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TESTIMONY OF
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BEFORE THE

SUBCOMMITTEE ON SCIENCE, TECHNOLOGY, AND SPACE
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION

UNITED STATES SENATE

APRIL 16, 1991

Mr. Chairman and Members of the Subcommittee:

My name is Daniel L. Albritton. I am Director of NOAA's Aeronomy Laboratory in Boulder, Colorado, which studies the chemistry and dynamics of the Earth's atmosphere. Scientists of our Laboratory have played major roles in the recent advances in ozone science. I have also been involved in providing scientific advice to policymakers during this period. Therefore, I appreciate the invitation to present testimony to describe the current scientific understanding of stratospheric ozone and its relation to the policy decisions that lie ahead.

The key points that I will cover are: (1) the background to the stratospheric ozone issue; (2) the first world response, i.e., the 1987 Montreal Protocol; (3) the intensive research of the period that followed the Protocol; (4) the 1990 Amendments to the Protocol based on that the research; and (5) the scientific questions that we still face. As you requested, my remarks will be aimed at providing the context for the testimonies that follow.

A. Background

As you well know, the issue of stratospheric ozone depletion by man-made chlorine-containing compounds was first raised in 1974. In 1979, the United States banned the sale of chlorofluorocarbons (CFCs) in aerosol spray cans, since a thinner ozone layer would imply an increase of harmful ultraviolet radiation at the Earth's surface.

In the years that followed, a major emphasis in stratospheric research was the building of a better theoretical understanding of stratospheric processes and a testing of that understanding by ozone monitoring and other observations. By the mid-1980s, theoretical models were predicting that about 1 percent global ozone depletion should be occurring by then (1985) and that, if CFC emissions continued to grow, ozone depletion would very likely grow to several percent in the next century. Furthermore, it had become clear that (1) there were growing uses of other ozone-depleting compounds, such as the bromine-containing halons used in fire extinguishers; and (2) the CFCs were also particularly efficient "greenhouse" molecules and hence related significantly to the global warming issue.

While the ozone monitoring record and analysis in 1985 could not say whether the predicted 1 percent ozone loss was actually occurring or not (the natural variation is 2 - 3 percent), the implications of this growing understanding sounded a call for new action. That call was answered with an unprecedented recent international accord regarding these compounds.

B. The 1987 Montreal Protocol

On Wednesday, 16 September 1987, the United Nations adopted the "Montreal Protocol on Substances That Deplete the Ozone Layer". The contracting parties were required to take specific actions regarding certain man-made chlorine- and bromine-containing chemicals, i.e., the CFCs and halons.

In short, the Protocol required (1) an early freeze on the usage of several CFCs, (2) a phased reduction in their production that leads to an eventual 50 percent decrease by the year 2000, and (3) a freeze (later than that of the CFCs) on the production of halons. These features of the Protocol reflect the scientific understanding of how chlorine and bromine influences stratospheric ozone:

- <u>CFCs</u>. From a scientific perspective, any regulatory policy should consider all of the fully halogenated chlorine-containing compounds, which are characterized by high Ozone Depleting Potentials (ODPs), as a group for the purposes of regulation. The Montreal Protocol did indeed include the major CFCs in its chemical scope.

- <u>Halons</u>. Bromine compounds are about ten more effective than chlorine in destroying ozone, as reflected by their high ODPs. The Montreal Protocol also included the major halons in its chemical scope.

- <u>Long Equilibrium Times</u>. The CFCs and halons have long atmospheric residence times; therefore, their stratospheric abundances would continue to grow for many decades, even if their emissions were to plateau or be reduced. Hence, from the standpoint of limiting the maximum concentrations of chlorine and bromine in the stratosphere, emission reductions done earlier need not be as severe as those done much later. This is consistent with the Montreal Protocol's attempt to get a freeze on emissions as early as possible.

The Montreal Protocol was extremely important step forward in the ozone/chlorine-science/policy issue. It was both a specific start and a malleable document. With regard to the latter, the Protocol requires that its provisions be revisited periodically for adequacy in light of new scientific and technical knowledge. To provide that input, the Protocol established the preparation of periodic scientific and technical reports, sponsored by the United Nations Environment Programme and the World Meteorological Organization.

The first of these reports,"Scientific Assessment of Stratospheric Ozone: 1989" was the product of an international group of over 100 scientists. It focused on the new advances that had occurred since the Montreal Protocol was crafted, namely, the discoveries made since 1986. The period 1986 - 1990 proved to be an extremely fruitful one regarding our understanding of the ozone layer.

C. Stratosphere Ozone: 1986 - 1990

(1) <u>Research Efforts</u>

There were four principal efforts that focused on making major advances in the understanding of stratospheric ozone:

- International Ozone Trends Panel: 1988. During 1987 and early in 1988, an international group of ozone researchers re-examined all of the existing ozone trends data, examined these improved data sets for systematic ozone trends, and compared those trends to those predicted for natural (e.g., solar variations) and man-made (e.g., CFCs) causes.

- Antarctic Ozone Campaigns: 1986 - 1987. While the Antarctic ozone "hole" had been discovered at the time the Montreal Protocol was being prepared, the cause of this dramatic seasonal ozone depletion in the Antarctic stratosphere was not then known. Indeed, theories were proposing at that time a variety of possible causes, ranging from natural to man-made influences. To address this remarkable phenomena, the National Ozone Expeditions I and II took instruments to McMurdo Station in Antarctica to observe the ozone changes in 1986 and 1987. In addition, the Airborne Antarctic Ozone Experiment used high-flying research aircraft from a base at Cape Horn to probe the stratosphere over Antarctica.

- Arctic Ozone Campaigns: 1988/89. Although no "hole" comparable to that over Antarctica had been identified over the Arctic, the findings from the Antarctic expeditions posed questions about the northern regions that required addressing. This was done in 1988 with limited aircraft flights to Alaska and ground-based measurements from Greenland. These were followed by a large-scale aircraft campaign, the Airborne Arctic Stratosphere Experiment, which was based out of Norway in the winter of 1989/90.

- Laboratory Studies of Chemistry on Particles. Most atmospheric studies had focussed on chemical reactions between gases. Reactions that occur on surfaces were much more difficult to examine. Yet, the recognition of the potential importance of such surface-enhanced reactions was growing. Innovative laboratory methods were developed and greatly expanded the information available.

These "ozone years" have been the most intensive period of ozone research to date. Thanks to the prodigious efforts of a large fraction of the ozone research community, the results have been phenomenal. They have changed our view of the stratosphere and have set stratospheric research on to a new course.

(2) Major Findings

There were four major findings from this period regarding the impact of human activities on the Earth's protective ozone layer. Each heightened the concern that chlorine- and bromine-containing chemicals can lead to a significant depletion of stratospheric ozone:

- Cause of the Antarctic Ozone "Hole". Scientists concluded that chlorinated (largely man-made) and brominated chemicals are primarily responsible for the decreases of stratospheric ozone over Antarctica in springtime. The ozone loss is accelerated in this region in comparison to elsewhere by chemical reactions that occur on the surfaces of polar stratospheric clouds that shift the chlorine compounds into a more reactive form.

- Long-Term Global Ozone Decreases. The re-analysis of data from ground-based ozone networks show downward trends that cannot be accounted for by any known natural causes. Specifically, after accounting for solar variation and systematic atmospheric-circulation effects, these ground-based data showed downward trends from 1969 to 1988 of 3 - 5 percent (i.e., 1.8 - 2.7 percent per decade) in the northern hemisphere (30 - 64{N latitudes) in the winter months. This decrease is larger by factors of two to three than the chlorine-induced decreases predicted by our current theoretical models. **The cause of this decrease is one of the most important remaining questions in stratospheric ozone research.**

- Perturbed Arctic Chemistry. The 1989 expedition to Norway demonstrated that enhancements of ozone-depleting chlorine species also occur in the Arctic stratosphere. Thus, at the end of the winter night, the Arctic is "primed" for ozone loss. Whether ozone destruction occurs with the arrival of sunlight depends on whether the Arctic is warming (no loss) or remains cold and isolated (ozone loss) for a period of weeks (as the Antarctic routinely does). Therefore, the degree of any future Arctic ozone depletion will depend on the particular meteorology of each Arctic winter, as well as the future increases in chlorine and bromine abundances.

- Surface-Enhanced Chemical Processes. Laboratory studies demonstrated that the reactions on the surfaces of ice particles, as well as on those of the background particles in the global stratosphere, were fast and could shift chlorine compounds to a more reactive form.

(3) Implications

The results from the ozone research over these years had several major implications as input to public policy decisions regarding restrictions on man-made substances that lead to stratospheric ozone depletion:

- Observed CFC-Induced Ozone Losses. The scientific basis for the 1987 Montreal Protocol was the theoretical prediction that, should CFC and halon emissions continue to grow, there would eventually be substantial ozone depletion. Recent research has demonstrated that actual ozone loss due to the CFCs has already occurred, i.e., the Antarctic ozone "hole ", albeit in a unexpected place and fashion.

- Continuing Predictions of Future Ozone Losses. Even if the control measures of the 1987 Montreal Protocol were to be implemented by all nations, today's atmospheric abundance of chlorine of about 3 ppb (parts chlorine in a billion parts of air) would still at least double to triple during the next century, yielding large predicted ozone losses.

- Potentially Underestimated Ozone Losses. The fact that the downward ozone trends up to 1988 from the ground-based data at mid-latitudes were larger than those predicted for that time has led to the speculation that the models do not contain all important ozone-losses processes. The speculations were twofold: The surface chemistry that causes the ozone depletion in Antarctica due to the presence of polar stratospheric clouds could be occurring on the background layer of particles naturally present in the stratosphere. Furthermore, the poles could be acting as "chemical processors" that could be influencing the atmosphere well outside of polar regions. Hence, future global ozone depletions could well be larger than originally predicted, if such processes were significant and if models could correctly incorporate them.

- <u>Eliminating the Antarctic ozone "hole"</u>. Large-scale ozone depletions in Antarctica appear to have started in the late 1970s and were initiated by atmospheric chlorine abundances of about 2 ppb, compared to today's level of about 3 ppb. Therefore, to return the Antarctic ozone layer to levels approaching its natural state, one of the limited number of approaches available is a complete phase out of all long-lived CFCs, halons, and carbon tetrachloride, as well as careful considerations of the shorter-lived compounds such as methyl chloroform and the CFC replacements. Otherwise, the Antarctic ozone "hole" is expected to remain indefinitely, assuming that the present meteorological conditions continue. For example, it is estimated that the earliest that the Antarctic ozone "hole" could be "repaired" is roughly the year 2075. This estimate would require that (1) the above long-lived compounds would be phased out as early as possible and, (2) the shorter-lived compounds would be phased out in time for the atmospheric processes to purge them from the atmosphere by 2075.

D. The 1990 London Amendments to the Montreal Protocol

Based on these findings and their implications, the contracting parties to the Montreal Protocol chose to strengthen its provisions substantially when they met in London during the summer of 1990. The high points of those new provisions are the following:

- <u>CFC elimination</u>. A faster step-wise reduction in production, leading to a complete phaseout of the CFCs by the year 2000.

- <u>Halon elimination</u>. A faster step-wise reduction in production, leading to a phaseout by the year 2000, except for essential uses.

- <u>Inclusion and elimination of other substances</u>. A step-wise reduction, leading to a phaseout of carbon tertrachloride and methyl chloroform by the years 2000 and 2005, respectively.

Several chemical compounds that have lower ODPs and relatively short atmospheric residence times may have significant value as CFC replacements. These compounds are not excluded under the London Amendments, but are identified as "transitional substances". The label implies that they will be closely scrutinized with regard to their ODPs, as well as their other possible environmental effects, such as contributions to the "greenhouse" issue.

The U.S. Clean Air Act Amendments of 1990 included a section on stratospheric ozone protection. It requires generally the same type of reductions as the amended Montreal Protocol, but also puts "sunset" dates on the CFC and halon replacements, depending on their ODPs.

E. Remaining Scientific Questions

While the ozone research of the past few years has provided remarkable results on which amendments to the Montreal Protocol and the Clean Air Act were crafted, it would be incorrect to imply that we understand all that we need to. Even with the most stringent and economically painful efforts:

(1) the chlorine abundance in the stratosphere will still reach perhaps 4 - 5 ppb by the turn of the century,

(2) that peak abundance could persist if the CFC replacements are widely used, rather than phased out globally,

(3) the chlorine abundance will not drop to the 2 ppb required to eliminate the Antarctic ozone "hole" for about 75 years, and

(4) the return to natural levels lies centuries away.

Should we be worried about this state of affairs, or does the fact that we have reduced emissions mean that there is no reason to continue to pose questions? Two observations are relevant:

- o We have created a new global feature, the Antarctic ozone "hole", that will be with us for about a century. While we think we know how we did it, we cannot yet forecast the consequences of our creation. There are several open questions:

  - What does a century of seasonal ozone losses imply for the effects of ultraviolet radiation on Antarctic fauna?

  - What are the climatological implications (temperature and circulation patterns)?

  - Does the ozone "hole" leak, i.e., what are the implications for nearby countries like New Zealand?

  - With ozone loss linked to stratospheric ice particles (and hence temperature and climate), what does the climate variation of the next century imply for ozone loss?

- o The peak chlorine levels of 4 - 6 ppb will persist for at least a decade. We were caught unaware by the appearance of the Antarctic ozone hole at about 2 ppb some years ago. How confident are we that there are no surprises in store in the 3 - 6 ppb range?

  - What will be the amount and frequency of springtime ozone loss in the Arctic?

  - What will be the effect of midlatitude aerosols on global ozone loss?

  - How well do we understand the Ozone Depletion Potentials of the CFC replacements and the Halons?

As the dialogue between science and policy heightens regarding the 1992 reassessment of the adequacy of the Montreal Protocol Amendments and the implementation of the Clean Air Act Amendments, policy will rightly ask science for the answers to these questions. These answers will require a better fundamental understanding of, for example, the couplings of meteorology and chemistry, which is a challenging task.

Nevertheless, the fundamental understanding of natural processes that relate to the well-being of mankind are almost always cost-effective. For example, comparison of the cost of a Salk/Sabin vaccine for polio to the economic and human costs of life in an iron lung teaches us what can be achieved when the cause of a thing is truly understood. Regarding our environment and what it means to us all, it is the price of ignorance that we cannot afford.

Mr. Chairman, this concludes my prepared remarks. I would be pleased to answer any questions that you or the members of the Subcommittee may have.