Applied Research

IN THE UNITED STATES

Eugene W. Scott, editor

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Report of the
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to the
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PREFACE

In this report we give a broad sketch of American practices in the organization, administration, and financing of applied research in the natural sciences and engineering. We treat also the ways in which new results found in the research laboratory are communicated to those responsible for their practical utilization.

The report is directed mainly toward administrators of research in governments and industries of other countries. We hope that they may find features of interest for their own work in this account of American practices.

Fixed limitations on length as well as the needs of a non-technical audience unfamiliar with American ways have led us to simplify the presentation. Thus many general statements are made without the exceptions and qualifications a more complete account would contain.

The basic material for the report was provided by Eugene W. Scott; David Bendel Hertz, Professor of Industrial Engineering, Columbia University; and the Cooperative Research Foundation of Palo Alto, California. They furnished written material on the research activities of the Government, of industry, and of universities and research institutes, respectively. The contributions were extensively revised and rearranged into the present form by Eugene W. Scott and Ann L. Marcus. Carl G. Thompson, Jr., Hill and Knowlton, Inc., provided valuable assistance in the final editing. Dr. Archie M. Palmer, Chairman of the Government Patents Board, gave many helpful suggestions concerning research in universities and institutes.

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INTRODUCTION

Research has proved its value to the leaders of industry, government, and education in the United States. Their support of research has resulted in well-recognized benefits to the health, security, and economic well-being of the people of the country. Consequently, the scale of support of research activities has been steadily increased. This increase has been accompanied by a growing interest in the analysis of American research practices. The aim of such analysis is to learn how to use most effectively the creative abilities of our scientists and engineers.

To what extent can the policies and practices of existing research groups be used as guides in organizing new ventures or improving those already established? In our belief much that is useful can be learned, provided one recognizes that the operations of existing research groups have been adapted to the peculiar needs of their company, their industry, or their institutional or governmental organization. If this is recognized, then clearly the policies and practices of existing groups cannot be transferred unchanged to a new set of economic, social, or industrial conditions. They must be adapted to suit the new situation. This report attempts to relate research activities to the external factors that influence the planning and conduct of research.

Since the terms "research" and "applied research" appear throughout the report, our usage of them must be clearly understood. Research has been defined in various ways by numerous writers. It is used here as a general term to include all the categories of scientific and technical endeavor usually called "basic research," "applied research," and "development." These terms are commonly defined according to "what" is being looked into—the type of problem each seeks to solve. The difficulty with this approach is that research is a spectrum of activities with continuous gradations of utility from the most abstract to the most practical. The classification of any particular effort as basic research or applied research therefore depends on the experience of the persons who are classifying.

There is another way of distinguishing different kinds of research. This approach is based on "how" and "why" the task is undertaken, rather than on "what" is being studied—on procedure and motive rather than on subject matter. This operational distinction is related to the subject matter distinction in so far as the suitability of a research procedure is determined by what is under investigation. Also, certain motives are more naturally associated with some problems than with others. If classification is done according to motive and procedure, however, the same problem may be considered "basic" or "applied", depending on the conditions under which it is being studied.

In the present discussion we intend to restrict our attention to research activities that have been organized not as ends in themselves but as means to attaining various practical, non-scientific objectives. It is useful, therefore, to define "applied research" in terms of motive and procedure—the "why" and "how"—as follows:

> Applied research is a technical undertaking aimed at solving problems of practical significance in which the scope and extent of the work are determined by the degree of likelihood that it will lead to practical rewards.

By this definition "applied research" includes those activities frequently distinguished as "development." It includes also fundamental studies when these are undertaken with a specific practical end in view and supported in proportion to their estimated contribution to that end. "Applied research" excludes activities of investigators whose choice of problems and manner of attacking them are determined almost entirely by personal curiosity and purely scientific considerations. This "uncommitted" research, pursued mostly in our universities, to some extent in our Government laboratories, and more rarely, in industry, we shall term "basic research."

Most scientific research in the United States is "applied research." Up to about 1920, the United States was not a major contributor to the common store of fundamental scientific knowledge. Since 1920, this country has been steadily increasing its contribution and is now a major source of knowledge. For the most part, Americans have been interested in science as a means of obtaining material benefits. In this they have been highly successful. Some of the factors held responsible for this success are: rich natural resources, abundant opportunity for education and for business enterprise, the highly competitive economy, the social and political freedom of the individual, and the popular faith in "progress."

Research in the United States has been used as a tool to advance health, security, and economic welfare. It is carried on by Government, industry, universities, and research foundations. Before going into the respective roles of these groups, we shall describe briefly the general extent and scope of applied research activities in the United States. Applied research is financed by the Federal Government and by industry, but is performed in laboratories of universities and research foundations, as well as in industrial and Government laboratories. Industrial laboratories include private consulting firms and trade association research groups not attached to individual manufacturing companies. The Federal Government not only performs research in its own facilities, but also supports an extensive program of grant and contract research in industrial, university, and foundation laboratories. Similarly, industry supports specific projects of applied research in universities and research foundations on a contract basis. Both industry and Government maintain research fellowships and grants that enable promising men to do research at universities on problems of their own choice.

As might be expected, the bulk of applied research is performed in the heavily industrialized states—Massachusetts, Connecticut, New York, New Jersey, Pennsylvania, Ohio, Michigan, Indiana, and Illinois. This region also contains most of the large university research centers. The 15 largest universities in these areas granted over half of all the Ph.D.'s in science in the years 1936-45.(1) Of the remaining states, only Texas and California have research activities of magnitude comparable to those already mentioned.

The over-all expenditure for research, development, and related costs in 1941 was $800 million; in 1952 it is estimated at nearly $3 billion. This includes estimated spending of all sources—industry, Government, and non-profit institutions. These figures are not very accurate for a variety of reasons. One of these is the lack of uniform definitions of research and its sub-categories. Another is the variation in accounting practices in use by university, industrial, and Government organizations. An added difficulty in determining Government research expenditures arises from the custom of providing for maintenance and construction in one appropriation and for salaries and laboratory supplies is another. In spite of the uncertainty in the absolute values, the figures given show relative increases and changes which are of significance.

Not all of the increases can be attributed to increased scientific activity. Some rise in research expenditures during the last 10 years is due to the general inflation. The greater complexity of equipment used in research also contributes to increased costs. A final factor which must be taken into account is the growing tendency to include in research many activities formerly classified as production or design.

Relative changes in scale of the national research effort can also be shown by use of figures giving the number of scientists and engineers employed. Here too, unfortunately, the accuracy of the available figures is uncertain since it is not known what care was taken to distinguish the activities which are solely research operations from ones which are not research at all. However, the rough estimates are of interest for purposes of comparison.

In 1950, industrial research laboratories employed 70,000 professional scientists and engineers.(2) A 1951 survey of universities and colleges showed that there were nearly 13,000 regular staff members and 25,000 graduate students and assistants engaged in some research in physical science and psychology.(3) On the assumption that students and faculty members spend about 50 percent of their time on study or teaching duties, it was estimated that these are equivalent to 19,000 full-time researchers. Medical and biological sciences add the equivalent of 6,000 research men.

Estimates derived from the 1952 Federal Budget indicated that 58,000 scientists and engineers would be employed in Government laboratories on research projects. There is reason to believe that these data include some technical personnel not in research. Another group studying manpower has arrived at an estimate of 35,000 Government scientists and engineers in research and development work in 1952. The best estimate must lie between these two figures and a compromise of 45,000 has been adopted for the purposes of this report.

Summing up estimates for industry, universities, and Government gives a total of 140,000 scientists and engineers now employed in research and development. According to a 1951 survey, there are 600,000 Americans of working age who have college degrees in science or engineering.(4) It appears, therefore, that one quarter of these are engaged in research activities.

Something should be said about the educational system that provides the technical manpower needed to do research of this magnitude and to support the vast industrial output of the country. It is estimated that 1,205,000 students graduated from high school in 1951. This represents 58 percent of the 2,114,000 individuals reaching an age of 18 years in 1951.(5) The same source estimates that 429,000 (35 %) of the high school graduates went on to college and that 285,000 (64 %) of these will receive a bachelor's degree in 1955. About 70,000 (25%) of these degrees will be in science or engineering. The total enrollment of students in colleges and universities in 1951 was 2,116,000, including 222,000 graduate students.(6)

There are about 1,000 schools in the United States that grant bachelor's degrees in science. Included among these are a number of "institutes of technology," one of the best known being the Massachusetts Institute of Technology. In these institutes, students may specialize in applied mathematics or physical sciences, but most are enrolled in a branch of engineering. They receive a training on university level in fundamental scientific principles as well as in the techniques of their specialty, and they are further prepared for careers in industry by special courses in economics, psychology, and sociology. Many large private universities and nearly all state universities have schools of engineering in addition to regular departments of the sciences, and these produce most of our engineers. The independent colleges, however, grant a substantial number of our bachelor's degrees in mathematics and the natural sciences. In 1950, 99 universities awarded over 3,600 Ph.D.'s, half of these originating in 13 universities.(7)

The United States is large in area, rich in natural resources, and has an average population density of only 50.7 persons per square mile. It was first settled by small groups of pioneers who came from the old societies of Europe to take up life at the edge of a wilderness. From early days, American leaders have emphasized the necessity for widespread popular education of a kind that, while keeping alive the non-material values, would prepare men to meet practical problems with greater skill. This emphasis on education has endowed the country with its most important economic resource, the trained manpower that is the foundation of American technical progress.

The present report describes in some detail organizations and procedures that have been developed in Government, industry, and universities in order to use this scientific manpower for the national interest. No evaluations or recommendations are provided; the report simply attempts to indicate what practices exist and what conditions led to their adoption.

CHAPTER I
GENERAL ASPECTS OF RESEARCH IN THE UNITED STATES

Historical Background

Research as a recognized activity within industry, university, and the Government cannot be said to have started in a particular year or period. Early in our history individuals received support for their efforts to solve specific problems using scientific principles and methods. The United States Navy from its establishment in 1789, and many of our first industries, employed inventors to improve existing devices and develop new ones. Before 1862, however, the few university scientists who undertook research of any sort did so as a private spare-time activity.

The first industrial firm to organize research as a separate and continuing activity was General Electric. Its laboratory, now famous as a research organization, was founded in 1900. In the Government, one should perhaps mark the beginning of research as a separate activity with the establishment of the Department of Agriculture in 1862.* At this time, Congress directed the Commissioner of Agriculture to acquire information "by means of books and correspondence... by practical and scientific experiments" and "by the collection of statistics." A series of related Congressional acts, the first in 1862, provided Federal support to 69 new higher educational institutions which emphasized science, especially applied science, in their curricula. In 1887, Congress authorized annual grants to the agricultural experiment stations in these land-grant colleges. These were perhaps the nation's first academic organizations whose chief function was to carry on applied scientific research.

A second major step in the early growth of university research was the founding in 1876 of Johns Hopkins University. Hopkins was the first American institution to recognize graduate research as a major purpose; in this, it followed the European tradition.

Research activities of the Federal Government expanded gradually until the inception of World War II, as more and more Government agencies were confronted with technical problems related to their operations. The Steelman Report** estimated that the Federal research budget in 1930 amounted to $ 25 million out of a total national research budget of $ 166 million. (8)

In 1915, there were about 100 industrial research laboratories; by 1930 the number had grown to over 1,600. This period saw the start of research laboratories by Bell Telephone, DuPont, Westinghouse, and many others now well-known. In 1930, industrial

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*The Smithsonian Institution was established in 1846 as a privately endowed institution. In its early years it did not require a Federal appropriation for research.

**Science and Public Policy, prepared under the guidance of John R. Steelman, was the report of a comprehensive study of Federal research made by the President's Scientific Research Board in 1947.

expenditures for research far exceeded those of the Government and the universities, being then estimated at $ 116 millions, or 70 percent of the national total. Growth was slow during the worst depression years of the '30s, but accelerated after 1935 until 1940, when industrial research expenditure was twice as large as it had been 10 years before.

The university contribution to the total national research expenditure was about equal to that of the Government in 1930. Up till 1914, only a few American universities had produced research comparable in quality to that of the more active European universities. The first World War, however, provided a great impetus to the growth of applied research as professors were called upon to study urgent military problems and some university laboratories were pressed into war service. This, together with the increasing number of technical problems faced by American industry, stimulated in the colleges an interest in applied research which has continued to expand. Nevertheless, the greater part of the university research expenditure is still on basic rather than applied research.

During World War II when research was subsidized extensively by the Federal Government, the problems studied by industry were those of immediate concern to the war production effort. After the war, industry retained the technical personnel they had acquired during the wartime expansion, built new research facilities, and continued research on an undiminished scale. Today there are 3,300 industrial research laboratories, and they employ 165,000 people.

During the war intensive research on radar, the release of atomic energy, underwater sound, and rockets was performed in laboratories specially organized at a few large universities, and staffed by university and college scientists from all parts of the country. The Government supported this work through the Office of Scientific Research and Development,* which financed the laboratories under contracts with the universities. At the war's end, large universities found themselves in possession of expanded facilities, enlarged staffs, and equipment well-suited to the conduct of applied research. Smaller universities and colleges, many of whose ablest scientists had been absent on leave during the war, participated to a lesser degree in the war research program and were less able than ever to meet the high costs of research in the postwar period.

The Federal Government did not withdraw from research and development activity as many expected it would do when the war ceased. The uncertain international situation led the Congress to support large research and development programs designed to strengthen national defense. Many of these programs are conducted by Government agencies in their own laboratories; some are operated by industrial research groups under contract to the Government.

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*The Office of Scientific Research and Development was a temporary war agency which mobilized university scientists for the war effort.

The fact that the most spectacular weapon of all, the atomic bomb, grew out of basic research done before the war brought home to Congress the importance of such research. A program of Federal support of university research seemed essential in order to insure a continuous stream of fundamental new developments. The present contract program of the Office of Naval Research, the grant program of the United States Public Health Service, and the new National Science Foundation were set up to provide for this. In 1950, 194 colleges and universities had $ 90 million in obligations from the Federal Government for contract research. While most of this money went to a few outstanding institutions, 127 colleges received amounts of $ 48 thousand or more.(9) This is in line with the current Government policy of encouraging smaller institutions in more remote locations in an effort to increase the total research potential of the nation.

The Federal research program is thus not one in which only Government laboratories and personnel participate. The Government uses half of the funds which are appropriated annually for research and development to support investigators located in universities, research foundations, and industrial laboratories. When considering the origin of funds, the Government research program appears to be the major portion of the national outlay for research and development. When considering where the research is done, one finds that 62 percent of the total national research expenditure is for work done by industrial laboratories and almost 10 percent for work done by the universities and research foundations. The figures in Table I show the growth of the estimated national research expenditure between 1941 and 1952, and its breakdown according to source of funds and type of organization performing the work.

TABLE I

ESTIMATED RESEARCH AND DEVELOPMENT EXPENDITURES IN THE UNITED STATES, 1941-52

(In millions of dollars)

Year	Total	Source of funds		Use of funds by type of institution		
		Other	Federal	Indust.	Univ.	Federal
1941	800	560	240	520	80	200
1942	930	590	340	600	90	240
1943	1,050	420	630	650	100	300
1944	1,200	430	770	700	110	390
1945	1,300	420	880	750	120	430
1946	1,490	830	660	890	130	470
1947	1,810	1,020	790	1,120	170	520
1948	2,060	1,140	920	1,290	200	570
1949	2,080	1,030	1,050	1,310	220	550
1950	2,240	1,200	1,040	1,430	240	570
1951	2,590	1,280	1,310	1,630	260	700
1952	2,930	1,290	1,640	1,820	280	830

Source: Research and Development Board, Department of Defense

Motives for Supporting Research

Almost all research done in industry is "applied" research, although some basic research of high quality is done in the larger laboratories. In view of the long-term importance of good fundamental work, businesses may give their especially gifted scientists complete freedom of choice and generous support for their research. For the most part, however, the research of an industrial organization must not only be self-supporting but must strengthen the financial position of the sponsoring company. It follows that the choice of most problems and the scope and extent of investigations undertaken are determined by the degree of likelihood that they will lead to practical rewards.

In the competitive markets of the United States companies recognize that they cannot maintain, let along expand, their sales except by continually improving their products. A company that permits itself the luxury of neglecting product improvement often finds its market threatened by a vigorous and challenging competitor. This competition exists not only within industries, but between different industries. Plastics compete with metals and ceramics in the fabrication of structural or ornamental devices; aluminum competes with stainless steel for numerous construction and household uses; synthetic fibers compete with natural fibers for every textile use.

The growth of applied research in industry shows clearly the American attitude of willingness to change. New products replace inferior ones, new processes supplant less efficient ones, and new materials are constantly examined to discover how their properties can be used to advantage. Although not all segments of industry have felt the need for research, many industries support it vigorously, not only for maintenance of competitive position, but also as a means of expanding into new markets.

Improvement in materials or design, which leads to increased sales, and development of more efficient production processes, which cut costs, are two ways in which research laboratories help to increase profits. Sometimes, however, they develop entirely new products which meet old needs better than conventional materials did; the general replacement of silk by nylon in women's hosiery is an obvious example. Methods may be devised for producing valuable by-products from the wastes of a company's primary production process; thus much of the ethyl alcohol sold today is produced by the petroleum refining industry using by-product gases from gasoline manufacture. New and cheaper sources of essential raw materials may be found; or a way is found to produce synthetically at low cost an expensive natural product; examples of this are common in the pharmaceutical business, which owes many of its most profitable products to the organic chemist. Occasionally, of course, developments emerge from the laboratory so novel that the public must be convinced of a heretofore unfelt need before they can be marketed; television, demonstrated first in 1926, is perhaps an example of this.

One of the best indications of the confidence of American business in the value of research is the large number of establishments that engage in research or have it done

for them. An entire group of organizations, the research foundations such as Mellon, Armour, and Battelle, have been established to supply the research needs of small companies. The extent to which small companies do research is shown by a survey published by the National Association of Manufacturers in 1948.(10) In 983 replies, 750 (76%) either had research organizations or contracted for research with an outside organization. In addition, there are more than 30 trade association laboratories which undertake to do fundamental research of interest to all members of an industry, leaving work on specific products to the laboratories of the individual companies.

Research alone does not account for the volume and quality of products on the American market. Getting the benefits of laboratory findings to the consumer is a cooperative enterprise in which scientists and research engineers, management, production engineers, market research groups, and sales organizations participate. The need for close cooperation between the research laboratory and other divisions of a company is widely recognized. As a result, more and more companies are including on their boards of directors research administrators who began their careers as scientists or engineers.

Research in industry is thus only the first link in a complex chain of activities which terminates with the product in the consumer's hand and the dividend in the investor's pocket. The fundamental importance of research to the whole enterprise is indicated by the fact that in 1950 American industry spent roughly $1 billion on product and process improvement not directly connected with the defense effort.

Even larger sums are spent on research by the Federal Government. In 1952, the Government will finance about 56 percent of the total national research expenditure of $2.9 billion. The research interests of the Government may be separated into two divisions: the division of "primary Federal responsibility" and the division of "general welfare."

The Constitution of the United States charges the Federal Government with primary responsibility for national defense, development of standards of weights and measures, regulation of interstate commerce, navigation and navigable waters, post office and post roads, and the reclamation and conservation of the public domain. Research has been deemed a necessary adjunct to these activities since 1789, when the first Congress authorized the Navy to conduct experiments on the improvement of ships and guns. Of the 1952 Government outlay of $1.6 billion for research, roughly 70 percent will be spent on projects related to the national defense.

In addition to defining the primary responsibilities of the Federal Government, the Constitution in the "general welfare" clause gives Congress broad powers to make laws affecting social and economic activities of the whole nation. Congress has interpreted "general welfare" as calling for scientific study in aid of agriculture, mining, health, education, and other national interests. The Congressional act of 1862, cited above, which authorized the Department of Agriculture to "acquire all information concerning

agriculture...by practical and scientific experiments" was the earliest act of this type.

Almost any research activity could be classified either as discharging the primary responsibilities of the Government or as tending to promote the "general welfare." There are thus in principle few restrictions on the kinds of scientific inquiry that may be supported by the Government. In practice the design of experimental research programs in the Government is strongly influenced by public opinion as expressed by the Congress. Agencies that have been granted the widest authority to conduct or sponsor research are those which deal most directly with economic and political matters of great national interest, such as the Departments of Defense, Agriculture, Interior, and the Atomic Energy Commission. The research these agencies sponsor is intended to solve technical problems of direct interest to the sponsoring agency. Within each agency's research program, emphasis on individual problems is shifted constantly in response to changing public needs.

For the most part the research conducted or sponsored by the Government has been "applied"—i.e., devoted to "solving problems of practical significance" and restricted in scope and extent by "the degree of likelihood that it will lead to practical rewards." However, in recent years the Government has given increased support to basic research both in its own laboratories and by grants and contracts to universities and other laboratories. The impetus for this came from the recognition that in some areas we have already reached a point where further practical applications must wait on the solution of an array of basic problems.

Except for the work on weapons by the Department of Defense or its agencies, the Federal Government generally limits its research activities to the study of technical questions. In a few cases, the Government undertakes developmental work as well. This occurs when the public interest requires the solution of certain problems for which industry cannot be expected to assume responsibility, either because the necessary capital investment is too large, or because there is no assurance of profits adequate to repay the costs of the research. The reactor development program of the Atomic Energy Commission is an example of the first type of situation. The capital required to study reactor design cannot possibly be provided by private means. An example of the second type is the establishment by the Department of Interior of a shale oil plant for the recovery of petroleum. For the present, industry occupies itself with the production of petroleum from oil wells. Industry still considers the extraction of petroleum from shale oil too expensive for commercial exploitation. The Government has undertaken this work in order to extend the natural resources of the country. It is hoped that by the time the present petroleum sources cease to meet the demands for motor fuel, we shall be able to tap economically the vast petroleum reserves occurring in shale formations.

The medical research activities of the United States Public Health Service are another example of research in an area of uncertain economic return which is nevertheless undertaken by the Government because it is vital to the general welfare.

The Government also does research in aid of industries that are not so organized as to provide research centers of their own. The leading example is agriculture, where the individual farmer cannot be expected to do research on the products which he grows, on increasing the efficiency of land use, or on the methods of controlling plant diseases and pests. Finally, the Government does research in certain fields for which it already possesses unique research facilities. This is particularly true of research in aeronautics, which was started during the first World War as a Government enterprise. Basic research as well as applied research in this field requires very expensive and specialized apparatus which a beginning industry such as the aircraft industry in 1917 could not provide. As a consequence, the Government has built up an organization, the National Advisory Committee for Aeronautics, which does basic, fundamental, and applied research in aeronautics.

Today some research in almost every field of science is a recognized obligation of the Government and willingly supported by the representatives of the people in the Congress. How much money the Government spends on research is determined by economic, social, and political conditions. What research the Government shall do is determined by the nature of the problems affecting the nation as a whole. In meeting this obligation to do research, the Government agencies have often developed an outstanding position in a particular field of research. This is largely due to the fact that some fields of practical importance are not explored by industry because they are unlikely to contribute to its profits, and are not studied in universities because of the cost of the equipment required. In practice, a dividing line between governmental and industrial research is rather carefully observed. Rarely do the Government agencies invade the territory in which a private company can expect to develop a profitable product through research.

Although the research activities of both industry and the Government involve many more men and much higher annual expenditures, the universities remain the chief source of fundamental scientific advances. The training of young men and women to appreciate, to use, and where possible, to contribute to the advancement of some department of human knowledge is generally considered the primary purpose of the university or college. In scientific fields, where frontiers are moving rapidly, the prevailing view is that advanced instruction can be given only by men who are themselves engaged in research. For this reason, demonstrated talent for research is emphasized more than scholarship or ability to lecture well in choosing men for the science faculties of larger universities and technical institutes. Another reason advanced for staffing the university with research men is that they are best able to recognize, encourage, and train students with aptitude for original scientific work.

The importance of an active program of basic research to the educational function of the university is generally accepted in the United States. In 1950, however, over 300 colleges and universities, including almost all of the leading ones, were also interested in obtaining contracts for applied research.(11) The extent to which universities should

engage in applied research is widely debated in United States educational circles today. Many educators fear that increased emphasis on applied research will lead institutions to neglect fundamental research and result in loss of those teachers best able to train students in the basic principles of the sciences.

The question of what is suitable in an academic research program depends on the type of student the institution in question aims to produce. Some institutions try to develop fundamental research men in engineering as well as in the classic sciences. Such institutions restrict their acceptance of applied research contracts to problems of a fundamental kind which can be justified on scientific grounds alone. However, an important objective of many schools is to provide industry with men competent for the production work which constitutes the majority of technical jobs. These schools will accept contracts for a wide variety of applied work in the belief that their instructional staff should participate actively in solving typical technical problems for industry and the Government.

It should be pointed out that many institutions do not have complete freedom of choice in accepting or rejecting contracts for applied research. In the present period of rising university costs, of falling enrollments, and shrinking endowment income, applied research contracts have become important sources of income for many universities. Laboratory equipment essential for certain kinds of research but beyond the means of most universities—for example, cyclotrons and wind tunnels—can be secured under applied research contracts. Furthermore, the extra income from contract research may assist the university in paying salaries necessary to retain its outstanding faculty research men. Research contracts also enable a professor to conduct investigations on several problems concurrently by employing graduate assistants.

Often requests for applied research assistance come about because the university has specialized equipment, such as an electron microscope, not readily available elsewhere. The university may have faculty members particularly well-qualified in some specialized applied research field. Finally, universities recognize an obligation to study problems which are important to the industrial and agricultural development of their locality.

At the present time most of our scientific leaders believe that universities are not doing enough fundamental research and that the reason is their lack of financial resources. Strenuous efforts are being made to encourage an increase in these resources by donations from industry and by increased allotments from the Federal Government.

CHAPTER II
APPLIED RESEARCH IN THE FEDERAL GOVERNMENT

Since the start of World War II in 1939, the Federal Government has increased about fifteenfold its dollar support of research and has broadened its research interests to include all fields of science. In 1930, the Government was financing 15 percent of the nation's $ 166 million annual research budget. Today, the Government pays for 50 percent of the country's $ 3 billion yearly research effort. The Government itself is the primary support of research in such areas as atomic energy, weapons of war, and aeronautics. It finances a major part of the national research effort in agriculture, geology, and medicine. For chemistry and fundamental biology it has thus far provided relatively little, but in recent years it has extended its interests to applied psychology, or "human resources."

Organization of Federal Research

At the present time there are 22 departments and agencies of the Federal Government which include estimates for research in their annual budgets. These estimates may be for research in their own facilities or for support of research in outside laboratories by grants or contracts. In some cases the amounts are small and the work is of a very specialized nature peculiar to the problems of the agency. In the fiscal year 1951, 10 agencies received over 98 percent of the total Federal research and development appropriations. Two of these, the National Advisory Committee for Aeronautics and the National Science Foundation, are specifically research agencies and have no other function. Research is only one of many activities of the Departments of Agriculture, Commerce, Interior, Army, Navy, Air Force, the Federal Security Agency, and the Atomic Energy Commission. All have substantial research programs.

Our Federal agencies have no standard place in their organizational structure for their research activities. In some of the eight departments and agencies mentioned above, the research activity is organized under an independent bureau. In others, however, research is one activity of each of several bureaus within the governmental unit. An example of the second type is the Department of Commerce, in which there are six groups concerned with research. These are the Bureau of Standards, the Weather Bureau, the Bureau of the Census, the Coast and Geodetic Survey, the Civil Aeronautics Administration, and the Bureau of Public Roads. The Bureau of Standards is almost exclusively a research agency, although it does some inspecting and testing in connection with Federal procurement. It also serves as a consulting research group for all other departments and agencies. The Bureau of the Census and the Weather Bureau operate relatively small research units, although they employ a great number of technical people in their operations. The Coast and Geodetic Survey by its very nature is concerned with research and conducts investigations in various phases of the earth sciences and geophysics. The Civil Aeronautics Administration is concerned primarily with safety standards and inspection. Its endeavor to improve methods of air navigation and

air traffic control necessitates a relatively large research program. The Bureau of Public Roads, responsible for highway research, finances studies in this field, particularly cooperative studies between the Federal Government and the States.

Each Navy bureau and Army technical service supports extensive research activities. These are coordinated by staff groups under the Chief of Naval Operations and the Chief of Staff, United States Army. The Department of the Air Force, on the other hand, has centralized its research operations under the Air Research and Development Command.

Research Operations in the Federal Government

Prior to 1939, the Federal research program consisted almost entirely of research conducted within Federal laboratories, although there was some support of research by direct subsidies to agricultural and engineering experiment stations in the state universities. In 1940, the National Defense Research Committee, predecessor of the Office of Scientific Research and Development, started a program of decentralized research for defense purposes in colleges and industrial laboratories. The Office of Scientific Research and Development, for the first time on a large scale, arranged Federal contracts with various research groups for the performance of research work.(12) In the postwar period, after liquidation of the Office of Scientific Research and Development, the Departments of War and Navy continued the same type of contract research. Congress established the Office of Naval Research and authorized it to operate a program of decentralized basic research. The Atomic Energy Commission, founded in 1946, took over the operations of the Manhattan District of the Corps of Engineers, United States Army. The Manhattan District had grown out of an original nucleus started by the Office of Scientific Research and Development and followed its pattern of arranging contracts with non-Government agencies. The Atomic Energy Commission did not alter this arrangement, has continued to sponsor research, and has not acquired any research personnel except in an advisory or an administrative capacity. The establishment of the National Science Foundation in 1950 gives us another agency which will follow the same pattern of supporting research without acquiring research groups within its own organization. Research supported by the Federal Government in this manner is now frequently designated as extramural research. This term distinguishes it from research in Government-owned and manned facilities. The latter work is termed intramural research. Sometimes one department uses some of its appropriation to support research in another agency or department. A large part of the present research program of the National Bureau of Standards is supported in this manner; the same condition exists in the Geological Survey. Such transfers avoid the establishment of laboratories and groups with similar interests in several agencies. Research activities of this type are termed interdepartmental research.

There is wide variation in the distribution of the research activities of the individual departments between intramural and extramural projects. Agencies established at different times for different purposes have naturally developed their research organizations

into a variety of patterns. Research activities of the Departments of Interior, Agriculture, and Commerce date almost from their foundation. These departments accomplish their research in their own laboratories, staffed with Government employees, and do not employ a grant or contract program to any extent, if at all. The Department of Agriculture, however, is responsible for Federal grants to agricultural experiment stations in the state universities. It does not control the research plans since these research organizations are administered by the state governments, which supply 80 percent of the operating expenses. The Federal Security Agency, whose chief research organization is the National Institutes of Health under the United States Public Health Service, follows a middle course. It operates a grant program almost equal in amount to the intramural program conducted by the laboratories of the National Institutes of Health. The Public Health Service operates two additional research organizations, the Communicable Disease Center and the Environmental Health Center. The Army, Navy, and Air Force research groups carry on research activities through both intramural and extramural programs. Although there are numerous laboratories directly operated by one of the three military departments, roughly 70 percent of the research appropriation of the Department of Defense goes to extramural research and development.

The Atomic Energy Commission has only an extramural program, if one uses a strict definition of extramural research that refers only to the activity of research itself. The Government owns the laboratories of the Commission, but they are operated under contracts by industrial and university organizations. The contractor for Brookhaven National Laboratory is Associated Universities, Inc., an organization made up of nine eastern universities. Oak Ridge National Laboratory is operated by the Carbide and Carbon Chemicals Company; Argonne National Laboratory by the University of Chicago; Los Alamos by the University of California; Hanford by the General Electric Company. Government ownership of the laboratories would bring the Atomic Energy Commission program into the intramural classification, but the research men and associated personnel in the laboratories are employees of the contractor, not of the Government. This brings the program into the extramural classification. Consequently, the Atomic Energy Commission is included with intramural research organizations when discussing facilities and budgets, and with extramural organizations when discussing personnel and the planning of research. Besides sponsoring these national laboratories, the Atomic Energy Commission conducts a contract program with a number of universities and industrial laboratories.

The National Advisory Committee for Aeronautics owns and operates directly three large laboratories. This organization conducts research in the problems of flight, and is one of two independent Government agencies whose main function is research. In addition to its extensive intramural program, it conducts a modest extramural program in universities having facilities for aeronautical research, but its program is essentially intramural.

The Veterans Administration carries on both extramural and intramural research on problems concerned with veterans' diseases and injuries. The intramural research

is conducted by decentralized groups in individual veterans' hospitals throughout the country. The extramural program is a contract operation carried on in the medical schools.

The Smithsonian Institution has both custodial responsibilities and research activities, the latter being chiefly in natural history and anthropology, sciences not extensively supported in the United States. It is one of our oldest research institutions and enjoys a unique position in the Government in that it has certain endowment and trust funds. It is, therefore, in part independent of direct appropriations by the Congress.

The National Science Foundation was established in May, 1950, after a long series of hearings and debates starting back in 1945. It was intended mainly to promote basic research, but is not permitted by law to own or operate laboratories. The Foundation will set up an extramural program, mostly in the universities, to finance basic research in the natural sciences, including engineering. It will also operate a scholarship and fellowship program. Its first annual report sets forth its present plans.(13)

These are the departments and agencies which support the largest research programs. There are many other research activities in the Government, such as the extramural work on synthetic rubber supported by the Office of Rubber Reserve under the Reconstruction Finance Corporation, and the mixed intramural and cooperative research program of the Tennessee Valley Authority, conducted with the aid of state and local agencies. This program deals with the diverse problems connected with the development of the natural resources of the Tennessee Valley.

Scale of the Federal Research Program

Annual appropriations to Federal research programs grew steadily from the turn of the century. From the onset of World War II, Government expenditures for research and development increased substantially each year. In the postwar period, appropriations for research programs started by the Office of Naval Research, the Atomic Energy Commission, and the United States Public Health Service more than offset decreases in other agency allocations. In the fiscal years 1951-52, there were substantial increases due to the defense research program. It is estimated that in the fiscal year 1952, over $ 1.6 billion will be spent by the Government on research in the natural sciences and engineering. This sum covers the cost of engineering developments and the production and testing of prototypes of defense items. Industrial organizations do not normally regard the latter type of work, which is extremely expensive, as a research activity.

In 1940, the Government spent $ 73 million for research and development. The estimated expenditure of $ 1.6 billion in 1952 is 22 times the 1940 figure. Since the 1952 figure includes engineering development and prototype costs, the factor of 22 gives an exaggerated conception of the increase in scientific activity. The fall in purchasing power of the dollar between 1939 and 1951 reduces this factor to 12. The greater complexity of present research equipment likewise contributes to the rise of costs.

The increases of the research expenditures of individual agencies and departments over the period of 1940-50 are shown in Table II.

TABLE II

FEDERAL EXPENDITURES FOR

RESEARCH AND DEVELOPMENT--FISCAL YEARS 1940-50

(In millions of dollars)

	1940	1945	1950
Atomic Energy Commission	.....	.....	121.1
Federal Security Agency: Public Health Service	2.8	3.4	32.1
National Advisory Committee for Aeronautics	2.2	24.1	42.5
Office of Scientific Research and Development	.....	114.5	.....
Department of Agriculture	28.4	32.0	50.6
Department of Commerce	3.3	5.0	10.0
Department of Defense:			
Department of the Air Force	8.7	136.0	193.4
Department of the Army	3.8	134.0	108.8
Department of the Navy	13.9	243.0	237.4
Total, military functions	(26.4)	(513.0)	(539.6)
Department of the Interior	7.9	18.0	27.7
Other agencies	2.4	20.0	16.0
Total, comparable items	73.4	730.0	839.6
Indirect costs, all agencies[1]	(*)	(*)	199.7
Construction of facilities, all agencies	(*)	(*)	149.6
Manhattan Engineer District, total expenditures	.....	859.0	.....
GRAND TOTAL	(*)	(*)	1,188.9

Source: Bureau of the Budget.

[1]Indirect costs for Department of Defense are included only in part.

*Not available.

The increases in numbers of Government research personnel that accompanied these increases in funds can only be roughly estimated. The present estimated total of 58,000 employees cannot be directly compared to the latest previous estimate of 30,000 employees for 1947. The differences in the estimates for each field are indicated in Table III. To some extent these differences are due to the inclusion in the 1952 estimate of groups not counted in the earlier estimate.

The figures in Table II show the funds allotted to research by individual agencies out of their annual appropriations. The scientists and engineers whose numbers were estimated in Table III are employed in studies of thousands of problems, each a part of an agency research program.

TABLE III

Field	1947[1]	1952[2]	Differences
Engineers	11,500	29,000	17,500
Chemists	2,600	3,500	900
Physicists	1,800	2,000	200
Other Physical Scientists	3,600	5,000	1,400
Biological Scientists	1,500	1,500	
Medical Scientists	1,000	4,000	3,000
Agricultural Scientists	8,000	13,000	5,000
	30,000	58,000	28,000

[1]Steelman Report, Vol. IV, p. 40.
[2]Budget Estimates, 1952.

Origin of Agency Research Programs

The scope of the research programs varies widely among the individual agencies. In the research establishments of the Department of Agriculture, for example, research is done in bacteriology, zoology, botany, chemistry, nutrition, and all the agricultural sciences. Problems that arise in supplying food for the nation require special skills of many kinds for their solution. In the National Advisory Committee for Aeronautics, however, the program is more specialized, being concerned only with aeronautics, aerodynamics, and special problems of metallurgy and fuel technology. In all agencies, the general areas of research to be undertaken are laid down by the research directors. Within the broad areas laid down by the director, studies undertaken may be fundamental or practical. The rule followed is that investigations supported must be useful in solving a problem which lies within the agency's responsibility. In practice this rule has been liberally interpreted.

Individual problems arise from an awareness of a need. This need may be recognized by the research investigators themselves, or it may be brought to their attention by a group especially affected. The magnetic clutch developed in the Bureau of Standards was a project of its inventor, Rabinow, who, aware of the need for a smooth, instantly responsive coupling between energy-generating devices and energy-absorbing devices, designed a new and superior type. The development of hog cholera vaccine by the Department of Agriculture bacteriologists was undertaken after disastrous epidemics of this disease on the farms of the Middle West. In a real sense this was a problem brought to the attention of the scientists by the people. Studies of cortisone and ACTH were carried on simultaneously in certain industrial laboratories and by several medical research groups, particularly the Mayo Clinic. Once it was discovered that these products were beneficial to sufferers from arthritis, the National Institutes of Health joined the effort to find ways of increasing the supply. Not infrequently problems reach a research agency through the demands of people on their representatives in Congress. A specific case is the study of desalting of brackish water, a problem of considerable importance to our coastal regions.

These examples indicate the general ways in which problems may be brought into the research programs of Federal agencies. In agencies which do intramural research almost entirely, the programs are made up mostly of projects suggested by the investigators themselves.

Evaluation of Federal Research Plans

Government research projects are not chosen in order to produce any direct increase in the Government's net income. Sometimes, it is true, estimates are published of the increase in total national product claimed to result from some specific laboratory finding. Such estimates, however, are very uncertain because of the complex interplay of social and economic factors involved, and even these estimates cannot be made until many years after the completion of the research.

In industry a more definite measure is available for evaluating a proposed line of investigation. Figures are generally on hand for the cost of similar projects in the past and for the contribution they have made to the net income of the sponsoring firm. On the basis of such figures the profitability of a proposed investigation can be estimated. Such estimates of profitability strongly influence industrial management in deciding the courses its research division shall follow.

The profit on invested capital is the final measure of the success of an industrial research program. In Government research, on the other hand, there is no direct and generally accepted scale on which the estimated return of a project may be expressed. Research proposals are judged according to their probable contribution to the reviewer's personal conception of the "general welfare." For this reason the arguments advanced by the investigators in support of their research proposals will have varying force to different individuals at each stage of the review.

To the Government budget reviewers, scientific research is just one activity among many competing for a share of the public money. The relative value that these management groups place on a research activity as a contribution to the "general welfare" will not usually agree with the value it has in the eyes of the scientists concerned. This situation is one that scientists in Government must accept: Our Government cannot represent single interests; it functions by finding compromises acceptable to a multitude of conflicting interest groups. Therefore, the success of a research administrator in gaining support for his proposed budget will depend strongly on the way he presents his testimony. The most successful presentations are those which emphasize the contributions the research program will make to the public welfare, rather than its purely scientific value.

Even if there were a generally accepted standard for evaluating research proposals in the Government, a type of research problem Federal agencies frequently undertake would offer special difficulties. One cannot judge how long it will take to produce a strain of wheat that will resist certain kinds of rust, nor does the failure to produce a desired variety necessarily justify the conclusion that the work should not have been

undertaken. Likewise, it is difficult to decide how much money should be appropriated to the study of rare diseases, like leprosy and multiple sclerosis. The extent of Federal support for research on such diseases will be strongly influenced by subjective considerations. Thus Congress's interpretation of the public interest frequently leads Government laboratories to undertake long and costly investigations of uncertain outcome which industrial laboratories avoid for the very reason that their outcome is uncertain.

Budgeting for science in the Federal Government is further complicated by the fact that final approval for the scale of effort in a research program must come from men who do not have a direct interest in the outcome of the program, as does the board of directors of an industrial firm. The reviewers are necessarily skeptical of all demands for money, and particularly cautious about granting increases. Moreover, these men—agency heads, Bureau of the Budget staff, members of Congress—can evaluate more readily non-technical activities, in which they have experience, than research programs, which are not only technical but always involve an element of uncertainty even to the scientist. In presenting the research budget proposals, it is necessary to formulate problems in language a layman can understand and to justify lines of approach to the solution of these problems to people with little scientific background. The difficulty of doing this job well is greatly increased by the reluctance of scientists to train themselves to do it.

Development and Review of Research Budgets

Development of a research program from the initial project suggestions to a final form acceptable for inclusion in the Federal Budget is a complicated procedure which we shall outline here. We have included this description for two reasons: to emphasize the major role that budget formulation plays in Government research administration, and to explain the management controls that exist in the Federal Government. While there are undoubtedly individual exceptions to it, the procedure here described is typical.

About 18 months before the beginning of the fiscal year (July 1), individual investigators in the Government laboratories and field stations prepare statements describing the research which they plan to do or would like to do in the fiscal year in question. Many problems that they include are continuations or extensions of work they are doing or will begin within a few months, but they also suggest many new problems. Frequently they must include estimates of time and money required to carry on the work proposed. Often these estimates are supplied by administrative assistants experienced in converting technical work projects into estimates for man-hours and money. The laboratory director and his staff put these individual statements together to form the laboratory program. The men suggesting the individual problems are consulted and permitted to make their cases for the ideas they wish to explore. When the budget leaves the laboratory director's office for transmittal to his superiors, it is a complete document setting forth problems to be studied, results of current work which indicate the desirability of continuing specific phases of it, estimates of personnel needed in various categories of

experience and training, and amounts of money required for salaries and other expenses. The next step is an amalgamation of the individual laboratory programs by the research director of the agency and his budget staff.

At this point in the budget formulation, the research advisory committee, if one exists, is asked to review the budget. The purposes and composition of these committees must be explained to show their tasks in this connection. The numerous research advisory committees can be roughly divided into two categories, i.e., those which advise the agency research head on general policies and scope, and those which evaluate specific project proposals.

The first type of committee is composed of scientists with broad research experience coupled with executive responsibilities. Such committees consider the technical program as a whole while it is still in a tentative stage. They assist the research director by suggesting changes in the general trend of the research and shifts to new efforts in the light of recent advances.

The second type of research advisory committee is composed of specialists in the particular area of research on which their advice is sought. They study individual research proposals and evaluate them in respect to one another and in comparison with similar work being done elsewhere. Such committees are usually associated with extramural programs dealing with fundamental or exploratory research. However, the National Advisory Committee for Aeronautics uses such groups extensively in its intramural program.

Some Federal research organizations do not use research advisory committees to evaluate their total research program and the budget estimate associated with it. The research director relies entirely upon his own staff in evaluating the proposed work. Research administrators tend to assume that the greatest experience in their research field exists in their own staff. This is unquestionably true in some highly specialized fields of research.

After review by the research advisory committee, management begins to take hold of the program: The research director must decide upon increases and decreases in specific work areas. This decision must be based not only on technical considerations, but also on the anticipated policies of the agency concerned, e.g., whether or not the agency will attempt to obtain an increase in its total appropriation, or whether it will divert funds from other operations to research.

It is in the research director's office that the first large cutting of estimates takes place. This is done only after the individuals concerned have had an opportunity to discuss their proposals with the staff of the director and with the director himself. By this time, four to five months after initiation of the budget work, a preliminary indication has been received by the department or agency from the Bureau of the Budget as to the amounts of money they may request. The agency research director re-examines the proposed projects as to technical importance, probable acceptability to the reviewers,

and likelihood of successful achievement. He then eliminates the least promising of them. His only guides in doing this are his experience in research and his knowledge of the viewpoints of the men to whom he must explain his program. His decisions cannot be based entirely on the scientific arguments for or against any phase of his program. He may decide to increase the total program and sell it on the basis of its merits both to his own management and to the Congress.

The next step in the budget process finds research in competition with other activities of the agency. This is a normal budget occurrence not only in Government but also in industry, and it will be discussed in Chapter III. The evaluation here will be based on a broader interest, namely, that of the agency as a whole. Final decisions on the total money request and its allotment to various groups within an agency are made by the head of the agency. The budget estimate is transmitted to the Bureau of the Budget about September 15.

During the next two months the Bureau of the Budget reviews the written material that accompanies the estimates and holds hearings for each of the executive agencies. Individuals concerned with the various functions of the agencies appear at these hearings to justify those portions of the budget for which they are responsible. The agency's research director, and sometimes research directors of the laboratories involved, explain the research program and attempt to justify increases in their programs or continuation of individual portions of the technical work.

Late in November each agency receives the total figure which it will be permitted to put in the President's budget estimate. Since the budget must be in printed form by the opening of Congress in January, there is little time to revise individual estimates within an agency. Sometimes the entire agency budget must be recast, new written material prepared, and substantial changes made in the amounts estimated for separate operations. This is particularly difficult for the research programs since many technical problems are closely interrelated.

Between the opening of Congress in January and the beginning of the fiscal year on July 1, the appropriations committees of the Congress review the budget estimates. Since appropriations must by law originate in the House of Representatives, it is the House committee which holds the first review. The material which was presented to the Bureau of the Budget is revised, often supplemented, to provide justification to the committee members reviewing the material. Extensive hearings are held by these committees, and the research directors are permitted to testify for the various programs they advocate, particularly for new programs of research. The success of the research director in obtaining Congressional approval for his technical program depends in large part upon the ability of the director and his staff to show the value of the research his group has done, and upon their ability to explain in clear, non-technical language the benefits which would derive from the work they plan to do.

The House usually reduces the budget estimate figure and often specific activities are cut out. The budget is again reviewed by the Senate Appropriations Committee, and the agency is given an opportunity to justify those items which have been dropped. After the Senate approves the appropriation bill for the agency, differences between the House and Senate figures are adjusted by a conference committee, and the bill is then passed.

Appropriation hearings and passage of appropriation bills are supposed to be completed each year before the fiscal year begins. In recent years, however, legislative jams have caused appropriations to be delayed for as long as three to four months. Agencies must frequently operate for the first quarter of the year without knowing exactly how much money they will have for the entire year. While this is a serious handicap in the operation of the intramural research programs, it is even more serious for the extramural programs, which operate by grants and contracts. It is to be noted that in this initial three months of the fiscal year, the succeeding year's budget of the agency is in the process of preparation or under examination. The fact that the research director is required to submit to the Bureau of the Budget a budget estimate for the succeeding fiscal year without knowing the actual amounts of money he will have during the fiscal year in which he is operating makes future planning hazardous.

Perhaps it is now obvious that the research director requires a budget staff. Not only must he see his budget through the many steps of the reviewing process, but he must be prepared to revise it on short notice, sometimes extensively, in the light of management decisions of his agency.

In any laboratory, if new programs of research are to be initiated, it is usually necessary to complete, or to discontinue, activities previously justified. Unfortunately, it is not easy to persuade individual investigators and laboratory directors that work carried on for several years should be discontinued to make room for new ideas and new programs. As a consequence, all research organizations show some degree of inflexibility or resistance to change. This inflexibility is accentuated in the Government research programs by the complexity of the reviewing process to which all new ideas must be subjected. The easiest course for all concerned is to work along in an accepted direction that shows modest but sure results. Federal research administrators recognize the tendency toward this attitude and strive continuously to avoid it.

The research plan is actually worked out in considerable detail a year before it is initiated. During that year, new knowledge may be acquired that would make basic alterations in the program desirable. The research director and the working scientists may agree on the desirability of the changes. It is, unfortunately, not easy to make any changes after justifying the original plan before the Bureau of the Budget. In industry the budget fixes only the total amount, and the research director can shift individual items around to suit changing conditions. The Government research administrator, after committing his program to print, does not have the same degree of freedom. This is a significant difference.

Recruitment and Utilization of Personnel

At present the Federal Government employs over 2.4 million people. Of this total there are slightly more than one million hired as Civil Service employees under the Classification Act. Within this last group, about 80,000 persons are classed as scientific and technical, including employees listed as sub-professional. Nearly 75 percent of the 80,000 hold bachelor's degrees in science or engineering.

All persons employed under the Classification Act must have passed written examinations and in certain cases proficiency tests. Individual skills of each employee must fall in one of the fixed series of jobs established by the Civil Service Commission. The total number of series runs into the hundreds, though many are rarely used. Each series is defined by the nature of the training and experience required for qualification; pay levels range from $3,410 to $14,800 per year, according to experience. Three super-grades, in the pay range of $12,000 to $14,800, were established in 1949 to reduce the loss of high caliber employees to industry and business, where pay is higher. The number of positions in these super-grades is only about 700, but scientists hold 15 percent of the total.

Each position that falls under Civil Service carries with it a "job description," ordinarily a relatively short exposition of the work entailed. Applicants for a job must meet these educational and experience requirements. An effort is made to match the capabilities of the individual to the requirements of the job.

Individuals seeking Government employment must prepare a statement of their qualifications, frequently written with a specific position in mind. This is particularly true of individuals seeking employment in the higher grades. These job applications are examined by special reviewing boards. The reviewing group may be within the Civil Service Commission, or it may be a board of expert examiners set up within a region or even within an agency. There is a strong tendency at the present time to establish agency boards for scientific and technical employees; this decentralization aids in the recruitment of graduating students. Examining boards are invariably constituted of experienced people who have no personal interest in the individuals being examined.

It would appear that the problem of utilizing personnel within the Federal Government is extremely complex. A great number of people are required to prepare job descriptions and to examine individual applications. Nevertheless, research administrators within the Government are moderately successful in obtaining employees with proper qualifications, in promoting employees because of meritorious work, and in retaining competent employees. The Federal employee in a scientific activity, once he is promoted above the lower grades, has a great deal of freedom in the solution of his problems, and as he grows older in the service is permitted a great deal of initiative in selecting the work he will do. He is better off than the industrial employee in respect to vacation time and retirement. His initial pay is not far below that of his equivalent in

industry, although this difference increases as he reaches the higher positions. In many ways the Government employee has greater opportunities to develop his particular interests. In fact, once he chooses his field, he has nearly as much opportunity as the university professor to investigate special phases of a particular science. In some fields, only the Government offers the opportunity of a satisfying career. Unlike the professor, but like the industrial scientist, the Government scientist cannot retain patent rights. He is free to publish the results of his work and many special journals and bulletins are open to him, in addition to the normal professional journals. This gives him an opportunity to acquire a wide professional reputation outside Government circles. The Government scientist is provided with excellent equipment and good working space. He is not faced with the same urgency of producing results as the industrial scientist. This is not always a blessing, although it does permit many men to work more satisfactorily.

One disadvantage of Federal employment is that, to attain the high grades, an individual must usally leave laboratory work and become an administrator. This disadvantage has been recognized in a number of agencies, and with the assistance of the Civil Service Commission, procedures have been established to promote the active and productive scientist without giving him heavy administrative responsibilities. To insure adequate recruitment and retention of highly qualified scientists, Congress has exempted the Atomic Energy Commission and the National Science Foundation from certain provisions of the Civil Service legislation. This permits these agencies to hire at salaries more comparable to those in industry. In general, however, the technical man seeking to reach an executive position in a large research organization with substantial financial reward cannot do so in the Federal Government. He can reach an important executive position with great responsibility if he is willing to accept prestige in lieu of money. Many Federal employees remain in their positions because they believe that they can best serve their nation by so doing.

Publication of Research Results

It is generally accepted that no research work is completed until results have been made available to science. Faraday said that there are three stages to research: to begin it, to complete it, and to publish it. Federal agencies recognize the importance of publishing their research results. Agencies that do intramural research have established publications in which the results of research done in their laboratories are described. The nature of these publications is about the same in all the agencies: printed reports, each giving the results of a single specific study. These reports are printed in large quantities, given to certain libraries and similar organizations, and sold by the Superintendent of Documents. The series have established editorial standards, and individual reports are reviewed as to technical worth prior to publication. They are equivalent in quality to technical articles published in the regular journals of the professional societies. In addition, most agencies publish supplementary series of reports which describe work of less importance but are distributed to

technical groups throughout the country. The Office of Technical Services, Department of Commerce, receives these reports and supplies copies on request. A few agencies also publish professional journals. The Journal of Research of the National Bureau of Standards and the Journal of the Cancer Institute are examples of such publications. These are distributed on a subscription basis by the Superintendent of Documents.

One of the most frequent criticisms of Government organizations is directed at the amount of printed material which they prepare and distribute. From the agency's standpoint, this activity is regarded as necessary to keep the public informed. On the other hand, mass distribution of specialized technical information is wasteful. Congress has established a number of regulations in an attempt to limit the amount of printed material. In the past these regulations have hampered the publishing of scientific information arising from Government research. In recent years, however, there has been widespread recognition of the need for distributing research results. Most Government intramural research agencies now have adequate budgets for publication of current findings.

Most, if not all, of the unclassified research performed in Government laboratories is of interest to industry and agriculture. Many results can be put to work at once to improve commercial products or to increase crop yields. The degree of dependence of our industry on applied research work of the Government is not generally recognized. Consequently, the importance of reporting new results promptly is frequently overlooked by management in Government. The problem of efficient dissemination of research findings confronts all research groups and even individual scientists outside the Government as well as in it.

Nature of Research and Facilities Utilized in Extramural Programs

The extramural research supported by the Government differs in many ways from intramural research, though there are also similarities.

In extramural programs, the personnel are not Civil Service employees, but employees of non-profit institutions or industrial groups; the facilities usually are not Government-owned, although there are a few privately-operated Government properties.

In considering extramural programs as a whole, we find the greatest expenditures are for developmental work under Department of Defense sponsorship. This type of work is almost invariably done by industrial corporations, but in a few instances universities operate development groups using full-time research personnel who do not enjoy full faculty privileges. The remainder of the extramural funds is spent on basic research, primarily in universities, and some applied research divided between universities and industrial organizations.

Federal support of basic research in universities is a development of the postwar period. It appears to have arisen from the practices of the Office of Scientific Research and Development, which operated an applied research program during World War II and utilized university scientists in the initial stages of its projects.

In 1945 the Navy established the Office of Research and Inventions which took over some of the contracts of the discontinued Office of Scientific Research and Development. This Navy group later became the Office of Naval Research, with Congressional authorization to operate a program of basic research contracts. Since its inception, the Office of Naval Research has maintained a successful program of contracts with experienced scientists, mostly in universities, who do research on problems of their own choosing.

In a similar way, using grants instead of contracts, the United States Public Health Service started in 1946 an extramural program of research in the medical and biological sciences. The Atomic Energy Commission followed the same pattern as the Office of Naval Research by establishing extramural programs in physical, biological, and medical sciences.

All three organizations operate as fund-granting foundations. Proposals for research projects are submitted to them by scientists seeking financial support. Each proposal is evaluated by a group of experienced scientists who are fully informed on current developments in the field of the proposed investigation. The granting or denial of support is based on their appraisal of the scientific importance of the problem and the ability of the investigator. Examination of individual grants and contracts reveals a very wide diversity in the scientific fields being explored. Furthermore, there seems to be no tendency whatever in the Federal programs to divert university investigators from the type of research they have customarily done to studies of a more practical kind.

Research groups brought into the extramural programs are enlisted on the basis of their capabilities to do specific jobs, and most of the work is done in privately-owned laboratories. Consequently, the research is highly decentralized, and many agencies with extramural programs have contracts with groups located throughout the United States. Most research money goes to those sections of the country which have developed their research organizations to the highest level. These are the North Atlantic States, most of the North Central States, California, and Texas. Every effort is made to distribute grants or contracts to other sections of the United States where there are men with adequate experience, even though facilities may be small. In any extramural program, therefore, one finds a number of participants located in the less highly industrialized sections, although the total amounts of Federal research money paid out in these sections is relatively small.

Nature of the Contracts and Grants

Before going into the administration of grant and contract research, it is necessary to make clear the nature of the grants and contracts in actual use in the Government research program. The contracts under consideration are written agreements between Government agencies and research groups in industry and universities. They are written for stated sums, but they are cost-type contracts. The agency agrees to reimburse

the research group for salaries and materials utilized in the research work, and also for indirect maintenance costs or "overhead." The contractor agrees to work on specified problems and to report results to the Government agency. In development contracts, the contractor agrees to supply one or more items of new equipment. The notable feature of the cost-type contract is that it protects the contractor against losses due to inaccurate estimates of the money required to complete a specific job of research or development. In contracts with non-profit institutions, there is no inclusion of a profit fee. In contracts with industrial organizations, however, a fee up to 15 percent may be allowed, but fees around 7 percent are more usual. Fixed-type contracts are sometimes used, but these are not as common as cost-type, and are used only when the cost of doing the work can be readily estimated. Cost-type contracts for research are arranged by negotiation rather than by award to the lowest bidder in open competition.

There are, of course, many other details in the contract such as patent clauses and statements on property ownership. These are also subject to negotiation. In the intramural program all patents arising from the work are assigned to the Government for free use by all; in the extramural program a different policy prevails. Most industrial companies follow a practice of accepting Government work only in fields in which they are experienced. On this account they are unwilling to forego patent rights even though they receive Government support for the research. The Government in turn goes to these contractors precisely because of their past experience. Under such conditions, most Government agencies agree to let the contractor retain ownership of patents arising from the contract, while the Government receives a royalty-free license to use the patents. There is now no uniform patent policy, but the practice just described seems to be a feasible working arrangement which recognizes the rights of both parties.

A grant is a lump sum given by an agency to an organization to support the research of a particular investigator or group of investigators. There is no requirement to furnish the Government with either a technical report or a piece of equipment, although some accounting is required at the termination of the grant to demonstrate that the money has been used properly. Generally, grants are intended to subsidize basic research by university investigators. In the fields of biology and medical research, however, grants are frequently given for applied investigations of importance for the control of specific diseases or the betterment of health. Only two agencies of the Government have authority to bestow grants: the United States Public Health Service and the National Science Foundation.

Development and Evaluation of Extramural Research Plans

As in the intramural programs, the research problems in some of the extramural programs come from individual investigators, even though they are not Government employees. This is true of the grant program of the United States Public Health Service, and the contract research program of the Office of Naval Research. In most instances, however, and notably in the development work of the defense departments, problems arise within an agency and are farmed out to suitable groups.

Some agencies classify the research projects they support as programmatic and non-programmatic. Programmatic research is that done on problems of direct interest to the agency and for which the agency usually solicits proposals. Non-programmatic research is of less immediate interest to the agency although it falls within the agency's general field. For such research the request for support comes from the unsolicited investigator. Projects falling in the latter category usually deal with fundamental or exploratory studies. The only limitation the agency imposes on these requests is that the field of the investigator be one in which the agency has a general interest. The aim of supporting non-programmatic investigations is to increase scientific knowledge along a broad front in order that such knowledge may eventually be utilized for practical purposes. The research which is suggested, however, need not be of a practical nature.

The first evaluation of the technical aspects of an extramural program is done by the agency research director in consultation with the directors of agency laboratories and staff scientists. If the major portion of an agency's research funds is to go into an extramural program, the research director invariably employs a research advisory committee of men outside the agency. The research director or administrator must, of course, bear the final responsibility for the development and formulation of the entire program. Once the budget estimate has been formulated, the same intricate review procedure as that used for purely intramural programs is followed.

In the grant program of the United States Public Health Service each grant is reviewed by a group of non-Government technical experts acting for the Government and specifically for the Surgeon-General. As with private foundation grants, the object is to provide support to able individuals for work on problems of interest to them and to science generally with a maximum of freedom. Little effort is made to enlist groups to conduct concerted research efforts under this program.

Administration of Contract Research

Extramural programs appear to have certain advantages over intramural programs. One is the lower capital investment so far as the Government is concerned. A second is the opportunity to acquire the services of individuals who would not accept regular Government employment. Another is the possibility of changing the investigative personnel or decreasing their number rapidly. In other words, there is less of a long-term commitment for support in extramural programs than in the case of Government laboratories and Civil Service employees. Some of this flexibility is lost, however, when the contract calls for purchase by the Government of heavy research equipment or buildings. Furthermore, it is questionable whether the present level of Federal support of research in industry and universities could be reduced substantially without seriously curtailing current technical progress.

As was pointed out in the Steelman Report, "The overriding importance of increasing our research potential through enlarged plant, equipment, and trained manpower, and the close relationship of dispersion to security requires that the Government distribute

more widely its research and development contracts in terms of geography and numbers of contractors."(8) An effort is made by the departments contracting for research to implement this general policy whenever possible.

The administrator of grant or contract research requires a more extensive office staff than is needed for intramural programs. The research director must be assisted by lawyers to handle contract negotiations, auditors to deal with expenditures under the contract, business agents to conduct the general business relations with the contractor, and technical men to inspect and evaluate the work done by the research investigators.

The fiscal and legal complexities of contracts are numerous and vary with the character of the research and the type of contractor. Even so, after many months of study and discussion, the Interdepartmental Committee on Scientific Research and Development has been able to develop a statement of recommended policies for the administration of grants and contracts. These policies are gradually being adopted. An effort is being made at the present time to simplify and standardize Government contracting processes. For example, through informal arrangements, if an overhead rate has been agreed on between an agency and an institution or company for a particular year, it will be accepted and used by any agency entering into a contract later that year. The computation of overhead costs for contracts with universities offered considerable difficulty when the extramural programs were first initiated. Within the past few years, however, changes in cost accounting methods and establishment of standard definitions of costs have succeeded in overcoming most difficulties. Another laudable simplification is the recently introduced procedure whereby a university having contracts with several different agencies is visited by only one set of auditors, who accomplish the job of auditing for all agencies concerned. Before 1948, most contracts provided for payments on the basis of vouchers submitted by the contractor to the Government. These payments were not made until the vouchers had been audited, and the delay in this operation required a considerable outlay of capital by the contractors. More recent contracts permit provisional payments prior to auditing. A small portion of the voucher payment is retained until auditing is completed.

Supervision of research and development contracts requires men competent to keep track of research in progress and make technical reports to the research administrator. Research often calls for unanticipated changes in plans, and this requires assignment of contract supervisors qualified and authorized to recommend modifications and adjustments. Sometimes a particular job no longer merits expenditure, and the technical supervisor must be able to recognize this.

Technical men on the research administrator's staff not only supervise contracts in existence, but are responsible for discovering new investigators and arranging the placing of contracts with them. It is their duty to examine, and perform the initial evaluation of, proposals requesting support of research. The analyzed proposals are then transmitted to special reviewing groups, as described above. In some agencies

evaluation is the chief occupation of the technical men on the administrative staff. In general, these men serve as liaison officers between the research administrator and the working investigators located in laboratories throughout the country. A few agencies have set up regional liaison offices outside of Washington.

Exchange of Research Information

There is one problem of research administration which plagues the Federal research program and is never effectively solved. This is the problem of exchanging information about new results or research in progress. It is not peculiar to the Federal program; large industrial organizations also contend with it. Formal publication of articles in technical journals or Government bulletins supplies information after the fact. Such publication usually takes months, frequently a year or longer. Current information about research is contained in the technical reports prepared periodically by the investigators in both intramural and extramural research. Strenuous efforts are being made by some agencies to utilize these reports fully. Procedures used are wide circulation of the original report, preparation and circulation of abstract bulletins and indexes, and maintenance of comprehensive subject files.

Security requirements prevent the free circulation of many of these reports, but an effort is made to classify them in a way to permit the widest possible circulation. In the case of reports on extramural research, where patent rights belong to the investigator and not to the Government, publication of some technical information may be delayed until patent applications are filed.

Grants to Experiment Stations

The cooperative research program is a special type of extramural program which forms a small part of the total Federal expenditure for research. The only sizeable program of this type is operated by the Department of Agriculture.

In 1887, the Congress passed legislation appropriating $ 15,000 annually to agricultural experiment stations established in the States and Territories of the United States. By 1889, 44 experiment stations were operating. There are now 53 such stations, in the States, Hawaii, Alaska, and Puerto Rico. The amount of money appropriated to these experiment stations has been increased from time to time. The present appropriation of about $ 12,266,000 is made to the Office of Experimental Stations in the Department of Agriculture, and the amounts allotted to the States vary from $ 150,000 to $ 538,000. The allotment is based on the proportion of a state's rural population to the nation's rural population. Although the Federal Government through its original legislation and appropriations can take credit for founding these research organizations, state governments have supported them since their establishment. The Federal grant is actually only about 20 percent of their annual budget.

The Department of Agriculture does not have direct control over Federal grants under this legislation (Hatch Act), but it does review annually the work and expenditures

of each of the more than 45,000 projects which receive support from Federal funds. The Department attempts to coordinate the work through its Office of Experimental Stations to avoid duplication of work by the stations themselves, or by the Department of Agriculture laboratories. The stations submit descriptions of proposed projects before any work on them is begun. The submitted descriptions are compared to descriptions of similar projects being carried on in other stations or in Federal laboratories. In addition to performing this coordinating function, the Department indicates research areas in which it feels more effort should be expended. The work carried on is usually of a practical type closely related to immediate problems of agriculture or industries dependent upon agricultural resources.

Relationships of Federal Research Agencies with Other Groups

Little more needs to be said about the relationship between Federal research agencies and private research laboratories in connection with extramural programs. Because the support and coordination of research is the responsibility of the Federal agency, close relations are maintained with the private research groups. However, in the intramural programs there has been a tendency for the Government laboratories to become cloistered. Individuals in the laboratories are frequently far removed from association with industrial and university research men. In recent years, however, more adequate recognition has been given to the importance of attendance at scientific meetings as a stimulus to productivity, and funds are provided for this purpose. Likewise, certain research agencies such as the Geological Survey hire university scientists to work for short periods on their projects in Government laboratories and in the field. In some applied or developmental work, industry also is brought rather intimately into the intramural program through advisory committees and subcommittees or panels functioning under these advisory committees. A specific and excellent example are the subcommittees operated by the National Advisory Committee for Aeronautics, which are made up of research men from the aircraft industry and the aeronautical departments of universities. There are research agencies, however, which conduct extensive programs without the benefit of established information exchange arrangements. This defect is recognized by these agencies, and there is a significant trend toward establishment of additional research advisory committees.

The present pre-eminence of the United States in the practical application of scientific knowledge results in frequent calls for American technical aid from countries seeking to develop their commerce, agriculture, or transport systems. Individual agencies in the Government such as the Department of Agriculture and the Department of Interior participate in many international projects by giving leave to technical personnel so they may carry on specific work in foreign countries. The Bureau of Standards arranges short-term appointments for foreign scientists who wish to use its facilities and frequently conducts short training courses for groups of scientists from Latin American countries. The Bureau of Public Roads operates a highway school six weeks of each year. This is attended by representatives from other countries.

Recently the Department of State appointed a Science Advisor to the Secretary of State, in recognition of the ever-increasing importance of technical knowledge in meeting problems of international relations and in human affairs generally. The Science Advisor maintains a small scientific group in Washington and is installing scientific attaches at important diplomatic posts throughout the world. The purpose of these attaches, who are scientists of some distinction, will be to foster cooperation and exchange of information between scientists of the United States and those of foreign countries. It is expected that the office in the Department of State will serve as a link between Government research groups in this country and foreign groups interested in similar technical matters.

The most active scientific liaison group of any Government agency at the present time is the London office of the Office of Naval Research. The Office of Naval Research supports in university and Government laboratories in the United States an extensive program of basic research in mathematics and the physical sciences. There are many fields of basic inquiry in which the work of European scientists is of prime importance. The extension of fundamental knowledge is well served by promoting in every way possible cooperation between American and European workers in these fields.

The Office of Foreign Agricultural Relations, maintained through the cooperation of the Departments of Agriculture and State, has representatives in many foreign countries. While primarily concerned with the collection of statistics, these representatives are also responsible for exchanging technical information on agricultural problems. They serve as a link between the Agricultural Research Administration and similar organizations in foreign countries.

Coordinating Mechanisms and Procedures

There is no single body in the executive branch of the Government which is charged with the responsibility of formulating policy for the Federal research and development program. This lack of centralization stems from the fact that the earliest Government-sponsored research was initiated in the individual departments as a secondary activity to promote the main ends for which the departments had been founded. Each department or other agency is responsible only for its own research program. In view of the importance of scientific research both as an item of Federal expenditure and as a vital national resource, a need exists for coordinating mechanisms outside the agencies that actually conduct the research. The main functions these must fill are:

(a) The formulation of an over-all picture of the Federal research and development program, indicating the relative emphasis placed on different fields, as well as the total support given.

(b) The interchange of information on administrative problems common to research organizations in the Federal Government and on the content of research programs, to avoid duplication.

(c) The provision of a point close to the President at which important questions about the research and development program of the nation can be brought into top policy discussions.

Comprehensive studies of research in the United States by the National Resources Planning Board(14) and the more recent studies of the Federal research program by the President's Scientific Research Board(8) did not result in recommendations that responsibility for the Government's research program be centralized within a single organization, such as a Department of Science. At present, determinations of the Government's policy on research are based on the recommendations of several coordinating groups which we shall describe briefly. The ultimate responsibility for the Federal research program rests, of course, with the Congress, which authorizes the programs and appropriates the funds.

Bureau of the Budget. To the extent that an over-all picture of the Federal research program does exist, it is a by-product of the activities of the Bureau of the Budget. The Bureau prepares the annual budget proposals the President submits for Congressional approval. The Budget is a program for allocating the estimated expenditures of the Government among the many executive agencies which put legislated policies into effect.

There is no organizational unit within the Bureau whose special function is to take an over-all view of outlays for scientific research. Two divisions of the Bureau, the Estimates Division and the Division of Administrative Management, deal with scientific research programs among other activities of the executive departments and agencies.

The Estimates Division is divided into twelve Estimates Groups, each of which analyzes, reviews, and revises the budget requests of a group of three or four departments or agencies. Thus Estimates Groups have an opportunity to compare plans of different research groups with one another and to question apparent duplication or overlap. Although most reviewers are trained primarily in fiscal and administrative matters, they do acquire an intimate knowledge of the research programs. This enables them to exert a strong coordinating influence in the planning and operation of the many Government research programs. This coordinating influence has been strengthened in recent years by the establishment in the Estimates Division of an informal working group to consider all research programs jointly. By this means the agency and department estimates for research can be compared and similar technical programs of different agencies be examined simultaneously. In addition, an over-all view is obtained of prevailing tendencies in the national research programs.

The Division of Administrative Management does not concern itself with the substance of scientific programs, but confines its efforts to organizational, procedural, and managerial matters. Owing to the special character of scientific research organizations and the absence among Bureau personnel of men trained in the natural sciences, questions of administrative technique in research agencies cannot be definitively dealt with by this agency.

In view of the tremendous growth of the Federal research program in the last decade, many groups have expressed concern over the possibility of overlapping of research activities. Estimates reviewers of the Bureau of the Budget, being for the most part without scientific background, can be expected to spot only the more obvious duplications. While research administrators of the Federal research groups are themselves quite alert to possible duplication, it is difficult for them and their staffs to have sufficient information about the other research groups to prevent support of identical or nearly identical programs. This is a communications problem which can be solved only by many agencies working together.

It is encouraging to note, nevertheless, that whenever investigative studies of rather narrow fields of research have been made, little if any duplication has been uncovered. Two characteristics of scientific activity in Federal agencies help to account for this. First, agencies tend to work in rather fixed areas, and the areas peculiar to each agency become well-known to groups in the other Government agencies working in related fields. It is rare that any scientist or research director attempts to enter into direct competition with other groups in the Federal Government who have attained a recognized position in a field of research. A second reason lies in the unofficial exchange of information which takes place in professional meetings and in inter-agency committees.

National Science Foundation. The Congress in establishing the National Science Foundation included among its duties "to evaluate scientific research programs undertaken by agencies of the Federal Government," but it is highly questionable whether the Foundation could do more than consider the general nature of the research programs under way. To provide for complete comparison of agency programs, it would be necessary to establish a clearinghouse of detailed project descriptions furnished by the individual agencies supporting research. Almost the entire budget of the National Science Foundation would be required to accomplish this one task, which is surely not among the primary purposes for which the Foundation was set up.

Interdepartmental Committee on Scientific Research and Development. Studies of administrative problems common to research organizations in the Federal Government are the responsibility of the Interdepartmental Committee on Scientific Research and Development. This Committee, set up by presidential order (Executive Order 9912, December 24, 1947) is made up of representatives from 14 departments and agencies: the Departments of Defense, Army, Navy, Air Force, Agriculture, Interior, Commerce, and State; the Federal Security Agency; the Atomic Energy Commission; the National Science Foundation; the National Advisory Committee for Aeronautics; the Veterans Administration; and the Smithsonian Institution. The representatives on the Committee are research administrators from the research-coordinating group, if one exists, or from a research bureau or division. Each member represents all research activities of his agency, although within his agency he may be responsible for only a part.

The Interdepartmental Committee studies more important administrative questions by establishing temporary committees to prepare reports on specific problems. Such reports, along with advisory recommendations, are sent, after approval by the Committee, to heads of agencies or departments which conduct research, to the President, or to certain planning agencies. After four years of operation, the Interdepartmental Committee tends to employ the following procedure: The group studying a particular problem attempts to develop a uniform policy which can be employed by all Government research organizations. This policy is based on the experience within the research groups and takes into account conflicting interests or different requirements of individual research groups. The Committee, on receiving such a report with recommendations, considers these recommendations thoroughly and decides which procedure should be followed to insure that the recommendations are brought to the attention of the individuals who can act on them. The report is then forwarded as an official document to the appropriate agency head or possibly to the President himself. The Committee thus performs the extremely valuable function of bringing problems of research administration to the attention of the highest administrators in the Government. Since the recommendations carry the approval of experienced research men from every Government department, they are given serious consideration by the agency or department administrators.

Science Advisory Committee-Office of Defense Mobilization. In 1951, the President recognized the need for an advisory group in the defense mobilization effort and established the Science Advisory Committee in the Office of Defense Mobilization. The duties of this group are to advise the President and the Director of Defense Mobilization on scientific matters bearing on research of defense significance, to keep account of research progress relating to defense, to suggest areas needing greater attention or emphasis, to advise on methods of implementing our defense research, and to bring into national councils the views of the scientific community.

The Committee membership is in part ex officio, that is, the Chairman of the Research and Development Board, the Director of the National Science Foundation, the President of the National Academy of Sciences, and the Chairman of the Interdepartmental Committee on Scientific Research and Development are members. In addition, there are six non-Government scientists and the Chairman. The success of such a group cannot be measured in the short period of its operation. In fact, the real accomplishments of such a committee are usually the indirect benefits derived from informal meetings of individuals engaged in directing important operations.

National Academy of Sciences-National Research Council. The National Academy of Sciences was established by Federal Charter in 1863 to provide mechanism for the Government to receive the advice of the country's scientists when problems of a scientific nature arose. It consists of several hundred scientists elected by the membership of the Academy. Its function is advisory only, and it acts only upon request by departments of the Government or other interested parties. Expenses of its investigations for

governmental agencies are paid by transfers from appropriations of the agencies requesting assistance. The Academy organized the National Research Council in 1916 in response to Executive Order. This is an operating organization made up of associations of professional and technical societies and of committees composed of individual scientists interested in particular fields of science. Members of these committees come from universities, industry, and the Government, and are chosen on the basis of their experience and capabilities.

The National Research Council operates no laboratories, but stimulates scientific research by awarding research fellowships, encouraging the publication of scientific papers, surveying the larger possibilities of science, and promoting research cooperation through its special committees on individual fields of science. As the national research expenditure, and more particularly, as the Federal research activity has expanded, the National Research Council has increased the number of its committees and increased the proportion of Government scientists among the membership of its committees. These Government scientists not only contribute expert knowledge as members of the committees, but provide information as to what research is going on within the agency which employs them. This represents perhaps the strongest coordinating mechanism which exists, but despite its valuable contributions, the Council cannot be expected to ensure coordination of the Federal research and development program since it has no organic connection with the executive branch of the Federal Government.

CHAPTER III
APPLIED RESEARCH IN INDUSTRY

Background of Research in American Industry

In the beginning, the organization of research laboratories in American industry was stimulated by two factors: the growth of technical industries and the work of individual inventors. Established companies (particularly chemical and electrical) such as E.I. du Pont de Nemours, General Electric, and Standard Oil of Indiana were able to persuade unusually competent university researchers to devote some of their time to business problems. At first the companies were mostly interested in the control of production processes; later on emphasis shifted to the improvement of processes and products.

The independent investigators who stimulated industry's faith in research were all characterized by strong determination to achieve commercial development of their ideas. Hall, inventor of the first practical process for extracting aluminum from bauxite; Baekeland and Hyatt, developers of two of the earliest commercially valuable plastics, bakelite and celluloid; and Acheson, discoverer of the harder-than-steel abrasive, carborundum; all were typical of the successful inventor-businessman. Each of these men played an active role in the organization of the new industry that grew out of his invention.

Companies that were based from their start on the commercial exploitation of laboratory findings maintained from early days an attitude of respect for the usefulness of systematic research. Their success had a profound influence on the remainder of American industry. As general competition grew sharper, the competitive advantages obtainable from applied research were more widely recognized and research was established as an integral part of other industries.(14) Frequently, however, the idea of supporting research captivated the American businessman even when competition did not force him to do so in self-defense. America was a frontier country, and expansion, invention, and material success were the watchwords of the new society. The rapid growth of our early industrial giants seemed plain proof that there were new worlds to conquer for men with talent and temperament for the undertaking.

Basic research is a necessary foundation for technical advance, but important fundamental discoveries do not automatically give rise to usable products. The discovery of the fissionability of uranium did not produce an atom bomb. The way in which all the technological resources of a country are organized sets the pattern for the utilization of science in industry. If scientific work is confined to universities, and if companies do not have research divisions to translate new knowlege into new and improved products and processes, research will have only minor influence on the economy and the standard of living. Not only must industry maintain laboratories, but industrial management must have in its top planning councils applied research scientists and engineers who follow new scientific developments and can spot those which might be successfully exploited.

To obtain practical benefits from fundamental discoveries, there is need for much additional work: applied research, engineering development, production engineering, and technical service. These activities are sometimes grouped under the title "technology." The number of technological man-hours required to provide the American people with new and cheaper products is many times that required to develop the basic scientific ideas involved. The capital necessary to support this technological effort is invested in the expectation that increased profits will result from the application of technology to business problems. The profit motive is thus an essential part of the American pattern of applied industrial research.

Different industries and different companies in the same industry place varying emphasis on engineering, as compared with the physical sciences, in their research programs. The chemical process companies, for example, lean heavily on both chemistry and chemical engineering; the automotive industry emphasizes engineering development. But whatever the emphasis, industry recognizes the need for putting results of fundamental research to work and generally provides some means for doing so.

Industrial research projects start with the recognition by a company of an existing or potential need. The need itself may be a direct outgrowth of basic research done elsewhere. For example, when it was found by the British bacteriologist, Fleming, that penicillin is a powerful antibiotic, the American pharmaceutical industry undertook to develop practical large-scale production methods for this valuable substance. In this they have been very successful; in eight years the commercial price for penicillin has been reduced from $20 to 2-3/4 cents per 100,000 units. More commonly, a company seeking to improve some aspect of its product or production process is led to believe that some new finding, possibly one obtained by a university research man, can be utilized for this purpose. The work of Nieuwland at Notre Dame on acetylene led to development of a special purpose rubber, neoprene, by the Dupont Company. Applied research is undertaken to study the implications of a new finding for the company's special problem. If the laboratory work leads to results that can be embodied by engineers in working plans or models, and if these are turned into economically sound processes or products, then the research project has been successful.

The industrial research process is circular: the successful product leads to improved earnings and enables the firm to apply more capital to the support of further research. It has been estimated that for every dollar currently put into research, $3 in profits are being obtained as a result of making use of past research.(15) And for every dollar expended in research in the United States, about $10 new capital must be invested before any benefits can be realized from the research. Companies continually invest in products of research and reinvest part of the resulting profits in new research in the belief that reduction of price or product improvement will lead to increased sales, and that greater volume of business will result in higher net profits.

Planning of Industrial Research

The selection of research projects for an industrial laboratory is made, as a rule, by the man who heads the research group. In the United States, the research director is a member of top management. While ultimate responsibility for choice and execution of programs is his, the emphasis of such programs is often decided by top management acting together. The research director then serves as key scientific advisor on the management team. The choice of what research projects are undertaken is at least as important as the quality of their technical execution.(16) Negative results may represent real achievement in pure scientific work, but projects which lead to negative results rarely yield profits. A mark of the successful research director is ability to produce positive, not negative, results.

Industrial research programs are designed to solve concrete problems that arise in the long- and short-term operation of companies. In planning research activities, time of accomplishment is considered an essential element, but, within limits, cost is not a controlling factor. If the time required to complete a project can be appreciably shortened, or results significantly improved, large sums will be appropriated to attain this.

Research budgets are drawn up with the idea that the company can afford to spend a certain amount for research work, and that this amount should be expended in accordance with a broad plan laid down by top management. The distribution of funds among individual projects is merely a guide to planning. The research director has the responsibility of directing the expenditure in a manner that will result in the maximum return, and he is free to redistribute allocations among projects as the necessity arises.

Certain expenses involved in research are regarded as fixed or semi-fixed. Good research personnel need experience within a company before the work begins to show profitable results, and replacement of research personnel is costly. In formulating the research budget, salaries for personnel are often regarded as fixed cost. Even when it seems desirable to reduce research expenditures, companies generally hesitate to release competent personnel. Investment in laboratory facilities and equipment is also relatively fixed, and probably amounts to about $10,000 per industrial scientist or engineer. The sum of these relatively fixed expenses serves as the first approximation to the final research outlay.

The proposed expenditures on individual projects are considered in terms of sales and profits, i.e., how much will total sales or profit per sale have to be increased to pay for the research? Present earnings must provide dividends for the stockholders and some capital for investment in the results of research. A balancing of research expenses against profits and sales is a basic necessity for sound planning.

A second major consideration is that capital invested in research is not available for other uses. The research director and top management make estimates of the probable return on research investment. They analyze proposed research projects

to determine how they will contribute to the maintenance or improvement of the company's net earnings.

It is understood throughout American industry that not all research projects can yield a return. In a carefully considered program, perhaps one out of 10 projects will lead to increased profits, and the successful projects must carry the rest. A proper balance must be established between financial risk and probable return. Placing a too low limit of expenditure on a given research proposal may jeopardize the entire investment before any work is undertaken. On the other hand, it is not good policy to permit expenditures consistently larger than the returns from previous research.

Past experience with research activities is very useful in estimating costs and probabilities of success for proposed projects. If the research department has been consistently able to effect savings on projects concerned with production processes, then management officers might feel that the general probability of success for a proposed project in this area would be high. In this situation they would require a lower ratio of probable return to costs than they might on some other type of project.

A third factor considered in setting up a research appropriation is the competitive position of the company. Trends in the economy which are forcing prices and sales down, or the fact that rival products are taking over portions of a given market, have an important bearing on research programs. Lower costs, better quality, or new products may be called for, and if the company is to stay in business, there may be no choice but to increase expenditures for research. To preserve a position for the future, it is sometimes considered necessary to spend much more than would be considered economically sound on the basis of current sales and profits.

Sources of Ideas

In general, the ideas which form the nucleus of research programs do not come from the research staff alone. The entire personnel of most companies is encouraged to submit suggestions for possible research, and substantial awards may be granted for those that result in savings or profits. Most of the ideas for projects that originate outside the laboratories are for specific developments. Suggestions relating to existing products and processes may arise from manufacturing and operating, sales and executive departments. (17a)

A typical analysis of the distribution of sources of ideas in a large chemical company is: (18)

Sources of Ideas	Total Offered	Percent of Total Accepted
Research & Development	50%	65%
Sales	25%	35%
Production	15%	
Management, Market Research, and others	10%	

It is usual for a preliminary appraisal to be made of what seems a promising idea. Brief technical and economic studies may be needed before management can decide whether to provide major funds for further work. Generally, the research director has authority to proceed or not with this preliminary appraisal, as he sees fit.

If the preliminary appraisal is favorable, the project is often reviewed with production, engineering, and development groups who may eventually be concerned with it. They try to iron out some of the problems of producing the new product or setting up the new process the research may yield. Suggestions are made which may save considerable time or enhance the value of the original idea. Market and economic studies and discussion with the sales department may be needed before making final decisions on major projects. This teamwork throughout the entire company contributes heavily to the success of the industrial research process in the United States.

Types of Applied Research (19)

In a progressive company, continual analyses are made of all products to determine their susceptibility to improvement and the desirability of adding new products. General economic studies may be made first; studies of specific technical feasibility will then follow. Changes in products and processes may be desirable to improve product performance, to cut production costs, to standardize parts, and to reduce selling prices. New products may be desirable to make better use of present equipment, to make fuller use of present sales organization, and to diversify the product line as insurance for earnings in the future.

Projects are frequently designated as "short-term" or "long-term" in industrial research. The more fundamental research usually falls into the long-term category. Short-term projects have specific objectives to be reached after a relatively short period of investigation. The long-range success of industrial research programs often depends upon the balance between these types of projects. The ratio of the two will vary from company to company. Also, what might be a long-term project in one industry will be a short-term project in another. In general, short-term projects are used to solve immediate problems facing manufacturing, customer service, sales, and the like, while long-term work is a safeguard against loss of future earning power to competitive products or services.

Process research is the search for the "one best way," under certain fixed conditions, of producing new or old products. Such research may deal with specific process steps or complete manufacturing processes. Sometimes a specific product which cannot be produced economically with known methods is chosen for exploitation. The development of a production process may require the highest type of scientific work. Process improvement research is usually a major part of research programs in heavy manufacturing industries. Studies on the use of oxygen-enriched air in blast furnaces illustrates this type of research.

Product research leads to either new or improved products and cannot be completely distinguished from process investigations. New product research comprises perhaps 10 percent of the typical industrial research program.

Research may be carried out to improve performance characteristics of products by direct or indirect modifications. Direct modifications come about through substitute materials, improved quality, or changes in technical design. The development of silicones for use in electrical equipment as dielectrics is an example. Indirect modifications might follow research into improved methods of product use or better materials for the consumer to use with the product. For the latter, much product research may be considered as technical service to the user. Product improvement may comprise from 40 to 90 percent of research programs, being heaviest in the consumers' goods fields.

Improvement of old products or development of new ones through applied research is preceded by the recognition of a demand, or the possibility of creating a demand. The study of the characteristics of this demand and the prediction of future trends are properly subjects of market research. Development of new products without adequate market research is considered extremely hazardous.

Raw material research has for its objective the improvement of a supply, cost, or quality situation. In many cases substitute materials are developed at a lower price or to provide alternate sources of supply. Such research is carried on intensively by companies that are large-scale converters of a few raw materials, like the metal producers and the heavy chemical producers. An excellent example of such research is the present work on utilization of taconite, an iron ore from the Mesabi Range in Minnesota, which has a lower iron content than the ore previously used.

Waste utilization research is undertaken to find uses for the waste products of a process, or to convert wastes to a useful form. Such programs may lead to considerably increased profit margins. Further, wastes may be found a social nuisance, and research may be required to prevent costly damage suits. Research and development may then be devoted to finding the least costly way of disposing of wastes rather than utilizing them commercially. Alert research departments have often succeeded in transforming a nuisance into a source of profits. Thus bagasse, the fibrous residue from sugar cane, has found wide use as sound insulation.

Market research, although usually considered an adjunct to the sales organization in American industry, is more and more becoming a well-defined applied research activity. Soap and cigarette manufacturers have found it essential for the maintenance of competitive position. Market research includes the investigation of the need and market for new and improved products, testing of consumer reaction to those products, and investigation of marketing channels to determine the best distribution facilities.(20) Market studies furnish information on proper styling for the consumers' goods market, and on quality and utility requirements of manufacturers in the capital goods market.

Operations research is a relatively new research technique. It was developed in the early days of World War II by scientists seeking to maximize the efficiency of complex military operations. Industry is beginning to employ this approach in which problems are tackled by closely welded teams made up of scientists, engineers, mathematicians, and social, economic, and financial specialists.(21) The object is to analyze the many factors that affect a company's income and to find what combination of these will yield maximum profits.

Research Programs in the Large Company

The organization of research takes various forms in the larger industrial concerns. Sometimes each operating division or subsidiary company has its own research department. The divisions of a company are usually established on the basis of a class of products or processes. Thus an electrical manufacturer may have a lamp division and a motor division. A synthetic textile company may have a chemical division and a textile unit. In such companies, research departments are responsible for work which relates to their division's products or processes. A drawback of this type of arrangement is that many possibilities for research may be ignored because they do not fall within the province of any existing division. To meet this need, central research laboratories are maintained by many large companies in addition to divisional ones. In other concerns special project groups or broad exploratory teams are set up at some of the divisional laboratories. Although these groups are responsible to the division head, their research is not directly related to the special interests of the division.

A typical organizational pattern involving a central laboratory is that furnished by a leading food company with several manufacturing subsidiaries, each producing a different type of product. Each subsidiary has a research and development laboratory; in addition, there is a central laboratory and pilot plant. Process and product improvement specific to the subsidiaries are studied in their own laboratories. Projects of interest to the entire company--general studies of food preserving, for example--are undertaken in the central laboratories, as are pilot plant investigations of new products not manufactured by any subsidiary.

Sometimes the central laboratory is even organized as a separate company, such as the Standard Oil Development Company which serves as the research department for the companies under control of the Standard Oil Company of New Jersey. Such research and development companies carry out research, install pilot plants, develop products and processes, and sometimes manufacture equipment or products on a limited scale. They pass the results of research and development to the operating companies in a completed form with an initial market.(17b)

Central laboratories which are not organized into separate companies function in essentially the same way. All research is usually under a vice president, to whom the director of the central laboratories reports. This vice president, through the board of directors, obtains the necessary support for the research program. Frequently, however, the research director is himself a company officer.(22)

The fact that companies establish central laboratories directly responsible to a top executive indicates the importance of the research operation to the whole enterprise. Its future may depend on the efficiency and imagination of the research department. Under these circumstances, the research organization is protected from demands by other divisions seeking assistance on minor problems. In many companies, technical functions such as sales service, quality control, and development engineering have no direct connection with the research organization. In others, these operations are performed by the research division.

Very often, within a central laboratory, there are several functional divisions representing the major interests of the corporation. These functional divisions may be concerned with process components, specific products, or a combination of product, process, and technical service. Specialization by developmental functions is held by some to be an important factor in the success of industrial research in the United States.(23) Some work of general interest to the company may, however, not come within the sphere of activity of any of the functional divisions. For this reason a basic and exploratory division may be provided. If a company is to be alert to the need for new inventions, it must engage continually in exploratory research. Furthermore, it requires on its research staff men who follow those fields of fundamental research that may yield knowledge of ultimate value to the company.

Industrial projects range from fundamental studies to specific product or process changes. Projects may therefore be initiated in any of the functional divisions of the research laboratory. This means that work programs of the functional groups in the laboratory must be coordinated so that projects which require the successive attention of several groups pass from one to another without undue delay. The size of the functional divisions and the nature of the research done will depend on the objectives of management, although management rarely dictates the choice of specific projects.

The flow of "ideas" and "projects" through such central laboratories generates a continuous feedback to the planning group. Ideally, the exchange of information along the entire route is a two-way affair. Stimulating viewpoints, new developments, and proposed changes move from the exploratory stages to the well-defined efforts of technical service and production engineering. In the other direction, suggestions, criticisms, and problems move from production, sales, and other departments at operating levels to groups immediately in contact with them. Exploratory groups work in an atmosphere of the company's practical affairs. The process of information exchange is considered of utmost importance for the success of industrial research.

Special schemes have been devised for integrating the central research department with the rest of the enterprise. It may be separated geographically from the production activities of the company, but contact is maintained through liaison groups, since the ultimate results of research must be "bought" by a customer, in the company or out of it.(24) Liaison groups may function further as "idea" teams which explore future possibilities of the company, of science and technology, of the economy, and of markets,

with a view to determining the most promising lines for company research efforts. Such teams may contain research, engineering, production, sales, and financial personnel. The mixed composition of these groups may enable them to provide profitable orientation for programs in the large laboratory.

Small Company Programs

The larger companies' research and development programs illustrate the degree of organization which applied industrial research has achieved in the United States. Equally, if not more, important are the less elaborate programs of the smaller companies. The latter provide examples of the way in which industrial research gets its start. Almost all large company programs began with the employment of a few scientists, whose successes were important factors in their growth.

The officer in charge of research in a small company is usually in charge of all technical matters, including engineering and design. In addition to actual research, he is responsible for quality control of the product, technical assistance to the customer, and operating specifications for manufacturing. A chief problem of the small company is to decide on the most profitable areas for research with its relatively limited budget. It cannot afford to maintain an exploratory group to study general problems. Research objectives have to be narrowed down, although thorough study may be possible on a specific problem.

Planning of programs and projects is undertaken by top executives, with the technical officer taking the lead. They generally consider the age of each process or product, the share of each process in the final cost of production, the contribution of each product to total profits, and the effect of each process upon the quality of the products. The older processes and products usually offer the best opportunities for improvement. Those products which are making the least contribution to profits may offer good opportunities for replacement, redesign, or improvement. The profitability of doing research is not questioned; the problem is to obtain the largest return. Once the most suitable areas for study are determined, the small company must carefully consider the likelihood of technical success. It cannot afford to have separate groups working on different methods of solving a problem, as is sometimes done in the large laboratories. Possible approaches must be sifted to eliminate all but one or two alternatives that promise the greatest profit, and experimental work reserved for these. Smaller companies, whose technical staffs are limited in scope, often supplement this staff by employing research advisors from consulting laboratories or universities. These advisors provide an independent appraisal of the projected research and often suggest more promising alternatives.

Organization of Research Groups

Two broad patterns of organization are found in American research laboratories. In one of them, the working group is professionally homogeneous; in the other, it is a mixed team comprising men of different scientific training. The first type can be

termed subject basis, and the second, functional basis organization. Where research departments are organized on a subject basis, the kind of company and types of problems to be solved determine the particular divisions of the research department. Assignment of scientists and engineers will be to such divisions as physics, chemistry, metallurgy, mechanics, thermodynamics, hydrodynamics, applied mathematics, electrical engineering, electronics, and mechanical engineering. These fields may be broken down further; for example, physics into ultrasonics, electronics, and optics.

Subject-type organization is relatively simple to establish, but often when large and complex problems are undertaken, individual parts must be assigned to each of several subject groups. Research men responsible to different supervisors must cooperate in the solution. This means that over-all responsibility for a complex problem cannot be delegated to one group leader. The necessary coordination must be done by the laboratory director. This type of organization has therefore been largely abandoned, except in laboratories where the problems are easily classified by subject, or where separate elements of problems require only a small amount of coordination.

The functional type of research organization can deal more easily with both simple and complex problems and is far more prevalent in American industry than the subject type.(25) Personnel are grouped according to the stage of the research process, such as fundamental or exploratory research, applied research, development, and process engineering; or according to end-product, industrial process, or practical field of investigation. Each group must contain a wide range of experience and training. Functional groups sometimes further separate their staffs according to subjects.

Functional arrangement gives the laboratory considerable flexibility. Duplication of skills, knowledge, and equipment is offset by greater simplicity of cooperation and planning. It is usually easy to determine the functional category into which a particular problem fits. Assignment of a problem to a given group fixes responsibility for that stage of the investigation. Most research directors consider that functional basis provides an excellent framework for control and operation.

To avoid duplication of certain basic facilities in organizations established on a functional basis, service departments are often provided. These include analytical laboratories, craft shops, and libraries. In addition to routine measurements and services, they may be able to furnish highly specialized technical assistance such as performance of microanalyses, and supplemental development work such as the design of special instruments.

Typical Laboratory Organizations

A typical research and development division in a small company is shown in Figure 1. Such an organization would cost around $40,000 per year, and might be found in a company whose annual sales are from $1 to $2 million. The group comprises a director of research and development and two section leaders. Duties would be to develop product specifications and control manufacturing quality. Outside consultants

would be utilized to provide specific technical knowledge not available within the organization.

A research and development organization based on subjects is shown in Figure 2. Here are a director and his assistant, general laboratory administration, and physics, chemistry, mechanical and chemical engineering departments. The cost of operating this facility in 1951 would be approximately $10,000 per year per scientist and engineer employed.

Figure 3 shows a typical functional organization in a large oil company. The director of research reports to a vice president. Under him, there are several functional groups representing the major interests of the corporation. Each is administered by an assistant director. There is also an assistant director in charge of business administration. Economic studies, analytical work, and all basic and exploratory work are done in the general laboratory division. Each functional division, formed according to fields of interest (petroleum processes, chemical processes, grease specialties, and catalyst development), is further broken down into functional sections according to the stage of application: product development, process design, and technical service. Within each of these are found working groups that carry on the actual research and development. Such an organization might employ 500 persons or more. This arrangement applies the team approach on a successively smaller scale, down to individual project groups.

Figure 4 shows a typical group arrangement in an equipment manufacturing firm. The vice president, who is also director of engineering and research, has under him the research manager and the manager of administration and services. Individual groups under the research manager may have one or several objectives. For example, one team might have the single objective of developing a new process, while another might have numerous projects for improvement of standard products of the concern. The manager of administration and services is responsible for the administrative and clerical staff, library, shops, and service facilities.

Laboratory Supervision

Although the individual scientist or engineer is the productive unit of the research organization, he cannot be expected to create on demand. His efforts can, however, be stimulated by professional contacts, reinforced by suitable assistance, and sustained by adequate rewards. Most industrial research laboratories adopt organizational policies that take these facts into account.

Research men are most productive when they have ample opportunity to exchange ideas with other scientists. A certain informality of working conditions is therefore maintained. Scientists circulate freely within the laboratory during working hours and frequent group meetings are held to discuss the work. Subordinates are invited to criticize research proposals, and suggestions from all sources are evaluated impartially. Individual initiative is encouraged, both to presserve morale and to foster originality.

FIGURE 1

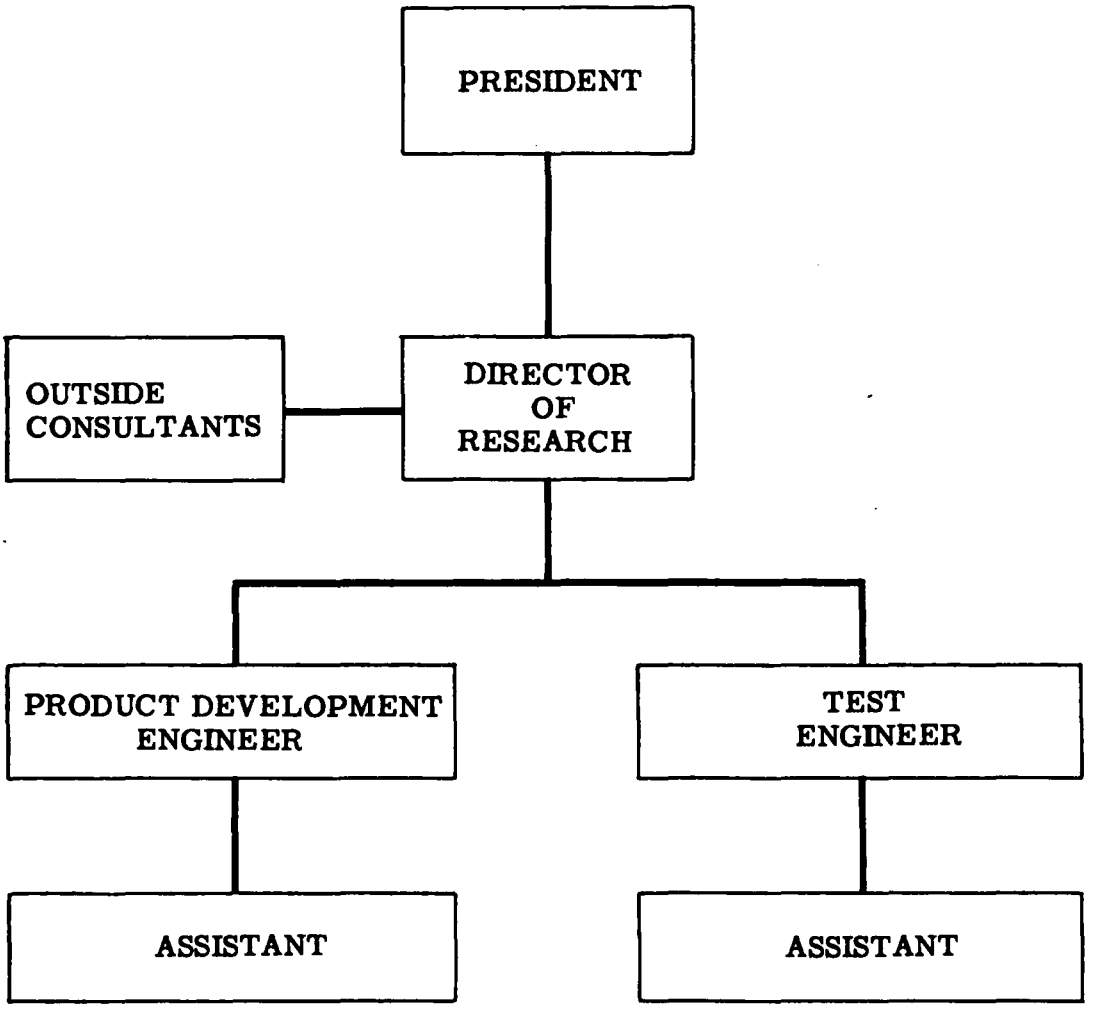

PRESIDENT
OUTSIDE CONSULTANTS
DIRECTOR OF RESEARCH
PRODUCT DEVELOPMENT ENGINEER
TEST ENGINEER
ASSISTANT
ASSISTANT

FIGURE 2

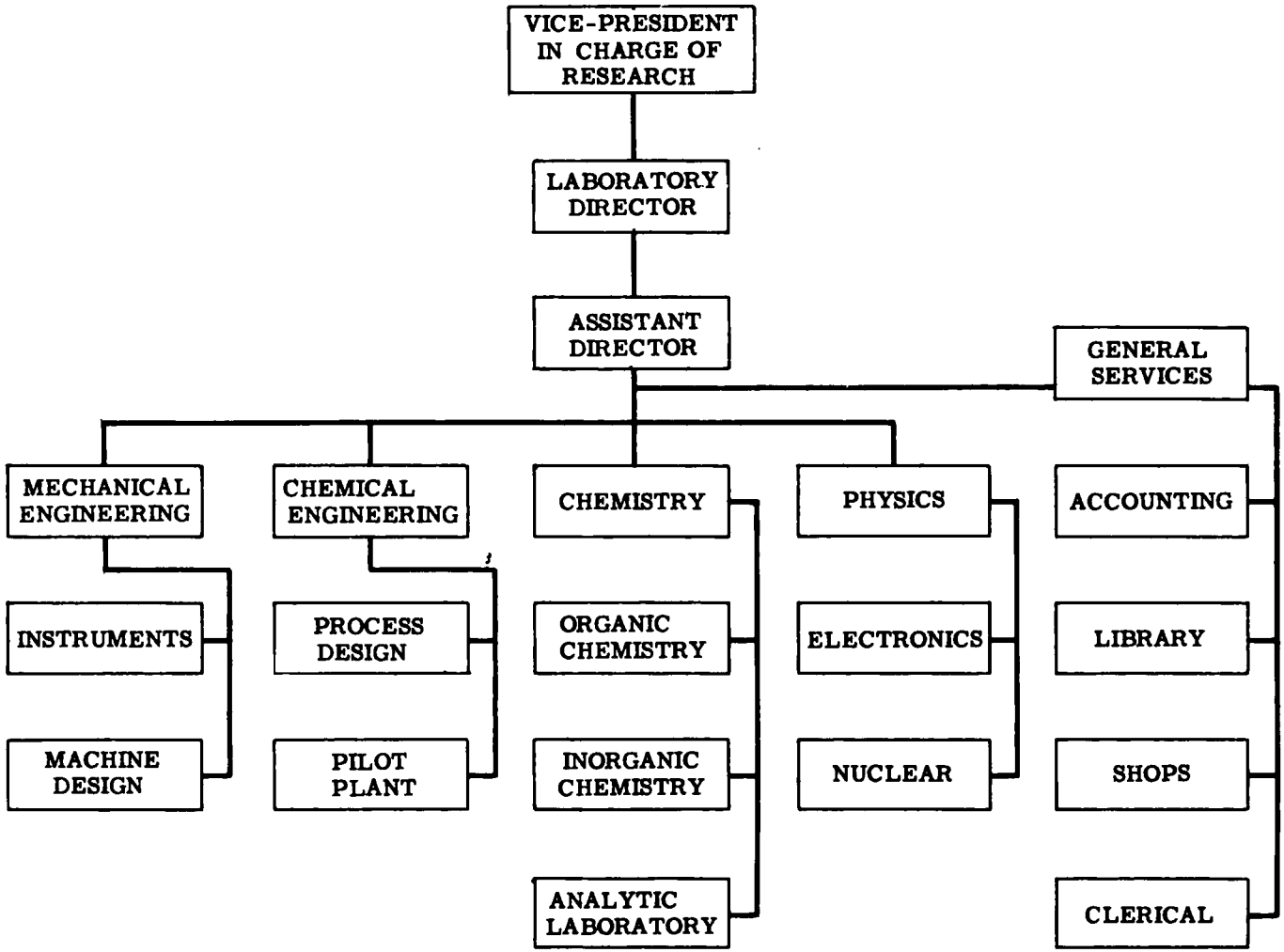

VICE-PRESIDENT IN CHARGE OF RESEARCH
LABORATORY DIRECTOR
ASSISTANT DIRECTOR
GENERAL SERVICES
MECHANICAL ENGINEERING
CHEMICAL ENGINEERING
CHEMISTRY
PHYSICS
ACCOUNTING
INSTRUMENTS
PROCESS DESIGN
ORGANIC CHEMISTRY
ELECTRONICS
LIBRARY
MACHINE DESIGN
PILOT PLANT
INORGANIC CHEMISTRY
NUCLEAR
SHOPS
ANALYTIC LABORATORY
CLERICAL

FIGURE 3

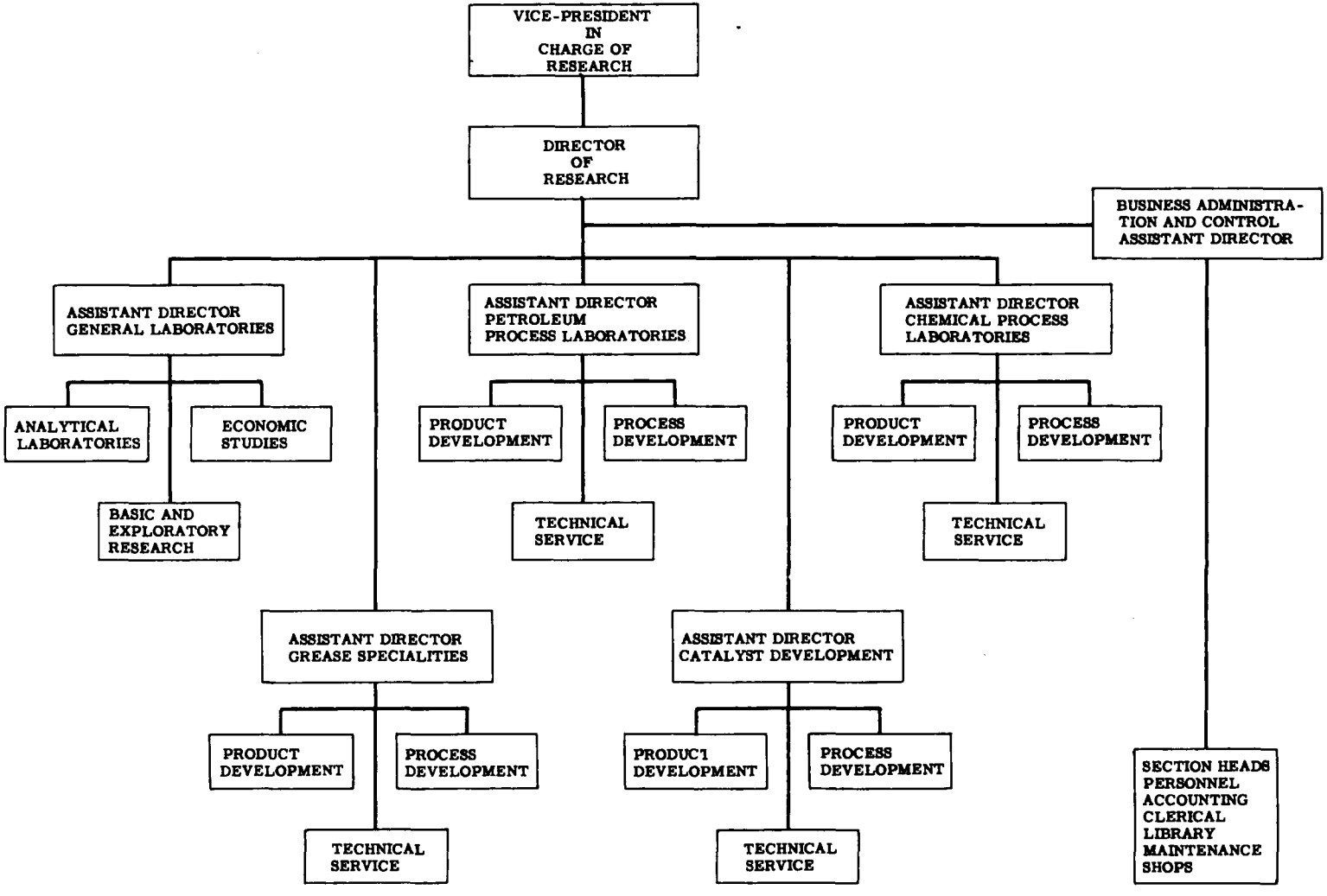
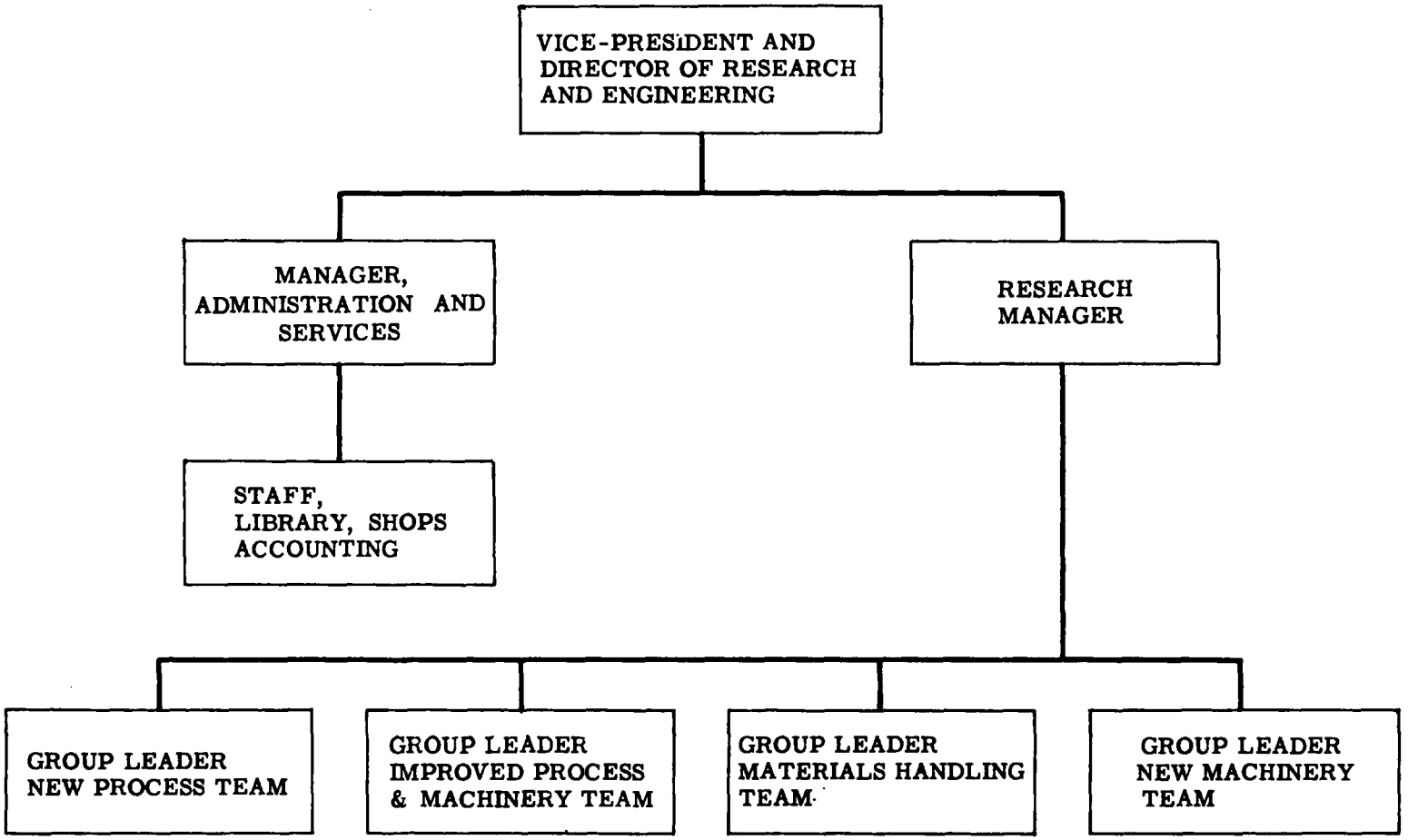

VICE-PRESIDENT IN CHARGE OF RESEARCH
DIRECTOR OF RESEARCH
BUSINESS ADMINISTRATION AND CONTROL ASSISTANT DIRECTOR
ASSISTANT DIRECTOR GENERAL LABORATORIES
ANALYTICAL LABORATORIES
ECONOMIC STUDIES
BASIC AND EXPLORATORY RESEARCH
ASSISTANT DIRECTOR PETROLEUM PROCESS LABORATORIES
PRODUCT DEVELOPMENT
PROCESS DEVELOPMENT
TECHNICAL SERVICE
ASSISTANT DIRECTOR CHEMICAL PROCESS LABORATORIES
PRODUCT DEVELOPMENT
PROCESS DEVELOPMENT
TECHNICAL SERVICE
ASSISTANT DIRECTOR GREASE SPECIALITIES
PRODUCT DEVELOPMENT
PROCESS DEVELOPMENT
TECHNICAL SERVICE
ASSISTANT DIRECTOR CATALYST DEVELOPMENT
PRODUCT DEVELOPMENT
PROCESS DEVELOPMENT
TECHNICAL SERVICE
SECTION HEADS
PERSONNEL
ACCOUNTING
CLERICAL
LIBRARY
MAINTENANCE
SHOPS

FIGURE 4


VICE-PRESIDENT AND DIRECTOR OF RESEARCH AND ENGINEERING
MANAGER, ADMINISTRATION AND SERVICES
RESEARCH MANAGER
STAFF, LIBRARY, SHOPS ACCOUNTING
GROUP LEADER NEW PROCESS TEAM
GROUP LEADER IMPROVED PROCESS & MACHINERY TEAM
GROUP LEADER MATERIALS HANDLING TEAM
GROUP LEADER NEW MACHINERY TEAM

Liaison with such departments as sales and production is maintained. Business and technical administrators in the research department are expected to take a personal interest in work at the bench. All this helps morale and spreads an understanding of the goals of the entire organization. In addition to these internal contacts, most companies encourage research men to keep up their contacts with professional colleagues outside the company.

The group leader or project supervisor is a key figure in research. He is responsible for individual workers in the smallest organizational unit. His task is both to do research and to lead the group to successful completion of its projects. Typical duties of a group leader are: to see that the activities of each man contribute to the general objectives of the group; to do his own share of research work; to maintain good work standards; to attend to service and personnel requirements; to report results, conclusions, and recommendations; and to train new workers. His administrative tasks involve requests for funds, equipment, and services; reports of expenditures; maintenance of inventory, and the like. For these jobs, he may be assigned clerical help, since it is poor practice to have group leadership become a strictly "paper-shuffling" activity. The group leader devotes much time to individual or group conferences with his workers, acting as a catalytic agent that increases their output. His group may range from one to 10 workers. A typical group might consist of a group leader, five researchers, and three technical aids. Group leadership calls for a more exacting combination of creative and administrative ability than any other supervisory position.

A laboratory business manager or administrative assistant helps reduce the burden of administrative functions on the scientists. His job is to see that the research worker has what he wants when he needs it, with a minimum of "red tape." In small departments, he attends to accounts, inventory, and other clerical duties. In a large laboratory, he may be an assistant director of administration with jurisdiction over purchasing, maintenance, and service, as well as clerical work.

The laboratory director is responsible for selection and efficient attainment of the research objectives. He supervises technical and non-technical activities of the research and service groups reporting to him, and controls their personnel and organizational functions. He establishes the basic procedures under which the groups operate, directs the research undertakings, and makes the final reporting of achievement and progress to management. He often serves on management committees, and perhaps on the board of directors.

In larger organizations the director delegates his responsibilities to several assistant directors, including an assistant director for administration. Each director may have technical or administrative staff assistants. Technical assistants serve as advisors on various phases of the research program. Administrative assistants help with budget, financial, and personnel operations.

Besides recruiting efficient and competent scientists and directing their work, the research director must be able to plan the laboratory activities to serve the interests

of the company. For this he needs a knowledge of the problems of sales, purchasing, and production, and of the future plans of the company. He obtains it by meeting with executives in other departments from time to time. Equally important is his task of keeping management aware of the value of research to the company. He explains the research program, reports on its progress, and outlines new projects to the board of directors. To win approval for his budgets, he must convince them of the worth of past work and the promise of work he plans to do. "He must sell new ideas to people who are operating successfully with old ones. He must have both the courage of his convictions and determination to sell them to management. He should be a good public relations man and have enough showmanship or sales ability to get an idea across to the executive group." Modern management considers that selling research is a substantial part of the research director's job.(24)

It is evident that research directors must combine managerial ability with technical competence. The most successful of them not only understand the problems of the businessman, but become businessmen themselves, imbued with the desire to apply scientific thinking to business problems. A recent survey of 150 directors of research indicated that the typical director was over 40 years old, with training more likely in electrical or mechanical engineering than in chemistry or physics, in the proportion of three to two. Of these men, 42 had had teaching experience, and most had reached supervisory jobs within five years after graduation from college. The time taken to double their starting salaries was two to seven years. The typical research director does not change jobs often; 40 percent had worked for only one company, and 30 percent for only two companies. Half of them had more than five patents; almost half had no publications at all.(26)

A research laboratory functions by means of, and in spite of, conferences. These consume some part of the working time of each professional employee—the research worker spends most of his time in his laboratory, and the director spends most of his in conferences. Coordination of many diverse activities must be secured at all levels in the successful research laboratory. Conferences provide an efficient means of communication between group members, between group leaders, and between the director and his immediate staff.

In the largest laboratories "steering committees" are formed to oversee individual parts of the research program. Their membership comprises the assistant directors and technical supervisors reporting directly to them. Committees are often established to consider special technical problems which require cooperation with other departments. Such committees may include department heads, and some section heads or group leaders. Policy committees may be established to consider the technical-economic significance of proposals and completed projects. Practice varies from organization to organization; in some places the emphasis is on committee operation, while in others individual contact is depended upon to give the desired coordination. In any event, it is important to note that the administrative emphasis throughout American industrial research is on establishing common goals in a company and achieving these by cooperative scientific and business efforts.

Research Reporting

Almost all industrial research organizations rely on systematized written reports for transmitting information and keeping permanent records. For efficient operation and also for patent protection, research activities must be recorded and reported in a regular fashion. Scientists are therefore required to keep either individual or project notebooks in which all data, calculations, and conclusions are included. Most laboratories also prepare periodic—weekly or monthly—progress reports which summarize the work of a group, or the work on a particular project, since the preceding report. These reports may be forwarded to the research director or to management, either complete or in summary form.

Final technical reports are written on completed investigations. Changes of objectives and emphasis, and other forms of action are taken on the basis of these reports. It is therefore important that they be technically accurate and clearly written. In some large laboratories with technical writing staffs, the researcher writes the first draft of a report, and a technical writer rewrites it in readable style. Before circulating the report outside the research group, it is approved by the director of research.

Publication of research results may or may not be encouraged. Publication that might interfere with obtaining American or foreign patents is not in order. To build their morale, however, and to establish a good reputation for the laboratories, scientists are usually permitted to publish original work of general scientific interest. All material must be approved for publication by management.

Patents

Successful industrial research usually results in patentable inventions. A new process development may be kept secret, in which case a patent cannot be obtained. Most companies, however, follow a practice of obtaining United States patents on all inventions arising from the research they support. Some inventions are also patented in other countries, particularly in those having a potential market. Patents are taken out, not to provide a source of income through licensing, but to avoid paying license fees on products the company is, or has plans for, manufacturing. The use of patented inventions to obtain a monopolistic position in an industry is avoided for legal and economic reasons.

When a substantial demand for a new patented product is displayed, competitors are usually quick to develop alternative products. The original company may find itself with a production plant much too large for its final share of the market. Most companies believe it safer practice to let others share the cost of developing the market. A common practice is establishment of a new company for which several concerns provide capital, patents, and experience to develop a new product or process.

A greater deterrent to the development of a favored position through patents is the vigorous stand the Federal Government takes in enforcing anti-trust laws. The use of

patented processes to secure a monopoly in any industry of appreciable size may involve the company in expensive litigation.

Under existent conditions, patents are usually licensed at reasonable rates to all companies within a particular industry. Since most of these hold some patents which the others can use, cross-licensing arrangements are frequently established. The net result is that money paid out by a company for licenses is offset, at least partially, by income from licenses on its patents. Competition between individual companies still exists, but it is based on manufacturing efficiency, quality of product or components, and company reputation. The radio-television and automobile industries both practice cross-licensing extensively.

Employees of industrial research organizations are required to enter into written agreements which assign to the employer inventions made during their employment and relating to their employer's business. Such agreements often specify that the employee will not divulge confidential technical matters during his employment (and sometimes afterward, when compensation is provided therefor).

Almost all large companies have their own patent departments. Smaller companies employ a law firm specializing in patents. The research director works closely with the patent attorneys and advises them on undertaking patent applications for specific developments. In some companies the patent department follows laboratory work through reports and conferences and undertakes to determine when patent action should be initiated.

Research Facilities

American industry seeks to provide the research worker with the best in equipment and facilities. When new laboratories are constructed, careful attention is given to comfort and convenience of the working arrangements. Facilities in excess of basic requirements are considered safer than inadequate facilities that might stand in the way of obtaining results.

Requirements of industrial organization change with time, and research policies must be modified correspondingly. For this reason, modern industrial laboratories are flexible. Laboratories are designed as a rule, on the basis of a module, which is the amount of floor space, bench area, and facilities required by the average worker. Partitions and services are arranged so that the modules may be set up in a number of differently coordinated combinations with a minimum of cost. A laboratory is planned to suit the activities of a particular company. This may entail provisions for unusually hazardous operations or heavy floor loads; particular climatic conditions; high head room, as for chemical pilot plant work.

Libraries are given a great deal of attention in the typical industrial laboratory. Most libraries contain adequate space for quiet reading and are equipped with microfilm apparatus. Library employees are expected to be familiar with all sources of information relating to the research program. They often prepare bibliographies and

abstracts and furnish full texts (translations, where necessary) of specific literature which the researcher wants. In addition, company material including specifications, operating notes, and reports is indexed and made available.

In larger research organizations the library is the main division of a more extensive technical information service. The staff of this service includes trained scientists who gather information from many sources, both within and outside the company. They provide critical reviews and informative summaries of current research work before it is reported in professional journals.

Research facilities may be located at the main plant or offices of the company, or in laboratories entirely apart from other company operations. Location at a plant increases the likelihood that research men will be distracted by demands for aid on production problems. Some research organizations have research facilities both at the plants and separate from them.

Type of research to be undertaken affects choice of location; thus, agricultural experimentation requires suitable climate and space. The attractiveness of the community to the scientists is also considered. As a rule, initial research facilities of a company will be located inside a plant. If the research organization grows, it moves to a location of its own. A composite choice would probably be: near, but not at, a major plant; near, but not at, the administrative offices; in a suburban area near a large center of population; and in a temperate climate.

Research Economics

Sound business practice requires that a company's investment in its research division be compared in profitability with investments in other divisions. There is a limit for profitable plowing of funds into research, determined largely by availability of capital and management to take advantage of the results. In consequence, continued expansion of research in the United States will chiefly result from new research departments being started by companies that do not already have them.

As an alternative investment, research has not generally been considered attractive except under conditions of economic competition. Normal desire for growth has not been the major incentive for industrial research in the United States.(27) Monopolistic control by a single company has, in fact, tended to reduce the amount of research undertaken by an industry. On the other hand, in fields dominated by a small number of large firms, each with considerable product diversification, research becomes an important means for securing competitive advantage. The chemical and electrical industries are notable examples of this.

In such industries any company which does not improve its product and lower its prices may soon lose its market position and suffer severe losses. It is not sufficient for these concerns to copy the advances of others; the first one with a superior product or lowered price can keep its improved market position for the particular item. Reduction of price by one company will force the same reduction on others, whether

or not their costs have been cut. Improvement in market position due to changes in design are less quickly offset, since it takes competitors a fairly long time to re-tool, re-design, or re-process. This is particularly true when the changes are of a fundamental nature. In this situation, research and development expenditures are as much a necessary portion of the costs required to stay in business as sales and advertising.

Once processes and products become well-standardized in an industry, expenditures for development become less necessary to maintain existence. As a rule, such stability comes with a reduced earning level for the product, so that companies must look for methods of cutting costs, or introducing new products if higher rates of return are to be maintained. An aggressive concern may undertake an intensive research and development program in the absence of pressing competition, simply to increase its earnings. By so doing, it can "unstabilize" the industry and force others to engage in research and development, to the ultimate benefit of the consumer and the economy.

There is no point in undertaking industrial research if funds are not available to invest in its results. To obtain returns from research, additional capital is required to make new products and processes commercially successful, as well as to replace or improve existing plant, equipment, and machinery.(28) The major sources of capital to invest in research are retained earnings and either borrowed or common stock equity capital. Since 1946 retained earnings and common stock sales have been responsible for over 66 percent of new funds, borrowing for 32 percent, and preferred stocks only 2 percent. The stockholder expects from the "retained earnings" an increase in the value of his holdings and, probably, additional dividends. Therefore, research return is sometimes evaluated as "venture" profit, as distinguished from the profit normally realized in the business.(29) The net profit on a given investment in research and new product or process is compared with the net profit that would have been realized if the same sum had been invested in expanding the output of old products. Successful research projects are those which produce an extra return.

Research Costs and Accounting

Most companies treat the operating cost of their research departments as an expense item. When research work has clearly resulted in a product or process which has value, the cost of the research may be capitalized as an asset and charged against income in future years. This is not regarded as a conservative accounting practice, and is usually only done on the insistence of tax officials. Taxes on excess profits have made financing of research less costly in recent years. Research can now be charged as a cost of doing business and deducted before taxes are computed. In fact, 50 cents of every dollar spent on research would go to taxes if that dollar were not spent on research but went into profit before taxes. Thus, the present high tax rate has been an encouragement to industrial research and is one cause of its growth.(30)

From 60 to 80 percent of industrial research costs are in salaries and wages, and approximately 70 to 80 percent of this cost is for scientists and technical helpers. Where engineering and pilot plant work is the major activity of the laboratory, the

personnel expenditures are at the low end of the scale; the more fundamental and exploratory the investigations are, the larger the proportion of salaries and wages in the total budget.

Administrative costs range up to 10 percent of the total, and supplies and equipment run from 5 to 20 percent. Maintenance, depreciation, and operation of laboratory facilities average approximately 10 percent.(31)

Miscellaneous expenditures such as travel, telephone and telegraphs, books and periodicals, fellowships and gifts, and consultants rarely run larger than 12 percent of amount paid the technical-professional staff. The average annual costs of operating various research laboratories per professional scientist or engineer ranges from $10,000 to over $30,000.

Accounting for research costs is relatively uniform in most industrial laboratories. It is felt that there is no need for assembling expenses with the meticulous detail of cost accounting. The primary objective is to produce adequate information for management to determine that expenditures are within the budget, are in accordance with approved research programs, and are justified by the results obtained. The system is usually the simplest that can be devised.

Accounting will often be carried out by charging personnel, material, and other costs to individual projects. Remaining costs will be included in laboratory overhead, usually prorated in relation to direct labor costs. Project numbers are established for accounting and record purposes. In some laboratories these are tied in with the library classification system, to make filing and locating reports, papers, and memoranda more convenient. Professional and technical staff usually report time spent on different projects by means of these numbers, as do craft shops and some services. Purchases of special equipment are also charged against individual projects. Practice varies as to what is overhead, but many laboratories include most clerical services and routine supplies as overhead items.

Authority for approval of research equipment purchases depends on their cost. Amounts above a stated minimum may require top-management approval. If such equipment becomes a permanent part of the laboratory (for example, an electron microscope), it is considered capital equipment and its depreciation charged as laboratory overhead.

Laboratories commonly charge other divisions of the company for specific investigations, tests, or other work. Thus, manufacturing problems may be undertaken on request from production departments and charged to their costs; sales and technical service problems may be charged to the sales department. Sometimes work is undertaken for customers and charged to them.

In some laboratories the research work of all groups is analyzed and costs measured against the dollar sales of products developed by the group. Other systems credit laboratory operations with an arbitrary percentage of the total savings or profits

on a particular operation. Another system is to estimate the cost of manufacturing a new or improved product under a license, if the improvement or invention had been patented by another company. The difference between this estimated cost and the actual cost is credited to the research department.

There are almost as many methods of measuring research results as there are companies doing applied research. These measures are often called indexes of return. Such an index is generally the ratio of estimated returns (savings and/or profits) from a completed research project to the cost of the research. These indexes are also used in computing probable returns for comtemplated projects. In this case, the estimated index of return is multiplied by the estimated probability of success. These systems are widely used although it is recognized that they have serious limitations. For example, many projects that ultimately produce large profits have an uncertain probability of success because of the novelty of the idea that is studied. Most laboratories have only a rough estimate of the value of their work. In all companies, the end results of research are everywhere apparent, whether done by the company itself, or in the research laboratories of others.

Transition to Production

If research work is successful, then management must decide when it is to be put into commercial use. In the automotive, metal working, and radio and television industries where the laboratories are engaged mostly in engineering development, the transition consists merely in turning over relevant drawings, specifications, models, and process instructions to engineering design and production engineering departments. Where sharp distinctions are observed between the research department and the engineering development section, the research moves through the development stage to pilot plant or pre-works trials and then to design and production.

Problems that arise in the commercial exploitation of research results deal with availability of raw material and equipment; future costs; by-products and waste disposal; toxicity and hazards; marketing acceptance and long-run demand; patents; adequate technical data for sales and advertising. At this stage, opportunities can be lost or business enterprises made.(32) Most companies give control of this operation to the production departments.

A number of methods are used to obtain data for predicting full-scale results. These include laboratory replicas of proposed production units, pilot plants, restricted area trials within operating plants, pilot assembly lines, user trials, and experiments in the actual plant. Each stage in the development program is closely checked. A new product or process will be discarded if strong doubts of its commercial success arise at any stage.

As a rule, once the project has passed the semi-commercialization or pilot plant stage and arrived at the point where it is released for commercial exploitation, the research and development organization becomes strictly advisory to the production

unit. It is desirable for research men to maintain close touch with plant design, construction, and operation. Their experience may enable them to make suggestions that will avoid costly blunders. The research department is expected to help eliminate difficulties—"bugs"—if they arise in new processes. Another common practice is for the research department to furnish some scientists and engineers to the production department as part of the supervisory and technical personnel for the new operation. In exceptional cases, the research department may also manufacture products for initial sale, if these are foreign to the company's regular operations. This may be continued until the market warrants a full-scale plant.

Industrial Research Personnel

Many college students expect to enter industrial research when they graduate—thousands of them do. The demand for science and engineering graduates at present is greater than the supply. To help meet this shortage, companies themselves conduct special on-the-job training.

The most important quality industry seeks in the research men it hires is inventiveness. Industry also expects its research personnel to have a good understanding of scientific and engineering principles, and to improve their knowledge and skills continually. Industrial research personnel are usually required to have advanced university training, and insistence on the doctor's degree is becoming commonplace. Training may be no substitute for inventiveness, but in the present state of technical development, training is a necessary condition for solving problems.

Research directors consider strong professional curiosity one of the marks of suitable research personnel. Directors also seek researchers who are dissatisfied with present ways of accomplishing things, but temper this dissatisfaction with a practical outlook. The research worker must understand that the laboratory exists to promote the earnings of the company, but creativeness and ingenuity in the service of the firm are well rewarded.

Industry also requires that research personnel be able to present proposals and solutions for problems clearly and correctly, and obtain acceptance of these from other people. Researchers are furthermore expected to be cooperative and get along well with others. Industry strives to promote the researcher's interest in the total activity of the laboratory, as well as his understanding of the part played by his own group.

Previous experience, scholastic records, and various aptitude and interest tests are used in singling out competent personnel.(33) Recommendations of specific teachers, or the record of having taken specific courses, have some weight. Most research administrators feel it is wiser to recruit from many educational institutions rather than from only one or two. Even so, not all the men hired will meet research requirements. Individuals who do not succeed in research or development are frequently shifted to production, sales, or technical service. Their scientific training and research experience give them excellent background for these kinds of work.

Since industrial laboratories hire personnel directly from college or university, research directors maintain contact with a number of educational institutions. Many companies have a member of the research administrative staff who visits the universities regularly to interview candidates before graduation. Some laboratories make a practice of hiring students for summer work. This gives the laboratory a chance to evaluate the student, while he obtains some working knowledge of industrial research. When group and section leaders are required and are not available within the organization, they are obtained through notices in the technical press, or at meetings of technical societies. On occasion firms choose outstanding university research men as directors of their laboratories. These men will have had extensive experience as industrial consultants, perhaps to the very firms that hire them.

Training of Research Men

American universities aim to provide their undergraduates with fundamental training in one major field. Original research is not expected of candidates for the bachelor's degree, but is a necessary requirement for the doctor's degree, and sometimes for the master's degree. Three important types of graduate training for research have emerged in the United States.

First is the classical pattern in which the student works independently of others on a specific and usually limited problem. The professor furnishes advice and information, but the student plans the work and is responsible for its execution, including, perhaps, construction of necessary apparatus. This was the accepted form of American technical training in the past and provided the bulk of young researchers to the industrial laboratories.

In recent decades graduate work in night schools (particularly in large cities), and also in seminars and courses provided by industrial laboratories themselves, has been a second means for augmenting undergraduate technical training. This permits students to work in industry during the day and pursue an advanced course of study at night. Night courses are an increasingly important source of trained research workers, who not only have the necessary "practical" outlook but have also proved themselves under difficult conditions.

The third method by which research workers are trained is in association with sponsored research work. Such work provides the country not only with the results of the research, but also with trained students whose education combines the practical and theoretical. Graduate students working on such projects can often use this work to satisfy research requirements for their degrees. The team organization commonly used in sponsored projects gives students a foretaste of industrial research practices.

Training of research workers after they have entered industry presents a varied pattern. A recent study indicates only a few companies (10%) have complete formal programs for training, but the majority provide for systematic orientation of new employees and train them on the job.(34) Job rotation, or on-the-job training, is

practiced systematically in 20 percent of the firms. Job rotation is considered desirable because the solution of individual problems may require combining several specialties.

Formal classroom work is not commonly used in industrial training programs, but some of the larger companies have full-fledged on-the-job schools of graduate study, and at least one company has a regular course in "inventiveness," the results of which appear to pay.(35) Advanced seminars on a formal or informal basis are quite usual in industry, and in some instances local technical societies arrange regular after-hours programs for industrial scientists in their areas.

Many companies encourage technical personnel without doctor's degrees to get additional education while on the job, and many refund some or all costs of such academic work. Others grant leave for graduate work, a few with pay. Some permit use of work done in their laboratories (subject to certain restrictions, of course) for graduate research or permit use of their laboratory equipment for such research.

Training programs in the large laboratories may be comprehensive. Small companies sometimes devote considerable effort to organizing a single educational activity of high quality. In the small company the training program is likely to be under the direction of the research administrator; in the large company it is usually run by the personnel department.

Morale in Industrial Research

Directors of American industrial research laboratories want the research man to be enthusiastic about his work, confident of reward for work well done, and genuinely interested in the progress of the company. When these conditions prevail, turnover is small. Key men are not lost to other employers, fewer new employees need be trained, and these can receive better training. Most important, however, is the increased output of the research laboratory when each individual is contributing his best efforts, undistracted by personal worries over salary or position.

The wage policy in the industrial research laboratory is designed to attract and retain above-average men. Salary schedules take into consideration education and experience, supervision required and received, exercise of independent judgment and initiative, and responsibility for attaining solutions to problems.

The opportunity to acquire a professional reputation is found to contribute to good morale in the industrial research laboratory. Scientists are encouraged to publish papers, to attend and present papers at meetings of professional societies, and to work with men from other laboratories on problems of interest. These presentations give the company a reputation for progressiveness, liberality, and good scientific quality among professional research men.(36)

Research Leadership and the Development of Administrators

Research activity cannot be directed in the usual sense of the word. However, the ultimate utility of a laboratory to a company will depend upon the administrative ability

of its higher-level directors. A number of United States laboratories, having lost their founding directors, have fallen into obscurity.(17c)

There are no programs for developing research administrators on a continuing basis. The increased scale of research operations in industry and the increased costs of producing results have resulted in growing interest in such programs by applied research institutes, universities, and professional societies. Although qualified administrators must be scientists first, the administrative side of their training must receive due attention. An increasing number of conferences and training programs are being organized to study research economics, personnel, leadership of groups, and other problems which face research administrators. Conferences on research administration have been sponsored by such applied research institutes as Stanford and Armour, and by such universities as Michigan and Columbia. The Center for Studies of Research Administration was established at Columbia University to deal with research administrative and organizational problems.

The Industrial Research Institute was founded in 1938, under the sponsorship of the National Research Council, to develop improved techniques of administering industrial research and to promote an understanding of its importance. The Institute now has 120 member companies representing a cross section of American companies engaged in industrial research. The National Association of Manufacturers has also maintained an active committee on research which has disseminated important information to its members and to industry in general. Finally, courses in research administration for graduate students are available at several universities.

Use of Consulting Laboratories

Consultants are used in industrial research operations in two ways. Individual experts or groups may be retained to advise on the general research program or on specific projects; or actual research work may be turned over to an outside individual or consulting group. Industry hires many university research men to serve as advisors and to work under contract on specific problems, using their regular university laboratories. Companies also bring problems to non-profit research institutes which may or may not be connected with universities. (These are described later in this report.) University professors and research institutes are generally consulted on fundamental problems important to the long-term operation of the company but not demanding immediate solution.

Concerns also employ consultants on short term investigations of specific and urgent difficulties. Such problems are usually brought to the profit-making commercial consulting laboratory. Some of these do highly specialized research, others cover a wide range of applied science. They aim to provide solutions which are technically sound and commercially practical. Their services include testing, analysis, product and process development, technical service, and economic and market studies. Supervision of the work is retained by the consultants, but general policy, including patent arrangements, is settled mutually in advance. Several of these consulting companies

have contributed important new products and processes to the American economy through their work for clients.

The laboratories of trade associations may also serve as consultants. These are founded primarily to work on broad problems of interest to an entire industry. Many of them, however, assist small manufacturers on problems they could not afford to study individually.(37)

The following are some situations in which companies hire outside consultants to do research: (38)

When the company itself does not maintain a full-time research staff.

When the project being considered requires fresh ideas or wider experience than is available within the company.

When the job can be done more economically elsewhere, e.g., costly additional equipment would be required.

When the project itself is the source of considerable differences in opinion within company circles and independent evaluation is desired.

Industrial Research and Public Relations

Every industrial company in the United States is concerned with public opinion. An active research department may appeal to the general esteem for "science" for the special advantage of its company. Much advertising is devoted to telling the public about industrial accomplishments. If this advertising increases sales, then research groups have an important secondary value as prestige builders, apart from their direct economic worth. Technical journals, company literature, catalogues, trade papers, technical societies, the general press and radio, trade associations, and open meetings are all used to communicate research results to the public.

Channels are also provided for information from the public to the research laboratory. The consumer's actual or potential needs as reported by sales personnel, and supplementary information from the production department, eventually reach and influence research. Sales departments follow with interest the regular features in popular magazines calling for industry to supply specific consumer wants. They subscribe also to the lists of needed inventions distributed by the National Inventors Council of the Department of Commerce.

Industrial research organizations consider it especially important to maintain good relations with such groups as academic institutions from which they draw their technical staffs. Numerous technical awards, talks, demonstrations, scholarships, fellowships, grants, and gifts are donated by American business to universities and colleges.

There is also growing recognition that the long-run interests of industry depend on basic research and educational activities of universities. Furthermore, under present tax laws in the United States, contributions to educational institutions may be deducted,

within limits, from taxable income. These factors have led to increased gifts by business to universities.

Scientific professional societies are also recognized by industry as performing essential services to research. In the United States these societies have assumed responsibility for publishing journals in which almost all research of general interest is reported. They hold regular meetings for presentation of scientific papers and general exchange of ideas on technical matters. Companies often grant local branches of the societies use of laboratory facilities for meetings. Tours of laboratories and demonstrations of research apparatus are also provided. Frequently, business groups furnish funds to professional societies for surveys of mutual interest to society members and business leaders.

CHAPTER IV

APPLIED RESEARCH IN UNIVERSITIES

University research may be divided into two broad categories—sponsored and unsponsored—depending on who pays the bills. Unsponsored research is paid for out of regular university income. Sponsored research is financed primarily by contracts and grants from industry and the Government. Most unsponsored research in American universities is basic research, while sponsored research is usually applied research, according to the definitions of this report. It has been pointed out previously, however, that some of the funds received from industry and Government support basic research. Moreover, some university investigators elect to do applied research without any support from outside organizations.

Faculty members of university science departments are generally free to choose the type of research they work on. Although most of them prefer to do basic research, one can find some applied research carried on in every school or department of science or engineering. In engineering schools the faculties tend toward applied research because of the practical nature of engineering problems. Fundamental studies of wide scope are nevertheless possible in this field and frequently undertaken.

Organization of Research Activities

The extent to which applied research activities in a university are organized will depend on the total amount of research done. The type of organization used will depend on the educational policies of the institution. The three types of organization now prevailing in the United States may be termed decentralized research, centrally coordinated research, and the research institute or foundation. These three types of organization in the order given are found associated with an increasing proportion of sponsored research.

The term "decentralized research" is used to denote the traditional situation in academic research. Individual faculty members pursue studies of their own choice and any cooperative investigations undertaken are informally organized by the participants.

The research projects under a program of decentralized research may be sponsored or unsponsored, basic or applied. In practice, they are mainly unsponsored basic research. The funds that are obtained from sponsors supplement the regular university research budget but do not greatly affect the type of research done. They simply increase the volume of research by providing additional assistants and equipment. The individual scientist usually obtains his grants or contracts through his own efforts, leaving business details of his grant or contract to the university administration. The actual research is performed in the university laboratory of the faculty member by him or by graduate students under his supervision.

Larger projects requiring special equipment and one or more postdoctoral assistants call for more formal arrangements. A small group of scientists must be organized by the senior investigator and a regular allotment of laboratory space obtained. The project must be approved by the head of the department or school. He decides whether it is of sufficient scientific importance to justify use of university facilities. Under this system, a large university might well have separate applied research contracts in its chemistry and physics departments, in its engineering experiment station, and perhaps in other laboratories, yet have no central coordination except that provided by the respective deans.

Some science departments have separate laboratories devoted to research in specialized areas within the larger field of the department. These often negotiate grants and contracts independently of the departments to which they are attached. Most of the 44 engineering experiment stations operating in colleges and universities are organized in this way. (39) Agricultural experiment stations, 53 in all, are concerned chiefly with applied research and usually have the same degree of autonomy with respect to the college or school of agriculture. Most of their funds are provided in annual appropriations by their respective states and the Federal Government; they also do some sponsored research for trade associations and individual manufacturers of agricultural products and foodstuffs.

"Centrally coordinated research" is characterized by the greater participation of the central university administration. It is found in colleges and universities where an appreciable amount of sponsored research is done in most departments. A separate office is set up under the central university administration to deal with administrative details arising from sponsored research projects. It may be called the research coordinating office, or the university research council. In some schools, an individual designated as coordinator of research, or vice president for research, oversees coordinating activities.

One purpose of central coordination is to provide uniformity in the handling of grants and contracts. Since the university is the nominal recipient of all funds from grants and contracts, it seeks to deal with all sponsors on the same basis. Uniform policies can only be maintained when the business aspects of grants and contracts are handled by one office. This office, whatever its title, assists professors in locating sponsors, and aids sponsors in finding investigators. It draws up research contracts to conform to policies of the institution, handles all patent negotiations for the university, and takes care of fiscal matters related to grants and contracts. Where justified by the extent of the program, the central coordinating office may employ a technical man to serve as liaison officer between the faculty investigators and the sponsors of their research.

Universities that have their research programs centrally coordinated frequently set up faculty research committees. They review contracts and grants prior to their acceptance by the university administration, to insure that the arrangements conform

to established university policies. The central coordination of research results in greater operating efficiency, since full-time staff can be employed to handle the common administrative aspects of all grants and contracts. It conserves professors' time for research and teaching and avoids burdening the university finance office and the individual departments with the details of administering sponsored research. Furthermore, it enables the university to control the amount and nature of the applied research conducted in its facilities.

The third type of university affiliated research organization is the "research foundation or institute." This may or may not be separately incorporated. Foundations or institutes are found in universities conducting extensive programs of sponsored research that require complicated administrative arrangements. In organization and operation, there are no distinctions to be drawn between institutes and foundations. Most institutes and some foundations employ full-time research men not on the university teaching staff; most foundations, however, confine their scientific staff to university faculty and graduate students.

University research foundations and institutes perform essentially the same administrative functions as do research coordinating offices described above. But whereas the coordinating office facilitates the conduct of applied research in the regular university departments, the foundation or institute may itself be the employer of some or all of the men doing work under its auspices. Patent management is generally a common activity of the research foundation or institute, since the research programs it administers frequently produce patentable results. There are even a few foundations which are simply patent management organizations for their universities.

The Purdue Research Foundation, established in 1930, is a typical example of the university research foundation. It seeks and negotiates contracts and provides overhead control, financial management, and patent assistance in connection with industrial and governmental research contracts. All the research it administers is performed by faculty members and graduate students in regular university facilities. There are now about 60 organizations that have many features in common with the Purdue Research Foundation.

The Division of Industrial Cooperation of the Massachusetts Institute of Technology functions like a research institute and employs both faculty and non-faculty research staff, including graduate students. The supervisory or senior personnel are professors in the Massachusetts Institute of Technology, but many full-time research men without full faculty status are employed on its projects. The research is carried on in the regular laboratories of the Institute.

The Armour Research Foundation, established in 1936, exhibits even more separation from its academic affiliate, the Illinois Institute of Technology. It performs applied industrial and governmental research in its own laboratories with its own full-time staff. There are fewer than 12 organizations of this type.

The differences in composition of the research staffs employed by individual foundations and institutes are reflected in the character of their research programs. The most common type of foundation performs administrative functions for the regular university staff. It only accepts contracts for such investigations as suit the scientific and educational purposes of the university. The mixed-type organizations with faculty supervisors handle similar projects. However, the employment of full-time permanent research men permits them to study highly specialized problems not suitable for the training of graduate students. They maintain university standards in all their scientific work and conduct research in accordance with university policy. Foundations and mixed-type institutes accept a substantial number of contracts with the Government because these often call for fundamental studies. The third type, the separate research institute, is staffed entirely by full-time non-faculty men. Its research programs are frequently technological and developmental in character, but the institute operates in cooperation with the university, even if separately incorporated. University faculty men often serve the institute as consultants, and institute scientists may also do some teaching in the university.

There is an important sub-type of the separate university research institute which receives direct support from industry. A group of cooperating firms in the same industry may set up a research institute affiliated with a conveniently located college or university. This institute, which has its own full-time staff, investigates basic problems of the industry, making the results equally available to all member firms. (37) Usually these institutes also perform contract research for individual members or non-members. The Institute of Paper Chemistry at Lawrence College (Appleton, Wisconsin) is a leading example. In addition to its research activities, the Institute operates a training program to meet the special needs of the paper industry for technical men.

There is considerable disagreement on the advisability of setting up applied research institutes as separate corporations and conducting them almost independently of the university. (40) Some advantages usually claimed for separation are:

(a) They offer industrial sponsors a full-time staff rather than one composed partly of individuals with teaching as a primary responsibility.

(b) They enable the university departments to concentrate on basic research.

(c) They make it easier to recover the full costs of sponsored research.

(d) They reduce the risk of involving the university in patent litigation.

Some disadvantages cited are:

(a) Faculty members and students have less opportunity to engage in applied research; this loss of contact with industry may handicap their professional development.

(b) Funds from prospective sponsors or donors may be diverted from the university to the institute.

(c) Differences in pay scales, tenure, and prestige between the staff of an independent university research institute and the departmental faculty often lead to personnel problems.

Research Financing

Most universities hold that research expenditures out of their own resources should be used to support basic rather than applied research. Since most sponsored research is applied research, universities seek to fix charges so that sponsored research will pay its own way. To satisfy this condition, sponsors must pay, in addition to the salaries of research men and cost of procuring equipment, a "reasonable" sum for use of university facilities.

Sponsors who approach university scientists for help expect to pay the full indirect costs of the research they contract for. Projects that arise in this way would not normally be undertaken without sponsorship, and no one expects the university to subsidize them.

Difficulties arise, however, when a university scientist solicits a grant or contract to do the same kind of research as he would do without sponsorship. In this circumstance, university facilities would be put to a use in accordance with one of the accepted purposes of the university. The question of what is a "reasonable" charge for the indirect costs of this type of sponsored research has not been generally settled.

If a grant or contract pays only for additional project staff and equipment, the increase in indirect costs due to the project must be borne by the university. When the ratio of sponsored to unsponsored research is low, the indirect costs associated with the sponsored research may not be difficult for the university to meet. As this ratio increases, the increase in the indirect costs may become substantial since administrative and maintenance staffs must be enlarged. In general, universities cannot readily assume large increases in operating costs without diverting funds that normally support other activities.

In practice a distinction is observed in financing indirect costs that arise from grants, as contrasted to contracts. Grants, as the name implies, are gifts for a specific purpose and relatively simple records suffice to show that the money was spent properly. They are intended to supplement existing research activities by providing additional staff or equipment. Under these conditions, it is expected that the increase in indirect costs due to a specific project will be small and can be borne by the university. However, the trend is for Government agencies and philanthropic groups supporting research through grants to allow a small percentage of the total grant for indirect costs.

The indirect costs of contract research, on the other hand, are met to varying degrees by the sponsor. Many institutions assume full indirect costs for projects which may be incorporated into the regular teaching and research program, but charge up to 100 percent of indirect costs on a graduated scale for projects of smaller

scientific or educational value. This policy must be modified, however, by the force of circumstance when existing financial resources are insufficient to meet additional costs.

Indirect costs are calculated by applying a percentage, i.e., an overhead rate, to the determinable direct costs. The total indirect costs are the difference between the total expenses of operating the university, and the total direct costs which can be determined. The ratio of total indirect costs to total direct costs provides the overhead rate. This is an over-simplified statement of the accounting procedure involved, but indicates the principle used in determining overhead. The items which are accounted for as direct costs vary from institution to institution. Consequently, the overhead rates show a variance.

Prior to 1940, most university income came from tuition, endowments, gifts, and direct appropriations by state and local governments. There was little reason to estimate the costs of separate university operations, such as research and instruction. Accounting practices varied tremendously, and in most instances the accounting records maintained were completely inadequate for calculating overhead rates and research project costs.

The establishment of large-scale extramural programs involved substantial changes in the sources of funds and consequently in the accounting practices. To obtain full reimbursement for the cost of a specific project, the university must keep records that permit determination of direct costs for individual projects, and allow an accurate calculation of the indirect costs for research. The university financial officers working with contracting groups in the Department of Defense have developed procedures for accomplishing these tasks. Today, most large universities have an established overhead rate for research operations. The rate varies widely because of differences in separation of costs between the two categories, "direct" and "indirect." The overhead on a particular project is usually calculated as a percentage of the direct labor costs for that project.

Patent Policy

When a large share of university research effort goes into applied research, patentable inventions are developed on university time and at university expense. Some of these inventions may have valuable commercial application. By acquiring title to a patent, the university can help promote public benefit from a new development. For certain discoveries, wide application will be insured simply by publication, the university retaining title to the patent to prevent private monopoly. Some discoveries, however, require large capital investment or previous patents for their exploitation. To insure commercial application of a discovery of this kind, it may be necessary for the university to give an exclusive license for manufacture under the patent on a royalty or cash basis. (41)

Some universities hold that commercial exploitation of inventions is not a proper concern of a university or its staff. Some adopt a laissez-faire attitude, leaving all

responsibility for handling patents to the faculty inventors. Some institutions have no fixed policy in regard to patents, but improvise procedures to meet individual circumstances. Others undertake the whole complicated business of patent management, sometimes directly, but more often through separately incorporated, but affiliated, patent management foundations. Many university research foundations and institutes have patent management as one of their functions. Thirty-four colleges and universities employ the Research Corporation, an independent non-profit patent management foundation whose net earnings are distributed in the form of research grants. (42)

A university that undertakes the management of faculty patents is faced with problems of considerable complication. The equities of many parties of interest must be considered: the general public, the inventor, the university, and frequently, the sponsor. The services of specialized legal counsel must be hired to attend to preparation and processing of patent applications. Once obtained, the patent itself or licenses for its use cannot usually be sold without active promotion. To protect the public interest, the university must oversee the quality of the finished product and make sure that exclusive licensees charge fair prices. Finally, constant watch must be made for infringement or interference. (43)

Publication of Research

In most instances there are no restrictions on the publication of results from sponsored projects of basic research. The investigator invariably acknowledges the financial aid he has received, but is free to publish what and when he wishes except under unusual circumstances.

On applied research projects the contract may require clearance of proposed publications with the sponsor; in a few instances the sponsor acquires publication rights as part of his contract. Many applied industrial research contracts, particularly those of the separate university research institutes or foundations, give the industrial sponsor complete control of publication rights, subject to provisions forbidding the sponsor to claim or imply endorsement of his firm or product by the institute or university. Some university departments, on the other hand, will not accept applied research unless unrestricted publication rights are guaranteed the department by the sponsor. In state colleges and universities, publication policy, like patent policy, is carefully scrutinized to guard against actual or apparent discrimination toward, or endorsement of, any private concern.

CHAPTER V

INDEPENDENT INDUSTRIAL RESEARCH INSTITUTES

The first independent research institute, Mellon Institute for Industrial Research, was founded in 1913 to do applied research for any company that wanted to hire such service. The second, Battelle Memorial Institute, was started in 1929. The success of these two organizations led to the establishment of others, most of them since 1945. The latest additions to the group have been set up with the object of providing consulting service to specific geographical regions: Southern Research Institute in Birmingham, Alabama; Southwest Research Institute in San Antonio, Texas; Texas Research Foundation near Dallas, Texas; Midwest Research Institute in Kansas City, Missouri; Stanford Research Institute in Palo Alto, California. The Armour Research Foundation is usually included, although it is a university research organization. Stanford Research Institute is affiliated with Stanford University but operates essentially independently of it.

The industrial research institute is a definite type among the more than 900 non-profit foundations, trade associations, trusts, and societies which support research. It closely resembles the university research institutes previously described. In fact, independent research institutes served to some extent as models for the organization of university institutes. But while the university institute generally gets its start through funds provided by the university, the independent industrial research institute is started either through private endowment or the establishment of a corporation with loans of working capital from interested individuals within a particular locality or region. The independent institutes are non-profit corporations and use net earnings to expand or improve their facilities and to support fundamental research projects in their own laboratories. They obtain support for research in the same way and from nearly the same sources as do university institutes, and they do about the same kinds of work. There may be a greater tendency for the university institute to obtain Government projects involving fundamental and exploratory work, whereas independent institutes rely mostly on support from industry.

The difference between an industrial research institute and a consulting laboratory is somewhat analogous to the difference between the central laboratory of a large concern and a subsidiary laboratory attached to one of the plants. The plant laboratory is employed on short-term projects, trouble-shooting, testing, and control. Concerns seeking assistance on such problems bring them to commercial consulting laboratories. The central laboratory usually studies long-term projects leading, when successful, to fundamental changes in products and processes. Individual concerns requiring work of this sort may employ the services of a research institute. Sometimes also, several concerns in the same industry join together to support research of common interest at an independent industrial research institute.

In addition to conducting laboratory investigations and solving engineering problems involved in applying the results, independent institutes provide a more general consulting service. They advise sponsors in the selection and planning of investigations,

taking into account the requirements of the sponsor's own business. They also furnish technical information for sponsors to use in advertising.

The organization of research in industrial institutes has certain attributes in common with university research. Scientists work individually or in small groups on well-defined problems. Projects of less than one year's duration are not generally accepted. Individual members of project teams are recruited from subject divisions according to the requirements of the job at hand. In spite of the constant shifting of personnel from one project to another, most research institutes allow staff members some opportunity to do fundamental research if they are so inclined. In practice, however, little fundamental research is done because the men are too fully occupied with applied research tasks.

Whereas the staff of a central laboratory is employed on a variety of problems for one concern, institute staffs handle problems for many concerns in different industries. Sometimes, however, individual groups within a subject division may become so expert in the problems of a particular industry that there is continual demand for their services by firms in that industry. Frequently, projects undertaken are of only one year's duration, and the program within a subject division may change markedly from year to year. The changing character of the problems requires that the research institute have on its staff men with training in almost all fields of science and engineering. It is this capacity to provide a wide range of experience and training that brings industry and Government to the research institute for the solution of particular problems.

The main purpose of the institute is to provide a service to industry, and most of their problems are submitted to them by industrial concerns. Interchange of information between project groups is limited to protect the interests of the sponsors. Moreover, it is usual not to undertake more than one investigation on a particular subject at any one time. Information of a technical nature arising from institute research is transmitted through the director's office or by conferences between technical representatives of the sponsor and the working group of the institute.

Business operations are handled by an administrative group in the director's office. This staff must maintain separate accounts for each sponsor, arrange contracts, and initiate patent applications on advice from the sponsor. It usually acts for the director in providing fiscal reports to the sponsor. Most business arrangements between institute and sponsor are settled by written agreement in advance.

Some idea of the size of these research institutes can be shown by specific examples. A recent publication (44) describing the Mellon Institute listed the following personnel: the director and six assistant directors; seven fellows and one assistant in pure research; 266 industrial fellows; 248 fellowship aides; a service and administrative staff of 242. The most recent report of the Mellon Institute lists 84 projects on which work was done in the year 1951. The data listed in the same reference for Battelle Memorial Institute was as follows: 173 engineers, 143 chemists, 104 metallurgists, 39 physicists, 386 additional technical people, and 382 administrative and non-technical

assistants. These are, of course, the largest and oldest of the industrial research institutes. Other important members of this group have been named above, except for Franklin Institute, established in 1824, which assumed additional responsibilities, those of an industrial research institute, in 1925.

The nine institutes mentioned above spend $35 to $40 million annually on research. In 1950 they employed over 1500 experienced scientists and engineers, and supporting personnel numbering more than 1,000.(44)

The wide adoption of research as a tool in the solution of industrial problems has been strongly influenced by the industrial research institutes. Their continued existence is entirely dependent on the success of their research undertakings. They have demonstrated to many companies in many industries that research pays dividends. They provide a convenient means for a company to get research done without investing in a permanent laboratory and staff. For the company which maintains a research department, research institutes offer a consulting service staffed with experienced specialists. The small company with little or no research staff can obtain research of a quality comparable to that large companies secure from their own facilities.

CHAPTER VI

INTERRELATIONS AMONG APPLIED RESEARCH ACTIVITIES

In previous chapters, research activities in the United States have been described under three headings: Government, industry, and universities. This classification provided a convenient way of organizing our description of the wide variety of groups that do and support applied research. The present chapter points out explicitly the interdependence of the different kinds of research groups and some effects of their combined activity on the national economy.

All applied research groups have certain common features. First, they are staffed by individuals with the same initial training in science and engineering. Moreover, there is a good deal of interchange of experienced research men between the three classes of employers, namely, Government, industry, and universities. Second, laboratories belonging to each of the three classifications study related problems although emphasizing different aspects. Evidently then, research staffs in all categories employ similar methods and equipment in solving technical problems. The chief variations among applied research activities of Government, industry, and universities are organizational. They arise from differences in the nature of the sponsors and in their motives for supporting research. Types of research undertaken, methods for choosing research problems, supervisory and coordinating procedures employed, and to some extent, conditions under which the scientists work, are all affected by these differences.

The role of the universities and colleges in the total research picture is twofold; they seek basic knowledge and they produce the trained manpower to extend and use knowledge. They supply not only research men, but also, and in much greater number, technical graduates who go into production, technical sales, and construction. A significant effect of our system of higher education is that one out of every 100 workers in the nation's farms, factories, business, and government has had at least four years of college training in science or engineering. Such a high proportion of trained manpower insures that in almost all activities there are individuals who have some knowledge of science or engineering and some appreciation of the usefulness of research in solving problems.

The training of graduate students in practical subjects has required some university groups to be diverted to applied research activities. The emphasis in the universities is still on basic research, however, and the universities are still the chief producers of fundamental knowledge. Both Government and industry recognize the importance of basic research to the whole technological enterprise and efforts are being made to insure it necessary financial support.

To safeguard the research potential of the nation, a balance in caliber must be maintained between men choosing careers in industry and those becoming university teachers. The higher salaries paid by industry draw many gifted scientists away from universities and into more practical work. In the United States, salaries paid by the

universities are, however, adequate for modest requirements. Our universities continue to attract and retain able men to whom added scientific prestige, freedom to do basic research, and the opportunity to train young people are of paramount importance.

Industrial research is fertilized by the new knowledge that basic research provides. Industry seeks to convert fundamental discoveries into new or cheaper processes and devices. This step requires additional technical work--applied research--and confidence in research as a means of producing profits. In highly competitive industries research may be necessary to stay in business. Likewise companies may expand into new and more profitable areas by marketing the products of research. It is estimated that 40-50% of all sales made by the du Pont Company in 1950 were due to new products developed since 1940.(38)

The investment of money in research, and reinvestment of part of the resultant profits in new research is sound business. In the long run, research resulting in lowered prices or improved quality is more than paid for through expanded sales. New products open up new markets for the enterprising. The carriage manufacturer of the Victorian Era in at least two instances--Fisher Body and Studebaker--has become the automobile body manufacturer of the twentieth century with sales running to millions instead of thousands. Frequently older products continue to exist side by side with newer developments. Thus synthetic fibers, particularly rayon and nylon, did not replace natural fibers, but shared an ever-increasing demand for fabrics--a demand today that natural fibers alone could not meet.(45)

A chief way for reducing costs in the high cost labor market of the United States is by reducing the number of man-hours required for a unit operation. When successful research leads to new ways of replacing men by machines within a company or industry, local disturbances may result--"technological unemployment." This problem has been alleviated through the simple expedient of increasing wages and decreasing working hours. Unemployment insurance helps to protect workmen from the hardships of sudden shifts in manufacturing processes. Major changes in employment caused by new developments are gradual and production of new items eventually absorbs the workers from obsolete industries. Today 50 percent of the nation's workers are employed in industries that did not exist in 1880.(38) There are encouraging examples of cooperation between labor and management to work out methods for introducing improved machinery and processes in a manner that minimizes dislocations and enhances the incomes of both.

Every gain from cost reduction, from substitute or improved product, or from better consumer service is a triple gain: to the consumer in the form of better products and services; to management in the form of improved earnings; and to the economy in the form of savings in labor, capital, and natural resources. In 1800, nine farm workers could provide enough food for themselves and one other person; today one farm worker provides food for himself and 14 others. The labor force freed from work on the farms

is used in producing all the numerous commodities that constitute the difference between the present living standard and that of 1800.

Industry is the direct producer of the wealth that supports both universities and government. It depends on the universities for the common store of basic scientific knowledge that individual companies seek to convert to their special advantage. In recognition of this it gives increasing support to fundamental research in the universities. It depends on the scientific activities of the government for background studies and exploratory research in science and economics useful to every kind of concern.

The role of the Government in conducting research is primarily supplementary to university and industrial activity. The Government is expected to engage in defense research since industry has neither the desire nor the capital to invest in such activities. Moreover, the very survival of the nation as a whole cannot be entrusted to any special group within it. The agricultural research program is one in which the Government engages because the producing units, the farms of the country, cannot themselves support research. The health and medical research program of the Federal Government is likewise one in which the public interest requires that the Government do or support research.

In the past two years, Government spending has diverted much research activity of industry and universities into studies of defense problems. The defense research program will undoubtedly produce developments of ultimate use to civilian industries. Many educators and industrial research directors are nevertheless concerned with what appears to be a slowdown in the rate of discovery of new knowledge. If Government support causes a further shift in the universities toward problems of an applied character, then our chief source of new knowledge will be seriously threatened. The Government is making efforts to avert this by furnishing increased funds for basic research in universities. Industry has been encouraged to increase its support of universities by a tax provision permitting tax exemption on amounts, up to 5 percent of a company's profits before taxes, that are donated to educational institutions. It is still too early to ascertain the long-term effects of Government sponsorship on the total research activity of the nation.

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APPENDIX

RESEARCH AND DEVELOPMENT FACILITIES OF THE U. S. GOVERNMENT DEPARTMENTS AND AGENCIES**

DEPARTMENT OF AGRICULTURE

Name	Location
*Agricultural Research Center	Beltsville, Maryland
Bureau of Agricultural and Industrial Chemistry	
*Northern Regional Research Laboratory	Peoria, Illinois
*Southern Regional Research Laboratory	New Orleans, Louisiana
*Eastern Regional Research Laboratory	Wyndmoor, Pa.
*Western Regional Research Laboratory	Albany, California
Fruit and Vegetable Chemistry Laboratory	Pasadena, California
U. S. Citrus Products Laboratory	Winter Haven, Florida
Naval Stores Research Station	Olustee, Florida
Bureau of Animal Industry	
Regional Animal Disease Research Laboratory	Auburn, Alabama
Regional Poultry Research Laboratory	East Lansing, Michigan
Animal Husbandry Experiment Station	Brooksville, Florida
U. S. Sheep Experiment Station	Dubois, Idaho
U. S. Range Livestock Experiment Station	Miles City, Montana
Iberia Livestock Experiment Farm	Jeanerette, Louisiana
Pathological Laboratory	Washington, D. C.
Zoological Laboratory	Albuquerque, N. Mexico
Bureau of Dairy Industry	
Dairy Products Research	Washington, D. C.
Bureau of Entomology and Plant Quarantine	
Forest Insect Investigations Laboratories	Portland, Oregon
	Ft. Collins, Colorado
	New Haven, Connecticut
	Berkeley, California
	Gulfport, Mississippi
Cotton Insect Investigations Laboratories	Brownsville, Texas
	Waco, Texas
European Corn Borer Research Station	Ankenny, Iowa

*Facilities with 100 or more employees.

**Industrial research laboratories and institutes are listed in reference (44) of the bibliography; university research laboratories in reference (11).

Fruit Insect Investigations Laboratories	Moorestown, New Jersey
Fruit Fly Investigations Laboratory and Substations	Honolulu, Hilo, Lanis, Maui, T.H.
Insects Affecting Man and Animal Laboratories	Savannah, Georgia Kerrville, Texas Orlando, Florida
National Museum Bldg. (Insect ident. & res. on insect classification)	Washington, D. C.
Stored Grain Insect Research Station	Manhattan, Kansas
Truck Crop and Garden Insects Laboratory	Twin Falls, Idaho
Wheat Stem Sawfly Research Station	Minot, North Dakota

Bureau of Plant Industry, Soils, and Agricultural Engineering

Soil Survey Office, Far Western States	Berkeley, California
Soil Survey Office, Southern States	Knoxville, Tennessee
U. S. Plant, Soil, and Nutrition Laboratory	Ithaca, New York
*Plant Industry Station	Beltsville, Maryland
U. S. Plant Introduction Gardens	Glenn Dale, Maryland Coconut Grove, Florida
U. S. Field Laboratories	Gainesville, Florida Bogalusa, Louisiana
U. S. Cotton Field Station	Shafter, California
Southwestern Irrigation Field Station	Brawley, California
Yuma Mesa Soil and Crop Laboratory	Yuma, Arizona
U. S. Horticultural Field Laboratories	Orlando, Florida Wenatchee, Washington Fort Valley, Georgia
U. S. Horticultural Field Stations	Fresno, California Meridian, Mississippi Cheyenne, Wyoming
U. S. Southern Great Plains Field Station	Woodward, Oklahoma
Northern Great Plains Station	Mandan, North Dakota
U. S. Sugar Plant Field Laboratories	Riverside, California
Sugarcane Field Station	Houma, Louisiana
Los Diamantes Experiment Farm	Guapiles, Costa Rica
U. S. Regional Salinity Laboratory	Riverside, California
U. S. Regional Vegetable Breeding Laboratory	Charleston, S. Carolina
U. S. Regional Pasture Research Laboratory	State College, Pa.
U. S. Cooperative Rubber Plant Field Stations	Turrialba, Costa Rica Marfranc, Herenne, Haiti
U. S. Natural Rubber Research Station	Salinas, California

U. S. Cooperative Plant Propagation Center	Cuyotenango, Guatemala
Barley and Malt Laboratory	Madison, Wisconsin
U. S. Forest Pathology Field Laboratory	New Haven, Connecticut
National Arboretum	Washington, D. C.
Office of Experiment Stations	
Federal Experiment Station	Mayagues, Puerto Rico
Forest Service	
*Forest Products Laboratory	Madison, Wisconsin
Pacific Northwest Forest and Range Experiment Station	Portland, Oregon
Intermountain Forest & Range Experiment Station	Ogden, Utah
Rocky Mountain Forest and Range Experiment Station	Ft. Collins, Colorado
Northern Rocky Mountain Forest and Range Experiment Station	Missoula, Montana
California Forest and Range Experiment Station	Berkeley, California
Southwestern Forest and Range Experiment Station	Tucson, Arizona
*Southeastern Forest Experiment Station	Asheville, N. Carolina
*Northeastern Forest Experiment Station	Upper Darby, Pa.
Central States Forest Experiment Station	Columbus, Ohio
Lake States Forest Experiment Station	St. Paul, Minnesota
*Southern Forest Experiment Station	New Orleans, Louisiana
Production and Marketing Administration	
*Research and Testing Division, Cotton Branch	Washington, D. C.
U. S. Cotton Spinning Laboratories	Clemson, S. Carolina College Station, Texas
Soil Conservation Service	
Field Station and Soils Laboratory	Coshocton, Ohio
Field Station Laboratory	Fleming, Georgia
DEPARTMENT OF THE AIR FORCE	
*Air Force Missile Test Center (Long Range Proving Ground)	Patrick Air Force Base, Cocoa, Florida
*Arnold Engineering Development Center	Tullahoma, Tennessee
*Cambridge Research Laboratories	Boston, Massachusetts
*Edwards Air Force Base	Muroc, California
*Electronics Development Center	Griffiss Air Force Base, Rome, New York
*Holloman Air Force Base	Alamogordo, N. Mexico
*Wright Air Development Center	Wright-Patterson Air Force Base, Dayton, Ohio

DEPARTMENT OF THE ARMY

Army Medical Service

*Army Medical Center	Washington, D. C.

Chemical Corps

*Army Chemical Center	Edgewood, Maryland
*Dugway Proving Ground	Dugway, Utah

Corps of Engineers

*Engineer Research and Development Laboratories	Fort Belvoir, Virginia

Signal Corps

*Signal Corps Engineering Laboratories	Fort Monmouth, New Jersey

Ordnance Corps

*Aberdeen Proving Ground	Aberdeen, Maryland
*Detroit Arsenal	Centerline, Michigan
*Frankford Arsenal	Philadelphia, Pa.
*Picatinny Arsenal	Dover, New Jersey
*Redstone Arsenal	Huntsville, Alabama
*White Sands Proving Ground	Las Cruces, N. Mexico

ATOMIC ENERGY COMMISSION

*Radiation Laboratory, Univ. of California	Berkeley, California
*Ames Laboratory	Ames, Iowa
*Argonne National Laboratory	Chicago, Illinois
*Brookhaven National Laboratory	Upton, Long Island, N. Y.
*Knolls Atomic Power Laboratory	Schenectady, N. Y.
*Los Alamos Scientific Laboratory	Los Alamos, N. Mexico
*Mound Laboratory	Miamisburg, Ohio
*Oak Ridge National Laboratory	Oak Ridge, Tennessee
*Oak Ridge Institute of Nuclear Studies	Oak Ridge, Tennessee
*Sandia Laboratory	Sandia Base, Albuquerque, New Mexico
*Atomic Power Division, Westinghouse Electric Corporation	Pittsburgh, Pa.
*University of Rochester Atomic Energy Project	Rochester, New York
*Atomic Energy Project, University of California	Los Angeles, California

DEPARTMENT OF COMMERCE

*The National Bureaus of Standards	Washington, D. C. Corona, California Los Angeles, California

The National Bureau of Standards, Central Radio Propagation Laboratory	Boulder, Colorado
Civil Aeronautics Administration	
*Technical Development and Evaluation Center	Indianapolis, Indiana
Public Roads Administration	
*Physical Research Branch, Research Div.	Gravelly Point, Va.
Weather Bureau	
Division of Physical Research	Washington, D. C.
FEDERAL SECURITY AGENCY	
Public Health Service	
*Communicable Disease Center	Atlanta, Georgia
*Environmental Health Center	Cincinnati, Ohio (Inc. labs at Savannah, Ga., Montgomery, Ga., and Kansas City, Kan.)
Arctic Health Research Center	Anchorage, Alaska
*National Institutes of Health (comprises the following):	
National Cancer Institute	Bethesda, Maryland
National Heart Institute	Bethesda, Maryland
National Institute of Arthritis and Metabolic Diseases	Bethesda, Maryland
National Institute of Dental Research	Bethesda, Maryland
National Institute of Mental Health	Bethesda, Maryland
National Microbiological Institute	Bethesda, Maryland
Rocky Mountain Laboratory	Hamilton, Montana
DEPARTMENT OF THE INTERIOR	
Bureau of Mines	
Southern Experiment Station	Tuscaloosa, Alabama
Southwest Experiment Station	Tucson, Arizona
*Eastern Experiment Station	College Park, Md.
North Central Experiment Station	Minneapolis, Minnesota
*Mississippi Valley Experiment Station	Rolla, Mo.
Mining Experiment Station	Raleigh, N. Carolina
*Petroleum Experiment Station	Bartlesville, Oklahoma
*Central Experiment Station	Pittsburgh, Pa.
*Intermountain Experiment Station	Salt Lake City, Utah
Northwest Experiment Station	Seattle, Washington
*Petroleum & Oil-Shale Experiment Station	Laramie, Wyoming
Alaska Experiment Station	Juneau, Alaska

Minerals Thermodynamics Branch Metallurgical Division	Berkeley, California
Ferro-Alloy Research Branch, Metallurgical Division	Redding, California
*Electrometallurgical Branch, Metallurgical Division	Boulder City, Nevada
Fuels Technology Division	San Francisco, Cal.
Petroleum and Natural Gas Branch, Fuels Technology Division	Franklin, Pa.
Mining Research Branch, Minerals Technology Division	Bluemont, Virginia
Lignite Research Laboratory	Grand Forks, N. Dakota
Anthracite Research Laboratory	Schuylkill Haven, Pa.
Helium Research Laboratory	Amarillo, Texas
*Northwest Electrodevelopment Laboratory	Albany, Oregon
Electrotechnical Laboratory	Norris, Tennessee
Synthesis Gas Production Laboratory	Morgantown, W. Virginia
Coal Branch	Denver, Colorado
*Oil-Shale Demonstration Plant and Mine	Rifle, Colorado
*Coal-to-Oil Demonstration Plants	Louisiana, Mo.
Hydrometallurgical and Ore Dressing Branch	Reno, Nevada
Rapid City Field Station	Rapid City, S. Dakota
Sponge Iron Pilot Plant	Laramie, Wyoming
<u>Bureau of Reclamation</u>	
*Branch of Design and Construction	Denver, Colorado
<u>Fish and Wildlife Service</u>	
Research Laboratories, Branch of Fishery Biology	Stanford, California Woods Hole, Mass. Beaufort, N. Carolina Galveston, Texas Seattle, Washington
Fishery Technological Laboratories	Boston, Massachusetts Seattle, Washington
Wildlife Research Laboratory	Denver, Colorado
Patuxent Research Refuge	Laurel, Maryland
<u>Geological Survey</u>	
Chemical Quality Laboratories	Fayetteville, Ark. Washington, D. C. Philadelphia, Pa.
*Photogrammetry Sections	Sacramento, California Denver, Colorado Rolla, Mo. Arlington, Va.

Investigations Sections Laboratories	Washington, D. C. Denver, Colorado
Trace Elements Section Laboratories	Washington, D. C. Denver, Colorado
Sediment Laboratories	Norton, Kansas Worland, Wyoming
Chemical Quality and Sediment Laboratories	Lincoln, Nebraska Albuquerque, N. Mexico Columbus, Ohio Stillwater, Oklahoma Austin, Texas Salt Lake City, Utah
Paleontology and Stratigraphy Branch	Washington, D. C.
Geophysical Instruments and Methods Unit	Baltimore, Maryland
Research and Development Unit, Topographic Division, Photogrammetry Section	Arlington, Va.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

*Ames Aeronautical Laboratory	Moffett Field, Cal.
*High-Speed Flight Research Station, Edwards Air Force Base	Muroc, California
*Lewis Flight Propulsion Laboratory	Cleveland, Ohio
*Langley Aeronautical Laboratory	Langley Field, Va.
Pilotless Aircraft Research Station	Wallops Island, Va.

DEPARTMENT OF THE NAVY

Bureau of Aeronautics

*Naval Air Development Center	Johnsville, Pa.
*Naval Air Material Center	U. S. Naval Base, Philadelphia, Pa.
*Naval Air Missile Test Center	Pt. Mugu, California
*Naval Air Test Center	Patuxent River, Md.

Bureau of Medicine and Surgery

*Naval Medical Research Institute	National Naval Medical Center, Bethesda, Md.

Bureau of Ordnance

*U. S. Naval Ordnance Laboratory	White Oak, Md.
*U. S. Naval Ordnance Plant	Indianapolis, Indiana
*U. S. Naval Ordnance Test Station	Inyokern (China Lake), Cal., Pasadena, Cal.

*U. S. Naval Proving Ground	Dahlgren, Virginia
*U. S. Naval Torpedo Station	Newport, Rhode Island
Bureau of Ships	
*David W. Taylor Model Basin	Carderock, Maryland
*Material Laboratory	New York Naval Shipyard Naval Base Station, Brooklyn, New York
*U. S. Naval Engineering Experiment Station	Annapolis, Maryland
*U. S. Navy Electronics Laboratory	San Diego, California
Office of Naval Research	
*Naval Research Laboratory	Washington, D. C.
SMITHSONIAN INSTITUTION	
U. S. National Museum	Washington, D. C.
Canal Zone Biological Area	Barro Colorado Island, Canal Zone
Astrophysical Observatory	Table Mountain, California Montezuma, Chile
TENNESSEE VALLEY AUTHORITY	
*Chemical Engineering Laboratories	Muscle Shoals, Alabama
VETERANS ADMINISTRATION	
Veterans Administration Hospitals	Long Beach, California Los Angeles, California Denver, Colorado Washington, D. C. Chamblee, Georgia Hines, Illinois Framingham, Mass. Minneapolis, Minn. Nashville, Tennessee Bronx, New York Brooklyn, New York Cleveland, Ohio Memphis, Tennessee Dallas, Texas Houston, Texas

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