Introduction

Science and technology permeate every aspect of a modern society; they are integral parts of our cultural, economic, political, legal, and social systems. Because national security, the economy, and the quality of life are seen to depend in part on the health of the scientific and technical enterprise, large sums are spent on maintaining and developing the enterprise, on applying its fruits to present and future problems, and on educating young men and women to participate in scientific and technical activities. More than a million -and-a-half persons are trained in fields of science, engineering, or medicine and more than half-a-million are engaged in research and development activities. More than $24 billion in Federal funds and $30 billion in private funds are spent annually on research and development. At the same time that we see science and technology as engines of progress we are also aware of the costs of consequent changes in the social fabric and the potential dangers inherent in reshaping nature. We look to science for a rational basis to regulate new products and processes, and to protect and even improve the environment.

Against this background of reliance and faith on the one hand and resistance and fear on the other, it is appropriate for Congress, the administration, the scientific and technical community and the public to ask “How are we doing?” Current assessments vary widely. Some contend that money is being spent frivolously on basic research, while others maintain that we are neglecting to build better foundations for the future through basic research and the nurturing of talent. Some believe we fail to apply what we already know while others feel we concentrate excessively on the application of science and technology to present needs. Many claim we forego opportunities for lack of adequate research effort. Plainly we must find better ways to judge both whether the needs of the country and society are being met, and whether the money and human effort is being well spent.

This seems straightforward but, in fact, it is hard to define either “the enterprise” or “health” in ways which are useful to Congress and the public. Assessment is elusive because science and technology have cultural and spiritual impacts as well as material ones. The difficulty is augmented because the consequences of the enterprise relate more to the future than to the present. Thus the health of the R&D effort concerns not only present performance, but also the capacity to anticipate and deal with future problems. For all these reasons, none of the attempts to construct criteria or indicators has been widely accepted as meeting the need.

This report does not attempt to judge the health of the enterprise. It does try to develop a useful definition of the enterprise and to present a framework within which policy makers can assess its health.

Science, Technology, and Society

The most distinctive feature of a 20th-century - developed society is the complete integration of science and technology into its basic way of thinking. It is taken for granted that living things, our planet, and the history of mankind can be deciphered, Travel to the moon—an engineering miracle—presents no conceptual novelty or surprises, especially to children. Few doubt that eventually the biological differences between cancer and normal cells can be utilized to prevent or cure cancer. This confidence that nature can be understood in terms of predictable regularities and relationships is a recent development in human history.

Science and technology represent not only knowledge and skills but specific traditions and ways of thinking about the world. It is often difficult to realize just how deeply we believe in and rely on our capacity to manipulate as well as understand the physical world. Nearly all our thinking about energy and environment, for example, is predicated on the capacity to manipulate the physical world.

One of the most important consequences of this state of affairs is that our dreams of what is possible are shaped by science. Even our values and ethical judgments are modified as we learn and understand more. An assessment of the health of the scientific and technical enterprise must incorporate such significant social factors as the continuing ability to lead and not mislead the public. It must assess the continuing ability to inform our thinking and comprehension of what the world is and what it might be, as well as its ability to meet material needs.

Another consequence of the technological character of our society is the high level of skill required to keep it going. Even if no new technologies were introduced, it would be necessary to train succeeding generations of highly skilled technicians simply to maintain what we have, to diagnose problems, and to make repairs. Actually, we would have to do more. Resources run out and have to be replaced. Nature often tends to undo spontaneously what has been achieved. Diseases and pests accommodate to antibiotics and pesticides. New blights arise to attack the food plants on which survival depends. New knowledge and technology are constantly needed just to avoid retrogression in the quality of life.

Because new products, procedures, and methods of production affect the structure of society and the health, safety, and rights of its members, laws and regulations are necessary to diminish the potential for harm. But here too, having contributed to the situation which requires regulation, science and technology can also provide knowledge and techniques to inform the regulatory process and give it a rational foundation. We need only consider the recent debates about nuclear energy, saccharin, and laetrile to see how immediate these questions are. The need for an adequate knowledge base for the regulating activities of the Food and Drug Administration (FDA), Environmental Protection Agency (EPA), Occupational Safety and Health Administration (OSHA), Nuclear Regulatory Commission (NRC), Federal Communications Commission (FCC), and similar agencies is becoming recognized as increasingly important. The ability of the scientific and technical enterprise to provide that foundation is an important criterion of its health.

The Definition of the Enterprise

1n its broadest sense, the scientific and technical enterprise can be defined as all activities which place new and existing knowledge and skills at the disposal of society and which utilize technology to maintain our society and produce changes in the way things are done.

This broad definition incorporates many of the factors previously discussed. However, what concerns policy makers and the public most is the role of the enterprise in the process of innovation: the process by which problems are identified and solved, needs are met, materials are made available, and new concepts are added to society. This is its role as an engine of change. With this in mind, the scientific and technical enterprise will be more explicitly defined and described after a consideration of how innovation occurs.

Problem-Solving, Innovation, and Change

General Considerations

Because most societal activity is directed toward meeting existing needs in established ways, change occurs very slowly in traditional societies. There is no natural law which impels a society to change independent of individual or collective decisions. What is relatively new in our own and other developed countries is the attempt to address needs and problems systematically by investing significant human resources and material output in problem-solving and the development of new capabilities. The result has been better health, a rising material standard of living, and constant change in educational, social, and economic activities. However, the benefits of economic growth and technological change have been accompanied by pollution of the environment, as well as social stresses and threats to civilized society resulting from its command over ever more potent instruments of violence.

The objective of assessing the health of the scientific and technical enterprise is to provide advice on how society can decide how much to invest and how to derive the greatest benefit from its investment in innovation. By innovation we mean the process by which new knowledge is generated and applied to the material and intellectual operations of society. Thus, innovation is more than discovery and theorizing, more than speculation or invention, and more than engineering design. For until the new "know-how" is incorporated into what is done, innovation has not occurred.

The Process of Innovation

The process of innovation is complicated and takes many forms, depending on the circumstances. It is often thought of as a linear process leading from basic research to practical results, either because of the "push" of new scientific knowledge or the "pull" of human needs. Both of these simplified models have elements of truth but neither describes the true process adequately. In one of the common models, innovation is thought of as a four-step process:

1. Basic research, which generates knowledge and understanding and builds an intellectual foundation for science and technology.
2. Applied research, which expands knowledge (science) related to specific goals and develops technology (skills and know-how) in a form which can be used.
3. Decisions to utilize the technology.
4. Application of the knowledge or technology to society's operations, e.g., through new products or processes, new Government legislation or regulations, etc.

Because this model directs attention separately to each of these four steps and their independent institutional development, it does not take adequate account of the omnipresent "pull" of market forces which exercise a major influence on all aspects of the scientific and technical enterprise.

Nevertheless, this "technology push" conception of innovation often appears in public discussions and is reflected in current policy and planning for the advancement and application of science. But it is a misconception to think that if a new technology becomes available it will eventually and inevitably be used. To be sure, "technology push" accounts for some recent, novel industrial artifacts such as nuclear reactors, communications satellites, and lasers, but it is not the normal mode of innovation. More commonly, technological innovation has been the result of a market or social "pull", a response to identified needs or desires in society.

Another simplified model takes account of market "pull" but fails to recognize the prior importance of advances in scientific knowledge and problem-solving capabilities. The "market-pull" model, often used by industrial managers, heads of mission agencies, and Federal policy makers, conceives of innovation as a different linear process:

1. Identification of a problem, need, or demand.
2. A decision about the kind of technology (skills, know-how) to be used to meet it.
3. Generation of the needed technology, together with whatever scientific foundations are required.
4. Application of the technology to solve the problem or meet the need.

This model, based on an initial recognition of a particular desire or need to be met, describes a great many cases of innovation, particularly those that do not depart far from the existing state of the art. However, experience has shown that radically new technology and especially new scientific knowledge cannot usually be developed in response to need. Vaccines are a case in point: although the need for them has long been recognized, their production is limited by the ability to solve basic scientific problems and they are not available yet for critical diseases such as gonorrhea.

Neither of these two models provides an adequate description of the innovation process. Both recognize, correctly, that what is needed is to match skills and know-how with needs and desires; but both imply, incorrectly, that the process is linear. By contrast, examination of past experience suggests that the process actually involves repeated interactions among the various steps rather than being a one-way street in either direction.

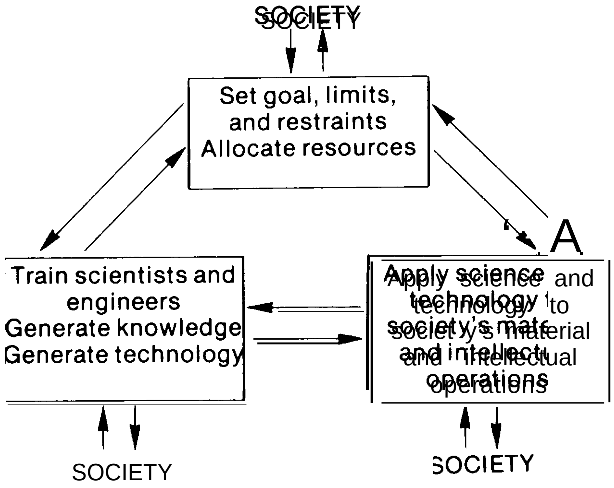
Organizational Components of the Innovation Process

Analyses of the innovation process in different settings, including Federal and State governments, individual Federal agencies, industrial laboratories, engineering organizations, and voluntary associations reveal that there are usually three functionally distinct yet interrelated types of suborganizations which work in concert and contribute to the process:

1. Organizations that recognize needs to be met, set goals and limits, and allocate the necessary resources. In general, these are the management and policymaking groups which guide the activities of an enterprise, be it a Federal agency, industry, or an academic institution. In industry, for example, there are suborganizations that assess policy options, and the technology needed to achieve the goals. These organizations conduct a dialogue with potential users and beneficiaries, set the level of resources to be devoted to the innovative process, and relate the effort to the goals of the organization.
2. Organizations that do one or more of the following: educate or train people to staff the enterprise, generate scientific knowledge and new technology, and package the knowledge and skills so they can be assimilated and applied successfully and efficiently. These organizations include universities and Government and industrial research laboratories.
3. Organizations that apply the new technology. Application is typically, but not exclusively, the function of industrial development and engineering laboratories. It is also the task of agricultural experiment stations, hospitals, and a variety of military establishments. Much technology is actually developed in the course of application, for example, in industrial engineering laboratories rather than in organizations established to perfect new technology for general purposes. An example of a very effective set of applications organizations may be found in agriculture. A quite different form of applications is the use of technical knowledge in the formulation of policy. The examples of energy policy, environment policy, and regulatory decisions illustrate the importance of such applications.

The general functions and relationships among the organizations can be diagramed as indicated in figure 1:

Figure 1



The functions associated with these three types of organizations are characteristically different and loosely coupled organizationally. Yet, if successful innovation is to occur in an area of social or material need, these functions must interact closely. Innovations may originate and get their driving force from entrepreneurship in any one of the three organizations. However, successful innovation is a highly iterative process and involves repeated interplay between the organizations and between each of them and relevant constituents of society.

It is not possible in a short report to discuss details of the systematic interrelations of these functions in all the settings in which they occur. Each is an element of a larger system which they sustain and are in turn sustained by. In the Federal Government, for example, the goal-setting and resource allocation function for science and technology is performed by the administration at all levels, as well as in the Congress. To do so they must be adequately informed, not only of the needs and desires of the society which they serve and which elects them, but also of the opportunities and costs: technical, social, and economic. Communication is essential: with the universities that train scientists and engineers and conduct much of the basic research; with Federal laboratories that apply science to Federal missions; with the industries that carry the principal responsibility for the application of science and technology to the material needs of society.

In industry it is a responsibility of management to ascertain the needs and possibilities of the marketplace and to allocate and develop the necessary financial and human resources. However, successful decisionmakers must be in close touch with the technical component of the organization to understand what is involved in an ongoing or proposed development. At the same time, the group responsible for applications must themselves understand the characteristics of the company's market since additional needs (which modify what they generate) are frequently uncovered in the process of applying technology. Potential applications are often only recognized by those actively engaged in research who understand what is possible.

There are similar close links between the generators of knowledge, the appliers of knowledge, and the educators of people. Basic research is frequently stimulated by applications, either because new questions are raised, new ideas come forth or new experimental apparatus is made available. Conversely, basic researchers are often the first to recognize practical applications of their discoveries. Moreover, because of the apprenticeship system of graduate education in the sciences and a university research establishment that depends heavily on the work of advanced students, basic research in universities is closely coupled to education. Basic research and higher education in turn are closely coupled to industry and Government because the flow of freshly trained people provides one of the major routes for carrying the newer results of basic science into an environment in which they are applied. And, there is a reverse educational link, too. Universities are not the only source of scientific and technical education. The continuing education of scientists and engineers takes place in the laboratory, design shop, and the factory; success in both ongoing activities and innovation depends highly on training programs conducted by industry for employees at all levels as well as constant self-education through reading and scientific meetings.

Finally, it must be stressed that the organizations responsible for innovation are each closely linked to society as a whole, and this relationship has taken on new dimensions. Society cannot be thought of only as customers, beneficiaries, or as an electorate which gives political legitimacy to the enterprise. Society is increasingly aware not only of the great potential for good but of what it perceives as a possible threat in technologies and even in basic science. One need only consider the concern over pollution, chemical carcinogens, and recombinant DNA research. Our body politic is simultaneously excited, awed, and frightened by a scientific and technical enterprise it does not understand. If the entire innovative process is not to come to a halt, or at least be badly distorted, better means must be found for constantly informing and consulting with the public at large concerning matters they feel may affect them deeply.

Therefore, strong interactions and good communications between all of the three organizational segments are essential to innovation. The fundamental rule of success in innovation is that there must be a responsive link between the potential users and the generators of knowledge or technology.

If we equate the scientific and technical enterprise, for our purposes with those who generate knowledge, generate technology, or train people, it is apparent that its health (i. e., how well it can carry out its role) will depend strongly on the links to the other two functions.

The Structure of the Scientific and Technical Enterprise

We have defined the scientific and technical enterprise as those activities which place new and existing knowledge and skills at the disposal of our society and which utilize science and technology to maintain our society, to solve some of its problems, and to produce changes in the way things are done.

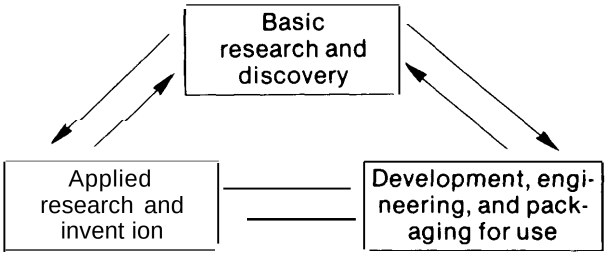
Specifically, we take the scientific and technical enterprise to include:

1. The performing organizations, chiefly research and development organizations. They are found in universities (including engineering and medical departments), in industry (research, development, and engineering activities), in Government (agency laboratories, national laboratories) and in various independent institutions, including hospitals.
2. The training organizations, both the formal educational organizations such as universities and technical institutes, etc., and those which provide on-the-job training.
3. The linking and communications organizations. These include professional and trade journals, scientific and technical societies, a wide variety of information systems, and all the formal and informal tools for transmitting knowledge and skills, both within the system and to and from those who are not directly a part of it. In many cases the best links are people who act as liaison between the various performing organizations, for example, the county agents who have been such a key link between agricultural research organizations and the farmer.

A further word maybe in order about research and development, which in many ways is the heart of the enterprise. R&D includes a variety of functions which are conventionally separated for budgetary and management purposes but which in fact are closely related and often overlap. These functions include basic research, applied research, development, technology transfer, and communications processes. The system can then be represented as in figure 2.

In this diagram basic research is that which is undertaken to turn up significant new knowledge and relate it theoretically to what is already known. Its value is measured by the extent to which it strengthens the intellectual structure of science and enhances understanding. The results of basic research may or may not be immediately useful, although experience suggests that almost all good basic research is eventually useful, directly or indirectly. It builds the foundation on which long-term progress rests.

Figure 2



Applied research is undertaken to generate knowledge or skills that are needed for some specific purpose. Its success is measured by the degree to which it answers practical questions, solves problems, or enhances technological capability. Its purpose is practical but it may be, and often is, of great theoretical significance as well. Frequently, important theoretical questions are raised in the course of application.

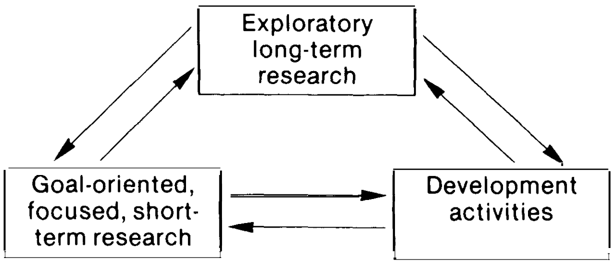
Research that is both basic and applied is classified in budgets, for example, according to the purpose of the funding agency, even though the primary motivations of the performer may be quite different.

The ambiguity arising from using motive as a criterion makes another division, illustrated in figure 3, useful for many purposes.

Many industrial organizations are organized in this way.

In both figures 2 and 3, development is the conversion of the results of basic and applied research into specific products and processes, taking into account such further factors as cost, reliability, safety, or convenience which are important to an end product.

Figure 3



Diagnosis of Health

In addressing the health of the scientific and technical enterprise the first question we must ask is what we mean by health. Definitions such as, "its ability to perform its function effectively" are nonspecific and difficult to use as a criterion for judgment. Although the analogy is imperfect, it may be helpful to look at the health of the enterprise as one might look at the health of a person. In medicine, too, "health" has a variety of meanings. Consequently, an assessment of health may include everything from explicit disease or injury to very general questions concerning a person's well-being. Questions concerning the scientific and technical enterprise appear to span a similar range; within obvious limitations, it is convenient and useful to pursue the analogy to medical diagnosis in organizing questions and developing criteria. Three levels of analysis seem appropriate:

Level 1: The Present State of Affairs: Current Maladies and Afflictions. At this level we focus on the immediate situation and seek indicators of overt breakdowns, gaps, and malfunctions. These indicators might, for example, include cases where American technology is deficient in some respect or has been misapplied; where people trained in specific scientific specialties are inappropriately utilized or in short supply; where one or another communication linkage breaks down and where the credibility of the enterprise has eroded.

Level 11: Vital Processes: Indications of Trends and Future Health. "Vital signs" in medicine refer to such basic factors as blood pressure and respiration rate, which are indicative of the long-term vitality and productivity of the human body. Similarly, this level of analysis of the scientific and technical enterprise focuses on symptoms of future malfunctions and evidence that present malfunctions are being corrected. To illustrate, whereas the adequacy of scientific instrumentation currently available is a Level I issue, whether there are adequate programs to replace obsolete scientific instruments and to develop new ones is a Level 11 issue, since it affects the long term rather than immediate viability. This level of analysis necessitates the development of "vital science indicators. " Such criteria relate both to the structure of the systems essential to the scientific and technical enterprise as a whole and to research and development enterprises in particular.

Level III: Optimal Performance: Assessing the System Relative to its Potential and to Idealized Goals. Analysis at Level III assesses the quality of the performance of healthy systems relative to what is possible. In medicine, the comparable question might be whether an athlete, for example, is performing up to his/her maximum potential. With respect to the scientific and technical enterprise we might ask whether the creativity, productivity, and yield of the system are as high as they might be. Level 111 involves the most subtle criteria of all, criteria not just of present or future malfunction but of optimal performance within human and material resource constraints. In this context, comparison with scientific and technical enterprises in other countries can yield information as to whether alternative systems perform better or not so well. Such international comparisons, admittedly imperfect, may nevertheless help us to develop criteria for improving our performance, even when present performance is apparently satisfactory.

In the pages that follow we shall offer a number of particular questions to illustrate these levels of analysis. It should be emphasized that there are no hard and fast distinctions between the levels; with but a slight shift in perspective almost any issue can be considered in more than one category.

Level I

Current Maladies and Afflictions: Indicators of Overt Current Malfunctions

This level focuses on current concerns about matters that are said to impair the present functioning of the enterprise. Complaints may originate with performers, managers, or members of the public; some have been identified in the National Science Board (NSB) report, *Science at the Bicentennial.* Criteria must be developed rapidly in order to assess their validity. We must know whether the concerns are groundless or whether remedial actions are needed; if the latter, remedies must be identified and the impact of their implementation assessed. Recently voiced allegations include the following:

1. That research funds are improperly allocated between projects and fields. Some of the concerns voiced publicly by Members of Congress fall into this category, as do the fears of many scientists about the large sums directed to particular applied subjects such as the cancer problem or the space shuttle.
2. That a disproportionate amount of time and effort of technical personnel is spent in writing and "selling" proposals and that greater continuity and dependability of funding is needed to improve the productivity of the system.
3. That excessive regulation and "red tape" hamper the introduction of new technology in areas as diverse as nuclear power and pharmaceuticals.
4. That too much or too little attention is given to the environmental consequences of new technologies.
5. That the scientific and technical enterprise makes judgments about personnel on bases other than merit, to the disadvantage of groups such as women and minorities.
6. That talented young scientists are diverted from basic research by the bleak prospects for academic employment brought about by the "saturation" of tenure positions in research universities and the resulting "aging" of the performers most engaged in exploratory, long-term basic research.
7. That the productivity of governmental programs, particularly in federally funded laboratories, is adversely affected by excessively detailed "micromanagement" by Federal officials.
8. That some areas of science are being retarded by the inadequate availability of sophisticated instruments.
9. That current tax and patent policies do not provide industry with incentives to engage in research, particularly long-range research.

Level II
Vital Processes: Predictors of Basic Health in the Future

Level II assessments require general criteria for health, upon which the long-term success of the scientific and technical system depends. The problem is to identify suitable indicators—a task undertaken by the NSB in its Science Indicator Series. Such indicators should not reflect merely transient problems but be relatively stable in their significance over considerable periods of time. Most of the indicators cited in the literature to date relate to input measures: e.g., national expenditures in dollars and manpower. Such indicators, while suggestive and provocative, avoid the real question of what is being achieved and whether we are likely to do better or worse in the future. One would like to have data which would allow us to ask such questions in analytical and operational ways. Unfortunately, there is no good model of an ideal scientific and technical enterprise which can supply the basis for a real systems analysis.

Despite the absence of such a model, qualitative and even quantitative measures of strength in the system can still be sought: e.g., measures of the capacity of U.S. science to make new discoveries, or at least the capacity of U.S. scientists and engineers to elaborate on and exploit scientific discoveries that have their origins elsewhere. We can look for measures of the capacity of U.S. scientists, engineers, and artisans to invent and create new ingenious solutions to practical problems. This capacity, often referred to as "Yankee ingenuity, " was the basis for the great surge in American productivity which surpassed Europe by the second half of the 19th century.

More broadly we can look at the ability of U.S. science and technology to provide intellectual stimulus and motivation to its practitioners and society alike. We can inquire into the capacity of the system to exercise broad leadership in identifying problems and opportunities, and generating institutional innovations relevant to dealing with society's problems. More and more we must satisfy ourselves concerning the capacity of the scientific and technical enterprise to use the world pool of knowledge to cope with specific problems such as energy production, food supply, environmental pollution and so on.

Finding measures that make it possible to approach these questions in analytical and operational ways is difficult. Even more so are the questions concerning the inner dynamics of the system such as its capacity to renew itself and to develop, to learn from its failures and successes, to attract and provide opportunities for the talented without regard to sex, race, or social origin. We know that the health of the enterprise depends on the general morale and pride of the scientific and technical community as defined by its self-image, self-confidence, and initiative, but how can that be measured? Equally, the effectiveness of the enterprise depends on public confidence in its integrity, goals, methods, and outputs. The newest, most difficult, and very significant questions concern the capacity of the system to respond to public concern and public needs and to communicate with other elements of society in understanding those concerns and needs.

There are many Level II problems that must be addressed without delay. To cite but a single example: the flow of biologically active compounds into our environment is steadily increasing and the need to manage that flow and its consequences becomes steadily more apparent. One urgent question, therefore, concerns the capacity of the system to provide a sound scientific basis for regulation, to indicate when it is needed, and to resolve regulatory conflicts.

The search for Level 11 indicators might include a series of specific and researchable questions. For example:

1. How well can the system develop priorities and order federally funded programs, both by internal criteria and by interaction with other parts of society? How well does peer review work and what alternative methods, if any, could better judge scientific priorities, not only for the purpose of making grants, but in developing agency and laboratory programs? Who is or should be involved in setting priorities and allocating funds; who should be consulted?
2. Is the scientific and technical enterprise evolving to meet the changing needs of society or is it excessively constrained by its traditions and structure? Is there a reasonable balance between the stability necessary for the enterprise to function and responsiveness to new intellectual ideas and needs?
3. Does the operation of the system encourage the emergence of truth, both with regard to science and to the impact of technology? Does the reward system derive chiefly from scientific truth? Are communications with the public open and honest and judged to be so by the public?
4. Is the balance between academic laboratories, industrial research and development organizations, and federally funded research laboratories (national laboratories, agency laboratories, and independent laboratories) appropriate to the sound evolution of the enterprise?
5. Do federally funded laboratories have a clear sense of role and purpose? Are they carrying out the tasks for which they are best suited? Are they productive and efficiently managed?
6. Is the scientific and technical enterprise properly structured with regard to the distribution of effort among sections of the country in which it is performed and among institutions (e. g., is there too much or too little concentration in the top performers)?
7. Is the long-range, exploratory basic research carried on at a level that will maintain the intellectual vitality of the enterprise, attract enough talented young people, or provide the intellectual foundation for practical advances (e.g., in treating or preventing cancer) which are currently stymied for lack of basic understanding?
8 Conversely, are our industrial and other applied research and development organizations converting the findings of basic research into useful forms promptly and effectively? Do Federal regulations as well as tax and patent policies offer adequate incentives to do so?

Level III
Optimal Performance: Assessing the System Relative to its Ultimate Potential

Even a healthy system is often capable of performance at a higher level than is actually attained. In humans the ability of the healthy system to perform at the highest possible level of achievement in a specified area may be tested by relative performance between individuals, as in athletic competitions, or by comparing the present performance with best prior performance or with absolutely established levels, as in some achievement tests. In this spirit one may try to compare the present scientific and technical system with a hypothetical ideal. The problem is that we cannot agree on what we are trying to achieve. Even further, what we imagine to be the ultimate system might turn out to be far short of what is possible, just as the 4-minute mile was believed to be beyond the physiological limit of humans until it was achieved and surpassed.

International comparisons offer some possibilities for comparing the performance of the pluralistically directed U.S. scientific and technical enterprise with systems such as those in Western Europe or Japan, which are more highly planned, or those of Eastern Europe and the Soviet Union, which are very highly planned and coordinated. One source for such comparisons is the ongoing series of the Organization for Economic Cooperation and Development (OECD) studies on national science policies and technology gaps. OECD is also conducting comparative studies of particular industries which can be utilized in the assessment of the health of the U.S. system.

Other indicators that might be used to judge the performance of the U.S. scientific and technical enterprise, and need to be interpreted and evaluated for that purpose, include the following:

1. The fraction of major scientific and technical advances, as judged by some kind of world consensus such as the award of prizes and patents, that have either originated in the United States or been brought to fruition in the United States and how that fraction is changing over time.
2. The fraction of major technological or industrial advances, including advances in the detection and control of undesirable side-effects, as determined either by a consensus of expert judgment, by economic impact and by social benefit, that have either originated in the United States or been brought successfully into use in the United States and how that fraction is changing.
3. The extent to which other systems have found it desirable to follow the” U.S. lead in dealing with drug registration, environmental protection, and so on.

Such comparisons are all retrospective. They may guide us in knowing how well we have been doing and are currently doing. The great unmet need is for predictive indicators of how well we will be doing in the future. That presents a most difficult challenge. The art of prophecy is not well developed, but it is worthy of thought and study.

Conclusion

The assessment of the health of the scientific and technical enterprise has many facets. The enterprise serves economic, social, and intellectual goals. It serves to advance the material, cultural, and even spiritual welfare of our society. Given this variety of purposes, it is little wonder that efforts to develop indicators have been fraught with difficulty and have generated so much discussion and controversy. Most of the quantitative indicators now employed are ambiguous and sometimes even deceptive, and better ways of assessing the situation are badly needed.

We have concluded that in many respects the scientific and technical enterprise resembles a living organism in that it is composed of closely interacting organs, none of which can be meaningfully isolated from the whole. Hence, the design of indicators, qualitative as well as quantitative, can profit by considering the corresponding problem of diagnosis and evaluation in medicine. There, too, health is an ambiguous term, but separating the considerations relating to various levels of immediacy, e.g., 25 current illness, future prognosis, and overall long-term fitness is a useful step in the analysis. Confusion results when the levels are intermingled in diagnosis as well as prescription. If the several meanings of health are examined separately, however, we believe that Congress and the administration, as well as the universities and industry, will be in a better position to assess the situation and to develop further indicators. According to this way of looking at things, indicators are like symptoms and laboratory tests; some may be qualitative and others quantitative. Taken individually, they may or may not identify a disease or source of future concern, but taken together in proper relation to each other, they may be very revealing.

With careful study of the collections of indicators which tell us whether something is wrong, right now, and what it is, immediate action can be prescribed. Similarly, indicators which purport to show future trends can be amplified, weighed against other criteria of advance or decline, threat or promise, and used to change longer term programs. Lastly, measures of performance against ideals are the least well developed, but this is not surprising; since these depend so intimately on political, ethical, and social values they have meaning only in the context of national goals which are often ill-defined and changing.

Science and technology have served the United States well. From a Nation which utilized the fruits of European science to build its industry in the 19th century and sent its brightest and best to Europe for advanced education in the first third of the 20th century, the United States has achieved preeminence both in its basic science and its application of science to meeting its needs and solving its problems. To do so it has assembled a complex net of people and organizations in Government, industry, and universities interacting in many and complex ways. But now we must ask whether we will do as well in the future. On the basis of such indicators as are currently available we have serious grounds for concern. There are indications that we may be losing ground to other countries. To maintain and improve the health of the scientific and technical enterprise we must constantly work at identifying further criteria and indicators which will help to diagnose the needs of this fragile and imperfectly understood undertaking. As with human health, a perennial series of checkups is unavoidable. Then it only remains to follow the diagnosis with action.

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