New Link Between Ozone and Cancer

New report halves estimates of ozone depletion by chlorofluorocarbons, but predicts much greater induction of cancer from increased UV

The reduction of the concentration of ozone in the stratosphere due to the release of chlorofluorocarbons will be only about half as serious as previously predicted, according to a new report from the National Research Council of the National Academy of Sciences.* The report also predicts that the biological effects of ozone depletion may be more severe than expected, particularly the effects on the incidence of skin cancer. Other evidence too new to be considered by the panel, though, suggests that other pollutants may further reduce the predicted depletion, but that there may be major rearrangements of the distribution of ozone in the upper atmosphere.

The new report is the fifth Academy report discussing the impact of chlorofluorocarbons, also known as CFC's, chlorofluoromethanes, or by the trade name Freons. The most important of these are CFC-11 ($CFCl_3$) and CFC-12 (CF_2Cl_2). The use of CFC's in aerosols was banned in 1977, but they are still widely used as refrigerants and as foaming agents for polymers. When they are eventually released to the atmosphere, their inertness to most biological processes allows them to be transported to the stratosphere where they are broken down by sunlight. Liberated chlorine catalytically destroys ozone, which acts as a shield against the sun's ultraviolet (UV) radiation.

The previous Academy report, issued in 1979 (*Science*, 7 December 1979, p. 1167), predicted an eventual ozone depletion of 18.6 percent if release of CFC's continued at the 1977 rate. The new report predicts a depletion between 5 and 9 percent. The steady-state depletion will not occur until late in the next century, and the projected value could be altered by other chemicals. If the concentration of nitrous oxide (from combustion, use of nitrogen fertilizers, and aircraft engine exhausts) in the atmosphere were to double—a situation that is not expected to occur for several hundred years—the total ozone depletion would be about 13 percent. Increasing concentrations of carbon dioxide in the atmosphere resulting from burning fossil fuels, in contrast, could counter ozone depletion somewhat by lowering stratospheric temperatures, thereby slowing certain reaction rates.

The differences between current predictions and those reported in 1979 reflect refinements in the rate constants for several reactions affecting the concentration of hydroxyl radical in the upper atmosphere. These refinements are the result of improved laboratory measurements of rate constants. The hydroxyl radical is important because the concentration of a key intermediate in ozone destruction, chlorine oxide, is particularly sensitive to it. The new rate constants bring predicted values of chlorine oxide concentrations below 35 kilometers into agreement with observed values. The rate constants used in the 1979 report had predicted chlorine oxide concentrations three times higher than observed values.

The report gives special emphasis to recent findings relating an increase in UV radiation to adverse health effects. It is well recognized that each 1 percent depletion in the concentration of stratospheric ozone will increase the amount of UV radiation that reaches the earth's surface by 2 percent. "It seems certain," the report says, "that more than 90 percent of skin cancer other than melanoma in the United States is associated with sunlight exposure and that the damaging wavelengths are in the UV-B region (290 to 320 nm)" most affected by changes in ozone concentrations.

As a result of recent studies, the panel estimated that there will be a 2 to 5 percent increase in the incidence of basal cell skin cancer for every 1 percent decrease in ozone concentration; there are currently between 300,000 and 400,000 cases of basal cell cancer in the United States each year. Each 1 percent ozone depletion will produce a 4 to 10 percent increase in the more serious squamous cell skin cancer; there are now about 100,000 cases of squamous cell cancer each year. These estimates are highly dependent on location, sex, skin type, life-style, and other variables, and the increase in cancer would obviously be much more severe in Dallas, for example, than in Minneapolis.

The situation with respect to the still more serious form of skin cancer known as malignant melanoma (15,000 cases per year) remains confused. The incidence of melanoma increases with decreasing latitude, suggesting that UV radiation is a contributing factor, but this contribution is confounded by occupational exposure and other factors. In the absence of appropriate animal models of melanoma, the panel concluded that it would be premature to make any predictions about the effect of increased UV radiation on incidence of melanoma.

A rather surprising new finding is that UV radiation can affect the immune systems of both animals and humans. A mild sunburn, for example, decreases the viability and function of circulating lymphocytes in humans for as long as 24 hours. In animals, otherwise tolerable doses of UV radiation can produce changes in allergic reactions, skin graft rejection, and other immune responses. Experiments in animals also show that UV-stimulated suppression of the immune system permits uninhibited growth of UV-induced skin tumors that would normally be rejected. Again, the panel concluded that it is premature to speculate about the effects of increased UV radiation.

It would appear that investigators are finally entering the homestretch in refining their understanding of the atmospheric effects of CFC's. "We are much more confident about most reaction rates than we were 2 years ago," says panel member Michael B. McElroy of Harvard University. Even critics of past reports concur. Joseph M. Steed of DuPont Company, who is chairman of the Fluorocarbon Program Panel sponsored by the Chemical Manufacturers Association (CMA), termed the report a "reasonable" summary of stratospheric science. The strongest criticism, in fact, was aimed not at the report, but at an Academy press release which, Steed says, "ignored the caveats surrounding the ozone depletion estimates as well as most of the other factors thought to affect ozone."

Nonetheless, there are still several problems that must be cleared up—many of which were discussed at the recent meeting of the American Chemical Soci-

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ety (ACS) in Las Vegas. One problem involves the detection of any existing changes in stratospheric ozone concentrations. The panel concluded that there is not yet conclusive evidence of any decrease in ozone concentrations attributable to human activities—despite recent reports (*Science*, 4 September 1981, p. 1088) that Donald Heath and his colleagues at the Goddard Space Flight Center have observed ozone depletions in measurements made by the Nimbus-4 and Nimbus-7 satellites. Heath has found that the concentration of stratospheric ozone has decreased about 0.5 percent per year during the past decade, while concentrations at lower altitudes have increased a similar amount. Heath's results have not yet been published (a paper is in press at *Science*), however, and the panel concluded that they must be classified as "preliminary." The total change in ozone concentration to date is expected to be less than 1 percent, and many scientists think that this is too small to be detected.

The report itself points out three potential problem areas: The observed concentration of chlorine oxide at altitudes above 40 kilometers is greater than predicted by the model; the behavior of nitrogen oxides in winter at near-polar latitudes is unexplained; and concentrations of CFC's in the stratosphere at altitudes greater than 20 kilometers are lower than predicted by the models.

The measurements of chlorine oxide in the upper stratosphere have been made with balloon-borne instruments operated by a team headed by James G. Anderson of Harvard University. In a series of seven flights, they observed concentrations of chlorine oxide averaging about twice the predicted value; an eighth flight, known as the Bastille Day flight because it took place on 14 July 1977, produced even higher results. These findings have been of great concern because they suggest a defect in the model.

At the ACS meeting, however, Robert L. de Zafra and his colleagues at the State University of New York at Stony Brook reported measurements of stratospheric chlorine oxide made with a ground-based millimeter-wave receiver. Some measurements that they made were comparable to those observed by Anderson, but the overall average concentration of chlorine oxide was much closer to the value predicted. At no time did they observe concentrations like those of the Bastille Day flight. Since they have made many more observations than Anderson, their results would appear to carry greater weight.

Another brouhaha apparently resolved at the ACS meeting involves the production of CFC-12. In the April issue of *Geophysical Research Letters*, F. Sherwood Rowland of the University of California at Irvine, one of the first investigators to suggest the possibility of ozone depletion resulting from CFC's, reported measurements of CFC-12 taken in January of each year in Oregon and at the South Pole. Extrapolating from these results, he concluded that production of CFC-12 has increased since 1974, contrary to production figures released by the CMA indicating a 20 percent decrease in production. Rowland accused the group of understating production figures.

At the ACS meeting, however, Ronald Prinn of the Massachusetts Institute of Technology reported results from the Atmospheric Lifetime Experiment, a large study of atmospheric concentrations of CFC's conducted by scientists at six institutions in the United States and England under the sponsorship of the CMA. More than 100,000 measurements of CFC concentrations (25,000 of CFC-12 alone) support the CMA figures for CFC-12 production. Since 1978, the atmospheric concentrations of CFC-11 and CFC-12 were observed to increase at annual rates of 5 and 6 percent, respectively. The concentration of methyl chloroform, another chemical relevant to the ozone problem, increased at an annual rate of 9 percent, while that of nitrous oxide increased 0.2 percent annually.

The trend observed for CFC-12 indicates that its lifetime in the atmosphere is in excess of 100 years, as assumed by theory. The trend for CFC-11, however, indicates an atmospheric lifetime of 54 years, much lower than the value of 75 to 80 years now used in the theory. These results, Prinn concludes, suggest either that stratospheric destruction is inadequately understood or that there exists an additional atmospheric sink for CFC-11.

A simpler explanation was offered by Aaron J. Owens and his colleagues at DuPont, who suggested that the fault lies in the one-dimensional models of the atmosphere typically used in the projections. They have found that destruction of CFC-11 increases at latitudes closer to the equator. Using a two-dimensional model that includes both altitude and latitude, they predict an atmospheric lifetime of 60 years for CFC-11, much closer to the observed value.

The chief deficiency of the Academy report, many scientists argue, is that it does not include any estimates of ozone depletion that include perturbations from other chemicals. These could include not only carbon dioxide and nitrous oxide,


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Do dumps ruin ozone?

Refrigerant leakage from cars, trucks, and buses is one way that chlorofluorocarbons are released into the atmosphere.

but also bromine (if sufficient sources exist) and perhaps even extraterrestrial sodium released by meteorites. Inclusion of these substances could change the projections substantially.

Donald J. Wuebbles, Fred Luther, and Joyce Penner of Lawrence Livermore National Laboratory reported new calculations that include some of these chemicals. Their model includes 133 chemical reactions and 43 different chemicals, and requires use of the laboratory's exceptionally powerful Cray computer. Their calculations indicate that CFC's and nitrous oxide may have destroyed about 4 percent of the ozone in the upper stratosphere during the last decade, but that other pollutants have added a nearly equal amount at lower altitudes—a conclusion in surprising agreement with Heath's observations. Projecting into the future, their calculations indicate that the total concentration of atmospheric ozone will decrease by less than 1 percent over the next 120 years, primarily because of increases resulting from carbon dioxide accumulation.

The picture they paint is not quite as optimistic as it would seem at first glance. Although overall concentrations of ozone would remain constant, concentrations at high altitudes would decrease substantially and concentrations at lower altitudes would increase by comparable amounts. The amount of UV radiation passing through the atmosphere might thus remain constant, but relatively large changes in temperature at different altitudes could have a significant effect on the world's weather. It would thus seem that the eventual resolution of the ozone problem will require a much better understanding of both atmospheric dynamics and the effects of carbon dioxide. It sometimes seems that the more we know, the more we need to know.—THOMAS H. MAUGH II