THE DIRECTOR'S STATEMENT

The Thirteenth Annual Report of the National Science Foundation is for the period July 1, 1962, to June 30, 1963. The activities described were carried on under the direction of Dr. Alan T. Waterman, the Director of the Foundation during that period. Appropriately, therefore, he has written the Director's Statement.

LELAND J. HAWORTH
Director

This Annual Report covers my final years as Director of the National Science Foundation. The years of my association with the Foundation have coincided with a period of great growth and many changes in the research and development activities of the Nation as a whole. I should like to devote this final Statement to a review and critical analysis of overall trends in research and development and scientific manpower and the significance these may have for the Nation's strength in science and technology.

It is hoped that such a review may contribute to a clarification of the misunderstanding, now increasingly widespread, regarding the nature of research and development expenditures and the returns that may be expected, particularly from those funds that come from the Federal Government.

In the immediate postwar period, the impact of research on national defense, so recently and dramatically illustrated by the war, was fully appreciated, and expenditures for this purpose kept pace with our worldwide commitments to the defense of the western alliance. The establishment, in this period, of the National Science Foundation in 1950 was significant in its explicit recognition of the critical importance in the overall effort of basic research and education in the sciences.

The years just past have also been marked by the development and gradual maturing of government-university relationships to the great benefit of both. Government practice, inaugurated during the war, of contracting for research and development with universities and other nonprofit institutions greatly broadened the scope and strengthened the national effort in R and D by enabling the Government to draw upon and to back the highest competence, wherever it might happen to be.

At the same time, this policy has had a profound effect upon the academic institutions involved. Not only has it provided direct and much-needed support for their scientific and technical needs, but it furnished, for the first time, major financial support and interest on the part of the Federal Government in the broad basic fields of mathematics, science, and engineering. As this support grew, many institutions began to revise and strengthen the central administration of programs and funds secured from outside sources. At the same time, the rising volume of federal support began to introduce problems: such as coverage of administrative and operating costs, balanced support among the sciences, engineering, and the humanities, and a certain loss of independence and flexibility on the part of academic institutions in the planning and carrying out of their own programs. Fortunately the most serious potential problem, namely undue Federal influence and control, is generally acknowledged not to have materialized.

In the spectacular growth of science and technology, the Federal Government has played a leading part, both in the provision of funds and in the introduction and support of large and critical national programs. The Government's enlarged role in research and development has been accompanied by certain major organizational changes, such as the establishment of the Department of Defense, the Atomic Energy Commission, the Department of Health, Education, and Welfare, the National Science Foundation, the Federal Aviation Administration, and the National Aeronautics and Space Administration. Essential coordinating and supervisory functions were provided by Executive orders of the President which established the President's Science Advisory Committee, the Special Assistant to the President for Science and Technology, the Federal Council for Science and Technology, and most recently, the Office of Science and Technology in the Executive Office of the President.

In a movement of this magnitude, complexity, and acceleration, it is, of course, essential that steps of this nature should be taken.

As the national research and development effort began to assume major proportions it has quite justifiably come under scrutiny by the Congress, as well as by the Executive Branch, and by thoughtful citizens throughout the country. Some of the outstanding questions are:

(1) Is the grand total for R and D justifiable in the national interest, in terms of money, manpower, and other resources?

(2) Do the objectives of the undertaking represent a wise, prudent, and adequate selection of national priorities?

(3) To what extent are the component programs of the effort feasible, and intelligently designed to meet these objectives?

(4) Is the effort conducted with the proper efficiency and economy?

(5) Do we now have, and will we for the foreseeable future have, the requisite scientific and engineering manpower?

The study of these and other questions cannot be conducted with any degree of efficiency and economy without a knowledge of the facts, an analysis of these facts, and a thorough-going review by well-informed, experienced, and competent persons. Especially valuable for such a review is a study of the trend in this movement, and the nature and extent of participation by the various sectors of the economy.

The National Science Foundation aids such an analysis in two important ways, both specifically set forth in its enabling legislation. The one is a systematic data-gathering operation, together with factual analysis and periodic reporting. This was begun in 1953. The other is that of developing national science policy, with special reference to the role of the Federal Government as it relates to the health and progress of science—particularly basic research—and to the education and training of scientists and engineers. Both functions emphasize the role of the colleges and universities where basic research and advanced training go hand in hand. In the National Science Board of the

National Science Foundation, the Federal Government and the Nation have a statutory body exceptionally well qualified to deal with policy in government-university relations.

In view of the searching scrutiny to which the Nation's research and development activities are currently being subjected and the urgency that seems to attach to finding the right answers, it may be useful to review the basic issues as reflected in the findings and the thinking of the National Science Foundation.

What are the salient facts? In analyzing these it is instructive to focus attention on two aspects: (1) the degree of participation among the various sectors of the economy—that is, government, industry, universities, and other nonprofit institutions—and (2) the significant trends.

The national total for research and development is currently estimated at about $16 billion, which is three times the 1953 figure. This is somewhere between 2.8 and 2.9 percent of the Gross National Product, an increase from 1.4 percent in 1953–54. The Federal Government provides about 65 percent of the total, and about 32 percent is provided by industry. Thus industry and the Federal Government are bearing almost the entire cost of R and D in the ratio of 1 to 2.

In terms of performance, industry is doing most of the work. About 74 percent of the total funds are used by industry in performance of research and development, 14 percent by the Federal Government in its own laboratories, and 12 percent by nonprofit institutions (three quarters of this by colleges and universities).

The distribution of scientific and technical manpower among these sectors is similar. Thus, of the total number of scientists and engineers employed in R and D activities (1960), 75 percent were in industry, 11 percent in the Federal Government, 12 percent in colleges and universities, and 2 percent in other nonprofit institutions.

A point of major significance is that the distribution with respect to both the performance of research and development and the sources of funds has changed very little over the 9-year period since the Foundation began its analysis of the data. It is true that the Federal contribution has increased from 53 percent in 1953 to the present 65 percent. However, this increase took place between 1953 and 1957; since then the federally financed proportion has remained practically constant.

The situation with regard to basic research is somewhat different. The total national funds devoted to its support amount to nearly $1.5 billion, about three times what they were in 1953. As a percentage of the total for R and D, however, basic research funds remained nearly constant at 8 percent until the past 2 years, when they rose to about 10 percent. The increase largely reflects major new undertakings in such fields as oceanography, atmospheric sciences, high-energy physics, and space research—where vehicles for research are especially expensive.

The Federal Government is the source of somewhat less than 60 percent of the basic research funds, industry about 25 percent, and the rest comes from academic and other nonprofit institutions.

In the performance of basic research, colleges and universities lead, as expected, with a consistent proportion of nearly half, industry contributing a little more than a quarter (greater before 1957 and less since), and government about one-sixth.

Thus, statistically and fundamentally, the growth of science and technology among the three economic sectors over the last decade appears to have been balanced and consistent. Although the Federal Government has been the principal source of funds, the other sectors have contributed in remarkably steady proportions, especially during the past five years.

In view of the spectacular rise in national investment in research and development which has tripled during this period, the relatively stable distribution of funds, manpower, and effort is strikingly significant for an understanding of the current situation and its problems for the future.

Most of the research and development being done today is directly in the national interest and should be judged accordingly. The Federal Government is not acquiring a larger proportionate share in the national research and development investment; nor has it increasingly encroached upon the private or other sectors. There is no clear evidence that any one sector has more than its fair share of scientific and technical manpower. These are, of course, statistical conclusions and do not always apply within particular programs, projects, or areas of science.

From the overall point of view, a natural first question is whether the country can afford to carry out a program of the present magnitude and technical character. There are certainly budgetary limitations within which such a national program has to be accommodated. The extent of such accommodation depends upon the priorities of the program objectives, their feasibility, and upon their acceptance by the American public. It is obvious that the trend cannot continue indefinitely at its present rate. Neither can it realistically be expected to level off completely as long as we live in a competitive world. The single most important limiting factor is the number of scientists and engineers and the extent to which we can provide facilities for their education and training. Here it is the time-scale that is immediately critical. It takes several years to plan and construct special facilities for research and development, and many more years to train competent research scientists and engineers—at least seven or eight beyond high school. It is therefore of first importance to ascertain the number of scientists and engineers presently available, and the estimated rate of output in the years ahead. One must estimate, also, the costs of the specialized education and training involved, including the present and potential supply of teachers and the construction of laboratories for teaching and research.

A report by the National Science Foundation in 1961, "Investing in Scientific Progress," points out a surprisingly definite cultural trend during the last 40 years, namely: the number of baccalaureate degrees for a particular age group has been doubling every 18 years, and the number of advanced degrees in science and engineering every 12 years. Wars and recessions have caused only temporary fluctuations. It is logical to conclude, therefore, that barring some catastrophe, the number of scientists and engineers with advanced degrees in 1970 would be about double the number in 1960. The report also points out that in order to maintain present standards of quality, at least 40 percent of the annual output must join the faculties of academic institutions to provide the necessary instruction and research training. However, the report stresses the fact that this desired increase will not be realized unless the country is prepared to defray the cost of the facilities, equipment, faculty salaries, and operating expenses required. As of the time of the report—2 years ago—these efforts were lagging badly. They still are.

Last year the President's Science Advisory Committee issued a report* which called for specific drastic steps in support of the training of engineers, physical scientists, and technicians.

Recently the National Science Foundation has completed another report, "Profiles of Manpower in Science and Technology," which analyzes the actual employment of scientists, engineers and technicians, with breakdowns by discipline, age, type of activity and employment, location and sector of the economy. A forecast based on this study indicates that the employment of scientists, engineers, and technicians is expected to double by 1970.

Both studies indicate, incidentally, that the education and training of this special group can be accomplished without depriving the country of professionals in fields outside science and engineering. Although the scientific manpower problem is of great urgency, the underlying problem is the much broader one of providing thoroughly competent training in all fields.

The opportunities for radical improvement in general education are very great. Thus, recent studies indicate that children in the lower grades have a far greater capacity for comprehending abstract aspects of advanced fields in science and mathematics than had hitherto been supposed. We are beginning to realize, too, that it is important to equip new generations with basic knowledge and understanding that will stand them in good stead in the face of a continually changing employment situation which automation and computer techniques will increasingly pervade.

It is also becoming evident that careful study directed toward the improvement of elementary courses in standard subjects may be most decisive in producing effective long-range results. For example, in spite of the large funds that have been made available to academic institutions for the support of science and engineering, the proportion of students majoring in science has remained approximately the same, about 20 percent, and the

*"Meeting Manpower Needs in Science and Technology, No. 1: Graduate Training in Engineering, Mathematics and the Physical Sciences"; The White House, Dec. 12, 1962.

proportion enrolled in engineering has actually decreased substantially during the past 5 years. On the other hand, the programs for improvement of instruction in the sciences and mathematics in the secondary schools has already produced significant increases in enrollment in these courses. This may be expected to continue in colleges and universities, especially as the teaching in these institutions becomes more effective. Thus, the evidence at hand suggests that the most decisive means of increasing the numbers of scientists and engineers may well lie in the improvement in courses at the introductory level. It is highly probable that similar consequences may ensue in other subjects of study, provided comparable attention is paid to their teaching.

In terms of policy, some further observations may be in order regarding the role of academic institutions with respect to the progress of science—and of basic research in particular. The present system for the support of basic research is largely the so-called "project" system, whereby a supporting agency selects projects to sponsor from among those proposed by individuals and groups with the endorsement of their institutions. The selection is made with the advice of authorities in the field concerned. This policy has the general endorsement of the scientific community. It enables the country's scientists and engineers to work cooperatively with the Federal Government in planning, and from the standpoint of progress in science it must be regarded as eminently sound. Since active research leaders are well informed on research in their specialties, the project system has the additional merit of built-in coordination and protection against undesirable duplication. Most of all, it promotes high national standards of quality in our national basic research effort.

However, as funds for the support of basic research have grown in volume, other critical problems of a policy nature have arisen. Thus, concentrated effort to meet certain objectives in fields essential to the national interest have given rise to the establishment by the Government of special research centers within the Federal establishment, and by contract, with industrial organizations and universities. These centers, in turn, have brought with them problems of their own. Among these is the question of the continuity of their missions. If and when a research center has largely accomplished its original purpose, what should become of it? Should its mission be altered, should it turn more to basic research, or should it be abolished; and if so, how can this be done?

As the volume of support for research has increased, another problem has become acute, especially at universities, namely, provision for full operating expenses for the work. Of particular importance is support for the institution itself, to enable it to work on research of its own planning to balance the work done with support provided from outside with earmarked funds. Good progress has been made toward this end by the institutional base grants from the National Science Foundation and the National Institutes of Health, whereby funds are furnished to the head of the institution to be used freely for scientific activities. Somewhat similar assistance is provided by a few selected programs under NASA, AEC, and the Department of Defense.

A further need, underscored in recent reports of the President's Science Advisory Committee, is for general assistance by the Federal Government to promising colleges and universities in the development of their latent research capabilities in order ultimately to broaden the base of academic research and graduate studies.

Still another perplexing problem has arisen, in the context of science itself, as well as in broad programs to solve national problems. I refer to the emergence of special integrated programs, which because of their great cost in dollars, manpower, and facilities compete with each other and with other large funding requirements lying wholly or partially outside science and technology. Even integrated programs devoted to scientific research, and not development, have caused considerable debate on "big" science versus "little" science. Recently the problem has become critical in such areas as oceanography, atmospheric sciences, and high energy physics. Sponsorship of such programs, impressive though they may be, should not be permitted to eliminate or unduly curtail support for individuals across all fields of science.

We have reviewed the growth of the national effort in science and technology, its distribution among economic sectors, its dependence upon available scientists and engineers and their future supply. It remains to consider the objectives of the enterprise, the efficiency and economy with which it is conducted, and to study the priority and feasibility of its major components.

Even a first glance at the national R and D budget will show that most of the money is spent for developmental programs, not for research. It is erroneous and misleading to consider the current level of R and D funds a "research budget," because 70 percent of it represents development. Neither is it a "science budget." Only 10 percent of it supports basic research, and only 30 percent research, both basic and applied. Most of the development funds go to support three main areas—defense, space, and atomic energy—and thus are primarily intended as expenditures for weapons and devices of warfare, space vehicles and launching devices, and nuclear power.

Clearly, if any substantial economies are to be effected they must take place in the 90 percent that is directed toward practical objectives, and not to the 10 percent for basic research. Any attempt to reduce the basic research effort would be false and even disastrous economy, because it is basic research that lays the groundwork for technological advances, that determines the potentialities of scientific progress, that leads to the outstanding breakthroughs, and provides the essential advanced training for scientists and engineers.

In concentrating attention upon the 90 percent which is devoted to applied research and development, we must reach a considered judgment as to our essential objectives and their priorities—whether present and contemplated R and D programs are designed to meet these objectives, whether they are feasible, and whether they are in competent hands and efficiently executed. We have a growing volume of experience in this type of analysis and review, particularly in industry. Especially valuable for the purpose are two modern techniques: systems analysis and operations research. The speed and thoroughness of such studies have been enormously enhanced by the application of modern computer techniques. The results of procedures and studies of this kind are of increasing importance to the decision-making process.

Any large developmental program requires evaluation from a number of different points of view, and it is important that each aspect be evaluated by an appropriate group of expert consultants, with a minimum of overlapping qualifications. Furthermore, final evaluation of large and costly national programs should be made by a body with high experience and competence in national affairs and not composed exclusively of scientists and engineers.

The national program in basic research has developed a variety and comprehensive strength that is a tribute to the generous and tireless collaboration of the country's scientists and engineers, in rendering consulting service on planning and evaluation. It is of the greatest importance to understand the significance of national support for basic research, so essential to the progress of science itself and to the training of scientists and engineers. It should never by regarded as competing with developmental programs. It represents the seedbed of technology. It brings to light new discoveries in many fields with wide potentialities for applied research and technological development. Basic research makes possible intelligent planning for the future.

Because basic reseach is the exploration of the unknown, however, it cannot predict the scientific significance of its findings, much less guarantee positive results of immediate practical value in any given field of investigation. It should be regarded as an investment, comprehensive in scope, and covering all areas of science. Like other investments it should include items of all degrees of promise, from those of almost sure return and low yield to those difficult and uncertain projects which would yield a high return if successful. When so planned and executed, the investment is statistically certain to produce results that more than pay for its cost, as industry well knows. Moreover, basic research is probably unique in that even negative results are valuable.

Basic research is a highly specialized activity; it is not one where the judgment of laymen has validity. Furthermore, complete evaluation of its findings must in general await corroboration by the scientific community, which may take years. Consequently, planning for basic research and such evaluation of its performance as is needed for the continuation of existing programs must be left in the hands of competent and experienced scientists.

So far as the future is concerned, if we are to do justice to the impressive potentialities of science and technology, one of our chief concerns must be a better public understanding of science and technology. Imparting a knowledge of the distinction between the two is the essential place to begin. Hopefully, in time, we shall be able to include science in the education of every child, but for the present it is important to try to give all citizens a clearer idea of the subject. This is not to say that every well informed citizen should expect to become a scientist, but merely that he should become aware of the coverage of scientific fields, the general purpose and nature of research, and especially that he should acquire some conception of its potentialities and limitations. Unless this general type of public understanding is developed, the country will not be prepared to deal intelligently or effectively with the major discoveries in science that are certain to occur.

Many of these will inevitably lead to issues involving technology that society will have to decide. Here the questions cannot be left to the scientists and engineers alone; their role is primarily to point out the scope and nature of a new field, its possibilities and limitations. We have already seen social questions of this sort arise, in the case of nuclear warfare and fallout, in particular. But it is certain that science will open up possibilities for development of an even more critical nature, in such sensitive fields as biology and psychology, for example. Imagine the social consequences of a discovery that would prolong human life to double its present span, or one that would predetermine the sex of a child. We do not know at the moment what discoveries of such critical magnitude will emerge, but we can be confident that discoveries of this degree of importance will ultimately occur. When that time comes, it is clearly of the greatest importance that all educated citizens be able to take an intelligent position on these issues.

One cannot conclude a discussion of the far-reaching sweep of scientific progress and its consequences without mentioning the involvement of international relations. An increasing number of scientific problems are global in nature and can be intelligently and effectively administered only by international cooperation. A brilliant example is the International Geophysical Year; the techniques developed during that period are being used with equal effectiveness in the Antarctic Program, the International Years of the Quiet Sun, and the International Indian Ocean Expedition.

As scientists well know, every field of science is international in the sense that its workers keep in close touch with the progress of their colleagues wherever they may happen to be. Geophysical subjects in particular contain a need for programing and collaboration of a different degree and kind, in that the collection of observations, the analysis of the data and its dissemination have to be planned and performed in a collaborative way throughout the world.

Another type of situation in which international cooperation appears to be the only rational solution is that where the magnitude of the effort is inherently great and where the consequences of experimentation are uncertain or possibly dangerous. If such enterprises are carried out in blind competition, they partake of the nature of "crash" programs which are expensive and wasteful. Furthermore, if the results of the research indicate the possibility of large-scale experiments that might involve the risk of altering the earth's environment, it is essential that the best minds available in all countries be brought to bear upon the problem. Some aspects of space exploration and research into weather modification are prime examples. No large-scale experiment or development should be attempted without the most careful research and every reasonable effort to anticipate its consequences, since it is possible that the sought-for effects might spontaneously implify to highly dangerous proportions.

For all these reasons it is of the greatest importance to move in the direction of increasing international cooperation in science, and where feasible, in development and technology.

When one considers the breadth, complexity, and inherent power of science and technology, one is moved to back away for a moment and ponder more deeply where we are heading—all of us. Man, by the use of his intellect, appears to have found ways to conquer most of the environmental hazards which confront him. The key to this triumph over nature is science. Man has learned, however, that the applications of science may also introduce new dangers.

Of especial significance to our generation is the realization that we may be able to take giant steps to create a new world—steps that are unprecedented in range and in novelty. Many of these we do not have to take, but we shall. This raises in new guise the problem of survival—survival in the presence of an environment we ourselves create.

How are we to meet this challenge and responsibility?

The history of science teaches that the survival of a species depends fundamentally upon striking an effective balance between two conflicting elements: competition and cooperation. In human affairs we seem thus far to have found that the most effective balance lies in a free, democratic society.

The limits of accomplishment of such a society rest ultimately upon the capabilities of the individuals composing it, their ideals, their standards of conduct, character, motivation, intelligence and, increasingly in this modern age, knowledge.

As the distinguished mathematician and philosopher, Whitehead, remarked 50 years ago: "In the conditions of modern life the rule is absolute—the race which does not value trained intelligence is doomed."

These are strong words, but they still are prophetic.

On the other hand, if we can help all men to acquire the knowledge that leads to understanding, we may hope to attain the wisdom needed to face the future with confidence.

ALAN T. WATERMAN