FUNDAMENTAL RESEARCH AS A FACTOR IN MAINTAINING NATIONAL SECURITY

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CAPTAIN MOSLEY: Good morning, gentlemen. We are going to continue our series of lectures on technological progress this morning.

Both Dr. Bronk and General Aurand have already mentioned briefly the importance of fundamental research in our postwar research and development program. We have felt that is important enough to have a full lecture on it. For that purpose, we are very fortunate in having Dr. Waterman with us today.

He has spent many years in the research field and has the point of view of both civilian science and the military. He spent many years with educational institutions, and he has been very active in various capacities, as you have seen on his biographical sketch, in OSRD during World War II. He has just returned, within the last few weeks, from a two months' tour in England as head of a mission of civilian scientists from the Navy, and he has more than an inkling of what they are doing over there.

I am very happy to present Dr. Alan T. Waterman, who is Deputy Chief and Chief Scientist in the Office of Naval Research.

DR. ALAN T. WATERMAN: Captain Worthington and gentlemen of the Industrial College: I am very glad, indeed, to have this opportunity to speak to you about one of my main interests and its application to matters in which we are all interested.

The subject of research is always a difficult one to discuss, because it means different things to different people. In the content of this talk, I plan to follow very much the outline which you have already seen. At the outset it seems profitable to present definitions of the various kinds of research that there are, so that we will understand each other when I use the terms.

The general topic, as you know, on which I am to speak is "Fundamental Research as a Factor in Maintaining National Security."

You all, of course, know the names of types of activity associated with research, the commonest being fundamental or basic research, applied research, and development. There is a name for the academic kind of research which has not had very wide acceptance in this country, for

reasons you will understand, namely, pure research. The obvious implication in connection with other kinds of research makes that term somewhat objectionable.

I shall use, as a start, the definitions for basic or fundamental research (making no distinction between these for convenience), applied research, and development which are employed by the Office of Naval Research and which are intended to cover the fields in which we are interested--that is a broad territory.

According to these interpretations, basic research is a theoretical or experimental study the aim of which is fuller understanding of the subject investigated. It may result in the discovery of new scientific phenomena, principles, techniques, or significant data, which add to the store of scientific knowledge. Practical application is completely irrelevant as a direct objective on the part of the investigator. This last is quite important, because it is the point of view rather than the method used which makes this distinction, that is, practical application not only is not an objective, on the part of the investigator, but actually such an aim is immaterial to him. Any such motive would interfere with the objectivity of his investigation and might therefore affect the validity of his result. Hence the phrase "practical application" is completely irrelevant as a direct objective on the part of the investigator. Before going further, however, I should like to point out that this by no means implies that basic research has no utility. In making the definitions, you notice, I stress the fact that it is the mind of the investigator in which there is no interest with regard to utility. But this by no means implies, as I say, that a sponsoring agency or an outsider cannot pick up a practical utility. This point is frequently misunderstood.

Now, this distinction is worth keeping in mind, because it really is the fundamental element in the importance of basic research to the military service. By watching basic research or sponsoring it, the service can pick out of it and use for its own ends things which are not in the mind of the investigator and probably won't be in the minds of any others than the interested parties on the user end. It is in this respect that basic research makes its most important contribution to development, via applied research.

Going to the next definition, I describe applied research as research directed toward a practical, useful end. Its aim is to make possible or demonstrate the feasibility of scientific or engineering development. It is research which, by use of novel methods or by new application of known methods, ordinarily precedes and is intended to result in the development of devices, materials, or techniques having novel, assigned functions or characteristics. (I am making these

definitions reasonably full, because it is difficult to get a short definition which is clear.) Applied research is generally better understood. As this definition states, it is intended to lead to a development or solve some problem connected with development. Obviously, in this case, the point of view of the investigator is to prove whether the particular application is feasible or to find out some way in which progress may be made toward development.

Finally, development is the application of scientific or engineering knowledge to the production of materials, devices, systems, or processes having useful, assigned functions and performance characteristics. That, too, I think is well understood.

As indicated in the title of my talk, I am going to speak chiefly about fundamental or basic research. I shall usually say basic research, for short.

First of all, with regard to the nature of basic research, perhaps a few words in amplification of the definition may be helpful. I think they are familiar to all of you, but I would like to sum them up.

Basic research requires long experience and special training, scientific judgment (which is similar to ordinary judgment applied to scientific matters), perfected technique, and imagination. It is a very special field and one in which not very many of those who try are highly successful. I don't think in that respect it differs from many other professions. I simply want to call attention to the fact that it is true of research, as in all professions, that comparatively few who go into it reach the top.

In order to succeed in basic research, it is important that the investigator have complete freedom of choice as to his work, his location, and environment. He also should have freedom to publish in scientific journals and communicate his results to others. That is, of course, fairly obvious when we stop to think of it. While there are individuals in research who can get off in a corner and work alone, in general, research is not done that way. A research worker needs to keep in constant touch with those who are in the same field, in the same specialty, because it is by comparing notes periodically with his colleagues that all are stimulated. This type of contact is extremely important for progress in research.

A question often raised in connection with basic research, as with all research and development, is: Should not duplication be avoided?

In this respect, basic research is somewhat different from applied research and development. Owing to the nature of the profession of a

research worker, he would be extremely foolish if he attempted to start a project or publish results which anyone had done before, unless it was for the purpose of corroborating those results. In this latter connection, no research work by a single individual or group is fully accepted by scientists unless it has been confirmed by someone else or some other group. The reason for this, of course, is that there may be something special about the technique or something about the instruments used that produced the result achieved so that a fresh attack is needed in order to be sure that the result does not depend on the particular way it was accomplished or on the particular apparatus used. Duplication, as you see, then, is necessary to a certain extent in order to confirm the results.

Apart from that, one of the important characteristics of the research worker is that he keep up-to-date in his subject and know what is going on in his specialty. It would be fatal to his career, as I said, if he came out with a result which some one else has already found and, in the act of doing so, showed that he knew nothing of the previous work.

For these reasons, it can rightly be said that basic research is self-coordinating and that undesirable duplication is a thing which does not occur, provided each research worker knows what the others are doing. If work is fully confirmed by several different research individuals or groups, there is no need for anyone else to do it, unless he can show that all previous workers failed to take some important factor into account. To act otherwise is to commit professional suicide. So that, granted the communication between research workers in the same field, duplication is not a problem in basic research. There is quite an important difference here, since avoidance of duplication in applied research or in development is in general desirable, for many obvious reasons.

By the way, if I should sound unduly enthusiastic about basic research, please understand that it is not because of a feeling that research of that type is superior to other forms of research or to development. Basic research is simply another kind of activity and requires a different sort of technique and a rather different sort of individual to do it. It requires special qualifications, as does any profession: but to say that basic research requires greater ability than applied research or development or production, of course, is talking nonsense. They are all important and form a chain of progress which is extremely important in matters of military security. Without basic research we have no scientific stockpile to draw upon; without applied research and development we fail to take advantage of opportunities essential in this modern world, whether in war or in peace.

This brings us to item two on the agenda--atmosphere: conditions required for effective research. You are fairly well aware, I think, of conditions that should be maintained in order that basic research shall be successful. I have mentioned some of them in talking about the nature of basic research. I have mentioned the freedom of the individual to choose his subject of investigation. I have mentioned his relative independence of action in connection with his work. To list the additional requirements one would include such items as adequate facilities in the way of apparatus and machine shop, library, technical assistance, close association with other research men in the same environment, opportunity to publish scientific papers, attend meetings, and communicate with other specialists.

In so far as salary is concerned, I suppose it would be fair to say that the average research worker is not primarily interested in this. For the sake of his work, it is important that he have a salary which will not cause him undue worry or make him feel that he is in a poor position compared to others in his general class. Opportunity for advancement, of course, is desirable as an incentive. Generally speaking, however, the research worker is interested primarily in opportunities for doing his research and secondarily in getting recognition from his fellow scientists. Fundamentally he is an explorer at heart; he wants to pioneer in his chosen field. In so far as he has personal ambition, he wants to be recognized as a leader in that field.

That recognition means that his work, in the eyes of his fellows, should show, above all, soundness and originality. His work should be sound--logical, in other words, and impervious to criticism. It should show an adequate background in his subject, expert technique, logic, and originality. Note that it is recognition by his fellow scientist that he seeks, and not recognition by the general public.

The requirements for applied research are quite similar, in my opinion, to those for basic research, except that one would remove from them, at least to a marked degree, his freedom of choice (unless he has really attained an advanced position) and, to some extent, independence of action. The applied research worker is more ready to take a suggestion and look into it. Also he must give attention to priority of problems put before him. There must still be the element of freedom in matters concerning his scientific judgment and conduct of work. This is necessary if one wants original and good work--or to put it another way, if you want a good man to stay on the job.

To be added here to the list of qualifications already mentioned in connection with basic research is close association with scientists and engineers engaged in development. It is very important for the applied research worker to know in what directions development is heading, and

what current needs for development exist, in order that he may have ideas for applied research. As already stated, this association is unnecessary and usually undesirable in the case of the basic research worker.

Now comes an item which has received considerable discussion. What is the interrelation between basic research and applied? I am convinced that a man who is engaged in applied research and development should have the opportunity to do some basic research on the side both to refresh himself with that field of work and to keep himself in touch with basic research workers. As Dr. Bush points out in "Science, the Endless Frontier," there is a perverse sort of process, or rather evolution, that generally occurs if you throw basic research, applied research, and development together. Applied research and development tend to drive out basic research.

That is to say that if you try to have scientists work on development, applied research, and also basic research, the tendency always is for development and applied research to monopolize so much of each man's time that he has no time for basic research. What generally happens is that a man's time gets filled up with research in answer to practical questions, with attending conferences, and being called in as an expert on knotty points in development to such an extent that he has no opportunity to do basic research, except perhaps evenings and week ends when he is really too tired to do a good job.

I believe it is extremely important that applied research and development keep contact with basic research; and it seems to be very advisable that every laboratory and establishment provide some opportunity for it and give it encouragement. Especially because of the tendency I have mentioned, it is necessary to keep feeding basic research in, not only by providing some opportunity for a scientific engineering staff to do basic research, but also occasionally letting them go on leave to do basic research. To accomplish this a man might be replaced temporarily by a scientist on leave from his own institution. Also, in new appointments an active basic research background may be encouraged. An important reason for this policy--and I know many establishments have encountered it--is that, in general, scientists are not happy unless they have the opportunity for some outlet for their ideas in basic research. If an establishment is to retain first-quality men, it must provide that opportunity.

With regard to the position of the United States in fundamental research as compared with other countries, it is clear that our potentialities are excellent, both in quantity and in quality. One has only to note the large number of distinguished foreign scientists in the country, most of them now American citizens, and the increasing

number of Nobel Prize awards to American scientists. We have an extraordinary number of universities and colleges, all with unprecedented enrollments. We also have an unrivaled setup for industrial research as compared with other countries, and when account is taken of plant, facilities, personnel, and suitable environment these constitute an overwhelmingly favorable opportunity for first-class research. Let us hope that we do not fail to capitalize on this opportunity for, without question, strength in research is one of the vital factors in a modern nation's security and welfare.

Time was when research in this country was somewhat handicapped for two reasons; (1) an inferiority complex on the part of our scientists with respect to research abroad, and (2) a misconception on the part of the public regarding the nature and value of research. Both have subsided considerably, but the latter still requires attention. The popular misconception with regard to research lies in failure to distinguish between research and invention. Invention has been valued highly but its dependence upon the findings of basic research has not been sufficiently recognized. One evidence for this may be found in the fact that basic research, the simple seeking for knowledge, has, in general, not commanded the interest and the respect here which it has enjoyed in European countries. Even now, with public interest in science higher than ever before, a Gallup Poll would probably find overwhelming emphasis on applied research.

Some indication of the relative position of the United States and other countries with respect to basic research may be found in a comparison of their current expenditures in support of research. According to published reports, Russia is expending about 1.2 billion dollars in 1947 for research and development. How much more the military services are expending I do not know. According to the Soviet Five-year Plan, they expect to produce in that period 1,280,000 technicians and 700,000 laboratory specialists with scholastic degrees. They also have an estimated ten to twenty thousand German scientists, of which Naval Intelligence has identified at least 600 as recognized, well-known scientists. This effort is certainly very considerable.

In England in the present year, 270 million dollars have been appropriated for research and development, of which 240 million dollars are primarily for military research and development. There is included a small amount for civil aviation (an unknown quantity), inasmuch as their research and development in aviation include both civil and military. Support of universities in all kinds of research--not merely science, but it is chiefly science--comes to **45 million dollars.** Considering the over-all national budget, this is a remarkably strong effort.

According to the report of the President's Scientific Research Board--the Steelman report--which undoubtedly you have seen, in the present year, the United States is investing something like 500 million dollars for military research and development.

I shall not attempt to break down the research part of the foreign figures; that is difficult enough to do in our own country. I would like to say this, though, by way of comparison: If one attempts to separate out basic or fundamental research from our military budget, I think something of the order of 500 million dollars would emerge. Any such separation is exceedingly difficult to make, but the figure given is probably of the right order of magnitude if one uses my definition for basic research. That is about one-tenth of the military research and development budget.

Now, the military research and development budget is about five percent of the total military budget. Thus the fraction of the total budget for basic research alone, according to these figures is half of one percent.

It might be fair to compare this with industry. As you know, one of the arguments for the encouragement of basic research in the Military Services is that industry has found that it pays. The largest industrial concerns commonly have a research department which is separated from the main organization and is responsible for feeding in ideas which can be worked out into development and use. It is difficult to find comparative figures in industry on this. Our Naval Research Advisory Committee of the Office of Naval Research, which has about fourteen very distinguished scientists and men familiar with scientific research, has estimated, however, that, in general, industry spends something between two percent and six percent on basic research. If this estimate is correct, the Military Services, with their half of one percent, are very far behind.

Since industry has an incentive, the user incentive, and in the Military Services, again, the goal is utility, though for a different purpose, the analogy seems fair. This conclusion certainly raises the question whether the Military Services should not devote more attention to basic research.

According to the Steelman report, the situation now is a very difficult one with respect to support of research. The universities are loaded. Industry is loaded. Government and the Military Services are loaded very badly and budgets are low. But the chief limitation is in scientific manpower. Until that can be remedied, there is no good possibility of having more research at the disposal of development anywhere.

The only answer to this is, of course, that more scientists should be produced. The place where they are produced is in the universities. At the research level, the place in universities where they are produced is in graduate schools where research is being done and where scientists are given their basic training. Clearly, then, in order to get out of this impasse, it is important to back basic research in the graduate schools of universities.

According to the evidence from the office I represent, the Office of Naval Research, the universities of the country can absorb more funds for basic research in their graduate schools. They are loaded on the undergraduate side, but there are still capable research men who can accomodate more research if they have the funds. This seems to be the logical approach to remedy the present situation.

As an illustration, at the present time, the Office of Naval Research has a planned annual expenditure level of about 20 million dollars, in round numbers. About 70 percent of that is with universities and research institutions, and the balance is divided between government establishments and industrial research laboratories. It is estimated that about 2500 graduate students are employed on research under this program and thus receive research training.

It is our philosophy that every agency which is doing development and applied research should also back basic research in fields of interest to its program, both for the significant advances that will be made and in order to break this deadlock on scientific personnel.

In my recent visit to England, I noticed on the wall of one of their Naval Establishments the statement: "The time is gone when improvization can furnish what forethought has failed to provide." Basic research can provide forethought of a most important variety; applied research can easily degenerate into improvization.

It has often and truly been said that the fund of basic research which we used during the war to furnish development has been largely used up. We did not, during the war, replenish that stockpile. It forms the capital out of which the ideas for development come. It is highly necessary that this capital stock be restored.

We can no longer merely modify existing equipment. It is vitally important to make use of every result in basic research which will lead to new development whether by way of weapons for attack or defense or to meet urgent situations that may arise. The ability to outthink the other fellow is as important in this game as in any other, and to outthink him scientifically is one of the important factors. This can only be done by bringing the very best in scientific talent to bear upon these matters. We should, therefore, be ready to back in every way sources which can produce ideas and manpower, both of which are going to be necessary.

One of the items on the agenda is the provision for fundamental research by the Armed Forces within military establishments and by contract outside. As I have indicated, by contract outside one can increase the supply of scientific manpower, can find ideas which may be useful, and can set up close relations with scientists. This works in two ways: It has its effect on the military organization's thinking; it has an effect on the scientist's thinking--both of which are quite important in the case of an emergency. It also provides a quick means, in case of emergency, to bring needed experts into the military picture.

Now a few words about provision for basic research and science in Military Establishments. It is, of course, one of the essential functions of many military laboratories and establishments to do applied research and development; and, as I have indicated, some level of basic research in these is especially desirable.

I have spoken of the conditions under which basic research is best performed and these should be maintained. It might be profitable to mention a few further points. For example, what should be the relation of the civilian scientists to the military officers at such an establishment?

I hope you will realize, when I discuss this, that the same sort of problem arises when research scientists are placed in nonmilitary establishments. They are put with men of different training and men who are usually more experienced in administrative matters, organization, and decision. The problem is much the same as it is in industry. So the relation is not simply one of the scientist to the military officer; it is the relation of the scientist to anyone with whom he is associated in a large organization. This is a rather general problem.

Bearing in mind the points that I mentioned about the proper atmosphere for the scientist to be effective in research, I think it is fairly well established that scientists should direct scientists. In scientific work, scientists should take orders from a scientist. Notice that this does not necessarily mean that the directing scientist should be a civilian; a properly qualified officer should be able satisfactorily to direct scientists or be directed by them. We have all seen successful examples of this during the war. But, in uniform or out, scientists should give direction to scientists in their own territory, namely, on research.

The logical conclusion is that there should be a chain of command in the scientific organization going up, I believe, to the top of the establishment and ending in a civilian director of the scientific part of the program.

I was interested in seeing that in one of the British establishments, as heads of the different groups on special research projects there were

always two men--a military officer and a scientist. I asked what that meant. They said, "Well, the military officer is a technical officer who knows existing equipment and operational needs; the scientist is a research man in that field." "Who is boss?" I asked. They said, "We don't know. They operate as a team." That was the tradition in this laboratory and it apparently worked well. There was a civilian scientific director of the establishment and a commanding officer; they too worked as a team.

In general, my experience would indicate the desirability of a scientific chain of command which is associated with the military command at the various levels.

Now, where difficulty occurs in this association the scientist may be as much to blame as the military officer. It is important to get the right type of scientist in a Military Establishment. In general, he should be chosen with a view to his ability to get along with people and be effective in explaining and justifying his work, as well as his ability in research.

After all, in most establishments under the present arrangement, the scientists provide the continuity. One of the embarrassing things, I think, to most scientists in Military Establishments is that the military command changes very frequently. The scientist, then, in respect to the scientific program, is in position to provide continuity of program.

Constant effort should be made to avoid insulation of the scientist from the outside. As I said, the scientist's career is in his subject, and unless he can hobnob with others in the field, get their recognition, and compare notes with them, his work is badly handicapped and he cannot be of maximum service to the establishment. This is in conflict with security restrictions, which is another reason for having some basic research in the establishment so that free communication can take place. Those projects which are under security can be adequately segregated, but basic research does provide the opportunity for outside communication.

I have said very little about the importance of fundamental research to the Military Establishment, partly because I think it is sufficiently obvious from the results of the last few years. In fact, this seems to be generally accepted. One only has to think of the very recent developments, the most outstanding of which were the atomic bomb, radar, proximity fuse, where from a scientific discovery which had no apparent utility has come a result of the first importance. History is full of these examples.

In placing a broad program, such as the Office of Naval Research has done, in a wide field of research--all the physical sciences, the

medical sciences, etc.--the philosophy is this: By placing a broad program, one, in the first place, overlooks no bets. Second, it is good camouflage; one may conceal the things one is really interested in. Third, if the program is broad, then statistically one can be reasonably certain that something will come out of it somewhere, although it is a characteristic of basic research that one cannot predict, the result of an individual project. It is only through this statistical method that results can be certain.

In closing, I should like to say that the encouragement and support of basic research is a very difficult thing to accomplish. It requires very distinct and vigorous effort at all times, and it is not hard to see why. Its results are unpredictable. There is uncertainty where the results will occur and of what utility they may be. There is no immediate tangible return. Even if a result of great fundamental significance is found, who knows its money value until applications have been worked out. These are things that make it very hard, budgetwise, to justify a basic research program. On the other hand, as I have said, history is full of examples, and very recent ones, where these basic, fundamental ideas have been made to pay off--and when they do pay off, they pay back untold quantities in justification of the whole effort.

In one sense, therefore, basic research is a very inefficient process. In another sense, in the long run, it is extremely efficient. But at any given time, there is a great deal of waste effort which is necessary in exploring a new territory, when you don't know what you are going to find. Also, economics hit a fundamental research program early for just these reasons. It is hard to attach a money value to things which are so intangible.

Furthermore, the results of basic research keep pressure on industry, the services, and anyone who is interested in development to make a change. It is only human to resist that pressure. The production manager, who is turning out a well-tested product, quite naturally tends to resist scrapping his proven item and changing to something new and relatively untried. The production end and the research end are, in that sense, somewhat antagonistic. Research continually needles production to make a change; once the inertia of a big production schedule is started, a great effort is required to make the change.

In conclusion, I think it is very important to weigh these matters, and, in particular, to do the sort of planning, considering, and discussing that is being done by the Industrial College here. It is in institutions like this that definite plans can be considered to deal with the problems I have briefly outlined, to weigh the importance of all the factors that enter into the problem, and to reach appropriate and forward-looking decisions for actions.

I thank you.

CAPTAIN BOLEY: When I said at the start that we believed fundamental research to be of such importance as to justify a complete lecture on it, I had no idea that we could get as much out of it as I feel we have from Dr. Waterman.

He has brought up some questions in my mind, but rather than take advantage of the opportunity to ask the first one, I will ask for questions from the audience.

QUESTION: You have stated, as have others, that basic research requires complete freedom on the part of the research worker. Yet you also state that there should be a chain of command within the research organization where one scientist tells another scientist what to do. Is that consistent with complete freedom of action? Or did I misunderstand your remark? Is it only in the development stage that you need that chain of command and not in the basic research stage?

DR. WATERMAN: I am very glad you raised that point. When I was talking about a chain of command, I was speaking about the average establishment or laboratory where a great deal of the work is development and applied research. There it is necessary to have the program planned out as an organized group activity. The freedom in choice of work is desirable on the basic research side.

Now, they can be handled together merely by ordinary common sense on the part of a group leader, for example. If one man in a group gets a bright idea in the course of his developmental work, he may talk it over with the group leader, for instance; and the group leader may say, "That looks good." He may call a conference if it is necessary, and then say, "Go ahead and try that." It was the man's own idea, you see. In that sense he had freedom. It may not take all his time, but only a part; I think that is quite compatible with the chain of command idea.

QUESTION: I have two questions, and they both apply to organization for basic research. The first is, would you compare or contrast the British system with our own. The second is, would you give an example of an industry that supports real basic research.

DR. WATERMAN: I will answer the last one first because I think I can do it briefly.

General Electric has a research department which amounts to several hundred scientists. They have a separate building, a separate budget, and are run separately.

Western Electric and American Telephone and Telegraph have the Bell Telephone Laboratory, which operates similarly. It has a complete staff, a separate budget, and separate research organization.

Those are two examples.

As to the first question, the British laboratories are quite similar to our own. The British laboratories are smaller, but their method of operation is similar. The organizational lines are much alike. There are heads of divisions, with branches and sections under them, each of a different specialty.

If your question applies to the running of an establishment, I think there is not a great deal of difference in that. The British invariably have a civilian scientific director; and one question they have been discussing recently is whether it is advisable in certain cases to have the whole establishment under a civilian scientific director or under an officer as at present. As in our own establishments, the commanding officer is responsible for setting policy and is the highest authority in the laboratory. He is responsible for the position of the laboratory in the military system. He is also responsible for the administration of the establishment; that is a great help to the scientific work, because the administrative staff, represented by the officer command, can remove a great deal of administrative detail from the scientists.

The officers in our own establishments are extremely important to the scientists--I am convinced of this--because they have the operational point of view. In applied research and development, this is a very essential thing for the scientists to appreciate. Also, the technical officers can bring to bear their technical experience. It is really a cooperative undertaking.

There is one general feature of the British system which I noted. It is difficult to make generalities, but I do think they plan their work ahead rather more carefully than we do. At the present time they have to because their position is much tougher than ours. They have smaller funds, smaller manpower, their facilities have had to be restored, and their production of equipment is less--they have to get along on much less. As a result, they rather carefully consider their programs and go right up to the top in planning them, to two committees. One is the Naval Advisory Research Committee; the other is the Defense Policy Research Committee--one naval, one military. There the priorities are carefully decided and allotted. So that when they undertake a project, they do so after considerable thought and conferring. They have had to pay very strict attention to priorities. There has been less of a tendency than in our own country for one group to come up with a bright idea and start working on it without checking with every one else in the country before it is tried. They have an advantage in that they can do this more easily than we can.

Does that answer your question?

QUESTION: Not exactly. I think both of your answers applied to applied research rather than to basic research.

DR. WATERMAN: By no means my first answer. Some of the best basic research work in the country has been done by men at GE and at the Bell Telephone Laboratories in the research departments. That discovery of electron defraction is an outstanding case; and that was made by Dr. Davidson of the Bell Telephone Labs, in his laboratory. That was purely fundamental research and very basic physics. They do a great amount of basic research there, and their men are on the research programs of the scientific societies, etc.

As to the British, we'll all say in England in general, with respect to the basic research in their establishments, the government is supporting universities--and most of the support is in science, and most of that is basic research--to the tune of 11 million pounds, or about 44 million dollars, which is a large amount for England. Most of that is going into science, and most of it is an unclassified basic research, because in England the opinion is very strong in the universities that they should not do classified work. They want to get back into basic work. That represents a very large amount in basic studies.

At the military establishments conditions vary. Some do not. For instance, much of their radar and electronic work is very basic. And they are doing rather fundamental jobs for some of the universities just because they have the men. In other places, it is very much more applied research.

Does that come closer to answering the question?

QUESTIONER: Yes.

QUESTION: Dr. Waterman, would you care to suggest an efficient way of mobilizing scientific manpower in the event of a national emergency?

DR. WATERMAN: This country has always done that differently in every war. It is hard to predict what we might do if there is another war.

I think there were very good advantages in the way OSRD was set up in this war. I do think that the Military Services themselves ought to continue plans and offices which would provide continuity of contact in research, such as all the services have done. In the Navy there is the Office of Naval Research, and there is General Aurand's office in the Army. I believe he has already spoken to you on this program. The Air Force has a Director of Research. These offices, it seems to me,

should engage actively in the sponsorship of research and general supervision of that type of program and should make plans for calling scientists in case of an emergency.

One of the quickest ways of doing this is to have existing contracts with the outside institutions which allow payment to be made for travel or work at a minute's notice. But considerable thought has to be devoted, I think, to the structure under which this is done. Another obvious answer is to have facilities for taking a number of scientists into the Reserve so that they could be put into uniform in case of an emergency.

These are just a few random thoughts.

CAPTAIN ROWLEY: That brings up one thought--and this may have been in your mind, too, Colonel; it has been mentioned before by others --as to the desirability of having a Science Corps in any one or all of the Military Services. Then there are these thoughts: Whether there should be a roster of scientific personnel, whether there should be special draft provisions, and how any induction or calling in of reserves might be undertaken. That might have been in your mind, too, Colonel.

What do you think about the Science Corps, sir?

DR. WATERMAN: You mean a Science Corps to be called in for an emergency?

CAPTAIN ROWLEY: Yes. I mean putting scientists in uniform in order to have better control, if you want to say that, or whatever people are put in uniform for in wartime, and keeping them in the same jobs, as in many cases they are.

DR. WATERMAN: I think that is a very desirable thing.

CAPTAIN ROWLEY: Do you feel there is enough use for it, though?

DR. WATERMAN: Yes.

CAPTAIN ROWLEY: After all, they have a Medical (Science) Corps in both Services now.

DR. WATERMAN: I know they are doing some work along this line. If the Services can and do develop officers who have the type of scientific training which civilians have, it is taken care of to a certain extent in that way. Key individuals in the Services certainly can provide a very strong nucleus. In addition to that, in time of an

emergency the Services would certainly require many specialists--scientific specialists--in uniform, and a corps such as you have mentioned would do that. Probably for certain other jobs it would be desirable to have them in a civilian capacity.

I think that the combination would be an excellent thing. Certainly they are needed in uniform. Certainly the nucleus, I think, should be trained in the Regular Army, Navy, and Air Force--a certain nucleus to set the thing up, and know just how to deal with the problem. That can be built on, I think, by the addition of a Scientific Corps which would come into uniform. Then, in addition, I think there would be advantages in retaining a civilian scientific organization which could plan, supervise and work directly on applied research and development as experts.

QUESTION: You have stated that before the war Europe occupied a preeminent position in the scientific world. In view of the large numbers of scientists that have been removed from their native countries, would you care to comment on the future position of Europe in the scientific field?

DR. BUSH: That is a large order. In the countries that were overrun, there are going to be a great deal of trouble getting back. There are those practical difficulties: lack of paper, lack of textbooks, inadequate salaries, lack of housing. Conditions are anything but good for research of any variety to be done, on a large scale at least. Of course, there are always individuals who can do their work under any circumstances if they are carrying a bright enough torch. I am not referring to those isolated instances but to the general output. On the continent it seems as if it will be some time, mostly because of practical difficulties, before they can come back.

There are, of course, still good scientists in Norway, France, Italy, Switzerland (Switzerland is less affected), Sweden, Denmark, Holland and so on. Those men will continue to produce. Except for Switzerland and Sweden, however, what is going to be felt in the future, I am afraid, is the lack of young scientists. There will be an age gap there which will take some time to get over. Some of their young people have not had any opportunity whatever to get the scientific training which is needed to step into the place of the older men. Those countries will have to do the best they can, by training them right now; that is a very difficult problem.

My guess would be that it will be some time before the European Continent will be able to get back much in the way of research.

QUESTION: It is evident, from the reading of preliminary reports of the various governmental agencies, that the Navy does a great deal of its research on a contractual basis. It seems inherent in that way of doing research that there will be a real possibility of interference, especially in basic research. How does the Navy take steps to avoid that?

DR. WATERMAN: You mean interference between the parts of its own program or with other agencies?

QUESTIONER: Between yourselves and the people who are contracting for basic research. To state it in a different way, it would seem to me that in entering into a contract for basic research you would have to have some agreement between yourselves. The element of freedom would seem to be somewhat interfered with. I was wondering what steps you take to give these people complete freedom and at the same time get some results.

DR. WATERMAN: The answer is fairly simple. Instead of going to a university and saying, "The Navy is interested in five or six problems and we know that you are experts in this field, which one of them would like to do?" we have gone to the universities and said, "What's on your mind? We know that you are working in this field. What do you think is the most important thing to do in this field?"

They are experts. You go to the man who you know is an acknowledged leader in his field and ask him what he thinks is the most important thing to do in his own field. What is he excited about doing? Then, after discussion of that kind with a number of the leaders, they may be encouraged to put their suggestions in writing in the form of proposals, so that what we get is a filtering of the free responses, or, rather, the free proposals which are made by them and not by us.

In general, that is the technique. Find out what they are interested in, what they are all set to do, what they have tradition for, where they have real experts, and what the experts think are important bottlenecks in the research field, and then make a selection of these to form the program. Once the contract is set up, of course, they are the experts and not we as to how to go about doing the job.

We are in touch with it. If the research changes scope or aim or runs up against a negative result of some kind, then we step in and consult with them. If we can get competent enough personnel at headquarters, we may talk with them as men to men and off er suggestions. One has to be pretty competent in the field in question, however, to do that.

That is the general philosophy. I thought at first you wanted to know how it was arranged so that there is no conflict between what the Naval Research Laboratory, for example, does and what is done in universities. The answer to that is that no single laboratory can possibly have all the experts in the country. The philosophy underlying our program is that if you want the best research done, you must go where the best men are. The best men may be in an Air Force laboratory, an Army laboratory, Navy laboratory, or in some outside institution. You go to the best men you know. If you have them in your own shop, so much the better. But they can't possibly all be there.

In fact, if one wanted to start a laboratory for a specific purpose--we will say, to take a live topic, the study of supersonic aerodynamics--the problems in this field would not be solved by setting up the finest laboratory you could imagine and assuming that would do the trick, because you never could get the country's best experts there, except during a wartime emergency. You could get only some, and you would be lucky if you got the top ones. The rest would be scattered all over the country.

If you want to do the best job in research, you have to go where the men are, do the best you can to get the men in your own shop, and let them go ahead where they can; but round the program out by going where the men are and letting them work in their home institutions.

QUESTION: In the same stream, Dr. Waterman, does the Navy, in its contracts, insist on a progress report? Do all papers that are worked up belong to the Navy? Does the Navy insist on screening all papers before they are published by those scientists working on projects for which at least the money is furnished by the Navy?

DR. WATERMAN: The Navy requires, in its contracts, a report which we call a periodic status report at no longer intervals than every three months. That is for our own benefit, primarily just to keep track of things. It may not have anything of scientific importance in it, except the mere mention of what has been accomplished. That gets no distribution to amount to anything. It is more of an administrative matter to keep track of what is going on.

Scientific or technical reports come out as opportunity offers, when there is a natural stopping place or something to report. Then there is a final report which includes scientific aspects.

In over 90 percent of the work with universities, the work is unclassified; the only instructions to the contractor are that no mention be made of any possible military application.

When a scientific paper or report is put on, it is generally also submitted for publication. If so, the manuscript is sent to us first to look over, and we determine the distribution list. This scientific report has wide circulation among scientists. It is usually a published article or will be published, and that is something in which the scientific world is very much interested. In general, these would come out in scientific periodicals, as they should, I think, to disseminate the news widely among men who can make the best use of it. I am talking entirely about unclassified material.

Does that answer all your questions?

QUESTIONER: Yes, sir; I think it does.

QUESTION: You have mentioned several budgetary figures, Doctor. I am a little confused as to what they really mean. I don't have a yardstick. What does a million dollars buy in the way of fundamental research?

DR. WATERMAN: Fundamental research, of course, is a lot cheaper than development. The cost depends on whether you do it in your own shop or get someone else to do it. If you get someone else to do it, he puts in an interest, so that the Government gets more for its dollar. That is our way of doing it. It works out that we pay for the large contracts, where, on the average, I think the universities are putting in about 50 percent of the money. They always have to put in the laboratory facilities and permanent fixtures of that kind.

Now, as to what it will buy: On the average, I would say that fundamental research costs are about one-tenth of development costs. That is one yardstick. For another, I think industries say that on an important research project, something of the order of 15,000 dollars per man will get the job done--between 10,000 and 20,000 dollars, perhaps, depending on the cost of overhead in the establishment. University costs are apt to be considerably less.

With our projects--I think we have over 600--about 50 percent of them in the university program amount to less than 25,000 dollars. In a university project you may have an expert who is a leading authority. He may be working alone or it is not a group project. All he wants is a graduate student and a chance to buy material and then construct the equipment in his shop. That, then, takes only the salary of the assistant and a certain amount for expendable supplies. He, being on the university pay roll, does not receive part of his salary that way, although it is customary for universities to pay the man if he stays on the job during the summer.

QUESTION: I understood that you have a figure for Great Britain on basic research of about 15 million pounds. It would appear that our appropriation was the same as the British for basic research. I was wondering whether we were missing the boat or we didn't have any place to put additional money.

DR. WATERMAN: I'm sorry; I may have been misunderstood in their figure. Their total figure for research and development is 69 million pounds. That is about 280 million dollars. That is for research and development.

QUESTIONER: It is more than our ten percent. Great Britain's is about twenty percent.

DR. WATERMAN: Yes. Perhaps this is the figure you had in mind. The universities are receiving about 11 million pounds--about 44 million dollars. That is all basic.

QUESTIONER: That is the equivalent, then, of all our basic research.

DR. WATERMAN: I said it was all basic. However, at the few places where they do engineering, like Cambridge, it would approach applied research.

The British have an interesting distinction in basic research which I referred to in a somewhat different way. They say that basic research can be planned, that the director of a department can say, "This is an important field to do basic research in." That, in a sense, is directed. Now, another man in some other place may have decided on his own initiative to do the same job. The two kinds of research are exactly the same, but the points of view in setting them up were different. The British do a great deal of that planned basic research, which comes close to applied.

CAPTAIN ROWLEY: Along that line--and possibly Captain Gladding was also thinking about this--you mentioned the figure of 20 million dollars with which the Office of Naval Research was supporting basic research alone, did you not, sir?

DR. WATERMAN: Yes.

CAPTAIN ROWLEY: We don't want to tie that up with any over-all British expenditure. Did you give any figure for our country as a whole on basic research?

DR. WATERMAN: No, I just gave it for the Military Services, and that was a rough guess. It is very hard to draw the line for basic research.

CAPTAIN POLEY: Not including agriculture, mines, and so forth?

DR. WATERMAN: No. The military figure I gave is something of the order of 50 million dollars.

QUESTION: How much of our fundamental research in this country is ultimately supported by the Government--what percentage? I mean the Federal Government, State Government, or any form of government.

DR. WATERMAN: I'm afraid I couldn't give you the figure on that. Perhaps the best place to look for figures would be in the Steelman report. I think that report estimates that all forms of Federal support in research and development in this country, including industry, are of the order of 1.1 billion dollars if my memory is correct.

QUESTION: But what percentage of the total research expenditure of the country actually comes from the Government in some form or other, in terms of the salaries to state university professors who are doing research, and all that sort of thing? Boiling the thing right down and getting at our total contribution, I think you will find that it is a great deal higher than your figure indicates, that is, by projecting our military expenditure.

DR. WATERMAN: It certainly is if you bring in the state support, because the state universities would come into that in a big way. Industry, of course, is supporting research. That is why I confined myself, when I was talking about basic research, to the military expenditures. I quoted the Steelman figure of about one billion dollars to give you an idea of the total magnitude of what is being spent by industry and the Government and so on. That figure is their estimate of what goes into the total research program from the Government. I am not sure whether that includes the states.

QUESTIONER. I think that, at best on the way, it tends to underestimate the actual effort that this country is making in fundamental research.

DR. WATERMAN: You are quite right. We would have to go into the source of income of the universities and then the source of income of the industries to get a complete picture.

QUESTION: Dr. Waterman, the Steelman report has placed a great deal of emphasis on the lack of scientific manpower. It has called it

a limiting factor, I believe. That might be very important in requesting funds from Congress. In other words, in the foreseeable future in requesting fairly large amounts from Congress, would we be stymied at all by the emphasis that is being placed upon the lack of manpower? It would seem you would have to make an affirmative statement that within the limit of the funds you can use the manpower available to carry out your program. I am wondering whether the general statement in regard to the limit of scientific manpower, instead of benefiting future development, might not be turned against us when asking for funds for a program which might be necessary within the next four or five years. Would you comment on that?

DR. WATERMAN: I know they have made a strong point of that. There is a great deal of truth in it, that our limit in spending funds is definitely a manpower one. If we try to put funds in inexperienced hands, it will be wasted. We have to wait for the talent.

My opinion is that--and we have evidence for this in our own program--the Steelman report was somewhat pessimistic, though, in one respect. We have applications for basic research from institutions, and those applications are passed, as is required, through the heads of the institutions and are approved by them. Our evidence is that good research men are available right now of doing more research than they are in fields that are important to the Government, the Military Service, and others outside. The total would amount to a considerable figure. That is the only approach I know where we have definite evidence in regard to this problem, and it concerns basic research facilities, not development.

I think the Steelman report was also concerned with the long-range program and called attention to the fact that before we could engage in research and development in a big way, we had to get more scientists. That I think is certainly true.

CAPTAIN ROWLEY: I have one other point along the line of Colonel Calchrist's question. You have stressed and others have stressed the necessity for an administrative staff of scientific personnel in our Military Establishments and in other Government departments. We know that we have a number of Government laboratories and that some of them employ large numbers of scientific personnel. All these scientists--engineers, applied research and development men, physicists, chemists, and what not--are taken away, presumably, from their universities and other institutions where they could have trained people. The Government needs them. Yet they are no longer able, while they are working for the Government, to be training students. Therefore, we are getting no further toward reducing this deficit of scientific manpower.

Do you have any ideas along that line, sir? We need them in our Government. I certainly wouldn't be willing to state that we ought to give up some of our men in the Government and Military Establishments and send them back to universities to do more work there, because I consider that there is work that is urgent and desperately needs to be done even if we do find ourselves in shortage.

DR. WATERMAN: There is a consideration to be kept in mind there. In many of those cases, the universities wouldn't take them back. They are often not the kind of people who should work in universities. The universities want a man who can teach, for one thing. They want a man who can do research, for another. Those are the two main considerations.

A laboratory doing applied research and development doesn't care about the man's teaching ability. He may be the world's worst teacher. But he may be able to get on with other people very well. That is an asset. But the university doesn't care so much about that. If he is on the ball with ideas, then either could use him.

But you have a question of difference of type, and I think that under the ordinary laws of selection, there are men who will gravitate to government laboratories where there is applied research and development with a chance for basic research, just as men gravitate to an industrial laboratory that does a similar thing. They like the atmosphere better. It is more businesslike, more straightforward, and they like it. They like dealing with people and getting things done, just the way the establishments themselves do.

In the process of natural selection, then, the establishment will get the type of man who are most useful. The thing to do, though, is to be sure they keep a fresh attitude and do not get in a rut. The danger may be that they consider they have an easy chair for life and don't exert themselves after a while. The thing to do is keep the work alive, and that is why these other considerations, I believe, are important.

CAPTAIN RORLEY: That was going to be the second half of my question.

I am sorry we kept you overtime on the question platform, but we are gratified for the information you gave us and very happy to have heard your lecture, sir.

(19 December 1947--450)S.