my view, the national labs, like corporate R&D labs, constitute a valuable resource that must be maintained for a number of reasons. These include the performance of long-term, high-risk research referred to above, and guarding against national surprise, whether economic, defense, or of some other nature. In order to serve these vital functions, national labs, as well as universities, must continue to be funded for basic research in selected areas. There is no inherent conflict between the roles of national laboratories and universities. There has been a long history of cooperation between these institutions as exemplified by the University of Chicago's 40-year association with Argonne National Laboratory and the University of California's similar long-term relationship with three national laboratories.

There are some steps that can and are being taken to increase the effectiveness of the national laboratories. Many of them need to increase their interactions with universities and with industry. They need to bring more students, faculty, and industrial researchers to the labs to do research and use the facilities. Researchers from the labs should be encouraged to spend more time at universities and in industry. Interactions of this sort are being encouraged at Argonne National Laboratory. The end result, I believe, will be an increase in the contributions of the lab to both the midwest region and the nation.

With the modifications suggested above, I endorse the guidelines for federal R&D policy suggested by Schmitt and believe that they will strengthen and rejuvenate the innovative powers of the nation's system of research and development.

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## Strategic Choices

Good intelligence and reliable communications would seem indisputable assets in a conflict, as Charles A. Zraket argues in his article "Strategic command, control, communications, and intelligence" (22 June, p. 1306); but they may not constitute the most effective deterrent to prevent the outbreak of nuclear war. Sometimes uncertainty about one's probable response to a provocation may be preferable. If, for example, an opponent thinks that a particular act will evoke a certain response, but this act may be mistaken for something more serious because of failures in command, control, communications, and intelligence ($C^3I$), he may well be deterred by these very failures because the risk will be greater.

Generally speaking, I think $C^3I$ should be upgraded, especially to prevent egregious errors that could result in a nuclear catastrophe. At the same time, however, if an opponent is uncertain about what one's response to a provocation will be, either because of $C^3I$ failures or one's intentional vagueness about one's retaliatory policy, one's deterrent may be enhanced. More formally, Davis and I (*1*) have shown using game theory that in certain kinds of nonzero-sum signal-detection games a policy of ambiguity is optimal in the sense that both sides can benefit if one side uses a "mixed strategy," which involves introducing a deliberate and calculable uncertainty into its strategic choices.

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1. S. J. Brams and M. D. Davis, *The Verification Problem in Arms Control: A Game-Theoretic Analysis* (Research Report 83-12, C. V. Starr Center for Applied Economics, New York University, New York, 1983).

I do not disagree with Brams' point. Uncertainty in policies and doctrines is always possible, regardless of how good or bad a $C^3I$ system is. More options are available to such a "mixed strategy," however, when the $C^3I$ system can be relied on.

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## Population Projections

Articles and reports in *Science* frequently make use of population projections to reach important conclusions, often with policy relevance. The article by H. E. Goeller and A. Zucker (3 Feb., p. 456) is an example. Much of their analysis (and conclusion) rests on an assumption of an asymptotic world population level of 8.5 billion in the year 2100. Their projection is an extrapolation of an estimate of 8.4 billion in 2075 by Keyfitz *et al* (*1*). Other estimates are also possible: for example, the United Nations 1980 estimates for the year 2025 range from 7.2 to 9.1 billion, numbers that are 15 percent lower and 7 percent higher, respectively, than the 8.5 billion level, for a date half a century earlier and with world population still growing (albeit with much regional variation). The World Bank's most recent projections estimate a population of about 9.8 billion in the year 2050 and an asymptotic population of more than 11 billion in the 22nd century (*2*). Thus, population projections can vary widely, and the use of one or another alternative can make a substantial difference to conclusions about the adequacy of resources.

Many readers will not have easy access to a set of variant projections and thus cannot easily judge the sensitivity of an analysis to the use of alternatives. If gullible, they may accept whatever is concluded; if suspicious, they may reject what may be a perfectly reasonable argument. We would suggest, in the interest of more informed communication, that editors and reviewers urge authors to provide explicit information on a range of plausible estimates and the sensitivity of their analysis to the alternatives. If authors are unable to provide such alternative estimates (that is, a range), they should stress that the projection used is strictly illustrative and dependent on the validity of the particular assumptions underlying that projection. The sensitivity of population projections to underlying assumptions has been emphasized by Demeny (*3*) and Keyfitz (*4*).

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2. World Bank, *World Development Report 1984* (Oxford University Press, New York, 1984).
3. P. Demeny, *Pop. Dev. Rev.* **10**, 103 (1984).
4. N. Keyfitz, *ibid.*, **7**, 579 (1981); *Population Change and Social Policy* (Abt, Cambridge, Mass., 1982).

We agree with Hammel that we might better have used a population range. However, this would have unduly complicated our discussion of a peripheral issue and would have changed our conclusions only slightly. Since our main conclusions were that process research and development is needed to increase the number of chemical elements ultimately in near-finite supply and that substitute development is needed to reduce future demands for the remaining limited elements, use of various population estimates increases or decreases the timing of such R&D by, at most, only a few decades over a 120-year time frame.

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