Consensus and Uncertainties

The Environmental Effects of Nuclear War

By Sir Frederick Warner

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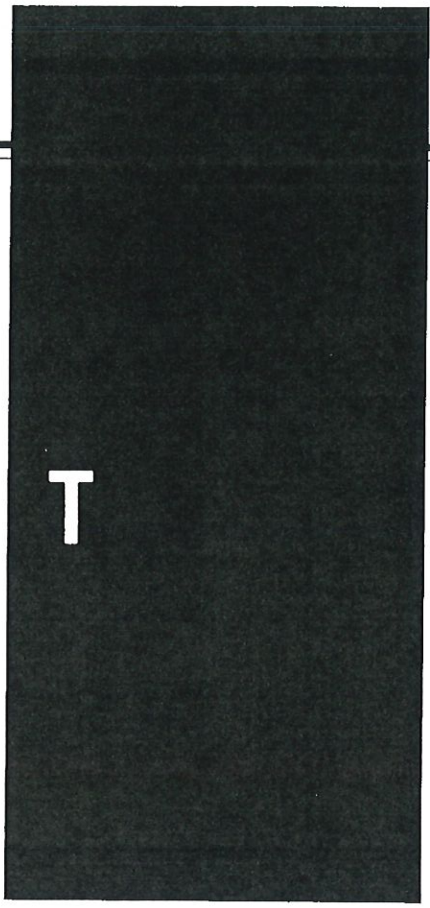
Earlier this year an international effort to estimate the environmental consequences of nuclear war completed a five-year period of unprecedented scientific cooperation. Having recorded wide consensus on the possible effects on ecosystems and people, the effort entered a new phase. At a March workshop in Moscow, the Scientific Committee on Problems of the Environment (SCOPE) terminated its coordinating activities for a wide field of research that will now go forward under a variety of auspices.

The ending of SCOPE's study on the environmental consequences of nuclear war (ENUWAR) marks a major initiative in international science in the tradition of the International Geophysical Year and heralds the developing International Geosphere-Biosphere Programme. The SCOPE ENUWAR study began with a workshop in Stockholm in November 1983 and continued in New Delhi, Leningrad, Tallinn, Delft, Paris, Hiroshima, Essex, Toronto, Caracas, Melbourne, London, and Essex before bringing a draft report to Washington, D.C., in July 1985. This was published in two volumes as SCOPE 28[1] early in 1986 along with a shorter version written for a general audience.[2] Since then, additional workshops have been held in London, Bangkok, Geneva, and Moscow. The reports in this issue of *Environment* summarize much of the thinking through the time of the Moscow meeting.

The work was guided throughout by a steering committee of leading scientists from eight countries and the International Council of Scientific Unions (ICSU), including Paul Crutzen, whose original paper with John Birks in *Ambio*[3] identified smoke arising from a nuclear exchange as a profound influence upon climate. This paper prompted SCOPE at its 1982 Ottawa general assembly to endorse a larger study. The endorsement was followed by a declaration of concern made at the 150th anniversary celebrations of the Pontifical Academy of Sciences by those present.

The thesis was simple: smoke cuts off sunlight; the Earth receives less energy and cools; a temperature inversion results and remains stable for some time, interfering with normal weather pat-



terns and accumulating pollution beneath it. This thesis was taken up and incorporated into a one-dimensional model of the atmosphere in the famous TTAPS paper (by Richard Turco, Brian Toon, Thomas Ackerman, James Pollack, and Carl Sagan)[4] and in a paper from the Soviet Union by Vladimir V. Aleksandrov and Georgi L. Stenchikov.[5] These papers, debated in a television hook-up between scientists in Washington, D.C., and Moscow in October 1983, awakened public interest in "nuclear winter." The ENUWAR work began with the University of Essex providing offices and the Royal Society of London supplying finance. This was supplemented by support from national academies in different countries—the Royal Swedish Academy, the Indian National Science Academy, the Royal Society of London, the Soviet Academy of Sciences, the Koninklijke Nederlandse Akademie van Wetenschappen, the French Academy of Sciences, the Science Council of Japan/United Nations University, the National Research Council of Canada, the Consejo Nacional de Investigaciones Cientificas y Technologicas in Venezuela, and the Royal Society of Victoria in Australia—for the workshops and by generous donations from the Carnegie Corporation, the General Service Foundation, the Andrew W. Mellon Foundation, the W. Alton Jones Foundation, the MacArthur Foundation, the Rockefeller Brothers Fund, and the Joseph Rowntree Trust as well as from the French Ministry of the Environment, SCOPE, and its parent organization, ICSU.

At the Stockholm 1983 workshop, the draft report[6] of the World Health Organization (WHO) on the immediate medical effects of nuclear war—with its forecast of 100 million to 1,000 million prompt deaths—was available. SCOPE decided to carry out its studies using updated assumptions about weapon exchange that were similar to those of earlier studies by the U.S. National Academy of Sciences,[7] Office of Technology Assessment,[8] *Ambio*,[9] and TTAPS.[10] These assumptions were generally endorsed in the 1985 U.S. National Research Council report on the atmospheric effects of a nuclear exchange.[11] The Stockholm discussion defined the boundaries for the ENUWAR study as the findings of WHO, on the one hand, and, on the other, the effects on living systems including agriculture, but it left societal effects for study by social scientists.

From the initial studies with their estimates of climatic effects, succeeding developments have shown the complexities that can arise. Many of these have been addressed in the more refined interactive models requiring the largest computers available. To do this, the continuing work on atmospheric modeling has been slightly interrupted to make computer time available for model improvements needed for ENUWAR studies. These intercepts in their turn have contributed to the basic understanding that is the objective of climatic research.

The studies can have no end, but this issue of *Environment* provides a summary of the conclusions warranted at the time of the Moscow meeting of the present state of understanding and the

Major Conclusions from the 1986 SCOPE ENUWAR Report

The SCOPE ENUWAR Steering Committee drew the following general conclusions from the group's earlier work on the environmental consequences of nuclear war:

1. Multiple nuclear detonations would result in considerable direct physical effects from blast, thermal radiation, and local fallout. The latter would be particularly important if substantial numbers of surface bursts were to occur since lethal levels of radiation from local fallout would extend hundreds of kilometers downwind of detonations.
2. There is substantial reason to believe that a major nuclear war could lead to large-scale climatic perturbations involving drastic reductions in light levels and temperatures over large regions within days and changes in precipitation patterns for periods of days, weeks, months, or longer. Episodes of short term, sharply depressed temperatures could also produce serious impacts—particularly if they occurred during critical periods within the growing season. There is no reason to assert confidently that there would be no effects of this character and, despite uncertainties in our understanding, it would be a grave error to ignore these potential environmental effects. Any consideration of a post-nuclear-war world would have to consider the consequences of the *totality* of physical effects. The biological effects then follow.
3. The systems that currently support the vast majority of humans on Earth (specifically, agricultural production and distribution systems) are exceedingly vulnerable to the types of perturbations associated with climatic effects and societal disruptions. Should those systems be disrupted on a regional or global scale, large numbers of human fatalities associated with insufficient food supplies would be inevitable. Damage to the food distribution and agricultural infrastructure alone (i.e., without any climatic perturbations) would put a large portion of the Earth's population in jeopardy of a drastic reduction in food availability.
4. Other indirect effects from nuclear war could individually and in combination be serious. These include disruptions of communications, power distribution, and societal systems on an unprecedented scale. In addition, potential physical effects include reduction in stratospheric ozone and, after any smoke had cleared, associated enhancement of ultraviolet radiation; significant global-scale radioactive fallout; and localized areas of toxic levels of air and water pollution.
5. Therefore, the indirect effects on populations of a large-scale nuclear war, particularly the climatic effects caused by smoke, could be potentially more consequential globally than the direct effects, and *the risks of unprecedented consequences are great for noncombatant and combatant countries alike.*

A new perspective on the possible consequences of nuclear war that takes into account these findings is clearly indicated.

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gaps, particularly in studying agricultural systems in different countries, that need to be filled. The summaries have provided a useful basis for the study group appointed to report to the United Nations Special Assembly on Disarmament (for a summary, see page 42) and for continuation of the ENUWAR national case studies.

There may be criticisms that the results are purely hypothetical, incapable of being checked by experiment, and subject to too many uncertainties in the mechanisms and in the way smoke may persist. Those who have been engaged in the continuing studies are naturally conscious of these criticisms and have been driven to refine and explore more deeply their assumptions, subjecting these to sensitivity analysis in order to judge whether or not the picture can be relied on even with many uncertain features.

The major conclusions have stood the test of time, although the details are still susceptible to change. As noted by Richard Turco and Georgi Golitsyn (see page 8), the cutting off of sunlight was first associated with the dust thrown up in nuclear explosions, before the greater role of elemental carbon in black smoke from burning materials in cities—dry wood, plastics, bitumen, oil, chemicals—was identified. The effects of black smoke were reckoned to outweigh the effects of dust or grey smoke from surface bursts and forest fires. The physics of smoke particles has recently received renewed attention after several research aircraft measured the actual effect of an experimental chaparral fire in California. Historical studies of forest fires in Siberia have confirmed a significant effect, as have the palace records in China of dust storms and crop yields. More evidence from wildfires in North America is also emerging.

In the development of atmospheric models, the study of fire plumes from individual cities was raised at the Leningrad workshop in 1984 and focused work on study of the intermediate region, or mesoscale, using a basic 1-kilometer grid in place of the 100-kilometer cells in general use for atmospheric modeling. These studies now in-

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dicate that the intense upward air currents that could develop in fire plumes could lead to the injection of smoke into the upper troposphere (5 to 10 kilometers in altitude) and even into the stratosphere. The interactive models show that the tropopause (the border between the stratosphere and troposphere) may be depressed by several kilometers in the Northern Hemisphere. Such changes would have profound consequences for the persistence of smoke, its removal from the regions where clouds and moisture could otherwise cause it to be removed, and the possibility of distribution in the stratosphere and transference to the Southern Hemisphere. The changing of the global circulation pattern is also projected to induce substantial perturbation to the stratospheric ozone layer, as are the effects of nitrogen oxide injections; this area is just beginning to receive needed attention.

Using the more refined three-dimensional models, it has been possible to examine the effects on climate of a range of smoke amounts and smoke optical properties. These have confirmed the predictions that the smoke produced by the burning of the majority of cities in the combatant nations could lead temperatures to drop by as much as 15° to 30° C for days to weeks in some regions during the Northern Hemisphere summer, when growing crops are most susceptible to damage. The prediction in early models of diminished light and energy had been based on the classical Mie theory of optical depth. This approach is now being challenged by work developed on the properties of fractal smoke and the way it ages under different moisture conditions. The present thinking is that smoke particles have nearly five times the absorption capacity assumed in initial studies, that this capability can persist through aging processes, and that by the lofting effect the particles can be carried out of the region where dry deposition and precipitation scavenging can occur. However, as smoke has become darker, estimates of smoke production have moderated. Taken together, the latest results generally confirm initial estimates of potential absorption optical depth.

The accident at the Chernobyl nuclear reactor provides an important opportunity to test our understanding of other important aspects of the problem. As Helen ApSimon and her colleagues show (see page 17), it is now possible to provide more evidence of actual air movements on a continental scale from study over the last two years of the dispersion of the radioactive particles emitted from Chernobyl. This matter received special attention in Moscow, along with estimates of ionizing radiation following a nuclear war. Alexander Leaf and Takeshi Ohkita (see page 36) and Charles Shapiro (see page 39) review the new knowledge about radiological effects.

The overall results of ecological effects studies, as reviewed by Mark Harwell and Ann Freeman (see page 25), are largely unchanged from the initial results reported in the second volume of SCOPE 28. That is, the climatic and economic-societal consequences of a major nuclear war could put a majority of the world's population at risk of starvation. Detailed understanding of the effects on agricultural yields of changes in temperature,

A Message of Hope for a Missing Colleague

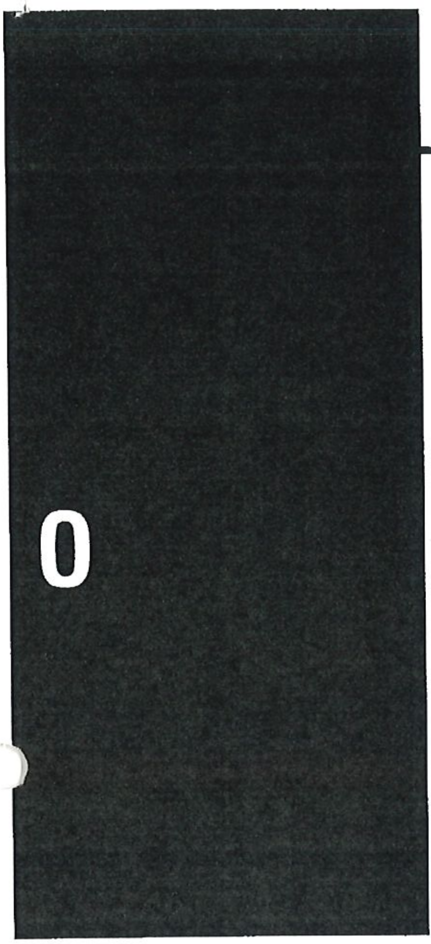
Vladimir Aleksandrov was among the first scientists to carry out global simulation studies of the "nuclear winter" effect. In his presentation at the 1983 conference in Washington, D.C., and later before the U.S. Congress and at numerous forums around the world, Vladimir, then head of the climate modeling section of the Computing Center of the USSR Academy of Sciences, convincingly described the severe climatic perturbations that could result from a major nuclear war. His work contributed significantly to the international scientific consensus that emerged as part of the SCOPE ENUWAR project.

On April 1, 1985, just as the ENUWAR consensus was solidifying, Vladimir mysteriously disappeared in Madrid, Spain, while returning home from an international conference on nuclear-free zones in Córdoba. Despite long and continuing inquiries as to his whereabouts, Vladimir Aleksandrov is still listed by the Soviet government as "missing without explanation."

Five days before the third anniversary of his disappearance, Moscow ENUWAR workshop participants Michael MacCracken and Alan Robock, together with Vladimir's colleague Georgi Stenchikov and his wife and daughter, had a poignant reunion with Vladimir's wife, Alia, and 18-year-old daughter, Olga. The visit brought both sorrow and joy. For Alia and Olga, the sudden, unexplained disappearance of Vladimir is still painful, leaving a "hole in the heart." But the evening also provided an opportunity to renew friendships and was reminiscent of earlier and happier times when Vladimir and Alia had hosted or visited with scientists from around the world.

As the evening concluded, Alia confided that she and Olga manage to go on by remembering an old Russian proverb, "Hope is the last thing to die." They asked that this final SCOPE ENUWAR report convey to Vladimir, wherever he may be, their continuing dream, and that of the ENUWAR project participants, that he may soon return.

—Michael C. MacCracken and Alan D. Robock



light, and rainfall is increasing as individual countries have initiated or planned case studies, especially in India, China, Venezuela, Australia, and sub-Saharan Africa.

The studies confirm what was said in the foreword to SCOPE 28: indirect effects could be greater than direct effects of nuclear war, with unprecedented consequences for noncombatant and combatant countries alike. There still remain, however, great gaps in the knowledge of how large-scale changes in the physical environment affect crops and ecosystems. Little is known about the longer-term atmospheric effects, which are controlled by the interaction of oceans and land, or about changes in atmospheric chemistry. Because the largest crops and stocks are located on the continental land masses, much more study is needed. Such study would be enhanced by the linking of models at different spatial scales, as suggested by Thomas Ackerman and Wendell Cropper, Jr. (see page 31).

The formal SCOPE ENUWAR program has now been concluded, although the various national case studies will need more time for evaluation. Our conclusions will need to be reassessed from time to time, particularly if fundamental changes occur that affect the scenarios used for nuclear exchange. The discussions on arms limitation are an obvious example. The agreement on the Intermediate-Range Nuclear Forces (INF) Treaty has been considered, but it involves only 2 percent of the weaponry and does not affect the conclusions even in the European area where the weapons at or above current levels might have been detonated. An agreement to reduce the arsenals by 50 percent would call for re-examination of the assumptions, but there seems little likelihood that substantial reductions in smoke emissions or consequent environmental perturbations would occur, so long as the burning of cities and major industrial installations remains as an element in nuclear war strategy.

NOTES

1. A. B. Pittock, T. P. Ackerman, P. J. Crutzen, M. C. MacCracken, C. S. Shapiro, and R. P. Turco, *Environmental Consequences of Nuclear War: Volume 1—Physical and Atmospheric Effects* and M. A. Harwell and T. C. Hutchinson, *Volume 2—Ecological and Agricultural Effects*, SCOPE 28 (Chichester and New York: John Wiley & Sons, 1986).
2. Lydia Dotto, *Planet Earth in Jeopardy: Environmental Consequences of Nuclear War* (Chichester and New York: John Wiley & Sons, 1986).
3. P. J. Crutzen and J. W. Birks, "The Atmosphere after a Nuclear War: Twilight at Noon," *Ambio* 11(1982):114–25.
4. R. P. Turco, O. B. Toon, T. P. Ackerman, J. B. Pollack, and C. Sagan, "Nuclear Winter: Global Consequences of Multiple Nuclear Explosions," *Science* 222(1983):1283–92.
5. V. V. Aleksandrov and G. L. Stenchikov, "On Global Consequences of Nuclear War," *Journal of Computing Mathematics and Mathematical Physics* 24, no. 1(1984):140–43.
6. World Health Organization, *Effects of Nuclear War on Health and Health Services*, Report no. A36/12 (Geneva: WHO, 1983).
7. U.S. National Research Council, *Long-Term Worldwide Effects of Multiple Nuclear-Weapons Detonations* (Washington, D.C.: National Academy Press, 1975).
8. U.S. Congress, Office of Technology Assessment, *The Effects of Nuclear War* (Washington, D.C.: U.S. Government Printing Office, 1979).
9. J. Peterson and D. Hinrichsen, eds., "Nuclear War: The Aftermath," *Ambio* 11(1982):75–176.
10. Turco et al., note 4 above.
11. U.S. National Research Council, *The Effects on the Atmosphere of a Major Nuclear Exchange* (Washington, D.C.: National Academy Press, 1985).