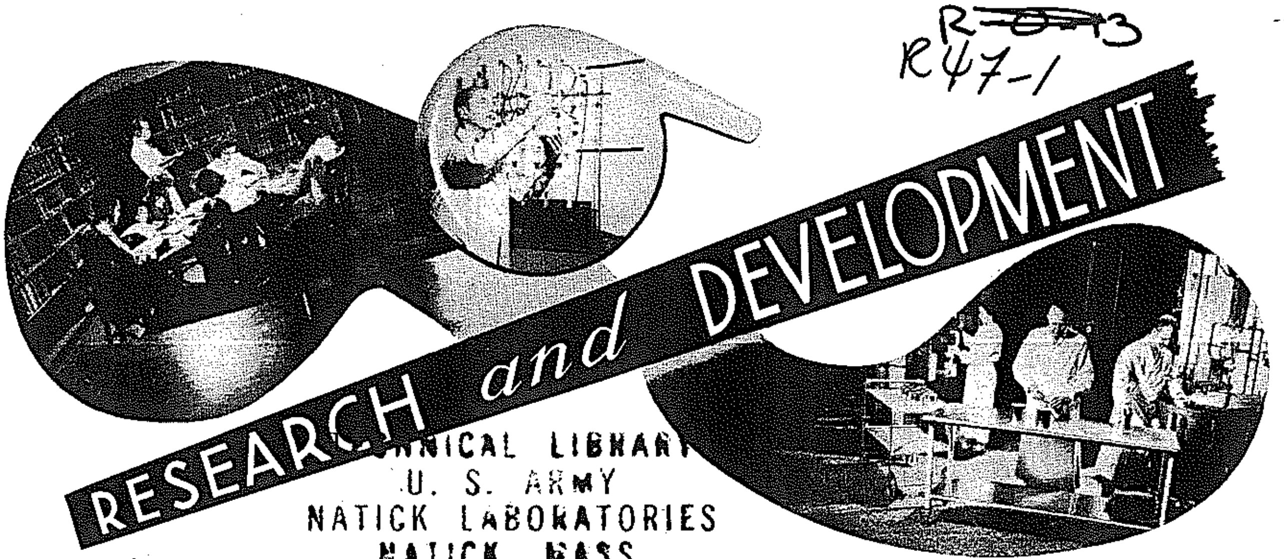

RESEARCH and DEVELOPMENT

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THE phrase "research and development," is probably the most overworked expression in the English language today. Normally, overworked phrases or words are used with only a hazy concept of their full meaning. Webster defines *research* as "protracted investigation for the purpose of adding to human knowledge," and *development* as "the act or process of unfolding or bringing to light something unknown or unseen before, to make it more available or usable." These definitions, of course, are general and, while in the case of extremes may be comparatively easy to apply, there are many instances where it is difficult to say definitely that a certain project is one of research or development.

We should think of research as paving the way for, and making possible the development of, new or improved products; as producing the fundamental scientific information that development uses as building blocks to construct a new or improved product. Research studies the composition of things down to the smallest particles of matter. It studies the behavior of things animate and inanimate. It studies the concrete and the abstract. Research involves all branches of science, sometimes creating new branches.

Research may be pointed in a general direction, but it cannot be confined to any charted course. Since the objectives of research always lie beyond the horizon of existing knowledge, we can see how difficult is the task of charting a course very far in advance. As new facts are brought to light and the horizon of knowledge is extended, succeeding steps are decided upon.

The scientist embarking on a research project may have a definite objective, but he cannot always know in advance the location of the objective or chart the road or roads that lead to it. As his work progresses he will find many interesting by-paths. He must be free to follow them. While many of them only lead back to the starting point, it must be remembered that along these by-paths some of the most startling discoveries have been made. Much of the information obtained by research is negative in character, but even this negative information may be valuable. If reported and published, it obviates the necessity of future investigators repeating that particular task. It serves as a warning sign to others and tells them that here is one line of approach that does not lead to a solution.

Research often brings to light facts for which we have no immediate use, or facts that have no application to the particular subject under investigation. The careful research scientist notes everything that he sees and much that he only suspects, for, in his notes, others may find the long-sought answer to some perplexing question in a quite different subject area.

Research requires two types of scientific personnel. First, those with a broad scientific background who can outline in a general way the investigations to be undertaken; the capacity to make a logical breakdown of a proposed investigation into the subject areas involved; and, finally, when an investigation is under way, the ability to coordinate the work of the various groups involved. The logical assignments for such personnel are as directors of research, technical directors, coordinators or advisers on the staffs of research organizations. The second type of personnel are those specialized scientists who, by confining their interest to a more or less limited subject area, have become authorities in their particular fields. These are the individuals who are responsible for the detailed work. Here is where we find them: In the universities and colleges; in research foundations; in

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commercial laboratories, in industry; and in Government laboratories. No single organization could hope to have a complete staff of qualified scientists because the number would be so great as to make the cost prohibitive. The American Chemical Society, for example, has more than a dozen divisions, and in some of these divisions there are twice that number of specialized fields. This specialization in science is not the result of a fad or fancy, but born of necessity.

In every science man has so unraveled the tangled skein of the unknown that today no one man can follow the intricate pattern of threads that go to make up the field of knowledge in even a single branch of science. Here is shown very clearly the advisability of breaking down a research project into subject areas and further subdividing these into specific problems, then placing the problems with the individuals or groups best equipped to solve them. In fact, it is the only method whereby the best minds available can be brought to bear on all phases of an investigation. It is the least costly and the most productive method of conducting research.

While research seeks to go beyond the horizon of existing knowledge to open up new horizons, development is primarily concerned with the utilization or application of existing information to create new or improved products and processes. We should think of development as having the same relationship to research as the great textile mill has to the cotton grower. As the textile mill takes the cotton from the grower and from it fabricates a variety of useful textiles, so development takes the fundamental information produced by research and from it fabricates new or better products and processes. To accomplish this requires careful evaluation and constant study, because the applications of scientific information are not always obvious. On the contrary, they are likely to be obscure. Unlike research, development may need a certain piece of equipment to do a specific job, or an improved one having specific characteristics. There, development will have a definite and well defined task, and it is sometimes possible to outline the approach in considerable detail.

Development requires a great variety of personnel. There must be scientists to evaluate the results of research and outline their application to the problems at hand; to point questions for research based on the needs of development; and to envision the new and better things implied by the results of research. There must be technologists and engineers to apply the results of research to the improvement of existing products or the creation of new and better products, and to adapt laboratory processes to industrial production. There must be trained military personnel to study military requirements; to interpret the needs of the armed forces; and to plan and carry out tests of items in process of development. Development needs certain mental qualities aside from education and experience. These are: Objective imagination, breadth of vision, analytical depth, and a will to complete; underscored by the proposition that, "what the mind of man can conceive, his hands can create."

Though research and development have different missions and functions, their ultimate objective is the same; one is futile without the other. Without development to apply its results, research is just so much wasted effort, and its reports, though containing a gold-mine of information, will serve no purpose whatsoever. Without research to supply the needed fundamental information, development is in the position of the building contractor who has workmen, tools, and equipment, but no building materials.

WHAT IS the role of research and development in national defense? Our modern civilization is the result of continuous application of research and development: the goal of science has been the enlightenment of man and the betterment of his way of life. Only continuous application to every field of human endeavor could have produced the results we see today. Any major war effort involves, in some way, every phase of the national economy. Therefore most of the problems of our national economy—often complicated by special military requirements—are the problems of national defense. The continuous application of research and development to these problems is imperative if we are to enjoy any degree of security in this changing world. Sporadic efforts are pitifully inadequate.

Change is the order of the day, and as our scientific knowledge broadens, the tempo of change accelerates. The scientific curiosity of today is our commonplace servant tomorrow, and a museum-piece next week. The foods we eat, the houses in which we live, the clothes we wear, all are undergoing radical changes; but the changes in progress today are mild compared with that which is brewing in the laboratories of research and development. The druggist of twenty years ago, stocking all the available drugs of that day, could not fill more than half the prescriptions he would receive today. There was a time when a modern instrument of war remained modern for several decades, but that is rarely true today. The flying fortress, only a few years ago hailed as the battleship of the air, is little more than an armed air freighter today. Even the atomic bomb that exploded over Hiroshima is already obsolescent. The VT or proximity fuse, one of the scientific marvels of World War II, is only the beginning of what science holds in store for the artilleryman of the future. To abandon the continuous and intensive application of research and development to the problems of national defense would be little short of national suicide.

If there is to be a continuous application of research and development to the problems of national defense, there must be some organization to administer this application. Because of the complexity of the overall problem and the multiplicity of industrial fields and scientific areas involved, no one unit could hope to do the job. Each technical service has its own group of problems and should have its own research and development organization. These organizations should be broken down into subdivisions by industrial or scientific areas. Each organization should have scientific personnel to plan and coordinate research, and a separate group of scientists, technologists, and engineers to evaluate and apply the results of research to development. There should be close liaison and a free flow of information between the technical services and the using services. The technical services must be kept aware of the needs of the using services, while the using services must be kept informed on potential developments to insure prompt utilization. There should be a free horizontal flow of information between the research and development organizations of the technical services in all branches of the armed forces, and this should extend even to the lowest operating echelons.

The research and development organizations of the technical services should maintain close liaison with, and secure the full cooperation of, industry by a free interchange of technical and scientific information, since much of the developmental work can best be carried on in industrial plants and laboratories. By maintaining proper liaison with industry, research and development can make full utilization of industry's "know-how" and, at the same time, keep industry aware of military developments. Then, in the event of a national emergency, industry would have the technical data necessary for quick conversion to military production. In any future emergency, industrial preparedness may well be the deciding factor. There is no assurance that we will ever again be allowed a year or longer in which to convert our industrial potential to war production by the slow trial and error method. What we are able to accomplish in the first few months may spell the difference between victory and disaster.

Research and development *must* work hand in hand with industry if the new and better things created are to be available for use when needed. The road from the test-tubes of science to the assembly lines of industry is sometimes long and difficult. It can be lined with many unsuspected pitfalls. Months or even years may be required to adapt a laboratory process to plant production. A good illustration of this fact is noted in a new and revolutionary method of processing certain foods that evolved in a laboratory during World War II. The rights to this process were purchased by a nationally known firm. They set up a pilot plant and started production. Immediately all kinds of difficulties arose. When they tried volume handling necessary to plant production, the finished product was altogether different from that produced by the small-scale laboratory equipment. Two years have elapsed and thousands of dollars have been spent since plant production was first attempted. To date not a single pound of finished product has been offered for sale, and the end is not yet in sight.

Research and development must maintain close personal contact with both science and industry. Our scientists, technologists, and engineers can accomplish this by being members and attending meetings of scientific and technical societies and industrial associations. Personnel from one Quartermaster research and development organization attend the meetings of more than sixty different groups each year. By this close association, research and development people learn of new scientific advances and industrial developments long before they appear in print. These personal contacts with the best minds of science and industry immeasurably raise the professional standards of those attending. The helpful suggestions and sound advice freely given them on the basis of personal acquaintance has, in the past, proven valuable beyond estimate in dollars and cents. The solutions to some of the most vexing problems facing the Quartermaster Corps have been suggested at these meetings. The benefits are by no means one-sided, because this is a mutual exchange of information and ideas. It often happens at these meetings that problems of common interest to the Quartermaster Corps and industrial organizations are brought to light and arrangements made for joint cooperative investigations. More than five hundred firms are now cooperating with one Quartermaster research and development organization on projects of mutual interest.

The "what" and "why" of research and development naturally lead to the question of "how?" How are research and development questions pointed? How are the investigations set up? How does an individual or a group of individuals attack a problem? These questions will deserve careful consideration; and, with this fact in mind, the Quartermaster Corps' case history of the "Biochemistry of the Browning Reaction" vs. Science will be presented in detail:

In 1911, a French physiologist, L. C. Maillard, noted that certain chemical reactions occurred when proteins and reducing sugars were combined in the presence of water at elevated temperatures, and that these reactions produced a brown or dark discoloration. This has since been known as the Maillard or "browning" reaction. The browning reaction is characterized by the development in foods of a progressively brown to black color, caramelized flavor, and change in texture. For a number of years not enough attention was paid to Maillard's work, but it is now realized that this so-called "browning reaction" is of great significance regarding certain foods important to Army rations. To quote from the research program of the Committee on Food Research, Quartermaster Food and Container Institute for the Armed Forces:

> Heat processed foods, such as powdered eggs and milk, dehydrated fruits and vegetables, canned bread and meats, have great operational utility in time of war but experience in the field has shown that they often have limited acceptability. A major reason for the low acceptability rate is the browning reaction, which occurs during heat processing and long periods of storage, especially at elevated temperatures.

The browning reaction causes the development of a brown or dark discoloration, off-flavor, and off-texture in many food products. This reaction has been characterized as involving amine groups in proteins and fats, with free aldehyde groups such as are present in glucose. Since little is known of this reaction, it is of military importance that its nature be investigated to establish methods for its control.

Investigations in this section are concerned with the preparation of critical surveys and bibliographies, fundamental chemistry in model systems and food products.

The information resulting from these investigations will be related to phases of lipid deterioration, especially where lipid amines are involved, and to food acceptance, which, in turn, has a direct bearing on food intake and nutrition. The information obtained on the browning reaction will also be applied to the biochemical investigations in the potato, dairy products, and cereal and baked products section.

The foregoing quotation sets forth the military significance, scope, and interrelation of the proposed investigation. This is the first step in an investigation.

The second step is to divide the investigation into its major sections, then further subdivide these into research projects, and then find the individuals or organizations best equipped to handle them. The latter is an extremely important function requiring scientific personnel with a broad knowledge of the general problem and a wide acquaintance in the scientific world. A wise or unwise assignment of projects to investigators may easily make or wreck a program. Such assignments should be made by a committee of scientists. In this particular case the assignments were made by the Committee on Food Research of the Quartermaster Food and Container Institute for the Armed Forces. This Committee is composed of six outstanding scientists in the field of food technology and related branches of science. Four of these men are on the faculties of universities, one is a director of research in industry, and the sixth is the Technical Director of the Quartermaster Food and Container Institute for the Armed Forces.

The investigation was originally divided into four sections, and the sections into individual projects as follows:

1st Section: A Literature Survey.

1st Project: To prepare a critical literature survey and bibliography on browning reactions with special reference to sucrose products.

2nd Project: To prepare a literature survey to bring together the available information on the browning reaction in malt products.

2nd Section: Studies of the Nature of the Browning Reaction.

1st Project: To investigate the chemistry of browning, starting with pure materials.

2nd Project: To investigate the nature of brown pigments formed as a result of the sugar-amino reactions of pure substances in foodstuffs.

3rd Project: To analyze the overall complex browning reaction into its constituent reactions, with particular emphasis on possible intermediary reaction of the original condensation between the sugar-amino acid compounds and the final formation of brown pigments.

3rd Section: Other Influences (Catalizers and Inhibitors).

1st Project: To investigate the sulfite inhibition of browning in foodstuffs by studying the reactions between sulfite and pure sugars.

2nd Project: To find methods for controlling those factors which influence sugar-amino browning reaction other than the sugar compounds and the amino compounds themselves, and the chemical conditions of the reaction.

3rd Project: To determine the nature of heat deterioration in dried beets, the nature of the beet pigments, and their relation, if any, to deterioration.

4th Project: To determine the factors which influence the browning of tomatoes during dehydration and storage of the dehydrated product.

5th Project: To study the non-enzymatic browning in dried eggs, to evaluate the reaction between reducing sugars and protein, and the reaction between cephalin and aldehyde in the lipoid phase, with particular emphasis on the study of cysteine and sulfite as inhibitors in browning.

4th Section: Measurements.

1st Project: To determine whether the brown pigments formed from different sugar and amino compounds under different conditions can be distinguished by their optical properties.

2nd Project: To isolate and identify the water-soluble brown pigments formed during the anaerobic storage of dried apricots; also the sulphur compounds formed from sulfiting.

Since the program was instituted, the transfer of information from the various participating agencies has stimulated other investigators to undertake new projects within the subject area. From time to time, as the investigation continues, some projects will be abandoned and new ones added. As Dr. C. F. Kettering has so aptly said: "Set the thing up, and there isn't one chance in a thousand that the thing will work out the way you expect it to, but it won't fail the way you expect it to, either. That is the way we learn." While the original projects were only a fraction of the number of possible projects, they did cover a considerable portion of the subject area, and, at the same time, were designed to furnish fundamental information that would have immediate application.

The individual problem is attacked in a different manner than popular fancy supposes. In the minds of some, research consists merely of the endless mixing of ingredients, hoping with each mixture to get the desired result. That may have been research in the early beginning of artisanship and craftsmanship, but the modern approach to research is something entirely different. The first step of the investigator today is the assembly of such co-workers as he deems necessary. Then, the problem is divided into its component parts and studied carefully. This study includes a thorough review of present knowledge.

It is a waste of time and energy to do something that has already been done and reported upon, or to try some method of attack that has already been tried and found useless. This preliminary study may require a few weeks or it may require several months. Further, it may involve considerable travel to consult other scientists working on parallel problems.

The success or failure of a project often hinges on the amount of this painstaking preliminary preparation. When the workers have been assembled and the preliminary studies completed, the missing links of information will be apparent; then each can be attacked in detail. At this stage the investigation would probably present a confusing picture to an observer, but, as the missing links are supplied, the whole takes on an orderly pattern. It is sometimes surprising how few are the missing links, and how easily they can be supplied, once the problem has been clearly stated, thoroughly analyzed, with all existing information assembled and correlated.

As the work progresses it produces just one thing of value—information. The information is contained in the notes and reports of the investigator. Merely accumulating this information is not enough. It must be channeled to those who need it and can use it. The reports must be made available to, and receive careful study by, the scientists, technologists, and engineers of development, for evaluation and application to developmental problems. They must be made available to, and studied by, research workers on allied projects. The horizontal transfer of information within the framework of research stimulates interest and enthusiasm; quite often the observations of a worker on one project contain the germ of an idea that will have far-reaching effects on other projects. Research reports should be published and given as wide circulation as possible. It is improbable that any one person will see all the possible implications of a research report because the implications often go beyond the subject area of the investigation, even extending to other branches of science. Increase the number of people who have access to a research report and its value is correspondingly increased.

The value of the transfer of information between research workers, and the significant implications of their observations, may be illustrated by citing two recent examples:

(1) Approximately twelve laboratories have been working on the organic and physical chemistry of the browning reaction already mentioned. In one of its reports the Food Technology Division, University of California, submitted the absorption spectra curve for one of the intermediates of the browning reaction. When this report reached the laboratories of the Corn Products Refining Company, their assistant director of research, who was doing some work with similar compounds, identified the curve as characteristic for 5-hydroxyl methyl furfural. Here, for the first time, a chemical intermediate of this reaction was identified, and thereby a tremendous stride forward was made in unraveling the chemical mechanisms of the browning reaction. Of course, the University of California and all other participants in the browning program were immediately notified of this discovery.

Work done so far has given rise to the belief that the browning reaction may play an important role in the acceptability of foods, aside from noticeable flavor changes. As we learn more of the fundamental chemistry of this amino-sugar reaction and the physiological effects of its resultant compounds, that knowledge will have a profound effect in the production of better and more healthful foods, not only for the armed forces, but for the civilian population as well.

(2) In 1942-43 so little was known about the chemistry of deterioration in powdered eggs that this product was stable for only a few weeks if subjected to temperatures of 100° F. Therefore, thousands of pounds of powdered eggs, upon reconstitution, were not acceptable from a palatability standpoint. It became desirable, then, to determine whether or not the food quality of these eggs had deteriorated as well as the acceptability. If the nutritional quality had remained constant, it would then be worthwhile to investigate various ways powdered eggs might be incorporated in baked goods or used in such other ways where the objectionable flavor could be cooked out or masked. Consequently, a nutritional project was set up at Iowa State College to compare the protein quality of badly deteriorated dried eggs, fresh dried eggs, and fresh shell eggs. While this was the primary purpose of the investigation, the results obtained not only indicated that there was virtually no difference in protein quality between the different samples of eggs but, in addition, the striking observation was made that the egg protein, when fed to animals on an otherwise protein-free diet, permitted better utilization by the animal of its own body protein. In other words, body protein plus egg protein is more readily utilizable than body protein alone or any other of the natural proteins investigated to this time. This had the additional significance of indicating that, under certain circumstances, less water is required when egg protein is contained in the diet than in a protein-free diet. This was contrary to the classical views, which previously held that the addition of protein to the diet necessitated additional water intake to flush out the nitrogenous by-products. The importance of this observation to the Army lies in its need for a survival ration which not only permits the maintenance of optimum health but requires a minimum water intake.

The present survival ration is composed entirely of carbohydrate, on the theory that protein will raise the water requirements. As a result of the powdered egg work we now know that the incorporation of the right protein into a survival ration will actually reduce the amount of water required. There is now under way an extensive research program to determine the minimum caloric requirements for a survival ration having optimum protein, fat, and carbohydrate content, and that will also permit a lowering of the water requirements.

The mechanics of the functioning of development are somewhat complicated, as they involve so many individuals with such a variety of interest. This may be illustrated by considering what is involved in the development of an operational ration for the armed forces. Such a project would be primarily the responsibility of the ration development group, composed of officers of the Quartermaster Corps, Army Air Forces, Army Ground Forces, and Navy. It would also involve scientists, engineers, and technologists in animal food products, cereal and baked products, dairy products, fruit and vegetable products, and general products (condiments, beverages, sweets, and so forth). These groups would furnish information regarding the items available for inclusion in the ration. The scientists of the biometrics, food habits, and statistical sections of food acceptance research would furnish data on the relative acceptability of the various items. The scientists of the biophysical, chemical, and microbiological sections of the technical laboratories would furnish information regarding the nutrient content, stability, and vitamin retention of the various items. The scientists, engineers, and technologists in packaging and packing would furnish information and recommendations on the containers to be used. Scientists in nutrition would furnish information on the balance and nutritional adequacy of any proposed combinations of items. Once the ration was decided upon, all of the groups would be involved in the preparation of specifications to be used by procurement in the purchase of the ration. And the responsibility of development does not end here. Its technologists have the further responsibility of carrying many of the items from the laboratory stage through the pilot plant and commercial operations.

In recent months there has been much discussion in print regarding the desirability or nondesirability of the Federal Government sponsoring scientific research. Aside from the question of who sponsors it, the need for fundamental research is acute. For years America has been a lavish user of science in product and process development, but we have never sponsored fundamental scientific research in our colleges and universities to an extent that would keep pace with our developmental activities. During the war years it was only natural that emphasis was on development, because we were faced with the immediate problem of producing and placing in the hands of our armed forces the newer and better instruments of war. As a nation we have always used fundamental scientific information at a much greater rate than we have produced it. In fact, our tendency has been to concentrate on product and process development to the neglect of fundamental research.

If we consider the scientific marvels of the past decade it will be seen that we contributed comparatively little of the fundamental scientific information from which they were developed. A few of the more recent examples are sulfa drugs, antibiotics, the atomic bomb, radar, and the VT or proximity fuse. These were not the results of new fundamental research on our part, but the application of already existing information to new problems. We have created an industrial potential far ahead of any other people on earth. America's industrial "know-how" is the outstanding wonder of the modern world, but today we are facing a critical situation. Unless there is concerted effort, backed by ample funds, to promote fundamental scientific research, development will eventually stagnate for a lack of basic materials with which to work.

The pressing question today is: Shall we continue as in the past, or shall we make a concerted effort to promote fundamental research? Our developmental machine is set up and operating efficiently. We must have a similar one for research if development is to continue at its present pace. Those concerned with national defense, fully aware of the existing situation, have taken definite steps to promote fundamental research. Both the War and Navy Departments are promoting it. Their immediate objective is not to produce bigger and better guns but to obtain fundamental information to provide a firm foundation for future development. Captain R. O. Myers, of the Office of Naval Research, recently said in an interview appearing in the *San Francisco Chronicle:* "Wars are fought primarily with weapons developed by applying the fundamental knowledge acquired before the fighting begins. That was true of rockets, guided missiles, radar, and even the atomic bomb. It probably will be true in the future."

Apparently the critics of Government-sponsored research were afraid that there would be too much Government control and red tape; that the scientists' hands would be tied and their voices muted; that they would be told what they could or could not do. This fear probably springs from the secrecy surrounding the development of the atomic bomb; but it is baseless. The atomic bomb project was one of development, not research, and it was carried out while the country was engaged in a life-and-death struggle. As far as fundamental research is concerned, no one has ever really directed or controlled it.

The programs of both the War and Navy Departments have clearly demonstrated that the Government is interested in promoting, not controlling, research. Most of the projects now under way were suggested by the university scientists themselves. The scientists are free to publish their findings when and where they choose. There is no cloak of secrecy. At the meetings of the various groups of research scientists discussions are open and free.

The promotion of fundamental scientific research on a sound basis implies more than merely subsidizing a few projects in universities and research foundations. It involves the education and training of research scientists. Research stems primarily from our universities and colleges, where it was fostered long before industry or Government became interested in it. Research is, and must remain, a primary factor in higher education. By sponsoring and subsidizing research in educational institutions the Government is accomplishing three things:

(1) It increases the facilities for the training of qualified men in the methods and techniques of research;

(2) It adds to the stockpile of fundamental scientific information;

(3) It supplies, by pointing some of the research toward our developmental activities, much needed fundamental information for immediate application.

The first requirement for an expanding technology is a steady flow of trained personnel at all levels, including the post doctorate. Our whole modern civilization rests basically on the creative efforts of the research scientists, and our rate of future technological advance will be determined by their numbers and the fruitfulness of their labors.

National defense must keep pace with an expanding technology and should contribute materially to the expansion. By doing so, national defense can pay handsome dividends to the taxpayer who supports it. Our armed forces are the nation's insurance against any interruption of our democratic way of life by outside forces. Viewed solely in that light, they may be considered non-productive consumers in the nation's economy, but they can, through a carefully planned and coordinated program of research and development, make substantial contributions to the productive side of the ledger. Whatever mechanism we devise to carry out a program of research and development for national defense, we must depend upon the research laboratories, the research workers of industry, and the universities to fulfill most of our needs. The funds spent on research in these institutions and organizations will result in an expansion of the total research and development facilities of the Nation. Much of the research and development carried on to meet the needs of national defense will meet the immediate needs of peace. Research pertaining to chemicals, rubber, synthetic gas, electrical instruments, engineering products, medicines, metals, and foods is not only research for national defense but also for peacetime use. Even end-products of a purely military character supply much intermediary information applicable to civilian use. Every dollar spent for research and development by the armed forces will be repaid to the national economy in new and better products and processes. Secretary of War Patterson has said: "... the future of our country, in peace and war, is to a great extent in the hands of American scientists." It is a primary duty of the armed forces to maintain the independence of these hands and to strengthen them.