CHAPTER 8

The Future: 2000 and More

The science establishment that emerged in the United States during the past half century is a phenomenon in its own right: a unique partnership of government and private institutions, of administrators and scientists and engineers, brooded over by the Congress, which finances it, and pretty much allowed to go its own way under the benign neglect of the White House.

Much of the success of the enterprise, particularly in the early years, was due to the informal, personal way in which the federal science agencies conducted their business. The agencies were staffed by administrators who had had careers as scientists and who saw themselves as brokers between their scientific colleagues and the government. The peer review system in which other active scientists were asked for value judgments on proposed research also contributed to a family atmosphere in each of the agencies.

In the mid-1950s, for example, the AEC offered to finance construction by universities of several high-energy particle accelerators in addition to those it had sponsored soon after WWII. The idea was to encourage two or perhaps three universities in the same geographical region to collaborate on the construction and subsequent operation of an expensive experimental facility for faculty research and student training. Use of the facility would be open to faculty at other universities, if their proposals passed muster by reviewers, but responsibility for the design, construction, and operation of the facility would rest with the governing universities. Princeton University and the University of Pennsylvania, located less than an hour apart by train, tried to form such a collaboration, and two physics faculty representatives from each institution began regular meetings to iron out the details.

That was not so easy. The Penn people thought a machine that accelerated electrons, with which they had some experience, was more promising for future research in elementary particle physics. The Princeton people saw the future in terms of a proton accelerator, which, at the time, was less risky to build and to which one of its representatives—a former student of Ernest Lawrence at Berkeley—brought direct design and construction experience. The disagreement persisted for the better part of a year, never turning ugly because the other Princeton representative was Henry Smyth, the former AEC commissioner, whose vast federal experience in disputes kept the meetings civil and on track.

While still far apart on the specific technical nature of the facility, how it would be administered, and its location, the four negotiators were asked to go to Washington to report to the director of energy research of the AEC, a well-known physicist named Tom Johnson. In Johnson's office the conversation went something like this:

JOHNSON: Well, I'm glad to see that you are actively collaborating at last. How far have you progressed with the design and location of the facility?

SMYTH (AS SPOKESPERSON FOR THE NEGOTIATORS): Tom, we're sorry to say that we are unable to agree on the design or the location, although we have struggled mightily to overcome our differences.

JOHNSON: That's too bad, really too bad! Here in the bottom drawer of my desk (reaching down and pulling the drawer open) I have five million dollars to give you now if you can agree to collaborate on a facility. But if you can't, I am prevented from giving anything to either institution acting alone.

(There was a long pause during which the university representatives surreptitiously eyed one another and waited for Smyth to respond. Instead, Johnson retook the initiative.)

JOHNSON: Now with that in mind, I suggest you go into the office

> next door to this one, which happens to be unoccupied, and see if you can't find a compromise that will make positive use of the five million dollars.
>
> (With much nodding of heads, the four visitors went next door and returned to Johnson less than five minutes later, when Smyth told him that the two universities would collaborate on a proton accelerator, for which the design was already prepared, to be located in the James Forrestal Research Area in Princeton, and with each university sharing equally in the administrative and scientific responsibility.)

That was the origin of the Princeton-Pennsylvania Accelerator. It attracted young faculty and students to both universities and had a valuable productive life until it was outmoded a decade later by construction of a much more energetic proton accelerator at Fermilab. Another high-energy accelerator, the Cambridge Electron Accelerator, was built by the two-university collaboration of Harvard and MIT under the same AEC support scheme. Scientists in other fields could tell similar stories about their experiences with the NIH and the NSF.

To their credit, all the federal science agencies have tried to preserve close, personal relationships with the scientists they support. But the rate of growth of the science establishment has made the task tremendously difficult. Over the years, the pressure to centralize and enlarge administrative functions to facilitate accountability to Congress has been resisted but not completely avoided. The future growth in breadth and depth of science will exert ever-greater pressure on the science agencies to become less personal and to streamline activities. The pressure is sure to increase as the nation adjusts to the end of the cold war, responds to new international commitments, and seeks to improve the quality of life and the health and long-term security of its citizens.

Imposition of limits on the flexibility of the science establishment, even when done with the lightest hand by the government, has been shown to be counterproductive. Nevertheless, the motivation to try again will be hard to resist. In time, therefore, the burden of guidance of the science establishment will rest more heavily on the scientists themselves than it does at present. They are most likely to be aware of the illusory advantages of increased centralization and of the need to uphold the primacy of the active researcher within the framework of the science agencies. Scientists in concert with science agencies have the knowledge and the firsthand experience to furnish advice that will bring about beneficial changes in the operation of the science establishment.

One way in which scientists might assume greater responsibility for their future and the future of the science establishment would be to participate more actively in formulating science agency budgets and agency recommendations to Congress.

Scientists and the Science Budget.

The U.S. science budget consists of many loosely defined categories that make up a substantial part of the so-called discretionary funds that in turn constitute roughly 16 percent of the total federal budget. Today, there are about twenty federally funded agencies whose missions involve research and technology. Four of those agencies supply almost all the federal funding for scientific research in colleges and universities.

The annual federal research and development budget is about $70 billion, of which roughly one-half is spent on functions that, while important, do not create new knowledge or develop new technology. Examples include evaluation of new aircraft and new weapon systems at the Department of Defense (DOD), nuclear weapons work at the DOE, and mission evaluation at NASA. The remainder, roughly $35 billion, is spent on basic science and technology, roughly as follows: the Department of Health and Human Services (DHHS), in which the NIH resides, spends about 30 percent; NASA, 15 percent; the DOE, 14 percent; and the NSF, 5 percent. Science and technology sponsored or done by the DOD accounts for 22 percent. Other federal agencies concerned with agriculture, the environment, and transportation, whose science and technology are peripheral, spend 14 percent. This distribution of science and technology funds indicates the situation during a multiyear period. Changes in the relative or total amounts occur slowly, usually in response to a stimulus from outside the science establishment.[1]

One question that might be asked of the science establishment is whether the pattern of fund sharing and the manner in which the pattern is shaped are adequate to respond to recent world changes and to the new economic and social climate in the United States. For example, the NSF spends all but about one-fifth of its 5 percent share of the science and tech-

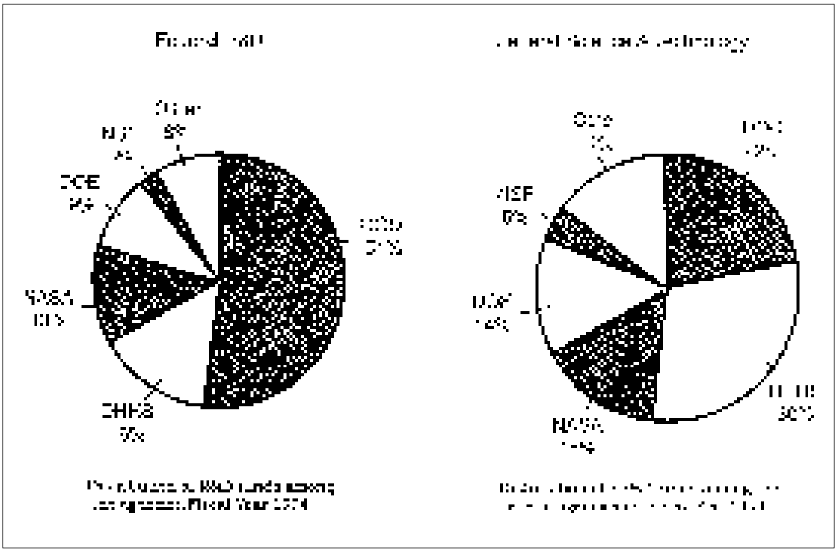


FIGURE 8.1. Pie charts showing the distributions of federal research and development (FR&D) funds (*left*) and federal science and technology (FS&T) funds as of 1995. Roughly one-half of the R&D budget includes important functions that generally do not create new knowledge or develop new technology.

Source: National Academy of Sciences Committee on Criteria for Federal Support of Research and Development, *Allocating Federal Funds for Science and Technology* (Washington, D.C.: National Academy Press, 1995), p. 137.

nology budget on the basic research of individual investigators. Envision the effect of an increase in that share from 5 to 7 percent, an increase obtained by very small decreases in the shares of the other agencies. The substantial fractional increase in the NSF's funding capability would allow as much as a 50 percent increase in the number of researchers it supports, particularly many gifted young investigators who otherwise find it so difficult to obtain support for their work. Compare that major benefit to the minor losses of the other agencies.

Concern with sharpening the focus of responsibility is, however, more general than the question of how much to take from one agency to give to another. It concerns, rather, how to assess the system by which allocations are made and how to modify the system to improve the components of the science establishment itself. To do this, the university science communities should be given and accept greater responsibility for the process by which their science agency budgets are generated.

In our system of governance, any substantive change in the operation of the science establishment needs to be enacted by Congress. But the specifics of the change and the impetus for it should involve university scientists. This might be done by enlarging their present role as informal advisers to the science agencies, including them as regularized consultants in the agencies' budgetary processes. At present, an agency may ask scientists to review a research proposal or a report on the progress of a research program. The agency's request and each scientist's response are submitted in writing, but the procedure is informal, limited to that advisory review function. The agencies accord scientists little voice in their science policies and no formal status.

It may seem foolish to suggest that university scientists, the principal beneficiaries of government funding for science, be assigned greater responsibility for the policies of the science agencies in general and their budgets in particular. Nevertheless, scientists are most likely to know what improvements are necessary and how they might be implemented. Moreover, the immediacy and closeness of their involvement will ensure continued participation, while diversity and self-interest will protect against excessive selfishness by any specific discipline.

Scientists and engineers are asked to review not only programs under consideration by an agency for inclusion in its budget; they are also asked by professional journals to review manuscripts submitted for publication. And universities and national laboratories make similar requests with regard to appointments and promotions of individuals. In the main, most reviewers do a good job reviewing manuscripts and evaluating individuals for appointments and promotions. It is principally when evaluating programs and facilities—new and old—that they perform inadequately and often adversely influence the budget process. The influence is not always short term because decisions on programs and facilities usually involve commitments that last for a number of years.

If a review concerns an older program or facility, factors other than scientific merit and accomplishment, such as an institution's past reputation, may affect a funding agency's final decision with a degree of importance not given by reviewers. Moreover, discussion to promote understanding of agencies' decisions rarely takes place. In renewals of many modestly funded programs and facilities, reviewers are usually unaware of the identities and opinions of other reviewers—unlike the legal jury system—and learn of the final decision of the agency only as it seeps down through the system as an accomplished fact.

If a proposed program or facility is new and expensive, the prospective funding agency forms a temporary review committee to which it gives detailed instructions. Those instructions, and not primarily scientific merit, occasionally determine the fate of the proposal. Neither this nor any other statement I have made is meant to question the integrity of the individuals in any agency but rather to reiterate that peripheral criteria such as the geographical distribution of facilities or separation of function and emphasis between facilities may outweigh scientific merit in agencies' decisions. Nor do these comments apply equally to each of the agencies I have discussed here. In rare but significant instances, political action outside an agency may be used to circumvent the clear recommendation of an agency's external advisory committee. The reviewing committee has no formal recourse when it disagrees with an agency's decision. Reviewers serve at the discretion of the agency and have no independent avenue through which to manifest their disagreement. And frequently there is no traceable path between the scientific review and the final agency decision. Scientists on the review committee and even the proponents of a proposal that receives a negative review rarely object to decisions of this kind for want of an accepted, formal means to do so. And the habit of conforming to the final decision of an agency—based on what is advertised to be a strictly scientific review—is not easily broken.

For these reasons many scientists lack confidence in the review system when it deals with scientific programs and facilities. They question the usefulness of their limited advisory role in the decisions the agencies make. This lack of confidence often leads them to put less than a full effort into the review process. It tolerates programs and facilities that do not satisfy the high standards of the profession and rejects some that do. Scientists implicitly view the effectiveness of the present system as a secondary—rather than a primary—responsibility of theirs. Consequently, the system does not adequately provide the quality assessment necessary to sustain and advance the health of the U.S. science establishment in the coming decades.

One big step toward bringing important policy decisions and the science budget into better focus would be to charge university and industry scientists with clearly specified responsibility for the information and advice on which scientific decisions within each agency are based. This would introduce in a regularized, formal way the "essential element of outside expert judgment that is the bedrock of quality assessment in research and development."[2] It would bring scientists and the science agencies into a better working relationship. The passive role now played by scientists would be replaced by an active role that would involve them more fully and responsibly in the reasoning at the heart of the decision process. They would participate in the compromises and trade-offs that are an integral, and perhaps the most important, part of the creation of any science agency plan. Scientists would be aware of and understand the fate of their recommendations as the process evolves within the agencies. This new responsibility placed on the science communities would provide for a mutually beneficial measure of feedback and a level of collegiality among scientists and present and future policy makers. But it need not and would not intrude on the responsibility for decisions of policy makers within an agency. That responsibility would remain, as before, in the hands of agency officials. Moreover, the new role of the scientists could lead to greater confidence on the part of Congress in the agencies' requests.

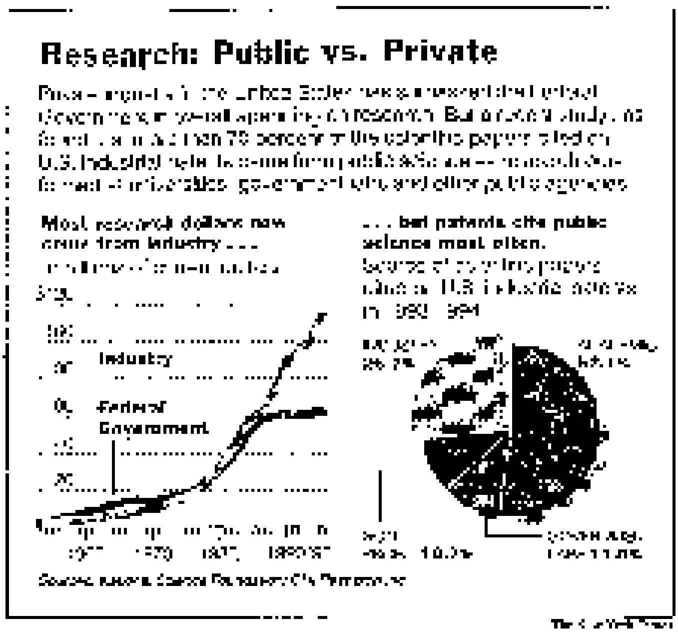
The intent of this proposal is to recommend a structure analogous to the advisory committee structure that was created by a clever compromise in the Atomic Energy Act of 1946. That compromise led to a Military Liaison Committee (MLC) and a General Advisory Committee (GAC) attached to the Atomic Energy Commission (AEC), each with clearly defined duties and limitations. These committees neither attended AEC meetings nor had a vote in commission decisions, but each had a recognized, formal advisory function to perform for the commission. The AEC in turn had the responsibility to inform the committees of each of its decisions at an appropriate time. In case

FIGURE 8.2. *Opposite page top*: Comparisons of overall spending on research in the United States by private industry and the federal government. Also shown is a comparison of the sources of scientific papers cited on U.S. industrial patents in 1993–1994.

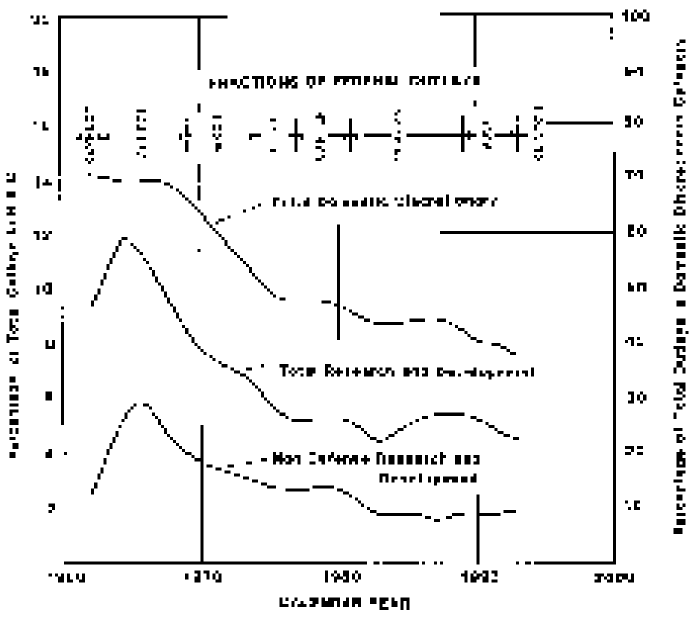
Source: William J. Broad, *New York Times*, May 13, 1997, p. C1.

Opposite page bottom: Trends in federal discretionary and R&D outlays during 1960–1993. Total domestic discretionary outlays, total support for federal research and development, and total support for nondefense research and development are plotted as percentages of the total federal outlays (right ordinate for total and left ordinate for R&D) for the period from 1960 through 1993. The different administrations are indicated for reference.

Source: William J. Broad, *New York Times*, May 13, 1997, p. C1.



Research: Public vs. Private
Most research dollars now come from industry . . .
Industry
Federal Government
. . . but patents cite public science most often.



FRACTIONS OF FEDERAL OUTLAYS
Total Research and Development
Non-Defense Research and Development
1970
1980
CALENDAR YEAR

of a severe disagreement with a decision, the MLC—with members appointed by the armed service secretaries—could refer their objections to the secretaries for further appeal; the GAC—with members appointed by the president—could take its objections directly to the president.

In general, that structure worked well for thirty years. The AEC had the benefit of knowledgeable, mandated advisory committees but—with certain restrictions—was formally independent of them. The committees, representing different constituencies, were kept informed and moreover had well-delineated avenues through which to voice their objections when necessary.

Consider the formation of several external advisory committees, one of which would be accredited to each of the four science agencies I have featured. Each committee, consisting of between five and ten members, might be chosen from a slate recommended by relevant professional organizations. To give them appropriate status and formalize their responsibility, each committee would be appointed by and be responsible to the president's science adviser.

The terms of committee members would be for two or three years, staggered so that at least one-third of the members would be replaced each year. Each committee would choose its own chairperson, who would serve for one year. Members would receive no compensation, but their expenses would be paid. No member would participate in any deliberation relating to the institution with which he or she is affiliated. Nor would members be considered as representatives of any institution, scientific organization, or discipline. Their loyalty would be to an agency to which they were appointed. Their job would be to help that agency carry out its science functions in the most efficient, economical, and productive way.

The duties of each science advisory committee would be to consult with and advise the policy and budget makers on issues related to the agency budget, in a manner acceptable to all parties. Each committee would have no administrative function and would be concerned only with matters related to the agency budget. Each agency, in concert with its external committee, would define the way in which the two bodies would jointly operate, keeping in mind the need to safeguard against excessive partisanship.

Skepticism on three counts is likely to fuel criticism of this proposal. First, can scientists overcome personal self-interest; second, will they be satisfied with their limited responsibility; and third, will they be able to maintain the requisite confidentiality? None of these counts is justified given the past behavior of scientists or of public-spirited citizens in general, but much care will be required to ensure that none is a future pitfall.

Indeed, the peer review system now in operation partly circumvents these objections. What I propose here is not to do away with that system but to strengthen it through a well-defined, formal structure, one that would share the burden of fact-finding and the weighing of alternatives between the agencies and scientists. Decisions would rest, as before, with the officials of each agency.

The most significant benefit to come from involving scientists more deeply and formally in the operation of the science establishment might be the demand placed on them—explicitly for the first time—to explain to Congress and the public what they do and why they should be supported by the taxpayers. Scientists will need to differentiate convincingly the support of science from an entitlement and to recognize that the people who pay the bills deserve to appreciate the intellectual and spiritual excitement of the scientific enterprise as well as its practical benefits.

The Power of Science and Technology for Good and Evil.

The new century we are about to enter will be filled with change that we can only dimly identify now. But it is certain that progress in science and the interplay of science and technology will not stop in the future. It is fueled by human curiosity and the immense satisfaction we humans find in learning and knowing. Increasing numbers of each new generation will rediscover the attraction of the endless frontier of science and choose to spend their lives exploring it, which leads to a question about the science establishment in the United States of the mid-twenty-first century: Is it likely to have the same form that it has now, or will it be the oppressive, bureaucratic monster envisioned in the novels of Aldous Huxley and George Orwell?

The story of U.S. science contains more virtues than not. The importance of encouraging and supporting the science establishment has long been a vital component of American prosperity and culture. But it is prudent to be aware that the enormous strength of the science establishment could be marshaled and directed toward misguided or even inherently evil goals. Earlier chapters in this book discuss the power that has been generated by science and technology when organized on a national scale and devoted to predetermined goals. Fortunately, the weapons that were pro-

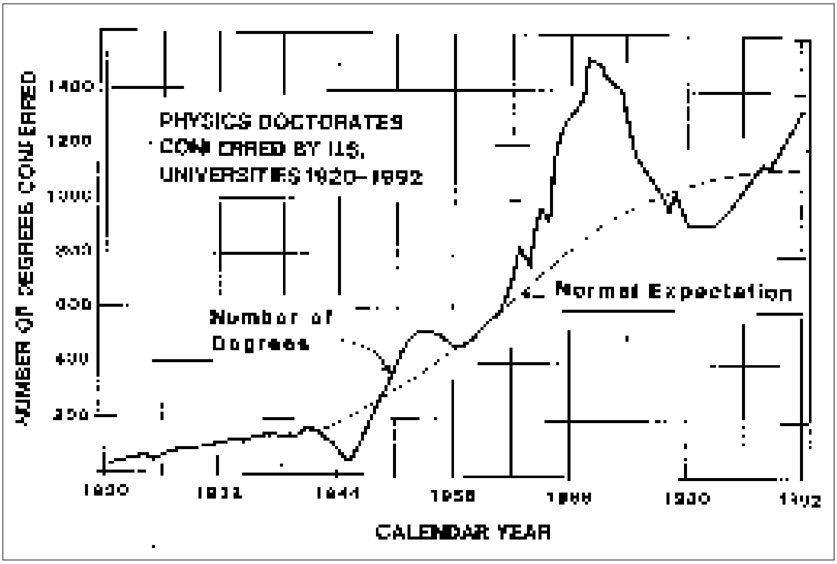


FIGURE 8.3. Physics doctorates awarded by U.S. universities, 1920–1992. The curve labeled "Normal Expectation" has been drawn in as a rough guide to what might have been a desirable expectation. It emphasizes, however, several features of these data. Those who were prevented by World War II from completing their Ph.D. education did so after the war. The rapid increase in Ph.D. production in the late 1960s came in response to the federal programs aimed at producing the trained personnel that projections at the time suggested would be required in the U.S. military and space programs. This crash program was terminated in 1968 when it was found that the goals established for 1970 had already been reached, and the resulting student disenchantment and the lack of anticipated opportunities led to the rapid decrease in production in the 1970s. Projections of coming shortages, published in the early 1980s, resulted in a new increase.

Source: D. Allan Bromley, *The President's Scientists* (New Haven: Yale University Press, 1994), p. 118. Courtesy of D. Allan Bromley.

duced in the United States during WWII were used with restraint. Even so, the soul-searching that preceded the use of atomic weapons in Japan and the subsequent debate that persists after so many years highlight the vital difference between an ethical government and a government corrupted by its own power. What a different turn the world would have taken if Nazi Germany had successfully created an atomic bomb before the Allies did.

In the fifty years since WWII, the power of organized, directed science and technology has increased many times. Advances in all phases of weaponry produced by scientists and engineers in the Departments of Energy and Defense, acting together with industry, are evidence of what can be accomplished.

A case in point is the intercontinental missile defense system known as Star Wars. As proposed by President Reagan in the 1980s, at the height of the cold war, the plan took many conceptual forms, which included satellite-launched interceptors with laser weaponry, Earth-based long-range missiles, and various combinations of them. Most scientists outside the government viewed the project as ill conceived and unfeasible. Indeed, it never deployed a defense system or even showed significant progress toward one. But neither did it die. Today there is a scaled-down version of the effort, the National Missile Defense, with a budget still in the billions, even though the consensus of the science community with regard to its promise remains negative.

We cannot easily call into question the existence of the military-industrial complex—so named by President Eisenhower—that makes possible and promotes such efforts, because that complex also engages successfully in other enterprises on which our national security rests. But that is all the more reason why we need to oversee its behavior with great care.

The line that separates science and technology organized for good from science and technology organized for poorly conceived or even inherently evil goals has never been sharp and is likely to become less so with time. Consider, for example, Earth-orbiting satellites equipped with high-resolution, digitized cameras feeding powerful computers that allow us to inspect and tally minute features and resources of our planet. This is a powerful instrument for good. But the same instrument serves also to monitor the hour-by-hour behavior of farms, businesses, and armies and, quite possibly, the smallest details of individual lives. Everything can be observed and studied for possible activity that might be described as injurious to world peace or the stability of the state. The capability exists to do this with an efficiency far superior to the spine-chilling but clumsy efforts of the Soviet secret police to control its fellow citizens during the cold war.

We know of only one way to protect against the evils that follow from the misuse of organized science and technology. That way lies through the fullest exchange of ideas and opinions among all segments of society and particularly between governments and scientists. In that way, any serious threat will be evident and can possibly be overcome. There will always be citizens in all walks of life who will not be taken in by specious arguments to justify the use of science and technology for questionable national goals. Scientists, however, are best equipped to recognize and expose the weaknesses in those arguments. They can defend most effectively against the abuse of their own work. Scientists constitute a vital element in the protective armor of a nation against such misadventure. Here again is reason for the inclusion of scientists within the science agencies. In their ceaseless search for the truth, scientists enhance the quality of life. Equally important, they serve to safeguard that quality and the integrity of science from those who would pervert them.