LETTERS

Antisatellite Weapons

R. Jeffrey Smith, in his article of 14 October (News and Comment, p. 140), quotes a remark of mine (incorrectly attributed to Robert Buchheim) about using rockets, balloons, and aircraft to supplant U.S. photoreconnaissance and meteorological satellites, thereby eliminating "the benefit to the Soviet Union from destruction of those satellites." He also quotes me as saying that, if the satellites were destroyed, "we would not be without information," and that " '[i]f it cost you a million dollars per flight and you had to do this for 100 days it would be nothing' . . . compared with losing an Army division."

These brief excerpts are accurate, but readers might misunderstand my views, long presented to congressional committees and in my writings.

1) I would regard the destruction of U.S. satellites in peacetime by the Soviet Union as a casus belli. For many years I have worked to preserve both principle and reality of satellite invulnerability.

2) During nonnuclear war (that is, absent attacks by the Soviet Union on the U.S. homeland and vice versa), the Soviet Union might have an incentive to attack U.S. satellites if they were aiding in a conventional war in Europe. It is in this context that I advocate supplementing (not supplanting because the worldwide satellite capability would not be destroyed in this case) satellite capability with drone aircraft carrying radar, photographic equipment, and the like, and (indeed) penetrating active enemy territory. The "balloons," and the "meteorological rockets" would be confined to NATO territory in order to provide the equivalent of Navstar and weather satellites for the European theater, and would do as good a job.

In central strategic war, not only would low-altitude satellites be vulnerable even to the limited Soviet ABM system, but their utility would be eliminated by virtue of attacks on their ground stations.

I continue to believe that the U.S. national security would be improved by serious and urgent negotiations to ban antisatellite weapon capabilities and weapons in space, responding to the Soviet initiative on banning the use of force in space of August 1983.

RICHARD L. GARWIN
IBM Thomas J. Watson Research Center, Post Office Box 218, Yorktown Heights, New York 10598

EPA's Studies of the Greenhouse Effect

A recent study of the greenhouse effect by the Environmental Protection Agency (EPA), *Can We Delay a Greenhouse Warming? (1)*, concludes that significant global warming throughout the next century is likely and that fossil fuel policies designed to slow the rate of warming will not be effective until 2050 or later. Three separate items in recent issues of *Science* bear directly on this study. Since each raises important issues regarding its assumptions or conclusions, a response is in order.

The first item is an editorial by Philip H. Abelson (25 Nov., p. 879), in which he expresses considerable optimism about society's ability to reduce CO_2 emissions. He bases this optimism on the "static" level of CO_2 emissions over the last decade, the promise of research on ways to remove CO_2 from flue gases, and hopes of greatly expanding the world's use of biomass fuels. We see nothing in the historical record or in the emergence of either CO_2 control technologies or alternatives to fossil fuels that would allow us to share this optimism.

Although informed investigators can and do differ on the expected rate of CO_2 increase, both the EPA report and a report by the National Research Council (*2*) underscore the immense difficulty of changing emission trends. New, lower CO_2-emitting fuels are likely to take at least 50 years to significantly penetrate energy markets, and CO_2 control technologies currently suffer from major technical uncertainties and enormous economic burdens. We agree with Abelson that "careful monitoring" of CO_2 and "efforts to develop contingency alternatives" are sorely needed. But we are not hopeful that strategies which rely on market-based fuel substitutions or the emergence of CO_2 control technologies will be effective in significantly delaying a greenhouse warming.

The second item is a letter from A. M. Perry (9 Dec., p. 1072). Perry agrees with our projections of temperature rise during the first half of the next century (roughly 2°C), but questions whether a rise as high as 5° to 10°C "from full exploitation of the world's recoverable resources of fossil fuels" is even a reasonable speculation (we estimated a total rise of 5°C—3.1°C due to CO_2 alone—by 2100). Perry argues that policies to limit fossil fuels might be both effective and practical. He also takes issue with our assumptions about the growth of greenhouse gases other than CO_2. He points out that (i) these gases (CH_4, N_2O, CFC-11, and CFC-12) are responsible for most of the projected temperature rise in our lowest CO_2 scenarios, (ii) the effect of these gases on temperature is uncertain, and (iii) some of the gases may be subject to control.

First, we agree that policies to limit the use of fossil fuels could substantially dampen the extent of warming in the long run. Our own results demonstrate this (for example, a simulated ban on shale oil and synfuels reduced the projected 5°C temperature rise in 2100 by 20 percent). We tried to maintain a clear distinction in our report between the almost universal ineffectiveness of fossil fuel policies in the medium run (by 2050) and the sometimes substantial effectiveness of these policies in the long run (by 2100). Unfortunately, this distinction typically was not maintained in press reports.

We also agree that greenhouse gases other than CO_2 are significant to global warming in our analysis. At several points in our report we underscored the sensitivity of our results to assumptions about future levels of these gases. Moreover, one of our key recommendations is that learning more about the sources, fates, and effects of these "trace" gases should be given high priority on future research agenda.

We did not formally test policies to control CH_4 and N_2O, primarily because relatively little is known about the sources of these gases. However, we were conservative in our selection of growth rates and used simple linear rates of 2.0 and 0.2 percent per year, respectively, rather than the historical compound growth rates of the same magnitude reported in the literature (*3*).

We were also conservative in our assumptions about growth rates for the atmospheric abundance of CFC-11 and CFC-12, since we held worldwide emission rates constant at 1980 annual levels. Unless a worldwide effort to curtail CFC's is undertaken, both aerosol and nonaerosol usage can be expected to grow in all countries that have not regulated aerosol use, and nonaerosol applications will increase in countries that have regulated aerosol use. We also did not consider the potential warming effects of increases in ozone in the upper troposphere and lower stratosphere (*4, 5*).

The third item is an article by Woodwell *et al.* (9 Dec., p. 1081) on biosphere contributions to atmospheric CO_2. Drawing from recent estimates of forest clearing and agricultural practices, they

argue that historical changes in vegetative cover have produced greater atmospheric loadings of CO_2 than previously believed. Although these conclusions are far from receiving universal acceptance (Research News, 9 Dec., p. 1107), their implications for global warming deserve serious consideration.

In our work, we assumed a small historical contribution of CO_2 from the biosphere and thus a relatively high fraction of anthropogenic CO_2 emissions which remained airborne (an airborne fraction of about 0.6 in 1980). We also assumed no net addition of CO_2 from the biosphere in the future. To test the sensitivity of our results to these assumptions, we developed a new scenario using the median estimate of Woodwell *et al.* of the historical airborne fraction (0.30) and their projection of future CO_2 contributions from the biosphere assuming zero population growth in 2100 (*6*). In this new scenario, we also held the airborne fraction constant over time rather than assuming, more realistically, that it would gradually increase.

Our new modeling results showed only a modest change in the medium term—the projected date of a climatically significant temperature rise (2°C) was delayed from 2040 to 2050. Longer term changes were more substantial—the assumptions of Woodwell *et al.* reduced the temperature rise projected for 2100 by 26 percent, from 5.0° to 3.7°C. Our results indicate that the estimates by Woodwell *et al.* of larger net releases of CO_2 from the biosphere and lower fraction of airborne carbon partially offset each other until forests effectively disappear (by 2060 in the scenario of Woodwell *et al.*). Thereafter, the lower airborne fraction reduces the rate of CO_2 and temperature rise.

In summary, the main conclusion of *Can We Delay a Greenhouse Warming?* appears to be robust—fossil fuel policies are unlikely to prevent a significant warming by the middle of the next century, although they could substantially reduce total warming that occurs by 2100. This study also demonstrates that learning more about the sinks and sources and thus future growth of greenhouse gases other than CO_2, and about the thermal sensitivity of the atmosphere to all greenhouse gases, will be critical to reducing uncertainty about warming in the next 50 years and beyond. Developing successful strategies for adapting to climate change will depend on better understanding of the timing and effects of global warming.

Much of EPA's research has focused on adaptation—that is, on ways to reduce potential negative effects of climate change and exploit positive ones.

For example, two pilot studies were undertaken to assess the value of anticipating future sea level rise in Charleston, South Carolina, and Galveston, Texas. The results suggest that preparing for sea level rise could reduce property losses due to storm damages and coastline erosion by hundreds of millions of dollars in each of these communities (*7*). The importance of anticipating changes in sea level to siting hazardous waste and sewage treatment facilities was also investigated. Another study analyzed the potential opportunities and risks faced by the forest products industries as a result of changes in CO_2 and climate. These and other studies clearly demonstrate the importance of narrowing remaining uncertainties about the trend and distributions of future climate change as fast as possible.

D. L. KEYES

1315 Kalmia Road, NW,
Washington, D.C. 20012

J. S. HOFFMAN
S. R. SEIDEL
J. G. TITUS

Strategic Studies Staff,
Office of Policy Analysis,
Environmental Protection Agency,
401 M Street, SW,
Washington, D.C. 20460

References and Notes

1. S. Seidel and D. Keyes, *Can We Delay a Greenhouse Warming?* (Environmental Protection Agency, Washington, D.C., 1983).
2. National Research Council, *Changing Climate* (National Academy Press, Washington, D.C., 1983).
3. See references cited in (*1*).
4. W. Wang and J. P. Pinto, *J. Atmos. Sci.* **37**, 333 (1980).
5. D. J. Wuebbles, F. M. Luther, J. E. Penner, *J. Geophys. Res.* **88**, 1444 (1983).
6. Solid line in figure 6 of the article by Woodwell *et al.* on p. 1084.
7. M. Barth and J. Titus, Eds., *Sea Level Rise to the Year 2100* (Van Nostrand Reinhold, Stroudsburg, Pa., in press).

Keyes *et al.* appear to have missed the point of our discussion. Any reduction in the total release of CO_2, whether through conservation of energy or through improved management of forests, will be reflected in lower rates of accumulation in the atmosphere. The possibilities for reducing the buildup of CO_2 or postponing the time of doubling appear considerably greater than Keyes *et al.* suggest from consideration of fossil fuel policies alone. Adaptation is not the only strategy.

G. M. WOODWELL, R. A. HOUGHTON
J. M. MELILLO, B. J. PETERSON
G. R. SHAVER

Ecosystems Center,
Marine Biological Laboratory,
Woods Hole, Massachusetts 02543