SCIENCE AND THE WORLD OF TOMORROW

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INDUSTRIAL COLLEGE OF THE ARMED FORCES

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Dr. Lloyd V. Berkner, President, Graduate Research Center, Dallas, Texas, was born in Milwaukee on 1 February 1905. He holds a 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 Polytechnic Institute, Dartmouth College, Columbia University, and the Universities of Calcutta; Uppsala, Sweden; Edinburg, 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. Prior to his recent appointment, he was president of Associated Universities, Inc. of New York (operators of Brookhaven National Laboratory and the National Radio Astronomy Observatory). 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 fifth lecture at the Industrial College.

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GENERAL MUNDY: I am sure that you will agree with me that our subject this morning, "Science and the World of Tomorrow," is one of great importance and great interest to all of us.

Dr. Berkner, our speaker, of course, is eminently qualified to speak to us on this subject, since he has been engaged in the field of scientific research all of his mature life. During World War II Dr. Berkner served as a naval officer. Today he is a rear admiral in the Reserves of that service. Dr. Berkner was also the original proponent of the International Geophysical Year, and during the course of that year he was very active in all of its work. He has just recently been appointed to head the Graduate Research Center of the Southwest in Dallas, Texas, and I would like to take this opportunity to extend to him the congratulations of the entire College on this appointment.

He has also been a friend of long standing to the College and he has been a member of the Board of Advisers to the College during the period of my incumbency as Commandant.

Dr. Berkner, it is a real pleasure to welcome you back for this, your fifth appearance, and it is a particular pleasure to welcome you to our new building.

Gentlemen, Dr. Lloyd V. Berkner.

DR. BERKNER: General Mundy, Members of the Faculty, Members of the College: It is a real pleasure to come here this morning because I, as one of the advisers, have looked forward for many years with General Mundy and the other leaders of the College to this opportunity to lecture in this fine, new auditorium.

I remarked this morning to General Mundy that you can feel the difference in the decks as you walk across, because they have a solid feel. Those of you who had the doubtful privilege of living in the old building will have the same sense of appreciation that I bring this morning in coming to these excellent quarters which the Industrial College so warmly deserves after its distinguished history and role.

As one comes into the building one cannot help being impressed by the words of President Eisenhower which are so indicative of the purpose of this fine College.

In discussing "Science and the World of Tomorrow," I probably would not be a better prophet than many of you, or even most of you, here this morning. So I am going to try to stick as close as possible to the actual situation which is our point of takeoff.

I propose, therefore, to discuss the organization of science in the United States, to get some feel for how our science is done, then briefly, to consider cost of science and technology, then proceed to compare and contrast some of the strengths and weaknesses of American science with reference to science elsewhere in the world, and, finally, very briefly, to discuss as examples some of the obvious implications of science with respect to the immediate future, some civilian and some military.

I will divide the basic organization of science in the country into four parts: First is the science done at the universities; second, the science done at the national laboratories and the great foundations; third, science at the industrial laboratory and its contribution; and, finally, science within the U.S. Government. In dividing the problem in this way, one can emphasize the special attributes of each element of our national science organization.

The university, of course, is the foundation stone of our American scientific activity. Now, it is interesting to note that this has not always been so. Science as we know it today emerges from what we call the new physics, which was generated by Galileo and by Newton, and by their successors in the 16th and the 17th centuries.

Oddly enough, only a few of the great scientists of that time worked in the confines of the university itself, because of the strong influence of the narrow scholasticism of the medieval period--Thomas Aquinas and the like. As a consequence of this influence, almost all of the experimental science of the early years was done outside of the university. Only slowly, in the last three centuries, has the basis of science migrated into the university halls. It's true that Newton and Galileo both operated in the universities, but the first great observers, such as Tycho Brahe who made the basic observations from which the modern astronomy and the emergent mechanics have been derived, did their work outside of the university. Indeed, it is amusing to note that Brahe was so interested in making precise astronomical observations that he never bothered to graduate from the University of Copenhagen, although later he became a lecturer there.

The growth of graduate education really marks the beginning of the great emphasis on scientific research in the university structure. This growth is relatively recent--less than 100 years old. The first Ph. D. graduated in the United States was graduated from Harvard College, I believe, in about 1873, less than a century ago. The first great graduate university, Johns Hopkins, was founded in 1876. Not until the 1890's did the university begin to graduate men at the doctoral level in any substantial numbers. When I refer to training at the doctoral level, I include the scientific research at the university emerging as an essential part of that doctoral training.

After 1890 the research at the university became extremely important. It became important because of the variety of advantages that the university could offer. There were, of course, the great university libraries available to research workers, and these libraries grew very rapidly. Then there was the freedom of selection of the problem on the part of the professor. While today we tend to accept this privilege almost automatically, because we think of freedom of selection of problems as something that is due to any university research worker, or for that matter almost any scientist, the problem of freedom in selection of the choice of problems was a very important one, as late as the turn of the century.

Following the growth of university research and as science expanded at a more rapid rate, it became important that the student learn from the professor, not the science or the engineering which the professor knew when he was trained but rather the newest techniques which would prepare the student for what he would meet in the future. This meant, of course, very advanced and imaginative research for both the professor and the student.

The university also offers the cross-fertilization between disciplines, the interrelationship among the different sciences which permits the synthesis of broad, new ideas that are so important to science.

So, we find that in the past 50 or 60 years the university has become the basis for scientific research in the United States. But, of course, there are problems when you have this basis for research. Among these problems is the fact that, if you tie your research to graduate students, there is some difficulty with respect to continuity of research. A research problem of three or four years, which is the average life, we hope, of the graduate student at the university, is about the average length of a problem that the average professor at the university can attack. In many cases the professorial staff is able to undertake problems of longer duration but rarely so within the confines of the university itself.

Then there is the limitation on facilities. As science becomes more complex, more complex facilities are required to solve advanced scientific problems. These facilities are sometimes very large and they tend to warp the university if constructed in the confines of the university itself.

I am reminded of a conversation I had with the President of a leading university a couple of weeks ago. I said, "How is your accelerator getting along at the university?" He said, "Well, all right." But he said, "I am not quite sure whether we are running the accelerator or whether the accelerator is running the university." The point is that, when projects get very large, they preoccupy too large an area of activity of a university department, and consequently the members of the department feel constrained to do problems which that accelerator poses rather than to select their own problems freely. So there is a limit to the kinds of facilities that a university wants within its walls.

This, then, brings us to the second aspect of research organization in the country, and that is the great foundation or the national laboratory. Indeed, it is of some interest to note that within a decade after the growth of substantial graduate education in America the great foundations began to organize the really large-scale research facilities.

At the turn of the century organizations such as the Rockefeller Foundation and the Carnegie Institution of Washington met the challenge posed by the growing need for elaborate research facilities by providing facilities which were beyond the capacity of the universities to construct or employ effectively by themselves. We saw, for example, the growth of the great astronomical observatories, Mount Wilson and Mount Palomar. This example is a very interesting one, because, although it couldn't have been forecast, there is a direct inheritance from this vast astronomical complex in the Far West in the industrial and research developments which have occurred in the same area. With Mount Wilson and Mount Palomar there were attracted astrophysicists from all parts of the world. Out of this great interest grew the distinguished astrophysical work of the California Institute of Technology, and out of this in turn grew the Jet Propulsion Laboratory. And presently, from the people trained there grew the Space Technology Laboratory.

So one sees the inheritance from the beginning of a fundamental research activity with elaborate facilities into the growth of a broad industrial and basic research complex in the Far West.

Thus these institutions which were founded privately at the turn of the century have played an extremely important part in the development of scientific and industrial opportunity which the university itself could not provide.

By the 1940's even the private institutions could no longer finance the growing needs for large-scale research facilities which science was then demanding, and we saw the appearance of the national laboratories. Typical among these laboratories was that at the University of California, the Radiation Laboratory at Berkeley, which serves the whole of the west coast complex. There was the Radiation Laboratory at the Massachusetts Institute of Technology, which was disorganized at the end of the war, but whose staff went over to the Brookhaven National Laboratory, on Long Island, and which I had the honor of managing for so many years. There was the Argonne National Laboratory operated under the University of Chicago, the Oak Ridge National Laboratory in Tennessee, and of course the Los Alamos National Laboratory in New Mexico.

The characteristics of these national laboratories, with a few exceptions, are that they are managed by university groups in such a way that their facilities supplement the facilities of the universities. For example Brookhaven had a faculty of about 350 members with a supporting organization of perhaps 2,000 or more technicians and workers. The emphasis was put on providing to the faculties of the universities the opportunity to carry on research with facilities that the universities themselves could not supply.

Out of the program at Brookhaven, with its great facilities, (such as the alternating-gradiant syncrotron that accelerates protons to 33 BEV, the two, and now three, reactors there, the smaller accelerator--the cosmotron--the gamma field, and so on) are attracted some 200 visiting man-years of professional research from university faculties. There are 100 to 150, in any one year, research associates who are post-doctoral students doing advanced research, to acquire capability directing the large independent research projects, or to train for the associate professorship or professorship at one of the universities. There are always a variety of graduate students around such a place. Mostly they come with their visiting professors, but sometimes they come from universities simply to have access to the facilities for their particular research problems wheré they work under the supervision of one of the local faculty of the laboratory.

There is the immense summer program in which men from a whole variety of colleges and universities come together to study fundamental problems, to lecture each other, and to advance scientific knowledge generally.

Out of the national laboratory, as it is now evolved, emerges the opportunity for greater continuity of science. The large facilities can be set up so that they do not warp the university, and moreover, the very large facilities can be operated continuously and efficiently by faculties from many universities as is really required by the huge investment involved.

At the cosmotron at Brookhaven, I recall that about 80 percent of the research work was done by visiting professors from other universities and only 20 percent by the local faculty. Under these circumstances it is possible to operate such large facilities continuously on one experiment after another. The alternating gradiant syncrotron, the 33 BEV machine, cost some $31 million. When you have an investment of this size you simply have to operate it on a 3-shift, 7-day week. If you try to do this in your own university, you find it difficult for want of scientific manpower. The faculty just are not available. So you provide the opportunity for its operation to a very large number of visitors through the mechanism of the national laboratory.

Thus the national laboratory, which is the outgrowth, really, of the original work of the foundations at the turn of the century, has become the second important element in scientific research in this country. It supplements the research at the university, and offers the professor the opportunity to do work with advanced types of instruments which would not be available at the university.

The third element of research activity is the industrial laboratory. I would emphasize this particularly, because, in my opinion, it represents one of the large differences between the organization of research in the Soviet Union and in the United States. In my opinion, the Soviets have not solved their organization of the transition from the ideas of science on one hand and the application of these ideas in industry on the other. In individual cases they have solved this very well, where they have used special means in these special cases. But they don't have any generalized means, applied right across the board, of solving the transition problem. 1/

Therefore, I suspect that, while they may be ahead in ICBM's and in space, and in one or two other fields where they have applied very special effort, their average industrial development tends to follow, rather than lead, the Western industrial development emergent from science. I think this occurs because of the great effectiveness of our industrial laboratories in achieving an excellent transition from science to technology.

The industrial laboratories in the United States, as they have evolved, are not simply technological laboratories. In most cases they are first-class scientific laboratories as well. There is a very important reason for this. When the engineer has to design something that has not been designed before, he calls upon science to supply him with solutions for the new problems that are posed. He has to understand science himself, he must have access to science, because he can't ask science all of the multiple-infinite questions that might be thought of. Instead, he has to know science so well that he must be able to ask science questions that lie within the range of hypotheses that are reasonable if science is to find a solution to his problem. Consequently, American industrial laboratories all include a fair share of basic scientific research. This is a very important American advantage.

At this point I might indeed emphasize the difference between science on one hand and technology on the other. Science, of course, is a creative, even an artistic, activity in which one endeavors to find generalized models from which you can predict the behavior of any system in the future. It is a very critical and analytical type of approach to the synthesis of observations.

On the other hand, technology uses the generalized knowledge emerging from science for purposes of application. Technology has to contain many activities that science does not implicitly contain. Technology has to deal with human taste, with human capabilities,

1/ On 17 Apr 1961 the Soviet leaders announced a new organization that will supersede the Academy in the effort toward better transition.

with human limitations. Indeed, there is a different kind of artistry in technology than is necessary in science. But technology must have intimate access to science so that it can know what science can reasonably do for technology at any single time.

As a result of the development of the industrial laboratory, with strong basic scientific and strong applied scientific activity, one finds many Nobel prize-winners, such as Davisson, for example, from the Bell Telephone Laboratories, or Langmuir, from the General Electric Company, who have done such distinguished fundamental research that it has been recognized throughout the world. So the industrial laboratory is a very major part of our scientific activity.

Then, finally, we come to government, which has had an ever-increasing part in the scientific effectiveness of the country. Science in government is not new. I would point out to you that as long ago as 1743, in the organization of the old Colonial Government, Benjamin Franklin and the American Philosophical Society then organized substantial science with government recognition. So there is a very long history in the United States, as in other countries, of government support of science, for a variety of reasons.

I think of the support of science in government as falling into three classifications. First of all, there is the scientific research done by government to support the direct objectives of the departments concerned. This is a very valid interest of government. In the Department of Defense, for example, you have the problem of maintaining an adequate military posture in the country. This involves the introduction of new weapons and better use of older ones. Thus it is quite clear that there is a very valid and justifiable reason for the Department of Defense to enter into basic and applied research to the extent necessary to further those objectives. I would emphasize, when I say "to the extent necessary," that the Department of Defense must have sufficient access to basic science to know what hypotheses of science are applicable to its problems. Therefore, the Department of Defense must be in basic science.

This is also true of such other great departments of the U.S. Government as the Department of Health, Education, and Welfare, the Department of Agriculture, et cetera. These departments have developed strong scientific programs in support of their objectives.

Then, the second kind of government activity is the direct support by the U.S. Government to strengthen science in the

United States generally. Here we have such agencies as the National Science Foundation and the National Institutes of Health which provide very extensive support to the entire scientific community of our country to strengthen the private scientific activities of the country as a whole. The National Science Foundation now has, I believe, appropriations in the order of $200 million a year, and these will grow probably to a half-billion within the next decade.

The third form of scientific activity is found in scattered agencies of the Government which provide services, not only to the Government but to the people as a whole. We have the Weather Bureau; the Coast and Geodetic Survey, the Geological Survey--a whole variety of agencies, 10 or 15 of them, in the U.S. Government, which provide services to the Government and its citizens as a whole, that must depend upon the advances of science for the improvement of these services. I might add in this latter category that there has been all too little research among these service agencies, and they have tended to become obsolescent in many cases. So these are the basic elements of our Government organization in science.

Now, what is the cost of scientific research in the U.S. Government, and in the country as a whole? As nearly as we can tell at the moment, we are spending a total of about $10 billion a year--compare this to our total gross national product of about $540 billion per year--on research and development and basic engineering. About half of this money is spent by the United States Government in one way or another, and the other half originates from private sources, principally in the operation of industrial laboratories or from private foundations. So we have about $5 billion from the Federal Government and about $5 billion from private sources.

Of these moneys, both Federal and private, less than 10 percent--indeed about 8 percent--go into basic research. There is about $400 million worth of basic research supported by the Federal Government and about $400 million worth of basic research supported by private industry. The other 92 percent is spent primarily on early engineering and development of hardware.

One of the great problems is how these proportions really should fall. Is 8 percent the right proportion of basic science to fundamental research? On one hand, if you spend too little on basic science your engineering tends to be tied to an obsolescent science and therefore produces very awkward or primitive solutions. On the other hand, of course, one cannot press basic science farther than you have personnel qualified to do it creatively. As you know, the training of scientists for basic research is a very special training and it takes very many years. It takes eight years after high school to get the doctor's degree, and you have four or five more years as a research associate at one of the great laboratories before you are really qualified to become a professor or the leader of a great research project--about twelve years of post high school training--although some of this time may be very productive in science.

On the other hand, in this problem of support we have the following question to examine: Almost all of new industry today is industry derived from science and the technology emergent from it. If we examine the power industry, the chemical industry, the metals industries, with all of the new metals that have been developed commercially in the last 20 years--industry by industry we find that new industry is almost wholly emergent from recent science. The electronics industry, with which I have been associated, is completely emergent from science of the present century.

In a growing country, with growing industrial activity, since it is true that the major part of our industry emerges from scientific advance, then quite clearly our investment in science must be sufficiently large to provide for a continually expanding industrial opportunity. So this is one factor that must be remembered in determining our allocation of funds to basic research, as contrasted to engineering.

A second factor is that, since most of modern industry is emergent from science and recent technology, the collections in taxes by the Federal Treasury are dependent principally upon recent industry and an adequate product from that industry which itself can be taxed. If one neglects the origins of industry in science and technology, one can expect not only of the loss of industry and the loss of employment but also a loss of tax revenue to the Treasury.

So in Government support of science it isn't just a question of giving away the money out of the Treasury to science. It is also a question of, shall we say, the Government's capitalizing growth of the ideas on which it must depend in the future for its tax revenue. The required balance is delicate, and I will leave it to you to work out as to just where this balance should finally be set for the optimum income to the Treasury at a given rate of taxation.

Now, what are the strengths and the weaknesses of American science? Well, the basic science of the country, I think on the whole is strong. That basic science has a character of which every American can be proud. Our physics, our chemistry, our biology, our medical science, and our agricultural science, all of these, stand at the very top in comparison to world science generally. These are areas of knowledge in which the world generally looks to the United States for the leadership of the world.

The Government agencies which support much of that science--National Science Foundation, Department of Defense, National Institutes of Health, Atomic Energy Commission--I think have a right to be very proud of the wisdom that they have shown generally in the support of scientific research. And this preeminence should be a matter of pride among scientists in Government agencies as well. Perhaps no money is spent under more rigid rules, or after more careful study, or with greater integrity, than the money that is spent in support of U.S. science. So I think the Federal agencies which have supported the basic scientific program in the country through Government have a just right to have pride in the job that they have done.

But, when one goes from the basic sciences into what one might call the derived sciences, the situation is not so good. Let's take, for example, the environmental sciences--meteorology, seismology, hydrology, water resources, and that sort of thing. One finds that these sciences are in a relatively primitive and even a decrepit state in this country at the present time.

You ask yourself, Why should this be so? Well, of course the environmental sciences deal with the earth as a whole, so they involve big problems, and they require special facilities. These facilities have not been forthcoming, and they are expensive. But I think the real trouble goes back to the organization of science in Government. I mentioned a moment ago that there are a variety of service agencies--the Weather Bureau, the Coast and Geodetic Survey, and the Geological Survey. These agencies are dribbled around the Government almost by accident. They are in departments where many of the new appointees of the Kennedy Administration will be in office for a year or two before they ever find out these agencies are in their departments. Consequently, these agencies, operating individually, find very little support, very little money for research, since they are not related to the basic interests of the departments concerned. The Weather Bureau is almost dry. It has almost no research going on--not because the Weather Bureau doesn't understand or want it. The Weather Bureau understands its needs very well. One need only talk to the Director of the

Weather Bureau or to its small Research Department to realize the keenness with which they grasp for research that could advance our weather activities. But the Weather Bureau just doesn't get the money because it is a minor agency in the Department of Commerce, which is preoccupied with a variety of things besides weather.

The Geological Survey, which is responsible among other things for our water resources, is in the same situation. It is imbedded in a department which is interested in our colonial activities, in Indians, and in grazing, but scarcely knows that the Geological Survey is there.

So, as one goes through the Government, one finds that the agencies responsible for the environmental sciences are scattered out in government and represent nothing like the concentration of responsibility that you have in the AEC for atomic work, or the NIH for our health and welfare, or the Department of Agriculture, for our agricultural science. Consequently, the environmental sciences are terribly neglected.

One finds other weaknesses in American science. There are cracks between the basic sciences. Take for example the field of biophysics. In biophysics you have the application on one hand of the electronics and physics and on the other hand biology. This marriage of two related sciences promises to lead to very important developments in basic science. But no one is responsible for biophysics.

In the universities you have departments of biology, departments of physics, departments of mathematics, and departments of engineering where they deal with electronics. Mostly these departments don't talk to each other. There are wide cracks between them. As a consequence, the sciences which fall across these university departmental lines tend to be neglected. Biophysics is simply an example of many areas of development in this country where our science is weak at the moment.

The national laboratories could, perhaps, do something to correct this. Unfortunately, most of these laboratories tend to be organized as universities are, with departments of physics, departments of chemistry, departments of mathematics, et cetera. Perhaps the national laboratories should reorganize to cut across the university lines in order to close the cracks that have developed between university departments where science is not receiving adequate attention.

Then there are other weaknesses of our science in this country. Oddly enough, in spite of the fact that the Government is one of the strongest supporters of basic research, nevertheless, if the Government makes a contract for the production of one item or another in an industrial activity, it does not permit the funds under that contract to be applied to any research by the corporation carrying the contract.

This is a very odd situation because it deprives the company concerned of the exercise of ingenuity and judgment with respect to the production of the item for which the contract is made. Quite clearly, the Government, and perhaps even wisely, should place some limitation on the amount of production contract money to be spent for research. But much advantage could be acquired to the Government by allowing the company, through its research and its development activities, to find more efficient methods of production and to produce, perhaps a less obsolete product through the application of its own ingenuity. So here measures could be taken by the Government to improve the situation.

Well, one could talk about other strengths and weaknesses, and surely the new Administration will find a very interesting challenge in correcting these weaknesses. I would mention just one of them. In spite of the fact that there is very substantial support for scientific research in this country, we have tended to let our research plant run down. If you go into the average university or college at the present time, you will find that the research plant involves very ancient obsolescent equipment. Somehow or other money can be found for projects or even programs but rarely for facilities. And so our facility plant for research in this country has run down very seriously in the last 20 years. Because an advancing science itself makes equipment and facilities obsolescent rather rapidly, we tend to be re-researching the same old things rather than pushing on into new areas of scientific activity. So there is a very definite danger that our scientific plant will be outmoded.

Now, what about the future impact of science--really the subject of the title of my talk this morning? Well, this takes a prophet with a Mark II crystal ball to try to figure out just where things are going. But I think there are some areas in which predictions can be made with relative safety.

The first prediction I would take as an example would be in the area of civilian activity, and can be made quite safely. It relates to communications derived from satellite space activity. The present limitations on communications in the United States go something like this: If you draw a line across the United States east to west and measure all the communications transmitted from north to south you find that this can be confined in a band width about 10 megacycles wide. As you know, the band width determines the total amount of communications that can be transmitted across that line in a given time.

If you draw a line right around the United States you find that the total communications are contained in a band width about one megacycle wide. This really is not very much communication. The availability of communication is sometimes greater than this, but unfortunately this varies with time, with sun spots, with the number of cables you have across the Atlantic, and so on.

You may be surprised to know, perhaps, that there are only 47 cable channels across the Atlantic between the United States and Europe at the moment.

With the coming of satellites, quite clearly we have the opportunity of multiplying this communication capability by a factor of as much as 10,000 with a comparatively small investment. When I say "a small investment" I mean a small investment compared to what you get for it. For example, a single satellite communication system, based on the 24-hour hovering satellite, would probably cost about $100 million. This is quite a lot of money, but the total communications carried by such a system might be of the order of 100 times the total communications now available across the Atlantic. So the investment, compared to the return, is not very large. Thus one can anticipate within the next decade that communications will be multiplied on a vast scale and that the cost will be greatly reduced. Even the most conservative estimates indicate that the cost will come down by a factor of 5, and less conservative estimates, and perhaps more realistic ones, indicate that the cost will come down by a factor of 10.

What does this mean to the country as a whole? Of course it means a good communication industry. You all know that AT&T stock is going up, and this sort of thing. But I think it means much more than that. It means that we are within the reach of worldwide dialing on telephones. But even this is a very elementary concept. Basically the availability of a vast amount, an almost unlimited amount, of communications at a very low cost, means whole new concepts with regard to locations of industry, with regard to organization of manufacture and sales. With our modern electronics one can anticipate writing specifications simply on a punch card or a magnetic tape and running those specifications through the machine without any regard to where the factory is; having the information communicated not through some salesman but directly into the machine at the other end which manufactures the part, packages it, and sends it along.

We can locate our industries in better proximity to the natural resources. A whole variety of industrial changes, I think, are quite certain to occur. One can look at the inventory situation. All modern companies today have the teletype system in which they look over their entire inventory daily to see what the effect of sales and manufacture has been on that inventory.

But, when you try to do this outside of the country, or when you try to look at competitors' inventories abroad, you find that it is too costly to set up a complete system. But satellite communication brings us within reach of a workable system so that the fundamental organization of our inventory system on a worldwide basis will be changed as a consequence of new communications.

Therefore, one can let his imagination run very considerably in prophesying the effect of these vast new communications, that have emerged out of our science of the 1950's and early 1960's, will be on the total economy and social adjustment of the world generally.

One might turn to a second example. This is a military one. I would refer to what I believe will be a major change in field operations simply as the result of the development of an area of solid-state physics in the area of the physical and the chemical sciences.

Some of you have heard that, with the growth of theory and practice in the field of transistors and conductor devices, it is now possible to make a complete oscillator or a complete amplifier with about 100 molecules. It turns out that because of the natural shapes of atoms nature simply wants to order certain large combinations of molecules so that they will behave very nicely as circuits. When one packages these, it turns out that one can now put about 5 million of these circuits per cubic foot and perhaps eventually some 50 million of these circuits per cubic foot. Because they are very small, they require very little energy and involve very little heat dissipation. Because they are made of basic materials, of course, they have not the reliability of the present electronics which all of us know--or shall we say lack of reliability of it. Instead, perhaps, the reliability is that of a piece of rock. There is very little that you can do to damage such circuits either with respect to temperature or with respect to shock.

Consequently, one can expect very complex circuits requiring no maintenance, no care, which once assembled will operate more or less indefinitely to do the job they are intended to do. These should be very light-weight and they can be just as complex as you like, because, after all, if there is no maintenance, if you never look inside of the black box, you just don't care how complex it is on the inside.

Now, what can you do with devices of this kind? All of you who have been associated with military operations realize the intense complexity of field planning and of battle planning. This is really a problem of intelligence. You want to know what you need, where and when you need it. You want to know where your supplies are, you want to get them from where they are to where they are needed. You want to use all of the intelligence at hand in the planning of the battle itself. You want to evaluate this intelligence as well as possible. Indeed, any assistance which can be provided which aids you in using all of the information available in the most effective possible way leaves to the field commander only the problem of making decisions on rather good and and well digested information. And if you can accomplish this we all know that, given sufficient forces, the commander has a fair chance of winning the battle.

All of us who were in the Pacific remember the immense piles of equipment which were shipped out there. Very often you would be very short of some equipment and then find later that some substitute was in adequate supply untouched nearby. This was a matter of intelligence in the logistics system. One who has gone through the planning operations in the Pacific realizes the immense job of going through the literally tens of thousands of items that had to be shipped to see that they could get to the right place at the right time and that commanders could have access to them, especially when something went wrong--when the enemy pulled off some stunt that was not anticipated, where extra supplies were unexpectedly needed.

Now, all of us know that an enormous number of men in the military forces are required to man this logistics supply system, to man the intelligence part of the system, to evaluate the intelligence, and to do this quickly enough so that it is effective at the time of battle.

The problem is, to what extent can our modern electronics, with new forms of reliability, with new forms of complexity, deal with very advanced types of problems? To what extent can this new electronics be substituted for the thousands of men who had to be used in the past and who, because of their limited training, were not always effective? The answer probably is that within the next 10 years we should be able to get electronics systems of logistics control, and of battle control, that will almost dispense with the intermediate individual, and will give us a far higher measure of reliability, of evaluation of information, of access to information. Then the field commander can make his decisions with much greater precision. One would suspect that a lot of effort in the future will go into this kind of activity to amplify a battle problem of ever-increasing complexity.

Doing this has one great advantage. While such systems will inevitably be expensive, they should be able to release large numbers of men from noncombat activities, putting these men over into the combat line. This certainly is something that any military commander would welcome.

My final example of what one might expect to get from modern science, if properly exploited, relates to the control of armaments. Let me be very clear that I am not talking about the word "disarmament." I find the use of the word "disarmament" in modern times a little nauseous. Everyone should know that a disarmed world would be the most unstable of all worlds.

We only have to be reminded of the adventurers just south of my home in Florida to realize that the idea of disarmament is really not acceptable to any country. I am sure that even the most dedicated pacifist, if he really thought the problem through, would not want a disarmed world, because this would be a world open to adventure, open to any minor Napoleon who aspired to be a conquering hero.

On the other hand, what we really would like to have is a control of armaments, a control of weapons of mass destruction, so that they could not be accidentally released in a surprise attack at any time.

Now, at the moment we don't know how to control armaments, and it is really quite foolish to talk about the control of armaments or to negotiate for the control of armaments, because even if you negotiated a control system, you wouldn't know what you had and wouldn't know how to do it. Consequently such a negotiation would be meaningless.

But it may be possible--I won't assert positively that it is--to set up systems for the control of weapons of mass destruction which are so well founded on a technical base that you could be satisfied that an enemy would not generate a system on a scale that would overwhelm you. After all, as long as we know we cannot be overwhelmed we can be in a position of relative safety, for we would always have a sufficient Armed Force to deal with whatever minor situation came to hand.

But the difficulty that we face with weapons of mass destruction is the danger of being overwhelmed. So science offers perhaps a number of opportunities for very careful study of how arms might be controlled. It is simply useless to talk about control of armaments until we go through these studies. I suspect that, if arms are to be controlled, expenditures must be made which are comparable to the development and manufacture of the arms themselves--the extent of research must be very great before we can really understand how to control arms. Such research on weapons-control must start from research and development, through production, go on through storage, logistics, the delivery of the arms, training of personnel and every element which is involved in production and delivery of weapons of mass destruction.

I do believe that science may be able to give us some key as to how these arms might be controlled safely. I consider that this is basically a military problem. I can't imagine an agency outside of the military dealing with this problem, since such an agency would not have access to the basic information about the arms themselves which would be so essential to the development of arms control.

Of course we all know that, even if we did develop an acceptable system of arms control, one which would warn us in the event that substantial violation was going on, we must also have agreement or acceptance of such system. At the moment acceptance of such a system seems to be very unlikely. After all, the Soviet Union is suffering from a massive case of McCarthyism--they invented it, really--and this is, of course, internal security carried to the nth order. I think they are really frightened about this matter of internal security. The question is: If you could find a system for the control of armaments, could you get the Soviets to agree to it?

At the moment, of course, I doubt that you could, because this disease of internal security has completely overwhelmed them. In the Soviets it is a genetic disease which seems to have come down from the Czars. It's a psychosomatic disease, because it is something in which one always imagines that something is wrong. Somehow or other they imagine that they are in a much stronger position because of their emphasis on internal security than we are without such delusions. But, if they really thought about it very hard, they would realize that we, with our much lower standards of internal security, are just as strong or stronger than they are, because of the advantages that are gained from our freedom of action and mutual confidence. So, perhaps because of the psychosomatic character of this disease, if we could demonstrate methods of arms control, they could compare the advantages of internal versus external security, and some future agreement might be developed. Well, this is very "iffy." But I point out that the ends to be gained may be very substantial, because it would be very advantageous to define the limitations on warfare more explicitly, so that we could deal with a problem that we understood rather than an undefined problem which might involve the destruction of civilization itself. Therefore, science may be able to contribute here very well acting through military channels.

What about more glamourous events in the future? Well, you've got lunar and planetary explorations coming along. This looks very exciting. Unquestionably, somebody--we hope, ourselves--will have someone on the moon in the next 10 years. We will certainly have instruments there much before this. The influence of lunar and planetary exploration on the advance of science will be very great, for we will be able to deal with other planets which are very different from our own. From the knowledge that we acquire from these bodies it will be possible to extrapolate back to our own history and situation and learn much more about our own earth. Certainly, when we get to the planets, we will deal with bodies which have different atmospheres, different ecology, and possibly different forms of life.

In closing I would remind you that every scientific advance brings us great advantage, but also brings concurrent problems. If we get health from modern medicine we get a population explosion that we must deal with in a new way. If we get plenty from our solid industry we acquire the hatred and the envy of the underdeveloped areas of the world. So that each step forward in science and its application in technology will give us problems. Sometimes people question whether science should be stopped because of these problems that it brings.

But I think that we all have faith that man has the ability to take advantage of the advances that science brings and to deal with the problems that emerge as a consequence of these advances.

We can't forget that we live in a dynamic civilization. This civilization has always gone forward, and we must be prepared to take advantage of the opportunity that science offers and to deal with the problems that are posed by this opportunity.

Thank you very much.

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

QUESTION: Referring to the scattered scientific activities within the Government now and the space projects of NASA and the DOD, I read where the President's Science Advisory Committee is going to be abandoned, I suppose by the 20th of January. My question is: What is the outlook for Government leadership in advancing science in the next four years?

DR. BERKNER: You are asking me to peer into the mind of Senator Kennedy. I feel that I am not qualified to do this. But let me make the following comments: I would doubt that the Office of the Science Adviser to the President, or the President's Science Advisory Committee, would be abandoned. This has proven so successful in advancing some of the neglected aspects of science both in the military and in the civilian area that I believe that not just scientists but the country as a whole would raise a sufficient fuss to insure the continuance of a mechanism at least similar to this.

Since sputnik there have been several measures taken in Government relating to science that have been important ones. These include the appointment of the Science Adviser to the President, the bringing of science in at the policy level of top Government administration--the Science Advisory Committee--which provides a forum for debate on some of the difficulties of the kinds which I mentioned here, and the Federal Council on Science and Technology. The Federal Council has not really yet had the opportunity to operate effectively. But it provides the mechanism for the coordination of scientific effort among the various agencies of the Government. Already it has led to the appointment of Assistant Secretaries for Research and Development of Commerce and Interior which is certainly a step forward in these somewhat decrepit departments. And we have the replacement, after a long hiatus, of the Science Attaches in our embassies abroad.

All of these steps have been important steps in improving Government relations to science and Government attitudes toward science. Certainly, additional steps will be needed. I think that one difficulty that I mentioned, the inability of the scattered Government service agencies to get money for research which has led them into a relatively obsolescent situation, simply must be met. I believe it will be met, probably during the next four years. Whether the Administration may recognize this at the start or not, various forces will bring their attention to these deficiencies.

QUESTION: You touched on a question that has bothered me, sir, in the closing moments of your talk when you stated that we must have faith in our ability to live in the environment that science is undoubtedly going to give us in the coming years. It seems to me that this will be more than what we meet now. When you take our seven astronauts who we know are going to have to live in an entirely new atmosphere, we have been spending quite a few years trying to adapt them to it. Would you philosophize a little bit on what you think we should be doing today to prepare our coming generation to live in this world that is going to be here whether they like it or not?

DR. BERKNER: One can't deny what you say, namely, that things are moving ever faster. The question is whether we can deal with a dynamic civilization that is not only rising but rising ever faster. Looking into the history of this matter, I believe I mentioned in my last lecture before this College that the history of civilization is really very short. It dates back to the beginning of writing, which was about 5500 B.C. when the Sumerians first hacked out their early tablets on which symbolic characters represented ideas. Since this invention of writing, which was about 7,000 years ago, we have arrived at our present point. If you take the length of a man's life as three score and seven and divide it into 7,000, you find that civilization is only 100 lifetimes long placed end to end, and this isn't very long.

This illustrates the dynamic character of the rise in civilization from savagery to our relatively high level--whereby man has acquired leisure and dignity, and slavery has been abolished--all in just 100 lifetimes. So I would emphasize first of all that every generation has faced a very dynamic civilization since history began. Writing started our civilization and each generation since has had to face very important advances.

Furthermore, each generation, each lifetime, has had to contribute very substantially to the growth of civilization to have arrived where we are now. So that, while our civilization continues to rise very rapidly, one mustn't suppose that it stood still in the past. The whole history of civilization is a dynamic one in which each generation has its responsibilities for contributions both to the advance of civilization and to the solution of the problems that arise because of those advances.

In one sense one is not looking at a civilization that poses problems much faster than have ever been posed before. Problems have always come pretty rapidly. Moreover I do think that measures are being taken in our educational process to meet this. After all, it may take a sputnik to do it, but I was rather interested in hearing a well trained young lady say the other night that in her family of five she had been able to see improvements in American primary and secondary education as each youngster went to school. Even mathematics is getting down to lower levels in the schools. This may not be true in every place but there is some indication of a move in this direction. We certainly have neglected education in some areas. I have just been studying graduate education in the Southwest. It turns out that the leading areas of the country are producing about 85 Ph. D.'s per million people per year. This is true in the East and Northeast, the North, and the Far West. The average for the whole country is 48 Ph. D.'s per million people per year. In the Southwest we are producing only 23, which is a little more than a quarter of the national average.

Why is this occurring? Clearly something is slipping here. This may lead to very serious cultural problems in the development of the country as a whole. But let me say it this way: We have no alternative but faith, because civilization is going forward. There is nothing we can do to stop it. Coupled with this faith--I will agree with you--we must prepare ourselves as rapidly as we can. We must never throw up our hands hopelessly.

QUESTION: Sir, I would like to have you define what you mean by a nuclear war which may be the end of civilization as we know it. We hear this phrase very often and I would like to know what you mean by it. Do you mean that we will be set back 100 years, that people would be destroyed, that we will lose our present form of government? Or what do you mean?

DR. BERKNER: I am not much worried about destroying people except for a relatively few people who have the core of our knowledge today. I suspect that if you were to lose the cream of your leaders--your leaders in science, your leaders in government, et cetera--who are obviously in the most exposed positions in a nuclear war, you would set civilization back several thousand years. We do not now have many scientists in this country or in Russia--and I speak of science because I know it, (and I think the same is true of government, and of military science) who really understand science to the core. You wouldn't have to destroy very many of them before you would find a population who no longer could make use of the tools that we now have at hand.

The real danger is of wiping out the more critical group of your population who necessarily are in the most exposed positions.

QUESTION: Early in your talk you spoke about the advantage of the work in universities on cross-fertilization between the disciplines, and then later on you spoke of the gaps between those disciplines. Do you find that there is any one of these that lends itself to bridging the gap--mathematics, the physical sciences? You talked a little bit about the generalists and the specialists, and the business of managing the sciences.

DR. BERKNER: Yes. On the whole science has tended to overspecialize. Scientists during, let's say, the late forties and the early fifties had the idea--and perhaps that was needed at that time--that they had to follow one specialty without looking anywhere else. But there is a subtle change occurring among scientists and among the men that they are training. The newer view is that a reasonably good person can encompass all of science. Of course a scientist needs to specialize heavily on some areas, not just to learn those areas but also to understand what specialization means, that is, to really exhaust the subject completely. Nevertheless, the modern scientist in the field of physics cannot ignore biology; he cannot ignore theoretical mathematics; and he cannot ignore other fields of science. The modern scientist I think is tending toward trying to encompass with fair familiarity the whole body of science, as contrasted with the specialist of old.

But this is a slow process, and when you have to convey this attitude to students from professors who have overspecialized in the past it is a very difficult thing to do. Consequently it will take a long time to accomplish this end. Therefore, while the university offers opportunity for cross-fertilization there remain some very serious cracks. The tendency now is to organize research across the university departmental structure, let's say a laboratory on molecular science, in which you mix together crystalographers, biologists, mathematicians, physicists, chemists, and so on, in order to expedite this cross-fertilization.

Carl Compton said in his lecture at the sesquicentennial celebration of M.I.T., that without doubt the great scientific advances in the last half of the 20th century would come from the synthesis of the sciences.

QUESTION: Doctor, you talked about the industrial laboratories. I presume you also include those on oil processing, such as laboratories like Shell, the Oil Institute, and so forth. They handle problems of industry, of, let's say, more middle-size and larger industries. But the little man has problems and he doesn't know how to tell the laboratory that he has problems. I am particularly aware of one researcher in North Carolina who is trying to get the little man interested in having a link with industry and the colleges. Could you talk on that a little bit, and on how this will grow and how we can solve this problem?

DR. BERKNER: It is a very serious problem. It is one which probably damages small industry more than any other. Big industry finds it very easy to spend $20 or $30 million a year on its laboratories, and has no difficulty. Furthermore, a laboratory isn't much good unless you spend $20 or $30 million a year on it, because you don't get enough range of activity to make it a really good laboratory. So there is a critical size to a laboratory, and it's a laboratory that costs about $20 or $30 million a year. Quite clearly, a business doing only $2 or $3 million a year can't afford a laboratory like this.

The question is--How do they get their research done, How do they get their access to science? There are a number of good laboratories--the Battelle, the Mellon--which can serve such industries. Some of the older ones have not been too successful. More recently the Stanford Research Institute has been organized. This provides all sorts of service to small industries, particularly in the $2 to $4 million class. I would anticipate that more of this kind of activity must be done.

Such research is much better done under private industry than under Government. If you are a private industry, you can hire Stanford Research to do a job for you, and if they patent something under your money it is your patent. If you have to depend on the Government for it, it is declared in the public domain, and therefore you probably couldn't afford to manufacture it because of the competition during the early stages of capitalization. So on the whole the industrial method will probably be more successful than the governmental method in this area.

QUESTION: My question, Doctor, relates to the production of Ph. D.'s. Some weeks ago a speaker asserted from this platform that the cream of the crop in the scientific field of the young graduate level was being skimmed off for Ph. D. work and the M. D.'s for the medical profession were second-place material. Would you care to comment on that assertion?

DR. BERKNER: Well, you are assuming, I suppose, that the cream ought to be M. D.'s. The fact is that the cream is by no means being skimmed at the moment. In the number that I just gave you were 85 Ph. D.'s in the Northeast, the North, the Far West. This is perhaps very curious that every State in the North, Northeast, and Far West produces between 80 and 85 Ph. D.'s per million people per year, excepting Massachusetts, with 127 (I suppose because of Harvard and M. I. T.) and Pennsylvania with only 43.

Then you go down in the South and the Southwest and you get the averages which bring the national average down to 48. Quite clearly, in these areas you are neglecting a lot of people who obviously must have the capability to do Ph. D. work but don't do it because they don't have the opportunity. You may say that the southerners go up North to get their degrees, but the National Science Foundation figures show that 92 percent of all graduates who go to graduate schools go to schools within 500 miles of their original high schools. So the fact is that, while a few southerners do go to the North to get their advanced degrees, not many of them do. So there must be a very large crop here of men who are intellectually qualified to do doctoral work but don't do it. Maybe you could get some of the M. D.'s from this area.

Moreover, I would suspect that we are a long way from having skimmed the whole cream off the top. We are probably a long way from this, and I suspect that we could double or treble our doctoral training without any difficulty.

COLONEL PRODANOVICH: Dr. Berkner, thank you very much for a very fine and informative presentation. We have certainly enjoyed having you with us today.

DR. BERKNER: Thank you very much.

(19 July 1961--5, 000)O/en:mr