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In June 1974, two California chemists, Mario J. Molina and F. S. Roland, announced that chlorofluorocarbons (CFCs) being added to the atmosphere might decrease the ozone layer surrounding the earth by 10 percent within the next fifty to eighty years.¹ Since the ozone layer about 15 miles above the earth's surface shields the earth from the sun's harmful ultraviolet rays, the decrease in ozone might allow these rays to reach the earth and induce skin cancer in humans. An earlier study in 1973 had predicted that a mere 5 percent decrease in ozone might produce at least 8,000 extra cases of skin cancer per year.² In addition, the 1973 study had speculated that increased solar radiation could damage the plankton in the oceans that produce much of the world's oxygen and might destroy many other plant and animal species. Other researchers suggested that an increase in solar radiation might lead to widespread climatic changes, including melting of polar ice, a consequent rise in sea levels and a flooding of coastal cities.³

Two months later, in September 1974, two more scientists, R. Cicerone and R. Stolarski, published a new computer study in *Science* that predicted a 10 percent decrease in the ozone layer by 1990. Fears increased when a third major prediction in October 1974 found that if CFCs continued to be added to the atmosphere at current rates, then by 1995, 40 percent of the ozone layer would be gone.⁴

All of these studies pointed out that much of the chlorofluorocarbon gas that was entering the ozone layer came from the propellents used in aerosol spray cans. When released from the can, the gas (CFC13) floats up into the stratosphere, where ultraviolet light from the sun causes the gas to release free chlorine atoms. A single chlorine molecule then acts as a catalyst to make tens of thousands of ozone molecules (O₃) break down into simple oxygen molecules (O₂). Whereas ozone filters out ultraviolet light, oxygen does not. The small amounts of CFC gas being used as propellents in deodorant sprays, hair sprays, perfume sprays, and so on, then, could destroy vast amounts of ozone once it reached the stratosphere.

In August 1975 government researchers reported that various atmospheric and laboratory experiments strongly confirmed the ozone depletion theory postulated by Rowland and Molina. Balloon samples indicated that CFCs had found their way into the stratosphere "in the predicted amounts" and that they were being broke down "as predicted and at the rates predicated by theory." Balloon tests also indicated that free chlorine atoms were being produced in the stratosphere as the ozone depletion theory predicted would happen.⁵

The DuPont Company was the largest producer of the one billion pounds of fluorocarbons (valued at \$450 million) manufactured in the United States in 1974. By itself it accounted for about 50 percent of the CFC market, the rest being shared by five other manufacturers. In addition, DuPont was constructing a new \$100 million chlorofluorocarbon plant in Corpus Christi which, when completed, would be the largest such plant in the world. DuPont was, therefore, highly concerned by the threat of a ban.⁶

DuPont management quickly moved to meet the threat. DuPont's research director, Ray McCarthy, pointed out that the ozone depletion theory had not yet been fully established and large research gaps still remained. It was entirely possible that the computer models employed by the theories were mistaken, that the chlorine atoms found in the stratosphere had sources other than CFCs, and that the speculations concerning the effects of ozone depletion were exaggerated. McCarthy and other scientists claimed that it would be at least three to six years before proper proof of the theory was obtained. "I hope," McCarthy said, "that the measurements now planned and under way will prove effective in unequivocally providing information on reaction of chlorine in the stratosphere. If not, we will seek other methods which will give us that unequivocal proof."⁷ Research should continue, but no regulations should be imposed until the necessary research had been completed.

All we have are assumptions. Without experimental evidence, it would be an injustice if a few claims--which even the critics agree are hypotheses--were to be the basis of regulatory or consumer reaction. [Statement of Raymond L. McCarthy]⁸

Other researchers, however, urged haste, since, if the ozone depletion theory was right, then there was little time left before its consequences would be almost irreversible. Ralph Cicerone, one of the authors of the ozone depletion theory, argued

Decision-makers do not have much room to hedge their bets . . . whatever the effects of fluorocarbons will be, the full impact will not be felt for a decade after release and it will persist for many decades. . . . Complete scientific proof to everyone's satisfaction will take years, so we are faced with a benefit-risk analysis. I have come to the reluctant conclusion that the risks are greater than the benefits and the evidence is already strong. [Statement of Ralph Cicerone]⁹

DuPont lobbied to prevent the passage of legislation that would ban the chlorofluorocarbons. In ten out of the fourteen states which had introduced CFC bills by the middle of 1975, the bills were defeated or tabled, in part as a result of industry lobbies.¹⁰ When New York State succeeded in passing a bill banning CFCs unless proved safe, Raymond McCarthy of DuPont complained that "the bill gives the industry the real but impossible task of providing that something will never happen."¹¹

To ensure that CFCs would not be banned, DuPont embarked on an extensive advertising campaign conveying their side of the story: The ozone depletion theory was backed by little evidence. The chairman of the board of DuPont published the following statement in several major newspapers:

The current controversy centers around the theory [of ozone depletion]. On one side are scientists, theorists, and some legislators who contend that these useful, inert gases, breaking down into chlorine, will lead eventually to an unnatural amount of ozone depletion. On the other side are scientists, researchers, and the aerosol industry who maintain there is not persuasive evidence to support this recently proposed theory of ozone depletion. And, they say, even if the theory has elements of correctness, other chemicals, reactions, and processes might be primarily responsible. Why, they ask, should an industry be prejudged and useful fluorocarbon products be destroyed before any answers are found? . . . As the world's leading supplier of fluorocarbon propellants, DuPont has an obvious stake in the outcome of the controversy. As a corporation we are committed to making products safely, and to supplying safe products to our customers. We have publicly announced that, should reputable evidence show that some fluorocarbons cause a health hazard through depletion of the ozone layer, we are prepared to stop production of the offending compounds. To date there is no experimental evidence to support the contention that . . . [these] compounds have caused a depletion of the ozone layer. . . . Nor will there be any hard answers until some hard facts are produced. In the meantime, aerosol products suffer under a cloud of presumed guilt, and other fluorocarbon-dependent industries are seriously threatened. We believe this is unfair. The "ban now-find out later" approach thrust upon an \$8 billion segment of industry in this issue, both in the headlines and in many legislative proposals, is a disturbing trend. Businesses can be destroyed before scientific facts are assembled and evaluated; and many might never recover, even though these facts may vindicate them. Except where available evidence indicated that there may be immediate and substantial danger to health or environment, the nation cannot afford to act on this and other issues before the full facts are known. [Statement of Irving S. Shapiro, chairman of the board, DuPont]¹²

In a surprising development, in 1976, Roland and Molina announced that their original calculations may have been mistaken because chemical interactions in the stratosphere were more complex than they had thought. Reactions with other compounds, they reported, may slow down CFC's ability to deplete the ozone, so their earlier estimates of the rate of ozone destruction may have been overstated.¹³ The National Academy of Sciences, taking this new information into account, issued a report in September 1976 that concluded that global ozone losses produced by CFCs should be revised downward to a

probable 7 percent during the next fifty years, although actual depletion could be anywhere between 2 and 20 percent.

Congress, uncertain what to do, decided in 1977 not to pass legislation directly banning CFCs, but instead voted to give federal regulatory agencies the authority to regulate CFC emissions if agency officials decided that these "may reasonably be anticipated to endanger public health or welfare."¹⁴ On March 15, 1978, the heads of the Food and Drug Administration, the Environmental Protection Agency, and the Consumer Product Safety Commission announced that they had reached a joint decision to place a federal ban on all "nonessential" use of CFCs in the United States. The ban outlawed the use of chlorofluorocarbons in 98 percent of all aerosol sprays, but allowed their use to continue as coolants in refrigerators, air conditioners, in the manufacture of foams and solvents, and to clean electronic parts, uses which together accounted for about 50 percent of the fluorocarbons being produced before the ban. Also, the ban permitted the sale of fluorocarbon sprays already manufactured until April 1979 and put no restrictions on foreign sales of CFCs. Canada, Norway, and Sweden passed similar bans, but other nations did not follow.

In November 1979, the National Academy of Sciences announced that its researchers had found that the ozone layer was actually being depleted at twice the 7.6 percent rate it had finally accepted as probable in 1976.¹⁵ According to the academy's National Research Council's panel on stratospheric chemistry, current uses of fluorocarbon chemicals "will result in ozone depletion that is calculated to reach 16.5 percent, half of which will occur over the next thirty years." The revised estimates were the results of improved atmospheric tests and improved mathematical models that had been used in a study done for the Environmental Protection Agency. These improved techniques also narrowed the range of uncertainty of the predictions to one chance out of twenty that the predictions could be wrong. In addition, the report warned of sharp increases in human skin cancer rates and of widespread destruction to food crops, ocean phytoplankton, and other sea organisms that provided the basic support of the marine food chain.

However, not everyone agreed with the Academy report. A committee of British scientists issued a study prepared for Britain's Department of the Environment in 1979 that concluded that although their computer models supported the findings of the Academy of Sciences, these models were nevertheless uncertain. Calling attention to the British study, DuPont officials argued that ozone depletion theories were all "based on a series of uncertain assumptions" and that "no ozone depletion has ever been detected, despite the most sophisticated analysis."¹⁶ Industry leaders pointed out that in the United States alone, CFCs were essential to keeping food from rotting in 100 million home refrigerators, to transporting food unspoiled on 180,000 refrigerated trucks and 27,000 refrigerated railroad cars, to selling fresh food in 40,000 supermarkets and 180,000 food stores, and to keep food fresh in 250,000 restaurants. Indeed, American society as presently constituted could not feed itself if CFCs were to vanish overnight. An estimated \$135 billion of equipment would become useless, and \$28 billion worth of CFC-dependent economic activities would be destroyed.

Nevertheless, in March 1980, several European nations (including Canada, Denmark, the Netherlands, West Germany, Sweden, and Norway) convened in Norway and in April 1980 agreed that all major CFC-producing countries should decrease CFC production. Japan agreed to do the same in September 1980. And in the United States, on October 7, 1980, the Environmental Protection Agency announced plans to propose a "no-growth" policy on the manufacture of fluorocarbons.¹⁷ Charles Masten, director of DuPont's freon products division, denounced the proposal as "unwarranted at this time." According to Mr. Masten new evidence had been found that cast doubt on the validity of the ozone theory.

With the election of Ronald Reagan and his promise to "get government off the backs of the American people," however, all U.S. government efforts to control CFCs slowed to a halt. In response, DuPont in June 1980 decided to suspend its research on alternatives to CFCs, reasoning that there was no economic justification for investing in alternatives for which there was not yet a ready market. This decision seemed to receive some limited support when in March 1982 the National Academy of Sciences issued a third report revising its estimates of future ozone loss downward to between 5 and 9 percent, half of the levels predicted in its 1979 report. In 1983 officials at the EPA began talking privately about quietly withdrawing their 1980 plan to propose a "no-growth" policy for CFCs. A fourth report of the National Academy of Sciences in February 1984 again revised its estimates of global ozone loss due to CFCs downward, this

time to only 2 to 4 percent, because of recent discoveries that reactions of methane and other atmospheric gases might generate ozone that would replace that destroyed by CFCs. While downgrading the ozone threat, however, the report issued an alarm about the growing concentrations of atmospheric carbon dioxide and its impact on atmospheric warming, or what has been called the "greenhouse effect."

In March 1985, representatives of twenty-one nations, including the United States, met in Vienna and agreed to cooperate in atmospheric research and monitoring of ozone levels. The United States, Canada, Norway, and Sweden supported a general worldwide CFC aerosol ban, but several other countries, including the members of the European Community, Japan, and the Soviet Union, were against such measures, and no agreement on curbing the use of CFCs was reached.

Then, in May 1985, Joseph Farman, a scientist from the British Antarctic Survey reported that detectors on the ground had for seven years been indicating the development each winter of a giant hole in the ozone layer over the Antarctic. Shortly thereafter, satellite observations confirmed the presence of the gigantic hole, the first frighteningly clear and direct evidence that the ozone layer was indeed breaking down at tremendously high rates: Observations in October 1985 indicated a loss of more than 50 percent of the ozone over the vast arctic region. The publicity given to the reports, coupled with a successful (in October 1985) lawsuit brought against the EPA by environmentalists who felt the EPA was moving too slowly, spurred the EPA into action, and on January 1986 it announced plans to regulate CFCs.

Industry reactions to the new discoveries and the EPA plans were protective. Speaking on behalf of the Alliance for Responsible CFC Policy, a group of CFC industry producers and users, chairman Richard Barnett downplayed the new observations, arguing that since ozone levels unexplainably returned to near normal over the Antarctic during springtime, it was still unclear what was going on in the stratosphere. In light of such uncertainties, he said, the CFC industry was being unfairly singled out for regulation. Moreover, he pointed out, even the models relied on by scientists pushing their ozone depletion theories suggested that there would be no significant change in total ozone for several decades.

DuPont decided to continue expanding its CFC production capacity in Japan, as it had announced it would do in 1985. Allied-Signal, the second-largest producer of CFCs, was reported to be planning to increase sales of CFCs to the expanding computer industry, which used CFCs to clean electronic parts. Other CFC producers continued with their plans to increase CFC production, especially in other parts of the world. DuPont and others, however, quietly decided to reactivate their research programs on alternatives to CFCs.

During the winter of 1986, a special scientific expedition to the Antarctic, funded in part by the chemical industry, once again recorded the return of the ozone hole in early September, its growth through the winter, and its gradual decrease and disappearance in early November. The scientists, reached no clear conclusions about its causes, but their report again alarmed people around the world.

Meanwhile, leaders of the CFC industry were changing their positions. On September 16, 1986, the Alliance for Responsible CFC Policy announced its support for "a reasonable global limit on the future rate of growth" of CFC production. On September 26, Joseph Glas, director of DuPont's Freon Products Division, released a letter to customers stating it was now DuPont's position that "it would be prudent to take further precautionary measures to limit the growth of CFCs worldwide."¹⁸ However, DuPont and other U.S. producers lobbied hard against any federal legislation that would limit American production of CFCs until there were international agreements placing similar global limits on producers outside the United States.¹⁹ The Reagan administration, through Interior Secretary Donald Hodel, suggested, moreover, that CFC reductions might not be necessary so long as people wore hats, sunglasses, and suntan lotion to ward off any increased ultraviolet rays.²⁰ Environmentalists pointed out that it would cost \$10 billion a year to provide glasses, hats, and suntan lotion for every American, ten times what it would cost to freeze CFC production for a decade, and that this would still leave wildlife unprotected since "its very hard to get fish to wear sunscreen."²¹

Stung by reactions to its lack of support for CFC limits, the Reagan administration in June 1987 came out in favor of international limits of CFC production as supported by the CFC industry. In September 1987, delegates from sixty-four nations, including the United States, met in Montreal, Canada, to negotiate an

international agreement on CFC production. On September 16, twenty-four of the nations attending, the United States among them, agreed to freeze CFC consumption at 1986 levels, beginning in 1989, and to cut consumption in half by 1996. A number of less developed nations, which account for about 15 percent of global consumption of CFCs, refused to go along with the agreement because of the critical role that CFCs play in their plans for economic development. Because of their refusal, and because of other exceptions to the agreements, global consumption of CFCs would be cut by only by about 35 percent by 1996, instead of the hoped-for goal of 50 percent reductions. Nevertheless, officials of KaiserTech and other CFC producers argued that the Montreal agreement would be "catastrophic" for their businesses.

Industry figures remained opposed to the complete termination of CFC production and, in fact, still urged gradual increases in production. Edwin E. Tuttle, chairman of Pennwalt, the third-largest U.S. manufacturer of CFCs, argued that ceasing production would "create economic chaos for the consumer," and "without far greater scientific justification . . . would . . . be irresponsible." Robert Traflet, president of Allied-Signal's Fluorine Products Division, assured Congress in May 1987 that "you'd feel very safe" with increased production rates of 3 percent a year. Elwood P. Blanchard, DuPont's executive vice president in charge of chemicals, suggested that annual production increases of 4 or 5 percent during the next 30 to 40 years would be tolerable and that ozone depletion should not "cause us concern" for "maybe a hundred years." EPA director Eileen Claussen, however, argued that "If CFC use continues to grow at 2.5 percent a year . . . the number of skin cancer cases in the United States would increase by 105 million and the number of early deaths by 2 million for those alive today and born through 2075." DuPont chairman, Richard Heckert, in a March 4 letter to Senator Stafford, stated that "scientific evidence does not point to the need for dramatic CFC emission reductions," and that suggestions that DuPont cease CFC production within a year were "unwarranted and counterproductive," since "there is no agreement within the scientific community on the potential health effects of any already observed ozone change."²²

In the winter of 1987, the frightening ozone hole over the Antarctic was again observed, this time larger and deeper than ever before. Researchers flying through the hole discovered the presence of ice crystals that seemed to have been speeding up the reactions that were depleting the ozone over the Antarctic. In the United States, an international panel of more than 100 scientists brought together as the "Ozone Trends Panel," was conducting an exhaustive survey and reevaluation of all the scientific data available to date on ozone depletion. The panel issued a report on March 15, 1987, stating that ozone levels worldwide had fallen 1.7 percent between 1969 and 1985, and that wintertime ozone levels were dropping 3 to 5 percent all over the world and as much as 6.2 percent over northern latitudes. Moreover, the panel of 100 scientists concluded, the presence of chlorine monoxide radicals inside the Antarctic hole was clear evidence that CFCs, together with atmospheric climatic factors, were responsible for ozone depletion.²³

The report sent a shock through DuPont executives who still held that there was little agreement within the scientific community about the ozone threat. Three days after the report was issued, DuPont's executive committee gathered at company headquarters in Wilmington, Delaware, to discuss the panel's findings. The committee closely questioned a DuPont staff scientist, Dr. Mack McFarland, who had served as a member of the panel, and Joseph Steed, a DuPont environmental manager, about the reliability of the report's findings. Both confirmed the report's conclusion that CFCs were the most likely cause of a worldwide decline in ozone to a level that had not been expected until early in the next century. Even if CFC production was cut by 50 percent by 1999, concentrations of CFC in the stratosphere would still climb to over five times the levels present the year the Antarctic ozone hole had first appeared. After intense discussions, the six-person committee came to the conclusion that DuPont would stop manufacturing CFCs by around the turn of the century. Six days later, on March 24, the committee announced the company's new CFC phase-out policy to the 2,000 employees involved in CFC production and to the press. DuPont's sales of CFCs that year were to total \$600 million, or 2 percent of its revenues, and contribute \$35 million to its profits. On the day of the announcement, DuPont's stock fell by \$3.13. DuPont officials stated that it was not clear whether any of the substitutes the company was researching were commercially viable or environmentally safe, that all of them would cost two to five times more than CFCs, and that it was uncertain whether losses of CFC sales revenues could be replaced by sales of alternatives. Other CFC producers did not follow DuPont's lead, although Penwalt, the third-largest CFC producer, released a statement on the same day, urging that CFC production be stopped as soon as

practical and committing itself to an eventual phase-out.

In December 1987, the EPA proposed regulations that would freeze CFC consumption in the United States at 1986 levels starting in 1989, and would reduce consumption by a further 50 percent by the end of the century, more or less in line with the Montreal agreements. The EPA estimated that the total social costs of its regulations would reach \$27 billion by 2075, but that if it failed to act, the costs in cancer deaths, medical expenses, damage to crops, materials, the fishing industry, and the effects of rising sea levels would reach \$6.5 trillion by 2075. Environmentalists criticized the EPA regulations, however, arguing that nothing short of a complete ban by the end of the century would be adequate. In 1989, twelve European Community nations agreed to a complete ban of all CFCs by the year 2000, a move that was endorsed by U.S. President Bush. In October 1990 Congress passed and President Bush signed the 1990 Clean Air Act, which required a complete end to the U.S. production of CFCs by the year 2000.

1990 world opinion and U.S. cooperation was partially due to the new records set by each of the ominous seasonal reappearances of the ozone hole over Antarctica in 1987, 1988, and 1989. While the 1988 hole was somewhat smaller than the record-breaking hole that developed in the winter of 1987, the 1989 hole broke all records. As early as August 1989, ozone within the hole had begun to decrease: The rate of ozone decline accelerated to about 1.5 percent per day during September, and by October 5, 1989, nearly half of the ozone over the Antarctic was gone. The hole has continued to reappear each year to this very day. Ozone-depleted air from the hole now migrates out of the Antarctica and is blown over other parts of the world. Ozone losses of 10 percent have been recorded over New Zealand, southern Australia, and other parts of the world.

Commenting on DuPont's change of heart in 1987, Senator Stafford of Vermont said simply, "I hope it isn't too late." Even if all CFC production were to stop tomorrow, the CFCs already released will continue to float upward and raise CFC concentrations in the stratosphere to one-and-a-half times present levels by the year 2000. They will remain there for 40 to 50 years, continuing their destruction of the ozone layer. Additional CFCs produced between now and the year 2000 will multiply and prolong this destruction. Further damage will be caused when inevitably each of us disposes or releases the CFC gases locked in the innards of each of our refrigerators, freezers, auto and home air conditioners, and the rigid foams insulating our walls. We have no idea how our world will change over the next fifty years.

1"Fluorocarbons and Ozone: New Predictions Ominous," Science News, 5 October 1974.