their 1985 article in *Nature*, the scientists of the British Antarctic Survey took pains to point out the striking correlation between this decline of ozone above Antarctica and the rapid increase of chlorofluorocarbon concentrations in the Antarctic atmosphere. Indeed, when one remembers that the British scientists did not measure any significant ozone depletion in the Antarctic between 1957 and 1977, what could be a more likely cause of the sudden appearance of an enormous hole in the Antarctic ozone layer than the explosive growth of chlorofluorocarbons in the world's atmosphere during the past fifteen years?"

NEWS of the catastrophic loss of Antarctic ozone notwithstanding, the Environmental Protection Agency had little to say about stratospheric problems during 1985. Many observers believe that the agency was still bound by the anti-regulatory fetters that had been imposed upon it during the early years of the first Reagan Administration. (Some idea of the mind-set of high E.P.A. officials during that era can be had from a recent book entitled "Are You Tough Enough?," by Anne Gorsuch Burford, who in the course of describing her two-year stint as the agency's administrator dismisses the ozone-depletion problem as a scare issue, calling upon her readers to "remember a few years back when the big news was fluorocarbons that supposedly threatened the ozone layer?") An indication that the E.P.A. might be reëvaluating the chlorofluorocarbon threat came in November, however, when officials of the agency and the Natural Resources Defense Council—an organization that has won a number of landmark court cases involving environmental problems—announced that they had reached an out-of-court settlement of a lawsuit brought against the E.P.A. by the Council in 1984. The lawsuit had called upon the E.P.A. to carry out its 1980 promise of Phase Two regulation of the uses of chlorofluorocarbons other than as aerosol propellants, and, as part of the settlement, E.P.A. officials had agreed to make a decision on the matter by November of 1987.

A further indication that the E.P.A. was rethinking its position came early last January, when the agency published in the *Federal Register* an announcement of what it called a Stratospheric Ozone Protection Plan. The announcement stated that by enhancing the E.P.A.'s research and analysis of stratospheric-ozone problems the program would provide "necessary technical information for use in future Agency decisions on whether or not to regulate chlorofluorocarbons (CFCs) or other chemicals that may affect the ozone layer." After reviewing the possible environmental and health effects of exposure to increased ultraviolet radiation resulting from the depletion of ozone by chlorofluorocarbons, the E.P.A. declared that the production and use of the chemicals might also "contribute to the predicted global warming from the 'greenhouse effect.'" The agency went on to say that a major review of atmospheric-science issues related to ozone modification had been sponsored by NASA, the World Meteorological Organization, the United Nations Environment Programme, and other national and international organizations, and that a report of this review would soon be published. It then described international negotiations concerning the protection of the ozone layer which had been conducted in Vienna under the auspices of UNEP, and had resulted, in March of 1985, in the adoption of the Vienna Convention for the Protection of the Ozone Layer. After acknowledging that the Vienna conference had "failed to agree on any appropriate global control measures," the E.P.A. said that in lieu of such measures a resolution had been passed "calling for an economic workshop to analyze relevant aspects of control options and for continued negotiations culminating in a second Diplomatic Conference planned for April 1987."

As for the E.P.A.'s own efforts at researching and analyzing the threat to the ozone layer, the agency declared that its new program would stress evaluation of future rates of growth in chlorofluorocarbon emissions, modelling of changes to the ozone layer resulting from changes in the chemical composition of the earth's atmosphere, assessment of the performance of atmospheric models in light of atmospheric-monitoring data, and continued study of environmental and health effects from exposure to increased ultraviolet radiation or to changes in climate resulting from ozone modification. As its first order of business, the E.P.A. announced that it would convene a domestic workshop in March of 1986 to analyze the future demand for chlorofluorocarbons and other atmospheric pollutants, as well as the costs and feasibility of emission-reduction technologies, and that UNEP would sponsor an international workshop in May to deal with the same issues. The agency reported that the United States and UNEP were jointly sponsoring an international conference on the environmental and health consequences of ozone depletion and climate change, to be held in mid-June in Washington; that it was planning to convene a workshop to evaluate global and domestic control strategies in July; and that UNEP would follow up with an international workshop on the same issue in September. In conclusion, the E.P.A. pointed out that once it had reviewed the results of all this evaluation and analysis it would publish a notice in the *Federal Register* no later than November, 1987, in which it would either promulgate new regulations or announce another decision to take no immediate action. Nowhere did the agency acknowledge that it had agreed to do so as a result of its out-of-court settlement with the Natural Resources Defense Council, nor did it make any mention of the hole that had appeared in the ozone layer above Antarctica.

In spite of the generally sanguine tone of the E.P.A.'s January announcement in the *Federal Register*, it soon became apparent that the chlorofluorocarbon threat to the ozone layer had finally begun to worry high officials of the agency. The hundred and fifty or so participants at its March workshop on the future demand for chlorofluorocarbons and the feasibility of controlling them were greeted by none other than Lee M. Thomas, the agency's new administrator. After assuring his listeners—they included a bevy of economists, E.P.A. officials, and chlorofluorocarbon-industry representatives, and a handful of atmospheric scientists—that the E.P.A.'s new Stratospheric Ozone Protection Plan should be viewed as a commitment to deciding whether there was a need for regulatory action rather than as a presupposition that additional controls were in fact needed, Thomas warned that a substantial change in global climate caused by ozone-modifying gases could "alter the current ecological balance of our planet." He said that after reviewing a recent NASA report on stratospheric protection he had been struck by the uncertainties in accurately predicting future atmospheric changes, and he cited as a prime example the discovery of the forty-per-cent depletion of ozone during the spring season in Antarctica over the previous decade, stressing the disturbing fact that this phenomenal change had not been predicted by any of the atmospheric models currently in use. He then described what amounted to a brand-new, if somewhat after-the-fact, E.P.A. attitude toward the chlorofluorocarbon problem: "In the face of all this scientific uncertainty, one might ask why has E.P.A. embarked on programs to assess the risks and to decide whether additional CFC regulations are necessary? Why not simply adopt a 'wait-and-see' attitude and hold off a decision until depletion is actually confirmed? Let me address this question squarely. E.P.A. does not accept, as a precondition for decision, empirical verification that ozone depletion is occurring. Several aspects of the situation suggest we may need to act in the near term to avoid letting today's 'risk' become tomorrow's 'crisis.'" In conclusion, Thomas said that the protection of stratospheric ozone was a vital issue, which his agency was "determined to deal with," and that its implications for human health and the environment were "as potentially vast as any I have to deal with as administrator of E.P.A." He then read a sentence from the NASA report which echoed the warning that Dr. Rowland had been issuing for more than a decade: "Given what we know about the ozone and trace-gas-chemistry climate problems, we should recognize that we are conducting one giant experiment on a global scale by increasing the concentration of trace gases in the atmosphere without knowing the environmental consequences."

As might be expected, Thomas's opening remarks to the E.P.A. workshop sent a chill along the spine of the chlorofluorocarbon industry and its lobbying group, the Alliance for Responsible CFC Policy. Industry anguish was readily apparent at a luncheon on the following day, when the workshop participants were addressed by Richard Barnett, the chairman of the Alliance. Barnett told his audience that the E.P.A.'s emphasis on further research and international coöperation should be perceived as "good news," but that the "seemingly good news may be an illusion," because the title of the agency's new program, Stratospheric Ozone Protection Plan, was apparently being used in some quarters as a synonym or code word for further chlorofluorocarbon regulation. "To say the least, we are troubled by the current strategy of the E.P.A. to hold a series of international and domestic conferences intended to build a consensus around the nature and severity of the [chlorofluorocarbon] problem and the major options for remedy," Barnett declared. "We should remain focussed on the stratospheric-ozone-protection problem." After complaining that chlorofluorocarbons were being singled out unfairly for scrutiny, he cited the NASA report, which stated that the chemical effects of trace gases such as carbon dioxide, carbon monoxide, nitrous oxide, methane, and chlorofluorocarbons on atmospheric ozone were "strongly coupled and should not be considered in isolation." He dismissed the suggestion that the depletion of ozone over Antarctica indicated that the "theorized depletion" of ozone by chlorofluorocarbons might already be taking place, declaring that atmospheric-model calculations "continue to suggest that no significant change in total ozone will occur through the next several decades," and that "although the observed reductions in the ozone over the Antarctic region are real, the ozone levels return to near normal soon after the October springtime begins, and no plausible mechanism has been proposed to explain this phenomenon." The many uncertainties regarding the effects of man's activity upon ozone could be resolved only through vigorous research programs, Barnett said, and science could not today provide definite conclusions to justify a specific regulatory policy. He warned that the economy of the nation would be severely penalized if chlorofluorocarbons could not be used in foam insulation, air-conditioning, and refrigeration, and that there could be "substantial risks to worker safety by converting to substances that may be of greater toxicity or possess less desirable properties."

Barnett's arguments were supported by Igor Sobolev, a scientist with Kaiser Aluminum—a major producer of chlorofluorocarbons—who suggested that up to ten years of further research would be needed to clear up the uncertainties in stratospheric chemistry; and by a number of papers submitted by various scientists whose work was being financed by the Alliance for Responsible CFC Policy, including one that listed the fast-freezing of French-style green beans as one of the important contributions of chlorofluorocarbons to the current quality of life. Less helpful—indeed, downright disconcerting to some of the atmospheric scientists who attended the meeting—was an admission by Donald Strobach, of du Pont, that the company had given up looking for chlorofluorocarbon alternatives some five years earlier. Moreover, it would soon come to light that du Pont was in the process of expanding its chlorofluorocarbon production in Japan, and was introducing it into China.

WHEN I telephoned Rowland, who had been at the meeting, to get his reaction to what had been said there, he sounded—as well he might—like a man who had heard it all before. "A lot of discussion was devoted to estimating chlorofluorocarbon production over the next ninety years," he said wearily. "There happens, however, to be the enormous reality of a vast hole that is opening up in the Antarctic ozone layer each October—an event that went totally unpredicted by the atmospheric models we have been depending on. Even though this hole is replenished in November, the fact that total Antarctic ozone levels are down some ten per cent from twenty years ago can scarcely be described as near-normal, and is certainly no excuse for inaction. I believe that the hole we are seeing in the Antarctic ozone layer is going to continue to grow deeper and deeper with each succeeding October, and that serious ozone losses are likely to occur in the stratosphere at *all* latitudes of the world during the twenty-first century. It is pointless to waste time estimating what the production of chlorofluorocarbons will be in the year 2050, because the environmental consequences of their use will have long since overtaken us. In short, the atmospheric experiment whose end cannot be predicted is well under way and the hole in the ozone layer above Antarctica is, unfortunately, just the beginning." —PAUL BRODEUR

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CONSTABULARY NOTES FROM ALL OVER

[*From the Police Log in the Winchester (Mass.) Star*]

Police asked a Myrtle St. man to turn down the music and "discontinue Bruce Springsteen imitations," police reported, after they received a noise complaint.

EPA JOURNAL

Our Fragile Atmosphere: The Greenhouse Effect and Ozone Depletion

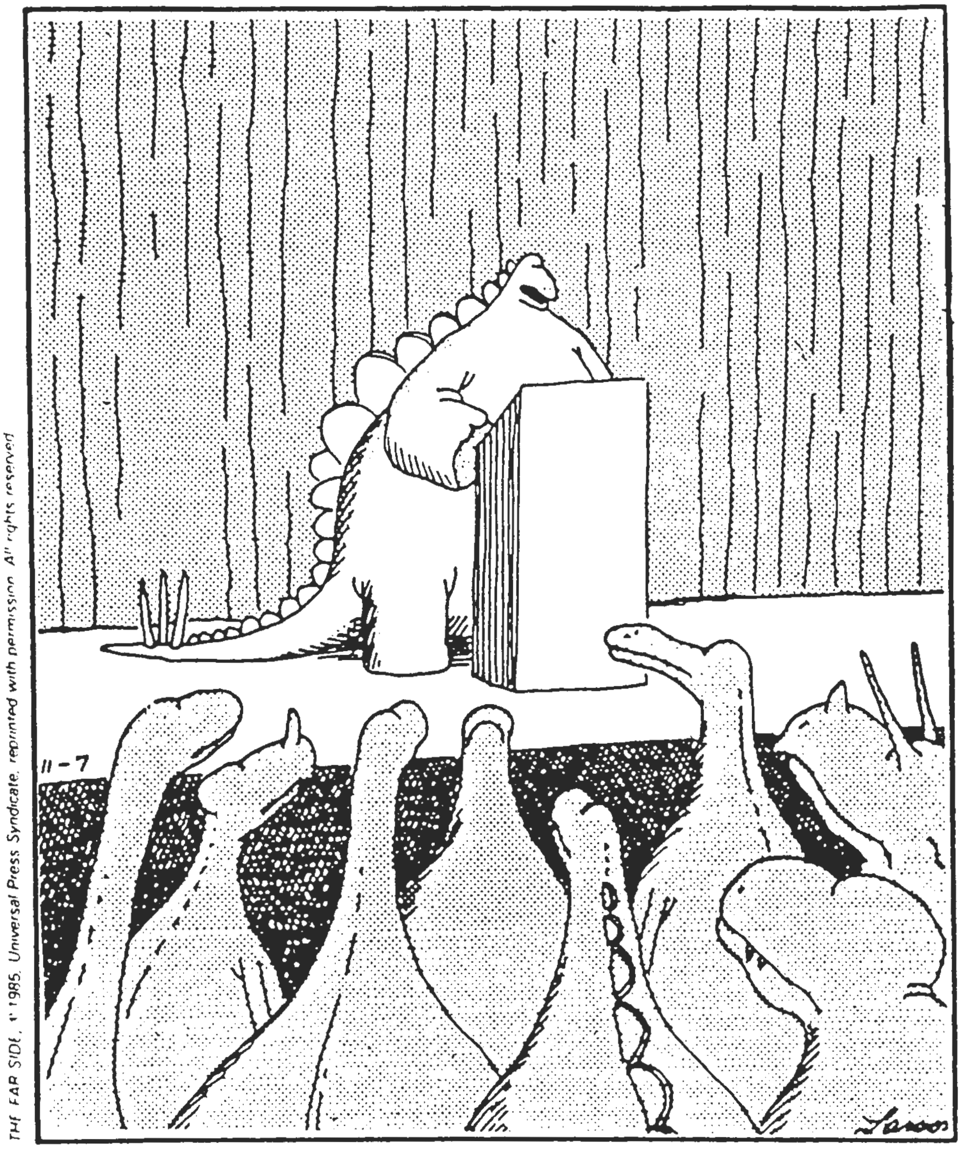
Seldom have environmental issues brought such a chilling awareness of the vulnerability of the human race as the "greenhouse effect" and depletion of the planet's layer of protective ozone in the stratosphere. This *EPA Journal* explores these problems and their implications for the future.

EPA Administrator Lee M. Thomas sets a perspective and presents the Agency's ideas on how to approach these two problems.

One of the originators of the ozone depletion theory explains that theory in layman's terms. A physician discusses the threat of skin cancer posed by a depleted ozone layer. A representative of an industrial organization looks at possible action that might be taken to limit certain chemicals that are useful to industry and consumers, but which may contribute to ozone depletion.

The theory behind the greenhouse effect—the other suspected atmospheric danger to earth's environment—is explained by a leading researcher. The awakening of the public to the greenhouse issue is chronicled. A major consequence of the greenhouse effect—a rise in sea levels—is explained by an EPA specialist on the problem.

Dr. Mostafa K. Tolba, head of the U.N. Environment Programme, discusses the global challenges that the greenhouse effect and depletion of the ozone layer are presenting. U.S. Senator John H. Chafee, R-R.I., who recently chaired Senate subcommittee hearings on these planetary problems, offers a key Congressional view.



"The picture's pretty bleak, gentlemen . . . The world's climates are changing, the mammals are taking over, and we all have a brain about the size of a walnut."

Closing the presentation is an article on the sophisticated, precedent-setting science that is making it possible to understand the phenomena of the greenhouse effect and ozone layer reduction.

In an unrelated article, a U.S. environmental leader discusses some new turns being taken by environmentalism in this country. A historical feature reports on two little-noticed, but major smog episodes in New York City in 1953 and 1966. And a final article presents some recent findings about the effects on the economy of spending for environmental cleanup.

This issue of *EPA Journal* concludes with two regular features. ☐

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EPA is charged by Congress to protect the nation's land, air, and water systems. Under a mandate of national environmental laws, the agency strives to formulate and implement actions which lead to a compatible balance between human activities and the ability of natural systems to support and nurture life.

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Front Cover: Sun at horizon, Casco, ME. The greenhouse effect and depletion of the stratospheric ozone layer illustrate the fragility of our atmosphere and the vulnerability of life on the planet. Photo by Dean Abramson, Folio, Inc.

Design Credits: Robert Flanagan; Ron Farrah; Donna Wasylkiwskyj.

Global Challenges at EPA

by Lee M. Thomas


Steve Delaney

Americans enjoy one of the world's highest standards of living. Our technological achievements during the past half century are unequalled. They have contributed significantly to improvements in our overall quality of life.

Today, we live longer and better than ever before. We have more conveniences. More labor-saving devices. More products and services designed to make our lives comfortable.

Unfortunately, the advances that contributed to the standard of living we enjoy today carried with them hidden costs. This is particularly true when we consider the environmental costs. As we improved our material well-being, the quality of our environment suffered from smokestacks, discharge pipes, and dumps that contaminated our air, water, and land.

Since 1970, we have made tremendous progress in addressing and remedying our past environmental mistakes. The air in our cities is far cleaner today than it was 20 years ago. The quality of thousands of miles of rivers and streams has improved. And our hazardous waste and toxics programs are protecting our land and ground-water resources.

But the job of managing and improving the quality of our environment is far from finished. Despite our successes with traditional pollutants, new challenges are at hand.

These new challenges are significantly different from those we have already met. They are more subtle and more complex. No longer are we fighting gross emissions from obvious sources. Rather, we are confronting trace toxics in our air, water, and food.

We are dealing with the cross-media effects of pollution control — the movement of contaminants from one environmental medium to another. For example, pollutants removed from the water and incinerated may threaten the air. If we place them on the land, they may ultimately contaminate our ground water.

We are learning, too, that some of the challenges we face today are global in nature. Both the sources of problems and the solutions to them are international in scope. Depletion of the stratospheric ozone layer is one example. The phenomenon of global warming — the so-called greenhouse effect — is another.

We do not fully understand either. Uncertainties exist concerning the causes of ozone depletion and greenhouse warming. The complex processes that lead to both are not fully defined.

There is consensus, however, that both are due to increased industrial and agricultural activity over the past 200 years, and particularly since the end of World War II. The burning of coal, oil, and natural gas today adds about five gigatons of carbon dioxide to the atmosphere each year. Combustion of these same fossil fuels and increased uses of fertilizers add substantial quantities of nitrous oxides as well.

Chlorofluorocarbons (CFCs), discovered in the 1930s, are widely used as refrigerants, aerosol propellants, foam-blowing agents, and solvents. The atmospheric levels of CFCs are growing at a rate of five to seven percent annually.

And methane from a variety of sources, many of them agricultural, has also been added to the atmosphere in substantial quantities during recent decades.

Many scientists believe that these chemicals are causing important changes in the chemical composition of our atmosphere. Some are ozone

(Thomas is Administrator of EPA.)

Sunset over the Atlantic Ocean. The future warming of the planet — the greenhouse effect — has serious implications for rising sea levels and changing weather patterns.

depleters. Others partially offset depletion. But there is growing concern that increased use of CFCs could lead to net ozone depletion.

Stratospheric ozone acts as a shield against harmful solar radiation. A significant reduction of ozone in the upper atmosphere could mean long-term increases in the incidence of skin cancer and cataracts worldwide. It could also have significant impacts on our terrestrial and aquatic ecosystems.

At the same time, the gases affecting ozone also exhibit greenhouse properties. That is, they trap solar energy in the atmosphere. Thus, they could contribute to future warming of the earth.

The effects of global warming over the long term go well beyond higher temperatures. The greenhouse effect could also result in substantially altered rainfall patterns, increases in sea level, loss of soil moisture, and changes in the movement of storms. These shifts could affect agriculture, forests, wetlands, water resources, and coastal areas.

While concerns about these problems are urgent, we do not believe that harm can yet be attributed directly to them. On the other hand, the nature of both ozone depletion and global warming are such that if we wait until health and environmental impacts are manifest it might be too late to take adequate steps to address these problems.

As we look at solutions, we must recognize the unusual nature of these new challenges. For both ozone depletion and the greenhouse effect we are faced with problems where the sources of pollution, as well as the potential impacts, are distributed unevenly throughout the world — not just between two countries or within one region. Furthermore, in neither case will the impacts for a particular country necessarily be proportional to its level of emissions of the gases in question.

Thus, traditional approaches to problem solving — domestic legislation, rulemaking, and enforcement — are inadequate to deal with this new class of problems. The United States has taken some important regulatory steps to control CFCs (we banned their use in aerosols in 1978), and we are committed to a decision on the need for additional rules by November 1987. But more will have to be done beyond these unilateral actions.

Recognizing this, EPA's stratospheric ozone protection program incorporates concurrent domestic and international efforts leading to a coupled decision during the next year on an international protocol and possible domestic regulations. We initiated the program over a year ago.

Since then, we have held a number of domestic public workshops, participated in two international workshops sponsored by the United Nations Environment Programme (UNEP), and co-sponsored a major scientific conference on the effects of ozone depletion and climate. In addition, we have conducted a major scientific risk assessment, which has just been reviewed by the EPA Science Advisory Board.

More recently, the U.S. played a leading role in the first round of international negotiations on an ozone layer protocol, held in Geneva during the first week of December. With EPA assistance, the U.S. delegation was a strong advocate of the view that meaningful near- and long-term measures are needed to protect the ozone layer. Although there is still a long way to go, I am hopeful that we will see an international protocol adopted in 1987.

Our experiences with the ozone problem have helped us to identify a number of elements that I am convinced will come into play as we strive to address this new generation of international environmental challenges.

First, we must understand the magnitude of global environmental challenges. Our goal, of course, must be to safeguard human health and the environment.

Second, we must realize that there will always be scientific uncertainty associated with these complex problems. We will have to be prepared to act despite these uncertainties.

Third, if we are to succeed in addressing global issues, we must deal with them in a global context. UNEP has shown strong interest in the area of ozone depletion. We will work with them to provide the leadership needed to move forward.

Fourth, we must conduct our work in a way that reflects the urgency of the problems we face but that does not create undue alarm. We do not believe we face imminent dangers. Our approach to solving these problems should be one of orderly and cooperative action that gets the job done in a way that will protect human health and the environment and minimize cost and disruption.

Fifth, wherever possible our actions should be technology-forcing. We need strong incentives for the development and use of substitute chemicals that are both acceptable to industry and consumers, yet benign to human health and the environment.

Finally, we must devise solutions that are equitable to all nations, including our own. The United States has led the way in regulating CFCs, but we cannot solve international environmental problems alone. All nations and their industries should help shoulder the economic burdens of protecting the global environment.

Dealing with global environmental problems like ozone depletion and greenhouse warming will be one of this Agency's most difficult challenges in the years ahead. I believe we are well on our way to establishing the international framework of scientific research and cooperative actions that will be critical to our success. ☐

WHAT IS PAST IS PROLOGUE...

A Threat to Earth's Protective Shield

by Dr. F. Sherwood Rowland

Steve Delaney

The recent discovery that an "ozone hole" has developed over Antarctica has once again focused public attention and concern on this critical component of the earth's atmosphere. Based on extensive measurements from both ground- and satellite-based instruments, we can state with certainty that very large decreases in ozone have occurred above Antarctica over the past decade during the months of September through mid-November. Ozone is the key atmospheric gas which shields us—and all other biological species—against damaging solar ultraviolet radiation. While the causes of the massive seasonal loss of ozone over Antarctica are not yet fully understood, and its implications for the ozone layer above the rest of the earth are also uncertain (see box on page 6), there can be no doubt that the gases released from certain human activities are threatening the integrity of this protective ozone layer.

(Dr. Rowland is Professor of Chemistry, Daniel G. Aldrich, Jr., Endowed Chair, University of California, Irvine, and is one of the originators of the ozone depletion theory.)

The Role of Ozone

Unlike the abundant atmospheric gases oxygen and nitrogen, ozone (O_3) represents only a tiny fraction of the total atmosphere, with an average global concentration of about 300 parts per billion in volume (300ppbv). If all of the ozone were compressed into a band of pure gas, the layer around the earth would be only three millimeters thick.

Despite its limited quantity, ozone plays a critical role in absorbing incoming solar radiation. The sun gives off radiation across a broad spectrum. The light detectable by the human eye covers the range from approximately 400 to 700 nanometers in wavelength, or from violet to red in color. Much of the "near" ultraviolet radiation (320-400 nanometers) also reaches the ground and can be tolerated by biological species at the surface. In contrast, the adjacent segment of the ultraviolet spectrum (UV-B, 290-320 nanometers) has been shown to be biologically damaging. Fortunately, most of this radiation is absorbed by ozone high in the earth's atmosphere. However, some does penetrate to the earth's surface, with larger quantities of UV-B near the Equator than at the poles. This natural variation in exposure to UV-B provides a real-life experimental setting which has supplied ample evidence of the potential damage from UV-B radiation to human health (e.g. skin cancer) and to the environment.

Complex natural forces are continually at work creating and destroying ozone in the atmosphere. This dynamic equilibrium involves first the breakdown of individual molecules of oxygen (O_2) into atomic oxygen (O) through its absorption of ultraviolet radiation. In turn, each atomic oxygen normally combines with an additional molecule of O_2 to form ozone O_3. Destruction of ozone can be caused by the occasional recombination of ozone with atomic oxygen to form two molecules of diatomic oxygen. As long as the earth's sunlit atmosphere contains molecular oxygen, as it has for more than one billion years, ozone will be maintained in this dynamic balance between formation and destruction. This balance can be altered, however, by the introduction into the atmosphere of additional ozone destroying chemicals, which shift the equilibrium toward smaller average concentrations of ozone. 1974 saw the first suggestion that a group of chemicals known as chlorofluorocarbons, or CFCs, could be a major avenue for adding chlorine to the atmosphere and disturbing the ozone balance.

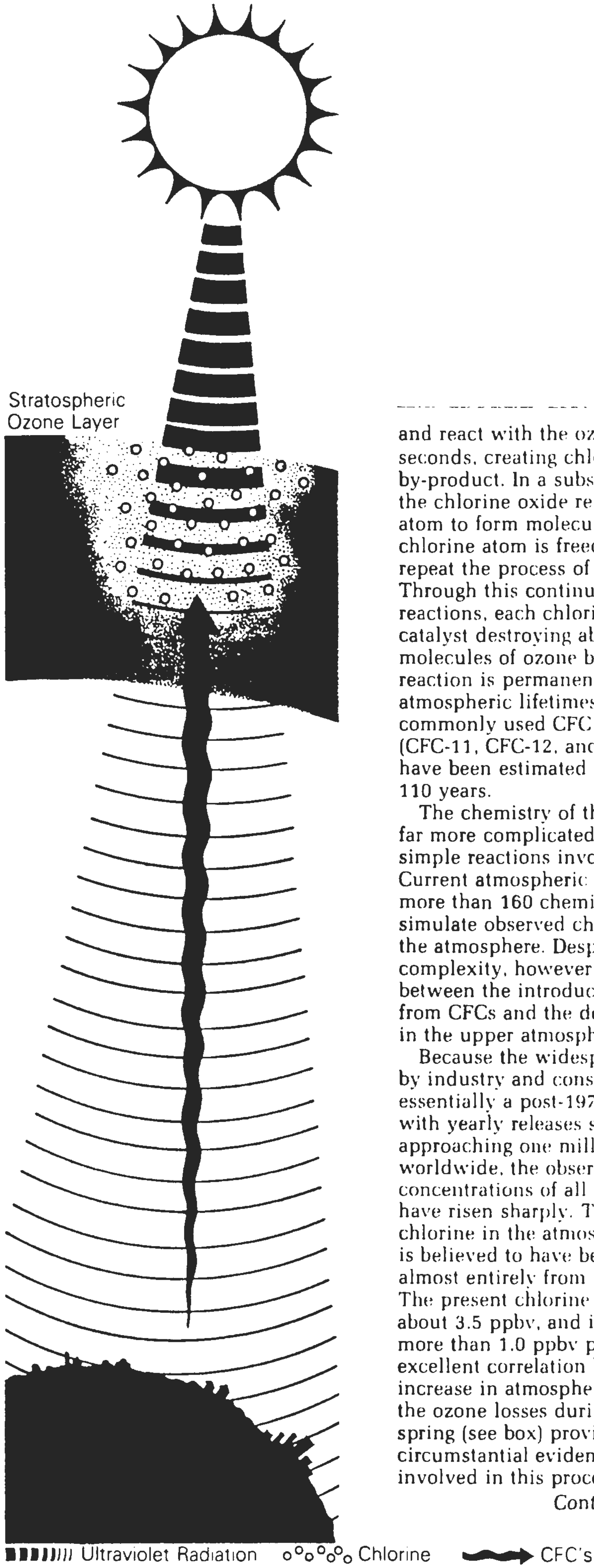
CFC's were first developed by General Motors in the 1930s, after a deliberate search for an ammonia substitute in refrigeration uses. The results of this search produced a family of chemicals with properties ideal for many applications beyond refrigeration. Chemically inert, nontoxic, and easily liquified, CFCs are now used in air conditioning, packaging, and insulation, as a solvent for cleaning electronic circuit boards, and as aerosol propellants.

It is this very absence of chemical reactivity that makes CFCs so dangerous to the ozone layer. Unlike less inert compounds, CFCs are not destroyed or removed in the lower atmosphere by rainout, oxidation, or sunlight. Instead, they drift into the upper atmosphere where their chlorine components are released into the atmosphere under the effects of ultraviolet radiation, and where they encounter and destroy ozone. Almost all of these freed chlorine atoms find and react with the ozone in one to two seconds, creating chlorine oxide as a by-product. In a subsequent reaction, the chlorine oxide releases its oxygen atom to form molecular oxygen, and the chlorine atom is freed once again to repeat the process of destroying ozone. Through this continuing cycle of reactions, each chlorine atom acts as a catalyst destroying about 100,000 molecules of ozone before the chain reaction is permanently ended. The atmospheric lifetimes for the most commonly used CFC compounds (CFC-11, CFC-12, and CFC-13), in fact, have been estimated to be from 75 to 110 years.

The chemistry of the atmosphere is far more complicated than just these simple reactions involving chlorine. Current atmospheric models require more than 160 chemical reactions to simulate observed chemical features in the atmosphere. Despite this complexity, however, a clear link exists between the introduction of chlorine from CFCs and the destruction of ozone in the upper atmosphere.

Because the widespread use of CFCs by industry and consumers is essentially a post-1970 phenomenon, with yearly releases since 1974 approaching one million tons worldwide, the observed atmospheric concentrations of all three major CFCs have risen sharply. The "natural" level of chlorine in the atmosphere before 1900 is believed to have been about 0.6 ppbv, almost entirely from methyl chloride. The present chlorine level is about 3.5 ppbv, and is increasing by more than 1.0 ppbv per decade. The excellent correlation between the increase in atmospheric chlorine and the ozone losses during the Antarctic spring (see box) provides strong circumstantial evidence that CFCs are involved in this process.

Continued to next page



A protective layer of ozone in the upper atmosphere normally prevents harmful ultraviolet radiation from reaching the earth's surface. However, CFCs emitted from the production and use of solvents, refrigerators, air conditioners, and foam-blowing agents drift into the upper atmosphere and eventually decompose under the influence of ultraviolet radiation. The chlorine released in this process reacts with and destroys ozone in a continuing cycle of reactions that may last up to a hundred years or more. The result could be a thinning of the ozone layer and an eventual increase in ultraviolet radiation at the earth's surface.

Safeguarding Our Atmosphere

CFCs have a long record as very useful chemicals, contributing across a broad range of products to our current standard of living. At the same time, they present a grave environmental risk which can seriously affect the basic conditions of life for both current and future generations. The risks from ozone depletion have been described in reports from the National Academy of Sciences since 1976 and include not only the increased UV-B effect on humans in the form of skin cancer, but also UV-B attack on many other biological systems.

Over a decade of research has substantially improved our understanding of all aspects of the ozone layer. All of the evidence produced to date continues to implicate the CFCs as possessing severe potential for ozone depletion. Despite this growing scientific record against CFCs, world use continues to increase as more and more nations seek to improve their living standards using CFC-based products.

Industry's search for less harmful chemicals a half century ago led to the discovery of the current family of CFCs, and that same kind of ingenuity must now be harnessed to find new solutions. For example, hydrogen-containing CFC-22 has long been in major use in home air conditioners and represents a much lesser threat to stratospheric ozone because the molecule is strongly susceptible toward oxidation in the lower atmosphere. Further, past research by several companies has already led to a number of patents on Fluorocarbon-134a, which has many of the same industrial properties found in CFC-12. This compound has a negligible potential for ozone depletion because it does not contain chlorine, but is not yet in large-scale manufacture. Alternatively, industries can begin to design closed industrial processes with recycling which could dramatically reduce emissions by using these potentially harmful chemicals more efficiently.

Research into reducing the global use of CFCs cannot wait for the final definitive answers from the scientific community. Because of the very long atmospheric lifetimes of CFCs, any damage done to the atmosphere will persist throughout the entire 21st century and on into the 22nd. The costs of moving expeditiously away from these suspect chemicals is a very small price compared to the large potential damages if we fail to act now. ☐

The Ozone Hole Over Antarctica

In May 1985, scientists from the British Antarctic Survey published data which have sent shock waves throughout the scientific community. These data showed that a 40 percent loss in total ozone has occurred since the 1960s over Halley Bay, Antarctica, during September to mid-November. These findings were totally unpredicted and unexpected. No such losses had previously been reported, either from ground-based instruments in operation since 1957 or from the extensive satellite measurements initiated in the 1970s. However, both U.S. and Japanese scientists quickly began sorting through their data sets and have confirmed that this phenomenon in Antarctica is indeed real.

With the existence of the ozone hole now thoroughly established, the research community has quickly come forth with a variety of possible explanations. Was the phenomenon part of a natural cycle linked to solar activity? Was it caused by meteorological conditions specific to the region? Why did the existing atmospheric models fail to simulate such losses? Are chlorine chemistry and chlorofluorocarbons (CFCs) the lone culprit, or do they act in combination with other chemicals or conditions?

As part of the search for scientific clues, an urgent research effort was quickly put together, and four different U.S. scientific teams were sent to Antarctica in 1986 to gather more extensive measurements of ozone and other chemical compounds as the ozone hole reappeared during September. This expedition was very successful, and the scientists held a live press conference from the McMurdo station in Antarctica in late October. They reported that evidence produced to date was inconsistent with proposed theories linking the ozone hole to solar activity or solely to meteorological forces. While stating that a chemical cause of the ozone hole was likely, they stopped short of pointing the finger at CFCs. Since their return to the United States, more detailed analyses of the data have been possible and have begun to appear. In addition, precision studies of the Antarctic phenomenon will continue for several years or more, seeking quantitative interpretations of all of the data.

In satellite photo, arrow points to hole in the ozone layer over the South Pole. Scientists are trying to determine if chlorofluorocarbons (CFCs) or other factors are the cause of the Antarctic "ozone hole."

Skin Cancer: The Price for a Depleted Ozone Layer

by Medwin M. Mintzis, MD

Skin cancer has reached epidemic proportions in the United States. It is the most common of all cancers, affecting one out of seven Americans. One-third of all new cancers affect the skin; upwards of a half million new cases are treated each year. This is a 30 percent increase in just 10 years.

The chief culprit in causing this sharp increase seems to be the sun, rather than chemicals and X-rays, and depletion of the stratospheric ozone layer would dramatically exacerbate this disquieting trend in the years ahead.

The ozone layer screens out much of the harmful ultraviolet B light (UV-B) from the sun and prevents it from reaching the earth's surface. But when the ozone layer is depleted, even a one percent increase in UV-B would result in a two percent increase in the number of skin cancers. According to a new EPA study, the number of cases of skin cancer in the next 88 years would total 40 million, with as many as 800,000 deaths if the current trends in use of ozone-depleting chemicals continues.

Skin cancer types are usually categorized in terms of melanoma and non-melanoma. The most dangerous form of skin cancer is malignant melanoma, which arises in the pigment-forming cells (melanocytes). When a melanoma reaches a certain thickness, it spreads rapidly to the vital organs of the body.

In 1986, 23,000 Americans will be diagnosed as having malignant melanoma, and another 6,000 will die of its effects. An individual's lifetime risk for melanoma has soared by 1,000 percent since the 1930s. Currently, one in 150 Americans is expected to develop the disease.

Non-melanoma skin cancers—mainly basal cell and squamous cell carcinomas—affect the skin's surface cells. Though often considered "harmless" annoyances, such cancers are far from trivial in their advanced forms. They can result in great disfigurement—the loss of an eye, ear, lip, or nose. And close to 2,000 Americans will die this year because of non-melanoma cancers that spread—or metastasize—throughout the body.

In 1986, 23,000 Americans will be diagnosed as having malignant melanoma, and another 6,000 will die of its effects.

This human devastation need not occur. These cancers are largely preventable. No one should die of skin cancer. The warning signs are there for us to see. When recognized early and treated promptly, skin cancer is 100 percent curable.

The connection between skin cancer and excessive exposure to the sun's damaging rays has been clearly established. In the case of non-melanoma skin cancer, the link is direct. With malignant melanoma, exposure to ultraviolet light is a causative factor, although its precise role is not well understood at this time. Other factors such as chemical carcinogens, oncologic viruses, and genetics may also be involved.

The incidence of non-melanoma skin cancer among the white population in the United States increases as one travels from North to South (that is, closer to the Equator where the daily hours of sunlight are greatest). Studies in Europe and Australia indicate similar patterns. The number of cases of skin cancer doubles with every eight degrees latitude nearer the Equator.

Altitude is also a factor. At greater heights, more UV-B light penetrates the thinner atmosphere. The highest rates of skin cancer incidence in the United States have been found in Albuquerque, New Mexico, which has both a low latitude and a high altitude.

Over 90 percent of all skin cancers occur on those parts of the body normally unprotected by clothing—the face, ears, neck, and backs of the hand. Protruding lower lips, lower eyelids, and ear rims are particularly vulnerable sites.

In temperate zones, people who spend a great deal of their time outdoors—fishermen, farmers, sailors, construction workers, athletes, for example—are the more likely candidates for skin cancer.

Of course, the darker a person's skin, the less likely he or she is to get skin cancer. Blacks and Hispanics are seldom affected; their highly pigmented skin (containing more melanin) is a natural sunblock. Overall, fewer women than men develop basal and squamous cell carcinomas. But among younger people, women develop the disease almost as frequently as men.

The sexes differ somewhat in terms of where skin cancer occurs. Men frequently develop skin tumors on the tips of the ears and on the scalp, areas unwittingly exposed to sunlight by the balding process. On the other hand, women get more cancers on the lower legs—exposed when they wear skirts or dresses—then men. (One may wonder

(Mintzis is a member of the Medical Council of The Skin Cancer Foundation and Assistant Professor of Dermatology at New York University School of Medicine.)

whether current styles of dress will affect the locations of skin cancers in the future.)

Another interesting confirmation of the cancer-causing power of sunlight is that in the U.S., skin cancer is found more often on the left side of the face and arms of men drivers, but in Britain, it typically occurs on the right side of the face. This corresponds to the opposite driving sides in force in the two countries and the amounts of sunlight coming through the open car windows.

Unlike basal and squamous cell carcinoma, melanoma is thought to be related more to intermittent, but intense, bursts of sunlight, than to the total amount of sunlight received over a lifetime. Recent evidence suggests that getting one or more severe sunburns—particularly as a child or a teenager—may increase a person's potential chance of getting melanoma.

As with the other skin cancers, malignant melanoma occurs most often in fair-skinned individuals. Caucasians are affected 10 times more often than blacks. Interestingly, the incidence of melanoma on blacks' non-pigmented skin (the palms of the hands and the soles of the feet) is identical to those areas in whites.

Studies of the influence of latitude on skin cancer in Caucasians reveal, once again, an increased incidence of melanoma closer to the Equator. One study found a connection between the rise of melanoma cases in Scandinavians and the number of cheap charter flights to the south of Spain. Other research has linked the rise in women's hemlines to the development of more melanomas on their legs. On the other hand, melanomas appear more frequently on the chests and backs of

Don Emmerich

The sun beating down on his back, a youngster paddles an inner tube on Green Bay in Wisconsin.

Ozone Depletion: Other Health Effects

The link between ultraviolet radiation (UV-B) from the sun's rays and certain skin cancers is well known. As concern has grown release of the science assessment by NASA and the World Meteorological Organization on stratospheric ozone was an important event with regard to our own continuing evaluation process.

Laboratory evidence and case studies demonstrate that exposure to UV-B can harm our immune systems. This finding developed almost inadvertently. Researchers trying to transplant a skin cancer from one laboratory mouse to another found that the cancer would not grow following transplant. However, the scientists found that if they irradiated the second mouse *before* transplanting the tumor, it would take hold and spread. This surprising discovery suggested that UV-B radiation was interfering with the mouse's immune system.

Although we do not understand the exact mechanism by which UV-B suppresses the immune system, further experiments suggest that the implications may extend well beyond skin cancer. Increases in UV-B from ozone depletion may increase the frequency of herpes outbreaks. Leishmaniasis, a disfiguring disease caused by parasites which is widespread in the tropics, may spread more rapidly and heal more slowly. Other diseases may also be affected.

Because the human eye is sensitive to sunlight, we involuntarily blink when we look at the sun. This instinct may be quite protective; laboratory and epidemiological studies show that UV-B is a major cause of cataracts. Cataracts are treatable when caught early, but even in the United States they remain the third leading cause of blindness. In developing countries, they are an even greater cause of blindness.

men than they do in women. The protection against ultraviolet rays provided by different kinds of clothing seems to be a factor.

However, most skin cancers can be prevented if people choose to use a few simple precautions that will minimize the sun's impact on their skin.

In the past, avoiding overexposure to sunlight involved using cosmetically unacceptable opaque barriers or, even worse, resigning oneself to an indoor life style—unacceptable for most people. Today's sunscreen products, developed within the last 10 years, are both effective and cosmetically pleasing. The typical number 15 sunscreen allows for exposure up to 15 times a person's ordinary tolerance to skin reddening.

In addition to regular sunscreen use, a very effective measure is limiting one's time outdoors during the hours of the sun's peak intensity (10 a.m. to 2 p.m. Standard Time or 11 a.m. to 3 p.m. during Daylight Saving Time.) Hats, umbrellas, long pants and sleeves, and tightly woven fabrics are all helpful. These and other simple steps will allow people to protect themselves from skin cancer while enjoying their time outdoors.

Protection from the sun should be practiced from the earliest stages of one's life. All those responsible for the well-being of children and young people—parents, relatives, teachers, babysitters, camp directors, scout leaders, Little League coaches—have a critical role to play in minimizing harmful exposure to the sun's strongest rays.

But for adults with years of chronic, heavy sun exposure, preventing steps may come too late. For this reason, the second major thrust in the war against skin cancer is early detection. In Australia, where a national education campaign against skin cancer was implemented, the debilitating and sometimes lethal effects of skin cancer have been greatly reduced because of widespread public awareness of what warning signs to look for.

The connection between skin cancer and excessive exposure to the sun's damaging rays has been clearly established.

The most common warning sign of an early basal cell carcinoma is a non-healing sore that remains open for several weeks or more. It also frequently resembles a pearly bump, which may eventually develop an ulcer in the middle. At first it may look like a pimple, but unlike a pimple, it does not go away. Sometimes, it appears as a reddish patch or even a scar-like area. Squamous cell carcinoma, which has somewhat similar warning signs, usually appears red and scaly from the start. In time it too may ulcerate in the center.

Malignant melanoma may start in a pre-existing mole or birthmark, or it may develop as a new blemish. Melanomas have four distinct characteristics in contrast to common (benign) moles:

Asymmetry. Some forms of early malignant melanoma are asymmetrical, meaning that a line drawn through the middle will not create matching halves. Common moles are round and symmetrical.

Border. The borders are frequently uneven, often containing scalloped or notched edges. Common moles have smooth, even borders.

Color. Different shades of brown or black are often the first sign of a malignant melanoma. Common moles usually have a single shade of brown.

Diameter. Common moles are usually less than 6 mm. in diameter (¼"), the size of a pencil eraser. Early melanomas tend to be larger than 6 mm.

In addition, melanomas can appear flat on the skin as well as raised. They may also bleed easily.

Itching, pain, or other discomfort is rare with skin tumors, which in part explains why so many people ignore them or delay seeking help.

When detected early, non-melanoma skin cancers are successfully treated with one of several surgical techniques, and less often with freezing of tissue or with radiation therapy. More complicated cases are best treated with microscopically controlled surgery (MOHS surgery), a technique in which each layer of tissue in the removal process is microscopically checked for malignancy.

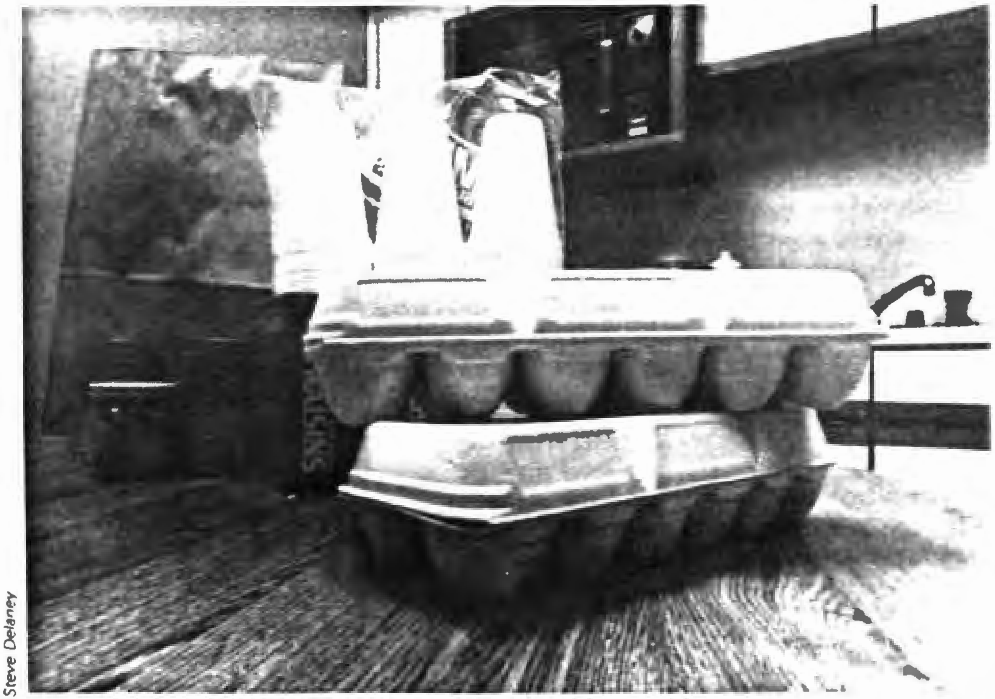
Malignant melanoma is usually treated by aggressive and extensive local surgery. If, however, it has spread beyond the skin, chemotherapy and/or immunotherapy may be used, although with limited success. Newer experimental immunotherapies such as interleukin-2 and interferon have shown some promise in initial trials in patients with advanced melanoma. Their long-term effectiveness has yet to be shown.

But with skin cancers, as with most diseases, the best treatment is prevention. And that means avoiding the harmful effects of sunlight. □

Ozone Protection: The Need for a Global Solution

by Richard Barnett

Some products found in [illegible] like these foam egg cartons [illegible] often are produced using chlorofluorocarbons. CFCs are also used in refrigerators, air conditioners, automobiles, and cleaning [illegible]



Steve Delaney

The potential for ozone depletion and climate change are real environmental concerns. There is ample time to develop effective solutions to address these concerns, but they will require a global focus and the cooperative efforts of industry and government.

Although many substances are thought to contribute to ozone depletion and climate change, attention has focused primarily on a family of synthetic chemicals known as chlorofluorocarbons, or CFCs. A balanced approach to these substances is necessary in order to preserve their valuable uses while limiting any long-term potential for environmental damage.

CFCs were first developed in 1931 as a result of an intensive research effort to identify an efficient, safe refrigerant for home use. They have come to be used in a wide variety of additional applications, the most notable of which are air-conditioning, the manufacture of foam products, and as a cleaning solvent for the electronics industry. The use of CFCs has become widespread because of their many desirable properties. They are non-flammable, non-carcinogenic, non-corrosive, have low toxicity, and are extremely energy efficient.

The contribution of these substances to worker safety and consumer health is substantial. The annual value of goods and services which depend to a varying extent upon CFCs exceeds $28 billion, and more than 780,000 full-time jobs are related to CFC uses in the United States.

(Barnett serves as the Chairman of the Alliance for Responsible CFC Policy and is the Vice President and General Manager of the Central Environmental Systems Division of York International, a large air conditioner manufacturer based in York, PA. The Alliance represents the interests of users and producers of CFCs.)

It is incumbent on us, nevertheless, to examine these substances and their potential for harming the environment in the long-term future. However, we should not rush into short-term regulatory decisions that could result in the use of alternatives that present immediate threats to worker and consumer safety and offer little or no theoretical environmental benefit. In this case, it appears that the penalties of premature regulation could be real in terms of an immediate increase in exposure to more toxic substances or increased energy consumption.

The Alliance for Responsible CFC Policy was organized six years ago to represent the interests of users and producers of CFCs. Alliance members established some basic goals with regard to the ozone depletion theory, CFC usage, and potential government policies.

First, it was our desire to encourage the pursuit of adequate credible scientific research on this important environmental issue, and then to ensure that any government policy be based on the best and most current scientific information.

Second, it was our goal to encourage efforts to resolve this issue in the international arena because of its global scope and to prevent any unproductive, harmful, unwarranted unilateral domestic regulatory program that would injure U.S. industry to the benefit of our international competition.

Third, it was our goal to seek amendments to the Clean Air Act that would provide greater international emphasis on this issue, and give better guidance to the EPA Administrator regarding stratospheric ozone protection activities and the need for regulation.

In the six years that have gone by, we feel that much has been accomplished to obtain our goals, but we believe that much remains to be done.

The United States and many other countries developed scientific programs to understand the ozone layer and the processes that control it. Practically all we know about the stratosphere has been learned in the last 10-15 years. Furthermore, intensive programs to study climate and possible modifications are continuing.

Although the scientific scrutiny has provided considerable information, some of it conflicting, it has also highlighted the many continuing scientific uncertainties. We believe the scientific research must continue.

Additionally, the Alliance has been an active participant in efforts to promote greater international cooperation, as exemplified by our support for the Vienna Convention for Protection of the Ozone Layer, and our participation in such domestic and international efforts to address ozone protection issues as the recently concluded series of workshops sponsored by EPA and the United Nations Environment Programme (UNEP). Given the enormous complexities of the issue, progress—from the scientific and international policy development perspectives—has been remarkable.

In 1980, the Alliance urged that at least three to five years were necessary to allow scientific research to gather critical monitoring information regarding the projections being made by computer models. Therefore, the 1986 release of the NASA/WMO science assessment on stratospheric ozone was an important event with regard to our own continuing evaluation process.

In general, the Alliance does not believe that the scientific information demonstrates any actual risk from current CFC use or emissions. We recognize, however, the growing concern for potential ozone depletion and climate change in the future as a result of large continuing growth of CFC emissions and the buildup of many other trace gases in the atmosphere, and the concern generated by the discovery of unexplained phenomena such as the large reductions in ozone levels during the Antarctic spring.

Scientific progress is not sufficiently developed to tell us that there is no risk in the future. In fact, all of the computer models calculate that large future growth in CFC emissions may contribute to significant ozone depletion in the latter half of the next century.

Therefore, we support further scientific research and believe that regulatory policies should be periodically reexamined in the light of additional research findings.

On the basis of current information, we believe that large future increases in fully halogenated CFCs (the most durable ones, thought to contribute most to ozone depletion) would be unacceptable to future generations. In our view, it would be inconsistent with the goals of the CFC Alliance to ignore the potential for risk to those future generations.

In furtherance of this position, the Alliance recently issued a policy statement which included support for a negotiated global limit on the future rate of growth of fully halogenated CFC production capacity; the development of voluntary programs by industries to conserve CFCs and reduce CFC emissions; and the continuation of research to develop acceptable substitutes for the fully halogenated CFCs.

This policy is significant because it eliminates the "worst case" scenarios being discussed; fosters a continued international cooperative spirit; recognizes the value of CFCs to present day health, safety, and economic concerns of workers and consumers; and will provide some stimulus for the development of CFC alternatives.

The using and producing industries of the CFC Alliance are committed to being active participants in the exploration and the successful resolution of these serious environmental issues; in the promotion of greater global cooperation in conducting the necessary scientific research and monitoring; and in developing coordinated, effective and equitable global policy decisions. □

The Saga of Spray Cans

Steve Delaney

Most people probably associate ozone depletion with aerosol spray cans. They remember back to the mid-1970s when public concern peaked that the chemicals given off by hair sprays, underarm deodorants, and shaving creams would deplete the earth's protective ozone shield, leading to increases in skin cancers. Front page stories, editorials, and political cartoons decrying the use of aerosols were widespread. Even Archie Bunker's son-in-law, Michael, in an episode of *All In The Family*, berated his wife Gloria about her continued use of this threat to our well-being.

A decade later, consumers in the United States can go into stores and purchase the same personal products without concern for their effects on ozone depletion.

In fact, it was not the aerosols themselves, but their use of chlorofluorocarbons (CFCs) as the propellant which raised concern. Most aerosols contain a statement that they "contain no fluorocarbons." Manufacturers have reformulated their products to use a hydrocarbon propellant system which is safe to the ozone layer.

In response to scientific evidence and public concern, EPA moved to ban CFCs in nonessential aerosols in 1978. But, even before then, the public and manufacturers had shifted rapidly away from these perceived dangerous products. In 1974, CFCs in aerosols accounted for over half of total consumption; by 1978, this use constituted less than five percent. Moreover, consumers still had access to quality aerosol products which, in fact, were less expensive to manufacture than their CFC-propelled counterparts.

By taking action to reduce CFC use in aerosols, the United States and several other nations which followed suit effectively bought a low-cost insurance policy, providing time during which scientific efforts could focus on resolving some of the remaining uncertainties. But, although this action granted some needed breathing room by reducing the rate of growth of CFCs in the atmosphere for almost a decade, that reprieve is over; CFC use has rebounded to match the peak amounts of 10 years ago. This fact, coupled with the recent discovery of the ozone "hole" over Antarctica, has renewed the scientific and the public attention to this issue.

The Greenhouse Effect: An Explanation

by Dr. David Rind

Monte Paulson, Dallas Morning News

The greenhouse effect has caught the imagination of the general populace in the last decade, and the respected, generally conservative scientific establishment has become associated with relatively dire predictions of future climate change. How much is actually known about the greenhouse effect? Can we really establish how climate will change, and when? By separating "hard" science—that which can be verified and is considered well understood—from scientific theory or estimate we can investigate how likely a near-term alteration in climate really is. We explore this subject through responses to a series of questions.

(Dr. [illegible] is an atmospheric scientist at the [illegible] for Space Studies, Goddard Space [illegible] Center, National [illegible] Space Administration. He [illegible] researcher on aspects of the [illegible] theory of atmospheric [illegible].)

Do we really understand the "greenhouse" effect?

The greenhouse effect is the name for the physical process where energy from the sun passes through the atmosphere relatively freely, while heat radiating from the earth is absorbed by particular gases in the atmosphere. Although a few uncertainties remain, we can generally calculate very accurately the radiation absorption by different gases. When the concentration of a gas changes, we know how much more energy is being absorbed. This additional absorption by itself warms the planet; for example, doubling the concentration of carbon dioxide in the atmosphere would eventually lead to an increase of the global air temperature by 1.2°C, without any other changes in the climate system. What we do not know, however, is how the rest of the system will react. Current models predict that the warming due to increased carbon dioxide will also increase the evaporation of water vapor from the ocean; because water vapor is itself a greenhouse gas, this will warm the planet further. In addition, as more snow and ice melt in the warming climate less energy from the sun will be reflected back to space (snow and ice are very good reflectors) which promotes further warming. These are examples of "positive feedbacks," and both of these system responses are very likely to occur, although we cannot be sure of the magnitude of the changes. The models also predict that cloud cover will change in such a way as to cause even more warming. Clouds are not yet well understood, and the predicted changes are very uncertain. But the net result of these different processes in the models is to amplify the direct doubled CO_2 warming by more than a factor of three, producing a 4°C temperature rise. Yet it is only the initial greenhouse effect due to increased CO_2, or increases in other trace gases, which we know with great confidence.

Can we use the temperatures on other planets to determine what the feedbacks of the system will be?

The atmospheres of other nearby planets validate the general concept of the greenhouse theory, especially in a qualitative sense, but they cannot tell us what the magnitude of the changes on earth will be. Venus, with a massive atmosphere composed essentially of carbon dioxide, has a surface air temperature almost 500°C warmer than would be expected without a greenhouse effect. Mars, with a very thin atmosphere and thus little greenhouse capacity, has an observed temperature close to the expected; and Earth, with intermediate amounts of greenhouse gases, is about 30°C warmer than it would be otherwise. The differences among the planets are very large, and cannot really be used to estimate sensitivity to small changes in greenhouse capacity. Furthermore, as noted above, the big uncertainty lies in the magnitude of the system response, or its "feedbacks"— the most important feedbacks all involve the reaction of processes having to do with water, and the other planets have no freestanding water.

Are greenhouse gases increasing?

An atmospheric monitoring system established in 1958 has measured systematically increasing concentrations of carbon dioxide over the last 28 years. We also believe that concentrations have increased since the turn of the century, although we are less certain about the magnitude of that change. Chlorofluorocarbons are artificially generated gases with greenhouse capacity which are known to be increasing; they have no natural sources, and probably did not exist in the atmosphere prior to the last few decades. Recent measurements indicate that other greenhouse gases, such as methane and nitrous oxide, also are increasing, although we are not sure how long this has been happening. As we are not sure of the reason for their increase, we have less confidence in their long-term trend. In addition, greenhouse gases of which we are only now becoming aware may be increasing, such as some of the more exotic man-made chlorine-fluorine compounds.

Is the temperature record of the past century consistent with this greenhouse gas increase?

Estimates are that the global average surface air temperature has increased by about 0.6°C in the past 100 years; available records are uneven. Temperature recording stations were much less abundant 100 years ago, and large portions of the globe were poorly sampled, especially in the Southern Hemisphere. Even today, full global coverage is not available. The record, such as it is, does not indicate a ubiquitous warming since that time, since the Northern Hemisphere has apparently cooled from the 1940s into the early 1970s. This cooling is inconsistent with the concept of greenhouse warming, but it may be due to other climate perturbations (such as variations in the solar constant or volcanic aerosols) or simply represent internal variability within the system. The overall warming for the past century is the right order of magnitude of the expected greenhouse effect; however, due to uncertainties in the actual temperature change, in the climate feedback factor, in the actual CO_2 amount in 1880, and in the rate of ocean heat uptake (which slows down the atmospheric warming), we cannot be more precise in determining what the expected warming should have been. Similarly, due to the other uncertainties, we cannot use the record to establish what the climate feedback factor really is.

Are current models adequate to allow us to forecast climate change?

Numerical models, called general circulation models, calculate the response of the climate system to the increases in trace gases. The three current models all estimate that the doubled CO_2 climate will have a global average temperature 4°C warmer than today. They are thus all calculating similar climate feedback factors, but as the different models handle many processes similarly, the unanimity does not guarantee accuracy. The treatment of cloud cover in all the models represents a major uncertainty. The models also show differences in the seasonal and latitudinal distributions of the calculated warming. It is unlikely that the models could be wrong by more than a factor of two, but this cannot be proven.

In addition, a climate change forecast should indicate when the warming would be expected to be evident. Only one model (the Goddard Institute for Space Studies [GISS] model) has been used in a time-transgressive mode to calculate the climate for the next 50 years. The results indicate substantial warming in the next decade. This calculation is affected to some extent by uncertainties in ocean heat uptake and the true climate feedback factor. By providing an estimate of how much warming should be observed in the relatively near future, we will have a chance to test the accuracy of these models.

How "dire" is the forecast of coming climate change?

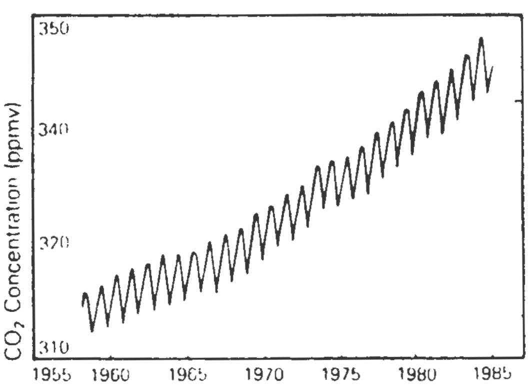
Ice covered what is now New York City during an ice age climate estimated to be some 4°C colder than today's. Considering that the doubled CO_2 climate is estimated to be warmer by the same amount, large changes in the climate system may well be expected if this comes to pass. The forecast for the next 50 years from the GISS model gives changes of 2°C by the year 2020, which would make the earth warmer than it is thought to have been at any point in historical time. Estimates for summer temperatures in the doubled CO_2 climate indicate that Washington, DC, which currently experiences 36 days of temperature above 90 F, would routinely have 87 such days; Dallas would go from 19 days with temperatures above 100 F to 78 days. Sea level rise due to thermal expansion of the oceans would cause severe problems in many coastal cities, and this effect would be exacerbated if additional glacial melting occurred. Rainfall patterns would likely be substantially altered, posing the threat of large scale disruptions of agricultural and economic productivity. The impact of the climate changes predicted by the current models would be immense, and, if the timing is correct, they will come quickly.

Is there any way to prevent these changes from occurring?

The climate is being altered by the release of trace gases due to fossil fuel consumption and industrial processes. These are factors inherent to our current civilization. It is hard to visualize changes sufficient to influence the overall trace gas trend, short of a major catastrophe, although it may be possible to limit specific trace gas increases (such as the chlorofluorocarbons). Our ability to manipulate the climate system deliberately, so as to offset the warming by some other process, is nonexistent. It is likely that the additional greenhouse capacity which has been added during the past 50 years has already built considerable warming into the system, which has not yet been realized due to the slow response of the ocean.

The climate of the next century will very likely be substantially different from today's, and uncertainties in our knowledge of the true climate sensitivity prevent us from knowing exactly how different it will be. The consequences of the estimated climate change would be enormous. With that in mind, it is worthwhile for us to factor climatic changes into our decision-making process, while appreciating the uncertainties that still exist in our understanding. □

Carbon Dioxide Concentrations



Measurements of atmospheric levels of CO_2 show a steady seasonal upward trend over the past 30 years. Chart shows levels measured in parts per million in volume.

Hotter or Colder?

Occasionally, predictions have been made that the increasing CO_2 in the atmosphere will lead to another ice age, or that another ice age is coming in any case. Dr. Rind responds:

Most suggestions about increasing CO_2 leading to an ice age involve the effect of climate change on the ocean. Perhaps the presence of warmer ocean water at high latitudes will provide for more precipitation, more snow cover, and the growth of glaciers. Or perhaps the "color" of the ocean will change as ocean warming causes changes in algae concentration, which might increase ocean reflectivity and cool the planet. Or maybe the entire ocean circulation will change, with reductions in the North Atlantic production of "deep water," which is cold salty water that sinks to the bottom. This could force the water that stays on the surface to remain cold.

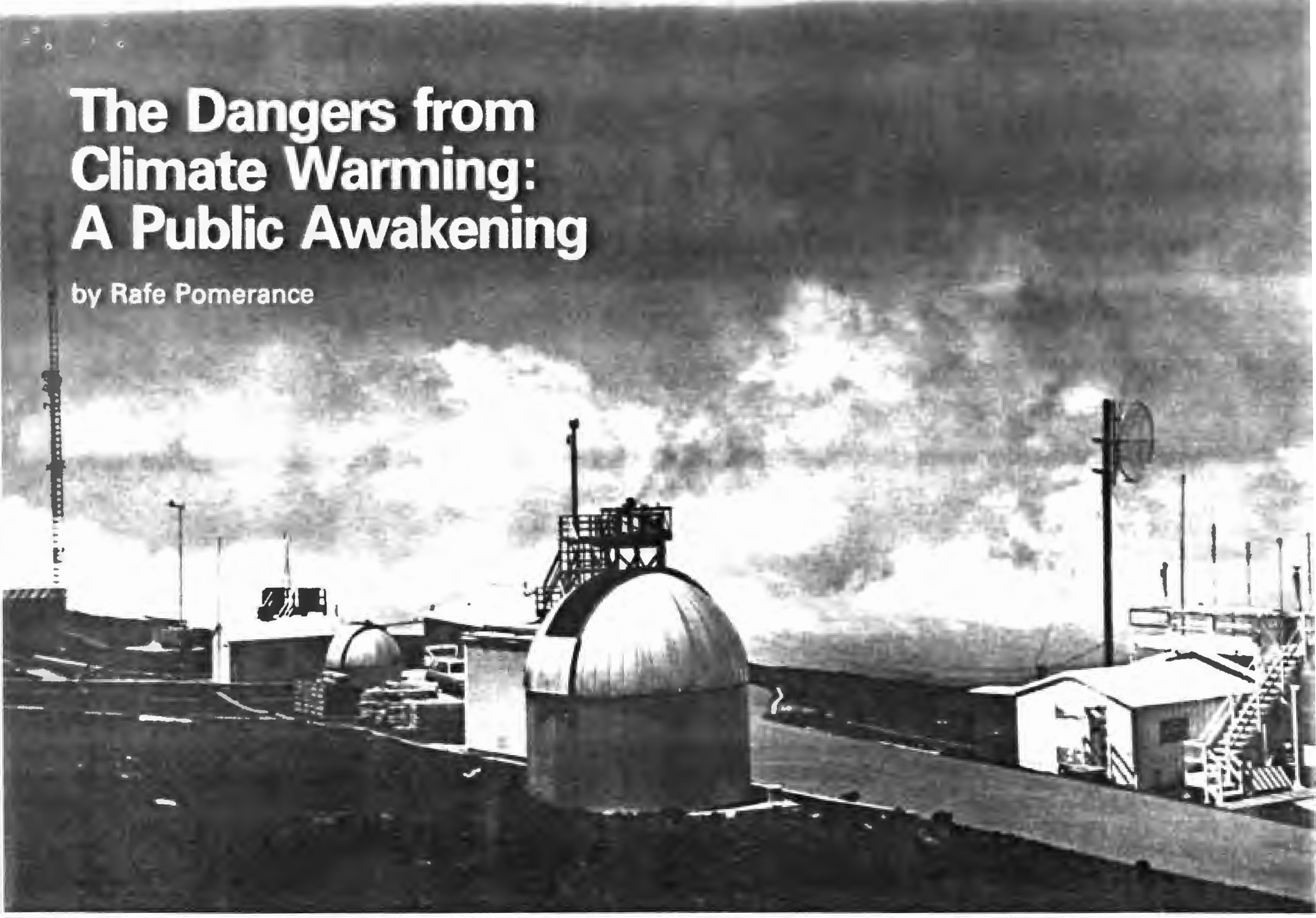
What all these suggestions have in common is that they are highly speculative. The growth of glaciers in a warmer climate, for example, is unlikely because glacial buildup occurs only when temperatures remain below freezing. In most regions of the Northern Hemisphere this does not happen today; and it would be less possible in a warmer climate. If some feedback process initiated by the warming, such as a change in cloud cover or ocean reflectivity, acted to cool the climate, its importance would probably diminish as the warming diminished (for example, cloud cover would return to its current level), and so end the cooling. Finally, while there is some evidence that climate has cooled rapidly in the past during warming episodes, perhaps because of changes in ocean circulation, the event(s) seemed to have occurred when much more extensive land ice already existed, providing cold fresh meltwater runoff for the ocean. Future ocean circulation changes cannot be ruled out, but there is little evidence that they are probable, especially in the near future.

On longer time scales, the likelihood of another ice age is based on the current understanding that ice ages result from variations in the earth's orbit around the sun. At certain periods the earth receives less solar radiation during Northern Hemisphere summer, which would aid in allowing snow cover to persist. The direct solar variation forcing is too small by itself to produce an ice age; the climate system would have to enhance the initial effect in order to produce an ice age. For example, analysis of gas bubbles trapped in ice cores indicates that during ice ages carbon dioxide in the atmosphere is lowered by about 25 percent (about 70 ppm), which would cool the planet. Currently, the orbital variations are such that the solar radiation received in the Northern Hemisphere during summer is decreasing, although it will be several thousand years before it reaches the minimum values which occurred during the last ice age. In this sense we are "going into" an orbital configuration that is more favorable for ice ages.

But the climate change that is our present concern is anticipated to be evident in the next decade, and to reach major proportions during the next one hundred years. Ice ages are lengthy phenomena, occurring over thousands of years, and it is unlikely that major effects would appear on the short time scales of interest here. Furthermore, with a warmer climate it is uncertain whether ice ages could occur; a reduction of 70 ppm of CO_2 today would simply bring the CO_2 level back to what it was normally in the past, well above the ice age values. If minimal CO_2 amounts are necessary for the orbital configuration to generate an ice age, such an occurrence may well be less likely in the future.

The Dangers from Climate Warming: A Public Awakening

by Rafe Pomerance



Mauna Loa Observatory NOAA

"A Dire Forecast for Greenhouse Earth" — The Washington Post

"Swifter Warming of Globe Foreseen" — The New York Times

"The Silent Summer, Ozone Loss, and Global Warming: A Looming Crisis" — Newsweek

"The greenhouse effect"...this term is part of the public vocabulary now. In just a few years, it has changed from a scientific curiosity to a major policy issue for industries and governments all over the world.

Why? How did a question of seemingly academic interest suddenly become the subject not only of headlines and talk shows, but of government hearings and international negotiations?

Simply put, the greenhouse effect is the process in which heat radiating from the earth's surface is trapped by gases, such as carbon dioxide and methane, in the atmosphere. The increased heat results in a rise in global temperatures which may significantly alter climate patterns. Scientists have known and studied this effect for decades, but only recently have they reached the fundamental consensus that rising levels of greenhouse gases may threaten the future of our planet. Now the implications of that possibility are reaching governments.

The greenhouse effect reached a new stage in its evolution as a policy issue in 1979, when four eminent scientists reported to the Council on Environmental Quality (CEQ) that "...man is setting in motion a series of events that seem certain to cause a significant warming of world climates unless mitigating steps are taken immediately." The authors were ecologist George Woodwell, one of the first to examine the role of deforestation in the buildup of carbon dioxide; geophysicist Gordon MacDonald, one of CEQ's original members; David Keeling of the Scripps Institute of Oceanography, who coordinated continuous measurements of carbon dioxide in the atmosphere; and oceanographer Roger Revelle, who established the carbon dioxide monitoring station at Mauna Loa in Hawaii in 1957 and who chaired the

The Mauna Loa Observatory near Hilo, Hawaii, is part of the Geophysical Monitoring for Climatic Change program run by the National Oceanic and Atmospheric Administration. The Observatory's carbon dioxide monitoring records date back to 1958.

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1977 National Research Council report, "Energy and Climate."

At about the same time, the National Academy of Sciences also began a study of the greenhouse effect. After reviewing available atmospheric models and analyses of past climates, the study chaired by meteorologist Jule Charney concluded that "We have tried but have been unable to find any overlooked or underestimated physical effects that could reduce the estimated global warming due to a doubling of CO_2 (carbon dioxide) to negligible proportions or reverse them altogether." The study estimated that a doubling of CO_2 in the atmosphere would raise global temperature by 3°C, plus or minus 1 1/2°C.

The greenhouse problem was debated in yet another forum that year when the Carter administration proposed a major synthetic fuels initiative. In *The Washington Post*, Gordon MacDonald argued that synthetic fuels produced even more carbon dioxide per unit of energy than coal, oil, or natural gas. MacDonald warned that subsidizing synthetic fuels was a mistake that would only increase U.S. dependence on CO_2 intensive energy systems.

The controversy attracted the interest of then U.S. Senator Abraham Ribicoff, who had recently been warned of the greenhouse effect by West German Chancellor Helmut Schmidt. Ribicoff convened a Senate symposium on the subject. The result was an amendment to the synthetic fuels legislation of 1980 mandating that the National Academy of Sciences undertake another, comprehensive, review of the problem. Also in 1980, the National Commission on Air Quality held a workshop on the greenhouse effect as part of its review of the Clean Air Act. That workshop may have been the first study to concentrate solely on public policy issues rather than science aspects of the problem.

In January 1981, under the leadership of Gus Speth, the Council on Environmental Quality released its report on the CO_2 problem. After analyzing the reductions in CO_2 emissions that would be needed to keep levels below 1 1/2 times preindustrial levels, CEQ concluded that "the potential risks from even moderate increases in the burning of fossil fuels...underscores the vital need to incorporate the CO_2 issue into the development of United States and global energy policy." Adding a major dimension to the problem, scientists at the Goddard Institute of Space Studies concluded later that same year that CO_2 was not the only problem gas: methane, tropospheric ozone, nitrous oxides, and chlorofluorocarbons (CFCs) could also contribute significantly to warming the atmosphere.

The Environmental Protection Agency made its first contribution to the debate in 1983, when it released its report "Can We Delay a Greenhouse Warming?" EPA's report concluded that levels of atmospheric greenhouse gases were already high enough to trigger a global warming, and that economic momentum would ensure even further warming.

Based on his climate models, Hansen projected that significant warming might be observed within five to 15 years.

The report further concluded that global temperatures would rise by 2°C within a relatively short time, even with major reductions of CO_2 emissions, although such reductions could have an impact in the long run.

EPA's report was followed shortly by *Changing Climate*, the greenhouse study of the National Academy of Sciences. In contrast to EPA's conclusions about fossil fuel use and CO_2 buildup, the Academy judged that "We do not believe that the evidence at hand about CO_2-induced climate change would support steps to change correct fuel use patterns away from fossil fuels."

Perhaps the Academy report calmed public fears. At any rate, the issue faded from the public eye until 1985, when new scientific information, a key international conference, and a series of Congressional hearings combined to return the greenhouse effect to public awareness.

Early in 1985, scientists V. Ramanathan and Ralph Cicerone and their colleagues from the National Center for Atmospheric Research announced that not only were other greenhouse gases contributing as much to global warming in the 1980s as CO_2, but also that these gases could eventually surpass carbon dioxide in their contribution to the greenhouse effect. These findings reinforced the growing consensus that some global warming was inevitable and that it would occur rapidly.

An international meeting in October 1985 came to the same conclusion. Under the auspices of the United Nations Environment Programme and the World Meteorological Organization, scientists from 29 nations met in Villach, Austria, and agreed that "some warming of climate now appears inevitable; the rate of future warming could be profoundly affected by government policies on energy conservation, on use of fossil fuels, and emission of some greenhouse gases."

Following on the heels of the Villach conference was a Senate hearing convened by Senator David Durenberger, as well as a call by Senator Albert Gore for an international "Year of the Greenhouse" to focus attention on the problem. Gore was not new to the issue, having conducted hearings on the greenhouse effect in 1982 and 1984 while he was a member of the U.S. House of Representatives. The pace quickened in 1986, when the World Meteorological Organization, the National Aeronautics and Space Administration, and numerous other agencies issued a three-volume report on atmospheric ozone. The report detailed the rapid atmospheric changes occurring as a result of human activity, particularly the greenhouse effect and the depletion of the protective ozone layer in the stratosphere. Concluded the report, " There is now compelling evidence that the atmosphere is changing on a global scale." Finally, Senator John Chafee's hearings in June of 1986 brought together key scientists and government officials to discuss the problem. Perhaps the most significant testimony came from Dr. James Hansen of the Goddard Institute for Space Studies. Based on his climate models, Hansen projected that significant warming might be observed within five to 15 years.

This was a surprise to many observers. The greenhouse problem had been viewed as taking decades to develop, and, indeed, doubled levels of carbon dioxide in the atmosphere were still projected to occur decades from now. It was the possibility that warming could occur at much lower levels of CO_2 that suddenly became a serious issue for government policymakers to address.

The Chafee hearings raised the visibility of the greenhouse issue, making it a more likely factor in policy discussions. Senator Chafee moved the issue another step by asking EPA to develop a set of policy options for stabilizing the level of greenhouse gases in the atmosphere. When completed, this study should mark the beginning of another era for the greenhouse effect and the problem of global warming. □

Rising Sea Levels: The Impact They Pose

by James G. Titus

Steve Delaney

[illegible] line the beach in Ocean City, MD. B[illegible] erosion due to rising sea levels could threaten many resorts with buildings close to shore. In Ocean City, officials have already tried rebuilding eroding beaches by bringing offshore sand [illegible]

(Titus is Project Manager for Sea Level Rise in the Office of Policy Analysis in EPA's Office of Policy, Planning and Evaluation.)

For the last several thousand years, the level of the oceans has risen so slowly that for most practical purposes it has been constant. This slow rate of rise has made it possible for ecosystems and human activities in coastal areas to develop more extensively than would otherwise be possible. Whether one is looking at an Ocean City or Rio de Janeiro beach resort, swamps in Louisiana, farmland in Bangladesh, marshes along the Chesapeake Bay, or the merchants of Venice, life along the coast is in a sensitive balance with the level of the seas.

This balance may be upset by the global warming that is expected to result from the "greenhouse effect" projected by atmospheric scientists. Climatologists generally expect that if human activities continue to release carbon dioxide, chlorofluorocarbons, and other gases that absorb infrared radiation, average temperatures on our planet will rise four to nine degrees (F) in the next century. This global warming could raise sea level one foot in the next 40 years, and two to six feet in the next century. The rising seas could inundate low-lying areas, erode beaches hundreds of feet or more, increase the risk of flooding in coastal areas, destroy coastal marshes and swamps, and increase the salinity of rivers, bays, aquifers, and water supply systems.

By "sea level" we mean the average water level of the oceans, coastal estuaries, tidal rivers, and bays throughout the course of a year. In the last two million years, sea level has been three to five hundred feet lower during ice ages than it is today. During warm "interglacial" periods, sea level has been at approximately today's level. But during the last interglacial period one hundred thousand years ago, the level was about 20 feet higher than it is currently.

The main reason sea level has fluctuated so much is that during ice

World Bank photo by Thomas Sennett

[illegible] Bangladesh [illegible] would flood about 20 percent of Bangladesh.

ages much of the northern hemisphere was covered with an ice sheet thousands of feet thick. As those glaciers melted at the end of the ice ages, the water flowed back into the oceans and the sea rose. From around 15,000 B.C. until around 5,000 B.C., sea level rose about three feet per century. Since then, the sea has risen only an inch or two per century on average. However, tidal records show that in the last hundred years it has risen four to six inches.

Although most of the ice sheets covering North America during the last ice age have melted, the expected global warming could raise sea level for a number of reasons:

- **Thermal expansion.** Ocean water expands when it is heated, which could raise the sea level a foot or two in the next century.

- **Alpine glaciers.** The snow covering various mountains throughout the world could melt, adding another foot to sea level.

- **Greenland.** Polar scientists estimate that glacial melting there could add another foot to sea level in the next century.

- **Antarctica.** Over the next two hundred to five hundred years, it is possible that the West Antarctic Ice Sheet could completely disintegrate, which would raise sea level 20 feet. Fortunately, polar scientists generally believe that Antarctic glaciers are unlikely to contribute more than three feet to rising sea level in the next 100 years.

Several scientific groups—the U.S. National Academy of Sciences, the Environmental Protection Agency, and an international conference in Austria sponsored by the United Nations Environment Programme—have estimated the future rise in worldwide sea level. The consensus for the most likely rise in the next century is in the range of between two and six feet, with a one-foot rise possible in the next 40 years. Because much of the U.S. coast is sinking, the rise along most of the Atlantic and Gulf coasts in the next century will be six to eight inches greater.

The major anticipated impacts of sea level rises are inundation, erosion, increased flooding, and saltwater intrusion. Areas that are now just above sea level will be inundated. A six-foot rise in sea level would flood about 20 percent of Bangladesh, and a similar portion of the Nile Delta in which almost all of Egypt's population resides. Some island nations built on coral reefs such as the Maldives in the Indian Ocean could be entirely under water. Were it not for the extensive network of dikes and drainage canals, one-half of the Netherlands would also be threatened.

In the United States, most areas just above sea level are coastal marshes and swamps, which are extremely important for the survival of many types of birds, fish, and furbearing animals. Because wetlands have been able to keep pace with the slow rates of sea level rise that characterized the last few thousand years, the area of wetlands is generally greater than the area just above sea level. If the sea should rise more rapidly in the future, a very large loss of those wetlands could result, even though new wetlands would form as inland areas are inundated. If the adjacent upland areas are developed, all the wetlands could be squeezed out. Recent estimates suggest that a three- to six-foot rise could destroy 50 to 80 percent of U.S. coastal wetlands.

The coastal wetlands of Louisiana—which account for almost half of U.S. coastal wetlands—appear to be particularly vulnerable to a rise in sea level. These marshes and swamps were formed by sediment washing down the Mississippi River. Although the muds sank two or three feet per century, annual flooding provided more than enough additional sediment for the subsiding wetlands to keep pace with relative sea level rise. However, in the last century, human activities have diminished the ability of the Mississippi delta to keep pace with sea level rise. Flood control levees and navigation channels confine the flow of the river so that the sediment no longer reaches the wetlands; it is now shunted off the edge of the continental shelf into the deep waters of the Gulf of Mexico. As a result, Louisiana loses 50 square miles of wetlands per year to the sea. Unless major efforts are undertaken to restore some of the natural processes, the projected rise in sea level will accelerate the drowning of wetlands and most of this valuable ecosystem will be lost in the next century.

Along the open coast, a rise in sea level causes the shore to retreat considerably beyond the part of the beach that is inundated. Higher water levels enable storm waves to strike further inland to erode more of the beach, and decrease the ability of calm waves to rebuild the beach. Along most of the U.S. coast, a one-foot rise in sea level will erode 100 to 200 hundred feet of beach. This could threaten many resorts that have buildings within 100 feet of the shore.

A rise in sea level could increase coastal flooding for three reasons. First, during hurricanes and northeasters, "storm surges" can raise water levels five to fifteen feet higher than normal, providing a higher base for these surges to build upon. For example, in Charleston, SC, areas that today are flooded only once a century would be flooded every 10 years if sea level rises five feet. Second, erosion can leave particular properties closer to the shore and thus more vulnerable. Finally, higher water levels decrease the efficiency of natural and artificial drainage systems, causing backwaters that can increase flooding from rainwater.

Sea level rise also increases the salinity of ground and surface waters in coastal areas; this can cause important shifts in coastal ecosystems. Although fresh water marshes may be replaced by salt marshes, freshwater cypress swamps are generally converted to shallow lakes when exposed to excessive salinity levels, which is already occurring in Louisiana. Saltwater intrusion also threatens drinking water supplies. A two-foot rise in sea level would result in Philadelphia's Delaware River water supply being too salty to drink during droughts when streamflow is diminished. Moreover, because the aquifers on which suburban New Jersey relies are recharged by the (currently fresh) Delaware River, increased river salinities could result in salty river water contaminating the aquifers.

How can the impacts of rising sea level be prevented or at least ameliorated? Society can respond to these problems either by reacting to them as they occur or by anticipating them as part of the planning and design of coastal communities and other long-term projects. The most general response to ameliorating the problem of sea level rises would be to limit emissions of greenhouse gases and limit the acceleration of sea level rise. But such a policy is only likely to be effective if implemented long before problems emerge, because it would take a few decades to carry out. Even if all emissions were curtailed, the earth would continue to warm for at least a few decades as the oceans came into equilibrium, after which the sea would continue to rise for at least a few more decades as glaciers came into equilibrium with the higher temperatures. By the time the sea rises one foot, it would be too late to prevent a several-foot rise in sea level.

Therefore, coastal communities must also look at ways of adapting to whatever rise does take place. Possible responses to inundation, erosion, and flooding will fall broadly into three categories: building walls to hold back the sea, raising the land surface, and retreating from the shore.

Levees and dikes are already used to hold back the sea to protect areas below sea level in the Netherlands and adjacent countries, as well as such U.S. cities as New Orleans and Texas City. This option will probably be the preferred response for most major low-lying metropolitan areas. However, it will not be appropriate for coastal barrier islands whose recreational beach economies require that the shore be a beach, not a wall. Moreover, this option can result in a complete loss of coastal wetlands. For communities built on coral reefs, levees may not be able to keep the water out.

Raising the land surface may be the preferred option for coastal barrier island resorts such as Miami Beach, where property values are high and there is a need to maintain a recreational beach. For communities on coral reefs, this may be the only option. This method may also be the only way to simultaneously protect wetlands and coastal property, however, technologies to accelerate the ability of wetlands to grow upward are expensive and not entirely proven. Nevertheless, raising the land surface is already employed in many coastal areas where dredges pump sand from offshore to rebuild eroding beaches.

In some cases, property values may not be great enough to justify construction of a levee or raising the land. In other cases, defending the shore may be economically viable, but the social goal of protecting natural shoreline environments may preclude those options. In these instances, the only alternative will be to adapt to a retreating shoreline.

If the current shoreline is to be

Greenhouse Effect: Other Impacts

The greenhouse effect may well shift our climate to conditions unknown in recorded human history. While our ability to predict the full implications of this shift is limited, one approach is to study the earth's past for clues to its future. Based on geological studies of life thousands of years ago, we know that many aspects of our environment are intertwined with climate. They have undergone dramatic changes, particularly compared to 18,000 years ago when the earth was about five degrees Centigrade cooler.

As the earth warms, we may see changes in all aspects of our climate: changes in rainfall patterns, more frequent storms, and more extreme temperatures. As a result, agriculture and natural ecosystems will be affected. Important changes in farm productivity can be expected throughout the world. Crops that now prosper may not grow, and today's breadbaskets may become tomorrow's dust bowls. The need to develop new agricultural methods and crops, perhaps through advances in bioengineering, will pose a critical challenge to future generations.

The makeup and extent of our natural ecosystems, including wetlands and wilderness areas, may shift. As mild-latitudes warm, evergreen forests may be forced to shift north. If human development blocks this migration, the entire ecosystem may be at risk. The implications for endangered species, many of which are adapted to specific environmental niches, may also be severe.

Climate change will affect the availability of water for industrial and agricultural uses, and for drinking. As rainfall patterns shift, reservoirs may dry up, or dams become overburdened. The water projects we build today will last 50 years or more. They are designed with the assumption that tomorrow's climate will be the same as today's—an assumption that may not hold as greenhouse gases build up in the atmosphere.

The implications of climate change are broad. The weather, a mainstay of conversation today, is likely to take on a growing importance as the world warms.

Kenner Rice USDA Soil Conservation Service

maintained, there is little advantage to defending it before the sea rises enough for defensive efforts to be necessary. However, retreating from the shore would require considerable lead time, since coastal structures can last 50 to 100 years and their owners would be reluctant to move or abandon them. This need for advance planning has been incorporated into many state coastal zone plans, which require that new construction be set back from the ocean shore a distance equal to the erosion expected in a given number of years. North Carolina requires houses that can be subsequently moved to be set back from the shore to a point approximately "30 years worth" of erosion and large buildings to be set back "60 years worth." In Maine, the set-back requirement is 100 years. However, these regulations do not yet incorporate the degree of shore retreat that might be necessitated by the accelerated rates of sea level rise that are now expected.

The need for advance planning may be even greater in the case of wetland protection. If the problem is not addressed until the sea has risen significantly, it may be too late to require development to retreat without costly purchases of land and structures. By contrast, long-term planning could help ensure that new structures are not built in areas where new wetlands are likely to form.

Long-term planning for saltwater intrusion into water supplies may also be useful. For example, in the case of the Delaware River, the water authorities maintain reservoirs and release fresh water when salinity levels increase. Sea level rise may require more reservoirs in the future. While there is no need to build those dams today, now is the time to identify the locations where they would be built if needed. Otherwise such sites may be developed for other uses precluding the options by which future generations can address the problem.

Fortunately, most of the consequences from the expected rise in sea level are still decades in the future. Why should we focus on these future problems when we are faced today with more immediate problems such as toxic waste dumps, urban smog, and dying estuaries? Former EPA Administrator William Ruckelshaus offered this perspective:

> *Our system of government has traditionally been biased toward a sort of institutional inertia, which is eventually broken by development of a massive consensus. The problem is that in our ultimate haste, we may not give adequate attention to all the options. Whether we can continue in such a manner is a subject open to question...in an era producing catastrophes of a magnitude greater than in the past, we can place our institutions in situations where precipitate action is the sole option—and it is then that our institutions can be imperiled and individual rights overrun.*

When, as in the case of the greenhouse effect and the rising seas, a period of several decades must pass between cause and effect, the future environmental problems should be addressed as they are being created, rather than waiting until their consequences are upon us.

Other nations are also beginning to examine the implications of future sea level rise. For example, in August 1986, a conference of 50 scientists and officials from around the Soviet Union sponsored by the Estonian Academy of Sciences recommended that decision makers be informed about "the cost of designing new facilities for a future rise compared with the cost of rebuilding the facilities if such a rise takes place." Professor Eric Bird, an invited observer from Australia, expects these recommendations to be acted upon: "The Soviets have a track record of implementing the recommendations of this panel."

Addressing the causes of sea level rise will require nations to work together. But individual nations and communities and individuals can decide for themselves whether and how to prepare for and react to the effects and, in so doing, will help create the understanding and public awareness necessary to address the causes. ☐