SCIENCE AND TECHNOLOGY IN THE UNITED STATES TODAY

25 August 1959

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NOTICE

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Publication No. L60-7

INDUSTRIAL COLLEGE OF THE ARMED FORCES

Washington, D. C.

Dr. Lloyd V. Berkner, President of Associated Universities, Inc., of New York (operators of Brookhaven National Laboratory and the National Radio Astronomy Observatory) was born in Milwaukee on 1 February 1905. He holds B.S. in EE from the University of Minnesota (1927) and did graduate work in physics at George Washington University. He holds honorary doctorates from Brooklyn Politechnic Institute, Dartmouth College, Columbia University, and the Universities of Calcutta; Uppsala, Sweden; Edinburgh, Scotland; and Notre Dame. In aviation he worked with the Department of Commerce in the installation of early radio range equipment. On active duty as a naval aviator in World War II he organized and headed the Radar Section and the Electronics Materiel Branch of the Bureau of Aeronautics, subsequently serving on the U.S.S. Enterprise during the Okinawa operations. He holds the grade of rear admiral, USNR. He was the first Executive Secretary to the Research and Development Board, later Special Assistant to the Secretary of State for the first military assistance program of the North Atlantic Pact, and Chairman of the Special Survey Committee for the Secretary of State to examine into the problem of foreign relations, authoring the official State Department report, "Science and Foreign Relations." He served with the Bureau of Standards and the Carnegie Institution of Washington in research relating to the physics of the outer atmosphere and radio propagation and is the author of numerous publications on these subjects. He has participated for more than 20 years in the work of international scientific unions and is past president of the International Council of Scientific Unions and president of the International Scientific Radio and was vice president of a Special Committee for the International Geophysical Year, organizing the international plans for scientific research with rockets and satellites. He is a member of the National Academy of Sciences, American Philosophical Society and other learned organizations relating to scientific fields. He is a member of the Board of Advisers of the Industrial College of the Armed Forces. This is his fourth lecture at the Industrial College.

SCIENCE AND TECHNOLOGY IN THE UNITED STATES TODAY

25 August 1959

GENERAL MUNDY: This morning we conclude our opening series of lectures on the United States position today with a talk on science and technology.

We are indeed fortunate to have so eminently qualified a man as Dr. Lloyd Berkner to be our speaker. Dr. Berkner, since his graduation from the University of Minnesota, has specialized in scientific research. He has recently completed a most successful tour as vice president of a special committee for the International Geophysical Year. Incidentally, he was the original proponent of the IGY, that is, of the International Geophysical Year; and he has been one of its most active workers.

At the present time he is President of Associated Universities, Incorporated. During World War II he served in the Navy with distinction, and today he is a rear admiral in the U. S. Navy Reserve. He is also a member of the Board of Advisers of the Industrial College. We also have another member of the Board of Advisers in the audience--Mr. Carlton Ward. We are happy to have him. Dr. Berkner was unable to be with us at the last meeting of the Board since he inconveniently broke his leg just before the meeting. We are pleased to see that he has recovered.

Dr. Berkner, it's a great honor and a privilege to welcome you back to the College and to introduce you to this year's class.

Gentlemen, Dr. Berkner.

DR. BERKNER: General Mundy, faculty of the Industrial College, students, and guests: It's a real pleasure to come back to the College today. The subject of my lecture will be somewhat different from the subject matter of previous lectures.

In starting on this subject I think we should really be scientific in discussing our terms. And so I am going to try to define science and technology.

I would define science as that branch of study concerned with the observation and the classification of facts acquired in precise form

from experiment and observation, and the generalization of these data to verifiable general laws, chiefly by induction and the test of hypotheses. Science involves the discipline of clear thinking, dispassionate inquiry, and respect for verifiable knowledge. It is a creative activity of human endeavor in representing experience precisely and, in the most general and enlightening form. The objective of science is to acquire the ability to predict in verifiable form the future behavior of any definable system through the application of the general laws that govern phenomena.

Technology is the practical art--note that I say "art"--of applying scientific knowledge, law, and method in the development and the production of any system for utilization by mankind generally, I refer to technology as an art since technology involves not only the creation of workable systems from scientific knowledge, but also the adaptation of those systems to function within the limits of human capabilities in a form suitable for human habits, needs, desires, convenience, safety, and artistic tastes. The art of technology does not, in itself, include creative science. Frequently technology must call on science to find means or methods whereby an acceptable system or device can be produced. Thus, a device may become possible only after scientific research to find materials of suitable strength, lightness, temperature-resistance, or other limiting property. Though such scientific research may be rather fundamental in character, it is usually called applied research, because it has been stimulated to satisfy a specific technological need. If technology is to ask science questions that science can answer in a useful way, then technology must know the probable limitations on science at any time. Therefore technology must understand the capabilities of science if it is to formulate its course of action with reasonable expectation of solution.

Technology is however, directly identified with development, which is the process of examining or assembling ideas, materials, and devices looking to a conceivable system or end-item. Development involves predicting or ascertaining the weaknesses or deficiencies of any assembly in a form that has significant expectation of correction through scientific research.

No complex system can yield to science by simple observation. When science faces such a system, it must devise a series of critical experiments designed to isolate, measure, and define the effect of each of the contributing variables of the complex. Since science cannot possibly perform all of the multiply-infinite experiments that can

be imagined, it cannot proceed blindly; but its experiments must be selected in accordance with tentative explanations, which are called hypotheses, that can be tested in order to proceed in a manageable way. As hypotheses are critically tested, they are discarded, or replaced, or modified, or verified; but their formulation and test is imperative in mapping the procedure to a scientific solution. Consequently, technology must have very direct access to science, not only as a source of new ideas, but also so that technology can orient related development so that the deficiencies of technology are formulated within the reasonable scope of science to correct. So, technology must be competent to comprehend the range of scientific hypotheses that are reasonable.

I emphasize this distinction between science and technology, between scientific research and technological development, since they are usually lumped together because of their close association in practice. But they are fundamentally dissimilar; and when described together, they form a kind of horse and rabbit pie, in which the rabbit of American scientific research amounts to less than one-tenth of the effort devoted to the horse of technological development of systems and hardware. In this proportion, when confused with technology, support for American research tends to be neglected altogether. But the proportion of science to technology influences the flavor and distinction of the stew; and with too little science, the great body of technology becomes backward, degraded, and mediocre.

Since technology depends implicitly on the extent and limitations of scientific knowledge, I would like to turn for a moment to the generation of that fundamental scientific knowledge on which the structure of technology rests.

Historically, the organization of scientific research has fallen under four major categories of sponsorship:

(1) The university.

(2) The national laboratory or research institute.

(3) The industrial laboratory.

(4) The governments, State and Federal.

Each of these forms of sponsorship has its place and is essential in a well-rounded program designed to provide American national scientific leadership.

Basically, the university must be at the heart of the significant national scientific research effort. For its ultimate advances in knowledge, science depends on the creative individual for the final assembly and ordering of facts and ideas, and their expression in concise form.

It is no accident that persons best suited to individual research are most often found on the faculties of colleges and universities. The diversity of the university atmosphere reacts to broaden the interest of the individual and to provide the intellectual tools required to associate diverse facts. Moreover, the need for clear presentation of ideas to the student forces a clarity of thought and expression that often contributes to concise formulation of scientific truths. It has often been the excitement of the dedicated individual, in pursuit of some obscure clue to nature, unnoticed or undeveloped by his predecessors, that has unlocked the door to a major scientific advance. The imagination of the individual generates the scientific perspective from which new and brilliant attacks on scientific problems can be organized. Therefore, in a society that would increase its intellectual contributions to science at an optimum rate, the opportunity for experimental and theoretical research by the individual must be supported to the extent that competent persons are in need of and available for such support. This support is best provided within the structure of the university dedicated to the protection and encouragement of the creative and dedicated individual.

In many fields, the university has done its job very well. But in recent years, the tendency to formalize education into standardized patterns of knowledge has led faculties to ignore opportunities to advance knowledge in some of the new and important directions. In part, the financial pressures of mass education and, in part, a growing attitude of what I would call "medieval scholasticism" by many members of faculties, through overconcentration on specialities, have tended to blind university faculties to their responsibilities for the whole range of human knowledge. This growing professional scholastic tendency to admire only the superspecialized approach and to admit no knowledge beyond a particular scientific splinter has, as one Nobel Laureate recently remarked, "put a premium on ignorance." Thus, in many important areas of science, the whole American university community does not support a single professor to whom the country can look for research leadership, or the student for his guidance in education.

Consequently, as a matter of national policy, we have the right to ask our universities to adjust more effectively to the changing environment of knowledge. Our Government and our students should not be forced to look to Europe, and particularly to Russia, for intimate knowledge of important scientific advances. That knowledge, with opportunity for its growth, should be found in one or another of our own universities.

The second category of sponsorship of scientific research is the national laboratory or scientific institute. The national laboratory as an adjunct to American research activity is emerging in our lifetimes as an essential element of scientific progress. By "national laboratory" I mean not only such centers as Brookhaven, Argonne, and the Berkeley Radiation Laboratory established under the aegis of the Atomic Energy Commission, but such new facilities as the National Radio Astronomy Observatory at Green Bank, West Virginia, and the National Astronomical Observatory at Kitt Peak, Arizona. These are coming into being under the sponsorship of the National Science Foundation. The national laboratory is designed to operate very large, expensive, and unique research experimental facilities to supplement the facilities of universities and institutions so that our scientists can have access to the most sophisticated research tools.

The very beginnings of modern science in the 14th century grew out of the insistence of the great Danish astronomer, Tycho Brahe, that the stars should be observed in an orderly way. To accomplish this enormous task, Brahe, with the generous patronage of King Frederick of Denmark, built his celebrated observatory in Uraniborg on the island of Hveen. Here in the main building and in the smaller "Castle of the Stars," which Tycho built later, were housed the mighty quadrants, sextants, and the great globe which were the wonder and admiration of 16th century scholars.

The point is this: Only one great observatory on the whole earth was needed to obtain the data that caused the revolution in modern science by substituting observation for speculation. But that observatory had to be large and expensive to do the job--as expensive in terms of the money of the time as a national laboratory is today in the United States.

From Brahe's observations, Kepler formulated his laws of planetary motion; and these led Newton to state the laws of mechanics--laws on which almost all of our present-day engineering, construction,

and transportation are founded. From this we draw the lesson that research facilities must be adequate to the problem at hand. Often the scope of the facility is beyond the capability of a university to manage. For this, the specialized observatory or national laboratory or the Russian "research institute" provides the means.

Unfortunately, in the study of the macrocosm--the universe--and the microcosm--the atom--such large and expensive tools are necessary to order and to convey the phenomena to our simple senses. Even in the study of the earth itself, highly organized and extensive efforts of thousands of scientists and scientific operations over its surface are necessary to provide a scientific view of our planet.

To explore the tiny structure of the atomic nucleus and its nucleons, we must use a form of what I would call "light" whose wavelength is comparable to the size of the particles that we would observe. Wavelengths of such small dimensions can be generated only with energies amounting to billions of electron volts. Therefore, giant machines, such as the Cosmotron at Brookhaven, or the Bevatron at Berkeley, or the new A. G. S. at Brookhaven, which, incidentally, had its first pulse put in to its magnet yesterday, are required to explore the atomic nucleus and to analyze the subatomic particles of which it is composed. Likewise, nuclear reactors are needed as a source of neutrons for a multitude of research activities that explore into special properties of atomic nuclei.

The departmental staffs of the universities, with some few exceptions, find the design, construction, and operation of very large research tools burdensome, with a tendency to divert their staffs from the broad range of activities expected at the university to the more restrictive range of activities imposed by the requirements of the machine itself. Above all, the large cost of the machine means that not many, and perhaps only one machine of a kind can be built. Therefore it is necessary that each machine be accessible to qualified members of the faculties of many universities and institutions; and often only one of each kind of machine can be built, because of economic reasons. The machine must be available to men everywhere who are peculiarly oriented in their thinking to deal with the results from these very specialized machines, or to stimulate new lines of development that emerge from them.

The reasoning has led to the conclusion that the most suitable organizational device for the construction and operation of very large-scale

and often unique, research tools, such as accelerators, big research reactors, and astronomical telescopes, for the benefit of American universities is the national laboratory. These research tools are planned to supplement the facilities that are available to the scientists at a large number of universities, so that every qualified American scientist can feel that he has access to machines of whatever size his experimental program requires. But the necessary greatness of such laboratories must not be confused with prodigality or luxury. The national laboratory can be as spartan as the individual experimenter. Waste in science is most often generated by misdirection of able scientists with tools that are inadequate to the job at hand.

Experience has shown that optimum progress and most effective use of research tools at the national laboratories seem to be achieved when the research effort of the permanent research staff of the laboratory, and of the visiting scientists from the universities, is about equal. Among the advantages to be acquired by these cooperative arrangements are: First, the visiting scientist can work with experienced people in setting up his experiment on a large and perhaps unfamiliar machine. Second, the extended contact between visiting scientists and permanent staff leads to an important interaction of ideas among both groups. Third, the growth of thought in the national laboratories can serve as a stimulus to the thinking of the university faculties. Here we are led back once more to Tycho Brahe; for, as his biographer so aptly observes, "The mighty impulse Tycho Brahe and Johann Kepler gave to astronomy caused the science to be taken up at the universities, and among them Copenhagen and Leyden were the first to found observatories."

The success of the Atomic Energy Commission in founding national laboratories to explore a variety of fields related to the atom has encouraged development of the national laboratory in many other neglected fields. While American scientists had pioneered all major discoveries on which the science of radio astronomy is founded, American radio astronomy had fallen far behind the scientific work of other nations for want of even a single large radio telescope. Now the National Science Foundation has sponsored the National Radio Astronomy Observatory, to provide American science with what will probably become the most advanced facility anywhere in the world.

But there are a variety of other fields, beyond the capacity of any one university to support, where national laboratories are still urgently needed to give American science the opportunity for leadership. At the

moment consider, for example, research in meteorology, which has almost come to a dead end. This is not for lack of adequate clues in nature, for they are prolific and exciting. But to explore these clues, men require very large and unique tools and rather massive group research. A squadron of aircraft with precise instrumentation is required to explore the properties of hurricanes in the Carribean, typhoons in the Pacific, and tornadoes in the great land areas. They are required to observe the fueling of the atmospheric heat engine in equatorial regions. Satellites must be put on patrol to observe continuously the earth's heat balance and its localized fluctuations. The design and observation of such specially instrumented satellites, and the reduction and analysis of their data, involve major and continuing effort. Raintowers, windtunnels, and computers involving solution of unique problems are essential to delineation of cloud physics and atmospheric flow. But solutions with suitable tools require intimate association with university faculties who must supply much of the brainpower to conceive hypotheses, design experiments, and broadly interpret observations. Meteorology is but one example of scientific areas where research is sterile and disjointed for the crying want of tools and mechanisms of sufficient scope and scale to break the bonds of ignorance. Certainly, the pattern of the national laboratory seems ideally suited to this kind effort.

Likewise, the Antarctic is producing vital geophysical data, far beyond the capacity of the universities to synthesize and interpret. I know at firsthand that the power of these data in advancing science would be immense if the tools and facilities for their synthesis and interpretation were available. Three years ago 60 leading American geophysicists meeting at the National Science Foundation called for the formation of an Institute of Theoretical Geophysics to deal with such problems. But nothing has happened. Such an institute patterned after the national laboratories is indispendable to national scientific leadership.

One might go on to mention other fields like seismology and oceanography.

In summary, one can say that the national laboratory as an essential element of American scientific activity has certainly grown far beyond the original concept of Tycho Brahe. Just as a dozen small telescopes among many universities cannot approach the scientific power of a single large telescope in penetrating the universe, so the rare and really great tools of science must augment the research

opportunities of the universities for optimum progress in science. Academic tradition of course, is not built in a decade, of course; but I believe it is safe to prophesy that the concept of the national laboratory, as we know it in the United States, or the research institutes, as it is known, in Russia, will grow as one of the major intellectual innovations of our time.

Turning to the third great sponsor of fundamental research, the industrial laboratory, we find that more generally its emphasis is directed to applied science in support of technology. This is easily understandable since the economic cycle from a basic scientific discovery emergent from fundamental research to a producible new item or a new industry is often as long as two or three decades. Nevertheless, industry understands that good technology requires an intimate understanding of, and access to, our rapidly evolving science. To provide this understanding and access to science, any good industrial laboratory appropriates a part of its effort to basic science. Without this admixture, the industrial laboratory becomes rather sterile and profitless.

Certainly such great laboratories as the Bell Telephone Laboratories, the General Electric Laboratories, and the Dupont Research Laboratories have not only transformed scientific discovery into human application, but also have greatly advanced fundamental human thought. Nobel Prize winners in physics, such as Langmuir of General Electric and Davidson of Bell, were encouraged to carry on their brilliant fundamental researches in the atmosphere of the industrial laboratory.

In the conduct of its scientific research, the industrial laboratory is not dissimilar to the national laboratory in character. A healthy industrial laboratory functions in close relation to the university research effort. Through university consultants, sabbatical leave opportunities for professors, and constant employment of young university doctoral graduates, the advance in the university thought is constantly injected into the industrial laboratory. Equally important is the vitality that industry returns to the university through returning faculty who have acquired a new perspective on the deficiencies of scientific knowledge. But with few exceptions, the industrial laboratory cannot provide the very large facilities, such as telescopes, radio telescopes, accelerators, research reactors, and other great scientific tools that are essential in pushing science to the limits of physics and astronomy. Instead, industry looks to the national laboratories to supplement their facilities where very expensive research

tools are required. At Brookhaven, for example, the scientists of almost every major industrial activity and laboratory work side by side with their academic colleagues from the university faculties and the laboratory staff. The Bell Laboratories, General Electric, Westinghouse, Dupont, and Monsanto are but a few of the major names of American industry that are represented at the Brookhaven National Laboratory. So the national and industrial laboratories supplement, but do not supplant, one another.

Closely related to industrial research activities are the organized research activities of the nonprofit academic institutes, sponsored predominately from industrial sources, to augment the capabilities of the industrial laboratory. Such institutes as Stanford Research, Armour, and Batelle have extended the capabilities of great industrial laboratories in many instances to the much smaller industrial activities of the country.

An important new aspect of basic industrial research is basic research done under contract for a profit, without the expectation of production motivation. This type of research is steadily becoming more important because of more involved defense requirements. But in recent years, basic research as a business is extending to other fields. Often, of course, such research falls into the category of applied or directed research. In many instances the Nation can use only one type of missile, or radar, or other special system; therefore, to gather the strength of its total industry, it must mobilize the research facilities of many industries to examine into the basic properties underlying all alternative elements of such a single system.

Similarly, in the field of health, pharmaceutical laboratories often provide the very best in skills of personnel, and quality of equipment, to examine certain very basic problems.

So I would predict that basic research carried out for an ordinary commercial profit will become more and more important as a business as we become more skillful in assessing the capabilities of the organizations to be employed. Certainly, applied research will be carried out under the profit motive and it is now generally recognized as a justifiable capital-generating activity.

Finally then, I turn to Government sponsorship of scientific research. This is very complex. To analyze this problem, I would tentatively divide scientific activities of Government into three parts.

The first part is the science and scientific research that is the integral part of the program objectives of certain Government departments and agencies. Such research is directly related to the missions of the departments and hence essential to their growth and evolution; it is equivalent to the industrial research of industry. Thus, the Department of Defense must have its supporting research for defense, and must further sponsor pure research so that it partakes of the reviving blood that science can provide it. To cut off the Department of Defense from access to the ideas that renew its vitality or guide its development would be to damage our defense irrevocably. Likewise, the very lifeblood of the Department of Agriculture is scientific research in agriculture, biochemistry, and plant and animal biology, soil chemistry, and so on. Similarly, in many departments one finds activities in scientific research, conducted or sponsored by the department concerned, that are imperative for the intelligent and healthy growth of that department. Much of this research is, of course, done under contract by universities, institutions, and industry; but it provides the Departments with criteria for their future development.

The second major scientific activity of Government is general research support for the universities and national laboratories. The Government supports a variety of scientific programs in many fields for the sole reason that such support is necessary to maintain the vitality of American science and technology itself. These are primarily the programs of grants and contracts of the National Science Foundation, the Atomic Energy Commission, and the Department of Health, Education, and Welfare. They are frequently described as "extramural" programs of Government, because their purpose is to aid the continuation of free, uncommitted research in colleges, universities, and research institutions. These agencies support graduate students and individual pure researches of professors. They contract for basic laboratory facilities that are necessary to a balanced American scientific capability. These agencies are not operating agencies in the usual sense; but, rather, have certain broad responsibilities with respect to the general welfare, including the encouragement of scientific education to the extent needed to keep America intellectually strong.

The National Science Foundation finally seems to be coming into its own. Established by the Congress in 1950, it struggled through its first few years with appropriations far below even its fixed ceiling of $15 million. When this ceiling was lifted by legislative action, the situation improved somewhat. Until 1958, however, its peak appropriation had been $40 million; and of this amount less than half went for the actual support of science. The remainder went for science education,

fellowships, and other activities specified by law. Yet Vannevar Bush, in his report to the President, "Science, the Endless Frontier," as early as 1944, visualized the Foundation as growing to a level of $125 million in five years. As a direct result of Sputnik, its 1959 appropirations jumped to a total of $130 million which is certainly a radical recognition of the neglected importance of undirected scientific research.

The third Federal scientific function represented by those Federal services that cut across State boundaries and departmental and private interests and must, therefore, be performed by the Federal Government. There are a whole variety of such agencies that must conduct very general technical services based on science that have no special relation to any single department of government, but are applicable to all departments, and to the country and to its business as a whole. As examples, among the agencies performing such services are the following:

Weather Bureau

National Bureau of Standards

NBS Central Radio Propagation Laboratory

Coast and Geodetic Survey

Hydrographic Office

Geological Survey

Office of Scientific and Technical Information

Antarctic Office of the National Science Foundation and of the Navy

Fish and Wildlife service

Naval Observatory

You can add others.

These agencies provide those technical and scientific services that are the normal functions of Government with respect to their citizens everywhere. They have no real organic relation to the

departments with which they are individually associated, but find themselves assigned to one or another department largely through historical accident.

Let me summarize, then, the three categories into which I have divided Federal responsibility for science for purposes of this analysis.

The organic research activities of the departments that are an integral and vital part to the achievement of department objectives.

External Federal support of scientific research and education, conducted by nongovernmental organizations, universities, and laboratories, and unrelated to any direct organic responsibility of the supporting agency.

Governmental scientific and technical services not principally involved in existing department objectives or strongly related in the organic sense to the functions or a single Federal department, but of the utmost importance to the Government and people as a whole.

This third responsibility is now not well discharged by Government, nor can it be, for a number of obvious reasons:

1. Since the technical agencies concerned do not vitally participate in the organic objective of the departments in which they find themselves imbedded, they are "stepchildren" of considerable nuisance value to their individual departments.

2. The organizational division of closely interrelated scientific responsibilities among a variety of departments prevents the close collaboration between those separated agencies that is imperative to the success of these services on matters of overlapping scientific and technical interest. For example, the Weather Bureau, which worries about water in the atmosphere, is in the Department of Commerce; while the Office of Hydrology is in the Geological Survey, over in the Department of the Interior. Those are two groups that should work very closely together.

3. These agencies, which are haphazardly scattered through the Government, are at a vital disadvantage in obtaining budget support in competition with other bureaus of the same departments whose objectives are much more closely related to individual departmental objectives.

4. Since these agencies are minor departmental responsibilities, I am sorry to say that departmental heads often have little knowledge of their real importance or national potentialities. There have been cases when they didn't know they were in their departments. Therefore, appeals for corrective action are not adequately understood or interpreted by departmental administrators.

5. Budget allocations for these agencies are received under a variety of departmental appropriations as a consequence of hearings of a number of different Budget Bureau examiners and congressional committees. Consequently, budgets of related functions of scientific agencies as, for example, water in the air and water in the ground, are never evaluated together for the total support and balance of effort. Therefore, the national value of adequate support for the total package of related scientific functions can never be officially appreciated. Moreover, even if the wisdom on one Budget Bureau examiner and Congressional committee provided adequate support to a scientific agency in one department, it is unlikely that a related agency in another department would receive related supporting funds through other examiners and congressional committees. Above all, there is no single budget or congressional committee to examine into or befriend this type of science in an expert way; and bits and pieces of scientific activity are in budget competition with much larger and wholly extraneous interests of the variety of departments before different examiners and congressional committees.

The present organization of these vital activities has grown haphazardly over the past century, and there are several historical references which describe this growth. The deficiencies in American scientific effort arising from scattered and unsuitable organization of these vital activities has led to the serious proposal that the agencies of this third category be reorganized under a new Federal Department of Science and Technology.

It has been suggested that such a department might well include the following divisions among others:

1. A Division of Physical Sciences and Standards.

2. A Division of Oceanography.

3. A Division of Meteorology, Climatology, and Water Resources.

4. A Division of Continental Structure and Resources.

5. An Office of Scientific and Technical Information.

6. A Government Map Service.

7. An Office of Time, Geodesy, and Astronomy.

8. A Division of Continental Fish and Wildlife, and perhaps Conservation.

9. A Division of Radio and Outer Atmospheric Research.

10. And perhaps an Office of Polar Activities.

You will observe that such a proposal does not disturb the organic research of the existing departments. It would not, for example, deprive Defense or Agriculture of their vital scientific and research functions. Nor would it upset the grant and contract functions of the National Science Foundation or other departments. It would be unwise to put money for scientific grants and education in competition with the operating funds of a Department of Science and Technology. But the proposal would give departmental status to areas of science that are now neglected in the United States--meteorology, oceanography, seismology, polar research, and the like. These neglected areas of science are vital to future welfare; they underlie the basis of future defense operations. They are areas of science that are not now neglected in the Soviet Union. So corrective action of some kind is needed in the very near future.

The most impelling argument that has been advanced against such reorganization of science in Government is that Congress is in no mood to stop with the kind of measures that I have described. There is a real fear that in organizing a Department of Science and Technology, Congress would end up by dumping all the scientific activity of the departments and agencies into such a department. An indiscriminate lumping together of Government activities in science would, of course, be little short of catastrophe. The damage so done would doubtless outweigh by far the advantages to be acquired. It is because of this very fear, I believe, that scientists generally have not advocated, and some have even opposed, the creation of a Department of Science and Technology.

But with the new Federal Council for Science and Technology, that was announced by President Eisenhower at the end of the year, together with the President's Science Adviser and his Presidential Science Advisory Committee, we now have, for the first time, the policy tools needed by the executive branch to plan a Department of Science and Technology and to guide it through the congressional phase in suitable form. I believe that with these tools, the Nation could safely face the corrective action required by the present grave deficiencies, through organization of a Department of Science and Technology without danger of creating a governmental monstrosity that might wreck the direction of Federal scientific effort.

Summarizing, we have divided the U. S. organization of scientific research into four parts:

1. The university.

2. The national laboratories.

3. The industrial laboratories.

4. The Government, which has three major interests:

a. The organic research of the departments.

b. The support of science and scientific education in universities and national laboratories.

c. The operational functions unrelated to any specific department, but related to all national interests that might well be organized into a Department of Science and Technology.

Just how much effort does this organization of science in the United States represent? Our best figures are provided principally by the annual reports of the National Science Foundation, but actually one has to dig very deeply in many places to get numbers.

The totals for research and development in science and technology run about as follows:

Origin of U. S. Expenditures for Research and Development for FY 1959
(Billions of dollars)

U. S. Government	4.2
Industrial (extrapolated from 1956)	4.9
Universities and nonprofit institutions	0.4
Total	9.5

This sounds like a lot of money until we look at the proportion for scientific research as a whole, excluding product development, but including applied research.

Origin of U. S. Expenditures for Research 1959
(Billions of dollars)

U. S. Government	1.1
Industry (est.)	1.2
Universities and nonprofit institutions (est.)	0.2
Total	2.5

This is about one-fourth of total research and development expenditures.

Now, excluding the applied research that goes into product design from this formula, and measuring only the effort put into basic research, I think the figures are most significant.

Origin of U. S. Expenditures for Basic Research
(Billions of dollars)

U. S. Government	0.28
Industry (est.)	0.30
Universities and nonprofit institutions (est.)	0.12
Total	0.70

Thus, less than 8 percent of the total research and development funds now go into basic research that provides the lifeblood of ideas on which technology must survive. Unfortunately, while total funds for basic research have grown something less than $100 million per year over the last two years, funds for applied research and development have grown faster, so that the proportion of research to the total of research and development is now diminishing. Perhaps the one bright spot is seen in the Federal expenditure for basic research,

that has in a year risen by $20 million to about $280 million in 1959, thus now nearly equalling our annual bill for chewing gum which grew from $280 million to $320 million in the past year. This is the future basis on which our technology is stuck.

In the administration of research, leaders are constantly faced with the dilemma of deciding the proper division of funds between the support of the large-scale research institutions or devices, such as big accelerators, and the amount of money to be given to much smaller individual or group-research efforts. One can point out, of course, that many individual or group-research efforts are completely dependent upon the access of the individual or the group to the large research tool.

But in the long run the decision to expend effort and support on large research tools or organized programs must rest squarely upon the evaluation by scientists of the contribution that that tool or program can make to the sum of human knowledge. This, of course, requires a Mark II crystal ball. Without specialized tools and highly organized programs, science cannot be provided the essential information on which even the individual research worker depends to tie his thinking to reality. The recent obliteration of the general concept or parity has certainly emerged from the stimulus of ideas arising from research with the great nuclear accelerators.

Had the knowledge and stimulus provided by these costly machines not been available, our physics might still be based on improper premises, and individual effort would still be proceeding under improper hypotheses.

Likewise, the great telescopes of astronomy have enlarged and sifted our concepts of the universe and of matter--they have led us from the morass of mysticism and provided the food from which such great concepts as the laws of motions and relativity have been nourished. The individual working in astronomy or radio astronomy requires access to the great telescopes and spectroscopes or to giant radio telescopes with their expensive electronic equipment, or at least to the vital information that they can produce. A dozen small telescopes scattered among a dozen separated workers can never provide the kind of scientific information that a single great telescope can produce. The small telescopes are essential for specialized researches and training. But the large telescope is imperative to broaden the vision of science to the bounds of the universe. So both are needed. The problem is to achieve balance between the support of the individual

research worker requiring modest means and the provision of adequate tools required for the significant advancement of scientific progress on every front.

In the same way, no amount of unconnected meteorological research in individual university laboratories can substitute for the need for an organized global attack on the physics of planetary manifestations of weather and climate.

The point to be remembered is that the effectiveness of the individual worker depends on the balanced progress of human thought in every field, even though some fields of research require tools and organized research programs that are disproportionately expensive. Without the support for these scientific activities that require expensive apparatus or effort, an unbalanced science would soon become overspecialized and sterile. Therefore, the distribution of funds must permit a balanced scientific program; it must provide sufficient funds for the individual worker to retain his freedom of opportunity, but it must also provide for large tools and organized research of a kind that permits a significant attack on any problem with clues that give reasonable expectation of solution.

This brings us squarely to the question: How much of our national effort should we spend on basic scientific research? To answer this question, we are led to the discussion of why we do research at all, and the relation of the economic and social health of the Nation to the technological capabilities derived from its science.

Basically, the objectives of the national program of scientific research can be stated very simply:

To provide the individual citizen-scientist the opportunity for inquiry into any significant limitations of human knowledge.

To create the scientific basis for a sound and advanced technology from which national leadership and safety and sound economic and social growth are derived.

But these simple statements contain immense implications with respect to national objectives that must be evaluated if we are to assess the extent of financial support that they deserve.

Certainly the right of the individual to free inquiry into any aspect of nature has been recognized since the early beginnings of

science. Of course, this right has been debated, or sometimes interdicted, under totalitarian regimes or during authoritative religious periods. Recognition of this right, however, has survived and received general recognition in our enlightened civilization. But it is not always realized that national interest requires the provision of opportunity and support to enjoy and to partake of the right of free inquiry into every aspect of nature. If we are to survive as a leading nation, our national interest requires that we must provide to our citizens opportunities that are at least as good as, and preferably superior to the opportunities found elsewhere. Thus, our universities and institutions must offer opportunities over the whole of science, so that our citizens are not forced to study or work abroad, particularly in Russia, when they wish to engage in any significant field of inquiry. Our students, our scientists, our professors, our industry, and even our defense activities should find the state of scientific knowledge in every field advanced sufficiently in American institutions so that we do not have to look to Europe, or especially to Russia, for the latest word in scientific progress; we should be able to find it or to develop it at home. Moreover, to retain a position of leadership suggests that the world should be able to look to us as the standard of national excellence in science.

Unfortunately, there are many fields where we now lag far behind the standards of scientific activity found elsewhere. This is why many believe that a Department of Science and Technology is essential to assume, as prime responsibilities, the stimulation, generation, and support of many seriously deficient elements of our national scientific stature.

But quite aside from the need for opportunity for scientific inquiry, the national need for an adequate scientific base to support a sound technology is even more striking. In the last half of the 20th century, we find that the greater part of our national production depends on advanced technology emergent from the scientific discoveries and developments of the past century. I ask you to analyze our whole productivity--power, raw materials, our new metals, chemistry, communications, electronics, transportation, space exploration, health, and agriculture. Above all, one cannot ignore defense. All of these depend primarily upon technology which has emerged from relatively recent scientific advances.

We could go on through the whole list of our industrial complex, and everywhere we will find the truth of the assertion that the greater part of our productive capacity depends on advanced technology derived

from recent scientific knowledge. Therefore, we must come to the main conclusion of my remarks today: Scientific knowledge and skill, and the creative technological arts based on that knowledge and skill, are the unique capital on which the health and growth of a modern economy rest unambiguously.

Land, structures, power, and factories are all forms of capital; but they have become secondary forms of capital in this second half of the 20th century. The primary form of economic capital today is scientific knowledge with the technological arts that are emerging from that science.

This leads us to a second major conclusion: That to maintain a healthy economy, just as the traditional forms of capital investment must keep pace with growing populations and demands, so must the investment in scientific research to create new scientific capital also keep pace with the gross national product.

This last conclusion is one that I think we have been slow to realize. Nationally we have tended to think of grants for research as a kind of gift to enthusiastic scientists, and to have a tolerant attitude of beneficence when such grants were made. Quite to the contrary, the limitations on that "beneficence" were limitations on the ultimate growth of our economy in the face of growing populations, with their added capability to utilize a more advanced technology. The limitations on support of science can only be measured by their ultimate effect in slowing employment, leaving unemployment and a recessive industry.

I think these conclusions give us a criterion for the most suitable level of support of basic scientific research. Clearly, our science must be financed to grow at a rate sufficient to supply the necessary capital of ideas to maintain the normal growth of our economy.

Obviously, the Government has a major stake in this new form of capital investment. Unfortunately, because of the great lag between basic scientific discovery and the subsequent development of the emergent technology--which is usually 10 to 30 years--the economic cycle is much too long for direct industrial support of basic research on a large scale. Moreover, in probing nature you can't predict what you may find in advance. However important the discovery, it may not be applicable to your own industry. Consequently, direct industrial support of basic research will always be limited. So the Government must provide the bulk of support for basic scientific research with its very long lead time to technology. And it is in the best

interest of Government to do so. After all, the tax income of the Government depends very largely on the health of industry.

When industry does not have the intellectual and scientific capital to produce useful and saleable products, tax collections drop and the Government goes to deficit financing. But Government has the power to avoid tax losses by wise and adequate investment in scientific research to maintain the flow of ideas that supply the scientific capital on which a healthy industry and economy and in its consequent tax collections depend. Such a capital of scientific knowledge, we must remember, does not deteriorate or require maintenance with time. It is permanent!

But to accomplish this, the Government can no longer look upon investment in science as a munificence to be granted in time of prosperity, and to be cut when tax collections are tight. To do this is literally to kill the goose that lays the golden egg. Quite to the contrary, investment in basic research must be considered as a most fundamental investment by Government in the national capital-investment underlying the technology from which tax collections will multiply.

We have said that the present Government investment in basic scientific research is less than $300 million annually. The total from all sources of $700 million is scarcely more than 0.1 percent of the gross national product. In my opinion, this amount could safely be increased over the next few years by a factor of 10 and this should be done as rapidly as possible. Certainly, such an investment, which is still only about 1 percent of our gross national product, would be small compared to other forms of less vital capital and small in return for the vast gains in:

National leadership.

A healthy economy.

A sound national budget.

I think in concluding we must say that, while the Government must play a major role, industry would be unwise to leave all to Government. This would be an abdication of our traditional American attitudes. Last year our capital investment in plant and materials by private enterprise is said to have exceeded $30 billion. Certainly, industry would be repaid to put a substantial proportion of its capital into the production of the ideas that make industry possible in our present day.

Last year less than $100 million was invested by industry in education of men to generate our scientific capital, and scarcely more than this amount in its own undirected basic research.

I would venture and I think Mr. Ward would agree with me--to predict that those industries that fail to invest an ever-increasing and substantial proportion of their earnings into research will fade into obsecurity in the next two decades. For as we approach the end of the 20th century, scientific skills, and the technological arts of employing them, will become the major criterion for capitalization of a successful and profitable enterprise. For only in this way can industry retain an optimum access to its basic source of capital which is ideas.

Thank you.

COLONEL BUCKNER: Dr. Berkner is ready for your questions.

QUESTION: Dr. Berkner, it has been my experience, and I think it has perhaps been yours too, that in recent years the trend has been to take a good bit of research that goes on in this country and carry it out in Europe, the theory being that there will be greater returns from the research dollar over there than in this country. Would you care to discuss the impact of this trend on research and development or on science and technology in this country?

DR. BERKNER: The American financing of European research, or, more generally, research in any other country, is a very interesting development since the war. There is no doubt with respect to some aspects of research that this has been very productive. But it has been the subject of very wide debate as to where this will eventually lead us. For example, it will develop very skillful technology abroad among a group that is especially qualified to undertake this scientific work or technological development, but it unquestionably leaves these skills abroad.

Now, you can say, and, I think, quite properly, that this is a very desirable thing to do among our allies, because it encourages their skills, it makes them more self-reliant, and it increases our own defensive powers since theirs are increased. But I think one must also remember that if you put yourself in a position of encouraging the development of skills abroad, at the expense of development of the same skills at home, you do acquire one disadvantage, which is a very important one. That is that when you have students that must be trained, it

is necessary for them to go abroad in order to acquire certain scientific knowledge or certain scientific or technological skills.

I think you do have another disadvantage and that is that other elements of the world will go elsewhere than to the United States to find the fountainheads of knowledge.

I am not sure that I would care to express an opinion that the practice is good or bad. One suspects that you have to examine into the individual cases rather carefully to determine whether it should or should not be done.

QUESTION: Doctor, some of the greatest scientific contributions that we have had in basic science have come from individuals that at that time were considered crackpots. You have mentioned that there are a number of institutions that we have here--university, industrial, and Government--and have mentioned what support is given and should be given. Would you care to comment on what support is being given to the individual, the loner, so to speak, not generally associated with an institution, or what support should be given to him?

DR. BERKNER: Yes. This is an extremely important question. Very often one is asked: "Are you really getting anywhere by supporting large laboratories or large groups when, after all, it's the individual who must produce the idea?" There is no doubt about it, that the individual must do so.

I mentioned in my lecture Tycho Brahe. Now, Tycho Brahe was an "odd ball" if you ever saw one. He couldn't get along with anybody. He never bothered to graduate from the university, although he was later appointed to its faculty. King Frederick supported him to a very heavy degree simply because he had confidence in Brahe, and Brahe, of course, certainly justified that confidence.

However, when King Frederick died, King Christian tried to continue this support. King Frederick's body was buried in a church which was on the island of Hveen, which Brahe was supposed to maintain. But Brahe spent all his money on science and allowed the roof of the church to fall in. King Christian was shocked when he came out to visit the tomb of his father and found that the rain was leaking in on the tomb. He ordered Brahe to spend some money to fix the roof of the church, but Brahe refused to do this, on the ground that he needed his money for his observatory at Uraniborg. This finally ended in a break, in which Brahe had to take off, and eventually ended up in Prague.

I might add that he was such an odd ball that Brahe finally died attending a banquet given by the Emperor of Austria. It seems that at that time it was improper to leave the table until the Emperor left; and Brahe had drunk to such an extent that, being unable to leave the table, he is said to have died of a broken bladder.

The interesting thing is that here you had a real odd ball; yet here was the man who led the change from the ancient mysticism into modern science by pointing out that observation and experiment were the thing. But I point out to you that during this process he had a very highly organized program. He had to get the backing of the King. He had an immense laboratory, which cost something like the cost of a modern national laboratory. He attracted scholars from all over Europe, who assisted him in his program. It was a highly organized research program.

Today if you have the odd ball who wants to look at the interior of the nucleus, he must have a nuclear accelerator to look at it or he just can't see it. Therefore he needs behind him the organized facilities which make it possible for him to look inside the atom, for otherwise he can't generate light waves short enough to look at them. If you have the odd ball who really wants to study the universe, he must have a big telescope, and this means that organized research effort is necessary to provide that big telescope to him.

So I think that when you say "organized research effort" you mustn't think of great teams of scientists who are producing ideas, but you must think of teams of men who are providing facilities to the individual who can do creative work. I think this is the way you say it.

In many areas organized research cannot be avoided. Let me give you an example. Van Allen discovered the Van Allen radiation belt, one of the great discoveries of modern times, by sending up some instruments in Explorer IV. But all of you know that an organized effort of hundreds of millions of dollars stands behind that simple discovery; and Van Allen could never have made this discovery--Van Allen, incidentally, isn't very much of an odd ball, he's a very practical scientist--if it hadn't been for the hundreds of millions of dollars and equivalent manpower in support of this complex investigation.

So I would emphasize that it is indeed the individual that will finally synthesize the data and produce the ideas, but behind him very often,

to give him that opportunity, must be a very highly organized operation to provide the tools and the material.

In conclusion in answering this question I would point out that in studying planet Earth--I have described the Geophysical Year at the Industrial College in another lecture--here literally we must organize the efforts of thousands of scientists to make observations simultaneously, and to make them in accordance with the same standards, in order to provide the basic data which permit us to describe and understand the Earth.

So the simple answer to your question after all this verbiage is the following: that the way to truth is not any single path, but through a diversity of routes, one of which can always provide to the individual the opportunity he needs to do the job.

QUESTION: Dr. Berkner, in organizing the idea of sponsors for research, what is the differentiation between the Government and the national laboratories, which I understand are all supported almost a hundred percent by the Government? Would you please explain that?

DR. BERKNER: Well, the national laboratories are supported by the Government, but in no case are they operated by the Government. They are operated by private organizations under contract.

Moreover, not all the support of the national laboratories comes from the Government. I would suppose that at Brookhaven something like 80 percent of it comes from the Government. I think that the Radiation Laboratory at Berkeley has perhaps a somewhat higher percentage and at Los Alamos probably all. At the National Radio Astronomy Observatory I would think considerably less than 80 percent. But in every case these are university-like institutions which are supported under contract with the Government. But they are different from ordinary universities in that, if you like, they are universities for professors. They provide facilities to the professors to do research which would be beyond the capabilities of the universities.

QUESTION: Doctor, the growing emphasis on research, not only in this country but throughout the world, must have created a tremendous administrative problem in the publication and exchange of scientific information. Do you feel that the machinery for doing this is adequate today?

DR. BERKNER: This is probably the most difficult problem that we have to deal with at the present time. The answer is, I don't think it is adequate, but I am not sure that I or anyone else can give you a completely adequate answer.

This goes clear back to the educational process. Probably to convey the ideas over a wide range of subjects to the individual, our whole educational process must evolve rather rapidly, so that the individual has a grasp of many more specialties than we have had in the past.

When it comes to the actual publication, the number of words is going up in terms of its publication almost exponentially. Some considerable efforts are made to reduce this, to simplify the language problem, to standardize the mathematical presentation, and this sort of thing. A lot of talk has been given to search and retrieval. But I'm sorry to say that this has been without what I would call any very obvious or successful conclusion. It's a very difficult problem, on which a lot of research itself would be justified.

QUESTION: Isn't the harnessing of the energy from the hydrogen bomb equally important with the development of the hydrogen bomb itself, and why don't we keep such information to ourselves when we get it? I am referring to recent headlines telling where a man discovered how to do it and then hastily went overseas to sell it to his fellow scientists, and it was also published in the papers.

DR. BERKNER: This is a very difficult question to answer, but on the whole I would say that it's not clear that we really have yet developed a means of controlling thermonuclear energy; and it's not clear to me that we will be the ones that will do it.

The general feeling is that before it really can be done so that it becomes commercial--this business of producing neutrons from very high-temperature reactions--there will have to be a whole variety of developments in a lot of different places by a lot of different people; and if each country keeps its work secret, the probability will be that you will simply extend by 50 or 75 years the date at which a solution will be available to the world generally.

What I am really saying is that if you put up too high a barrier of secrecy, it seems unlikely that you will get the development that you want. These developments usually come out of information developed

in a variety of places. When that information has been developed, then almost automatically everyone will discover it at the same time. In other words, when the time is ripe for discovery, the discovery tends to occur very quickly in many places independently.

One of the best examples I know of was the discovery of the hydrogen line in radio astronomy, which is an extremely important basic discovery. Three different groups were working on the problem without the other groups knowing about it--working quite independently. A lot of basic work had been done over the years on the line structure; and when the time came for the publication of the results, these three different groups had made the discovery so nearly simultaneously that the three papers, one from Australia, one from the Netherlands, and one from Harvard College, arrived at the publication "Nature" within three weeks of each other. And, indeed, Ed Purcell and Doc Ewing, who were really first by about 10 days, got their paper in "Nature," but the editor of "Nature" was forced to add that before he could print his magazine, he had received two other separate and independent announcements of the same discovery.

This shows you that when the fundamental work is done, the discovery is likely to come out in a lot of places, for one very fundamental and basic reason, and that is, people are bright everywhere. Never mind their nationality.

QUESTION: Dr. Berkner, you have said that we need a sizable increase in basic research in the next 10 years. It has also been said that there is a limitation on the availability of scientists and scientific talent here in the United States. Would you care to comment on the capacity of the universities and other organizations to handle an increase in basic research?

DR. BERKNER: Yes. The limitations in scientific talent are in some particular fields, but not everywhere. For example, at the present time you've got quite a bunch of good meteorologists in this country doing what I would call "sitting on their hands" doing minor research simply because they don't have the tools necessary to do really first-rate meteorological research. This isn't because they don't understand it. Let me give you the history.

The National Academy of Sciences, at the request of the Assistant Secretary of Commerce, made an investigation into meteorological research and made a report on 5 February 1957, I think it was,

pointing out that meteorology really was at a dead end, not for want of clues, but for want of facilities. The meteorologists needed tools like rain towers. They need a squadron of airplanes to range all over the world to look at certain physical phenomena. They need a computer that can count faster than nature forms weather. And so on.

Now, in absence of these facilities there is very little probability that meteorology can get on very far. There are a few significant researches going on as, for example, the work at the University of Chicago and MIT. But the National Academy made a recommendation that there needed to be a central facility to provide major facilities for meteorology so that the study of atmospheric circulation could be carried on on a global scale.

When this recommendation was made, the 12 universities giving graduate degrees in meteorology in this country all got their heads together and said: "Well, now, if the Academy report is right, we should really know about it." And so they organized a committee called UCAR--University Committee on Atmospheric Research.

This committee completely reviewed the studies of the National Academy, and a year and a half later the UCAR Committee came back--mind you now, it represented 12 universities in the United States giving graduate degrees in meteorology--and in their independent report they completely confirmed and extended the report of the Academy.

Now, what this means is that you are wasting a lot of meteorological talent at the present time for want of facilities which could put them on the major problems in meteorology--problems that they cannot now attack. There are many such fields in which research effort could be increased significantly without feeling the manpower problem.

On the other hand, I would not want to deemphasize the shortage of manpower. In many fields this is extremely serious. The most distressing fact of all is that last year the graduation of our scientific manpower continued to drop. The registration in freshman classes in engineering continued to drop. This is in the face of a very rapid increase in engineering trainees and scientific trainees in the Soviet Union.

So the answer is that certainly we can expand our facilities in many areas where people are now sitting on their hands for want of adequate facilities. But in other areas we are certainly dreadfully short of manpower.

COLONEL BUCKNER: Dr. Berkner, on behalf of the Commandant and all of us here at the College, I want to thank you for coming down from New York and giving us your views on where we stand in science and technology.

(5 Oct 1959--4,200)B/en/bn

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